Time-Strength Development of Steelmaking slag treated clay

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1. Introduction

Dredged material (DM), mostly clayey soft soil, composed annually in worldwide by port maintenance or other shores activities, is critical to be recycled and well organized to minimize the cost of disposal works. Meanwhile, in recent days, raw embankment material is highly demanded in several coastal constructions, e.g. port and airport reclamation in Japan (Japan Port and Bureau, 2006; Coastal Development Institute of Technology, 2017). By using steelmaking slag (SMS) as a binder, the dredged material is expected to be extensively utilized and capable of supplying needs as an alternative embankment material.

The main purpose of this research is to comprehend the strength development in steelmaking slag treated soft clay (SMSTC) with various elapsed curing time, two levels steelmaking slag addition and four levels of initial water content.

2. Research Method

Dredged material was drawn from Tokuyama Port, Yamaguchi Prefecture, Japan. Steelmaking slag used was provided by JFE steel company with a particle size less than 5mm. DM and SMS basic properties are shown in Table 1.

Primarily, dredged material was filtered using 2 mm sieve to remove shells and other coarse particles. Steelmaking slag was then air-dried in room temperature (20^{o}C) for 1 day to acquire the surface dry density. Artificial seawater with 3.5% salinity was prepared to accustom the field condition. Using a hand mixer, dredged material, steelmaking slag, and artificial water were mixed for 5 minutes. Mixing proportion and curing time in this research are shown in Table 2. A cylindrical tinplate mold (⌀50mm x100mm) for unconfined compression test and a cylindrical plastic mold for vane shear test (⌀60mmx60mm) were adopted in sample preparation. Strength development of mixed material in elapsed curing time was analyzed by conducting the laboratory vane shear test and unconfined compression test to obtain the early low strength and higher strength, respectively. Flow consistency was conducted by using a flow test using a cylindrical mold (⌀80mmx80mm) to attain flow value which very common for non-structural construction e.g. embankment fill or road bases.

Table 1. Properties of dredged material and SMS

Property	**Dredged Material**
Liquid Limit, LL (%)	107.15
Plastic Limit, PL (%)	38.64
Plastic Index, PI (%)	68.50
Particle density, Gs (g/cm^3)	2.647
Coarse-Grained Soil (%)	9.98
Fine-Grained Soil (%)	90.02
Unified Soil Classification System (USCS)	CH-OH
pH	7.2
Ignition Loss, LOI (%)	8.17
Property	**Steelmaking 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
Coarse-Grained Soil (%)	9.95
Fine-Grained Soil (%)	0.50
Free CaO, f-CaO (%)	4.27

Table 2. Mixing proportion and curing time of steelmaking slag treated clay

Normalized water content (w'/LL)	Steelmaking slag* V_{SMS}/V_{DM} (%)	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, 90 (days)

3. Result and Discussion

The strength development of SMSTC in four levels of initial water content ratio to liquid limit (1.2LL, 1.5LL, 1.7LL, and 2.0LL) is shown in Figure 1. It is well denoted that by mixing dredged materials with SMS, a significant development of strength occurs on dredged material with elapsed curing time. Prior to 5 hours of curing time, the strength increment developed relatively low, this inactive zone is commonly known as a “setting time” in the concrete material study, which shown a longer (up to 5 hours) slow rate of hydration reaction compares to cement as a binder. In later curing time, 5-72 hours, the strength increment embodied linear lines and stiff slopes. It is presumed that this phenomenon shows the existence of hydration reaction produced by free CaO contained in steel slag. On curing time more than 72 hours, the development of strength reduced to gentler slopes comparing to 5-72 hours curing time, which is likely implied that the pozzolanic reaction has started.

Variant to initial water content of dredged material and additional of steelmaking slag, the strength of steelmaking slag treated clay increased significantly by adding more steelmaking slag. At the early of curing time, the rapid change in

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the water content of dredged clay after mixing caused the gained strength. The lower water content (3.15% after air-dried) of steelmaking slag absorbed the initial water content of dredged clay which indicates the water content closer or slightly lower than the liquid limit.

After a certain point, this effect is canceled by the chemical reaction happened during the curing time. This could be shown by the mixing proportion of 30%SMS; 2.0LL which initially has a lower strength than 20%SMS; 1.2LL at 0 hours, but has a higher strength after 72 hours curing time.

Generally, those stress-strain curves shown in Figure 2, indicate that the stress-strain curve for SMSTC up to 72 hours curing time show similar behavior to low strength or soft soil. Within elapsed curing time, at >72 hours curing time, stress-strain curve altered into similar to general stiff clay stress-strain curve.

The secant modulus (E_{50}) of each mixed proportion varies with the strength of dredged materials, as shown in Figure 3. Based on the result, the relationship between 2cu or qu and secant modulus can be written in equation (1).

$$E_{50} = 18.16\, q_u^{\,1.3} \qquad (1)$$

where,
E_{50}: Secant modulus of Steelmaking slag treated clay (kN/m^2)
q_u : Compression strength (kN/m^2)

Four levels of the initial water content and additional 20-30% of steelmaking slag tend to form one trendline which is shown that the secant modulus development is not affected significantly by initial water content and the additional of SMS up to 30%.

In Figure 4, flow test result was taken 5 minutes after mixing procedure, is appraised of the SMS and initial water content effect on flow value. It is clearly shown that by giving more addition of