Characteristic of Strength Development on Converter Steel-making slag treated dredged clay

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1. Introduction

Dredged clayey soils (DCS), resulting from the maintenance of navigation channel and port, have been recycled as reclamation and filling materials in coastal construction by treating with agents such as lime and cement. Additionally, it was reported that converter steel-making slag (CSMS), industry by-product from a steel mill, can be substituted as solidification agent instead of other binders, which can be commonly used to improve the dredged clayey soils[1]. The DCS to be used as reclamation and filling materials in coastal construction after proper treatment with binder have been constructed by pneumatic flow mixing method and/or special working ship, where the soils can transfer through a pipeline connected to the construction site. For this construction, the property of strength development at initial curing time from immediately after mixing with binders is significant to determine the transportation and placing design of its.

This study goal to comprehend the strength development in dredged soils treated with converter steel-making slag (DTCS) with different conditions at various curing times (0.5h to 90days) and to propose the equations for estimating the strength of DTCS.

2. Sample Preparation and Experiments

DCS is collected from Tokuyama Port. CSMS used is provided by JFE Steel Corporation. The basic properties of DCS and CSMS are listed in Table 1. The mixing proportion of sample and curing time are shown in Table 2. The set water content was determined by the initial water content of clay normalizing with the liquid limit. The CSMS content was defined as the ratio of the volume of CSMS to the volume of soil and water. For sample preparation, DCS is sifted using 2 mm sieve to remove shells and other coarse particles. CSMS was dried in air with temperature (20°C) for 1 day. Artificial seawater was set with 3.5% salinity. The mixture was mixed for 5 minutes using a hand mixer. A series of unconfined compression test (UCT) and laboratory vane shear test (LVST) was adopted to evaluate the strength development in early and later curing time. The samples were prepared by cylindrical tinplate mold (ϕ 50mm×100mm) for UCT and cylindrical plastic mold (ϕ 60mm×60mm) for LVST. The starting time of curing was set to 30 minutes after mixing. A flow test was conducted by using a cylindrical mold (ϕ80mm×80mm) to assess the flow value.

Table 1. Basic properties of DCS and CSMS

Property	Dredged clayey soil
Liquid Limit, LL (%)	107.15
Plastic Limit, PL (%)	38.64
Plastic Index, PI (%)	68.50
Particle density, Gs (g/cm^3)	2.647
Unified Soil Classification System (USCS)	CH-OH
pH	7.2
Ignition Loss, LOI (%)	8.17
Property	**Converter steel making slag**
Surface Dry density (gr/cm^3)	3.15
Absolut dry density (gr/cm^3)	3.02
Water Absorption rate (%)	4.18
Particle size (mm)	< 5
Free CaO, f-CaO (%)	4.27

Table 2. Mixing proportion and curing time of samples

set water content (w'/LL)	Steel-making slag ($V_{CSMS}/V_{soil}+V_{water}$) (Vol.%)	Curing Time
1.2, 1.5, 1.7, 2.0	20, 30	0.5, 2, 3, 5, 7, 10, 15 (hours) 1, 2, 3, 7, 28 (days)

3. Result and Discussion

Fig. 1 shows the relationship between the strength development of DTCS and curing time in log-log scale. It was found that the strength increment (slop on the relationship between strength and curing time) prior to 5 hours of curing time was relatively small. It means that the rate of chemical reaction to increase the strength of DTCS is slower at early curing time. After curing 5 hours, the strength increment was sharply increased until 3 days and afterward moderated with curing time (3 to 28 days). Based on this behavior, the strength development of DTCS in the graph of log-log scale can be divided into three zone; 1) inactive zone (0.5 to 5 hours), 2) active zone (5 to 3 days), and 3) moderate zone (3 to 28 days).

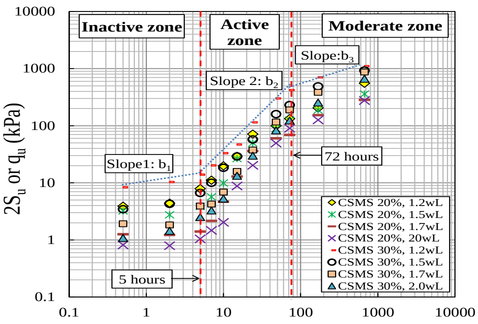

Fig. 1. Strength development in elapsed curing time in log-log scale

Hence, we can propose the equations for estimating the strength of DTCS each three zones. Fig. 2 demonstrate the relationship between the strength at curing 0.5 hours and flow value. For inactive zone, the strength at curing 0.5 hours has

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high correlativity with flow value and its correlation can be expressed as Eq. (1).

$$2Su_{(0.5\,hours)} = 0.53(FV/100)^{-10.97} \qquad (1)$$

Fig. 3 illustrate the relationship between the strength increment (b_1, the slope between strength and curing time in the inactive zone) within curing 5 hours and total water content after adding the CSMS normalized by LL. b_1 of CSMS 30% give a higher value than that of CSMS 20% and can be separated into two groups according to the value of specific normalize total water content, w_{total}/LL=0.6. Based on this relationship, b_1 can be expressed as given in Eq. (2).

$$b_1=a_1(w_{total}/LL)-a_2 \qquad (2)$$

Using Eqs. (1) and (2), the equation for estimating the strength in the inactive zone can be proposed as given in Eq. (3).

$$2Su_{(5\,hours)} = 0.53(FV/100)^{-10.97}[1+b_1\ln(t/0.5h)] \qquad (3)$$

The strength development of DTCS was changed at before (active zone) and after (moderate zone) 3 days of curing. For active zone, the relationship between strength and curing time on a log-log scale can be expressed as following;

$$q_{u(active\,zone)} = c_1 t^{b_2} \qquad (4)$$

where t is curing time, c_1 is strength corresponding to 1 hour of curing and b_2 is the strength increment parameter slope between strength and curing time in the active zone.

Fig. 4 shows the relation of c_1 and specific volume after adding CSMS by normalized that at LL. c_1 can be determined by normalized specific volume as given Eq. (5).

$$c_1 = exp(d_1+d_2)v'^{d_2/\ln v_{LL}} \qquad (5)$$

b_2 was correlated by mass of water/mass of CSMS ratio (m_{water}/m_{CSMS}) as shown Fig. 5 and its relationship can be indicated as Eq. (6).

$$b_2=e_1(m_{water}/m_{CSMS})-e_2 \qquad (6)$$

By substituting Eqs. (5) and (6) into Eq. (4), Eq. (7) for determining the strength in the active zone can be proposed as follows;

$$q_{u(active\,zone)} = exp(d_1+d_2)v'^{d_2/\ln v_{LL}}\, t^{e_1(m_{water}/m_{CSMS})-e_2} \qquad (7)$$

We can propose the formula estimating the strength in the moderate zone as given Eq. (8).

$$q_{u(moderate\,zone)} = q_{u(72\,hours)}[1+b_3\ln(t/72\,hours)] \qquad (8)$$

where $q_{u(72\,hours)}$ is the strength at curing 3 days and b_3 is the strength increment parameter in the moderate zone.

Fig. 6 shows the strength increment parameter in the moderate zone with m_{water}/m_{CSMS}. b_3 can be expressed as shown in Eq. (9).

$$b_3=f_1(m_{water}/m_{CSMS})-f_2 \qquad (9)$$

Eq (10) for predicting the strength in the moderate zone can be proposed based on Eqs. (9) and (10).

$$q_{u(moderate\,zone)} = q_{u(72\,hours)}[1+f_1(m_{water}/m_{CSMS})-f_2\ln(t/72\,hours)] \qquad (10)$$

4. Conclusion

In this study, the strength development of DTCS in the graph of log-log scale can be divided into three zones. the equations for estimating the strength of DTCS each three zones can be proposed.

Reference

3)木曽ら：転炉系製鋼スラグの混合による浚渫泥土の固化改良技術，海洋開発論文集，Vo.24，2008.

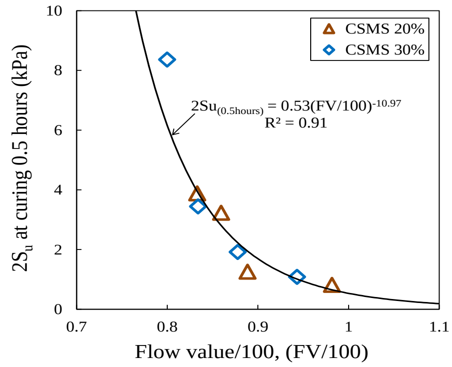

Fig.2. Relationship between strength at curing 0.5 hours and flow value

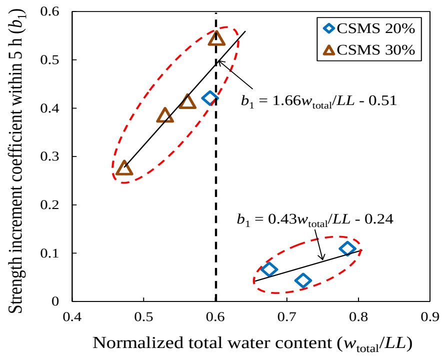

Fig.3. Relationship between b_1 and normalized total water content

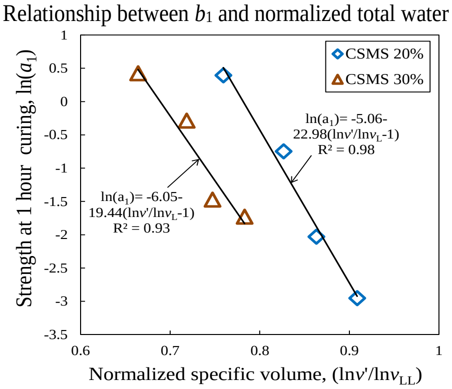

Fig.4. Relation of c_1 and normalized specific volume

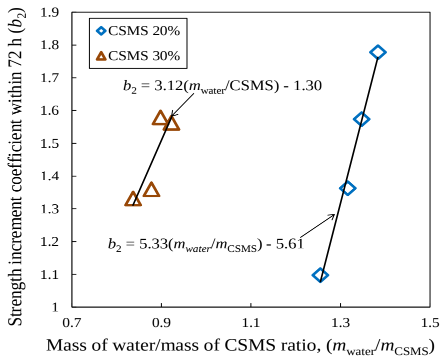

Fig.5. Relationship between b_2 and m_{water}/m_{CSMS}

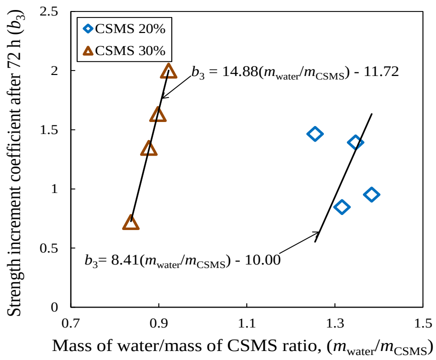

Fig.6. Relationship between b_3 and m_{water}/m_{CSMS}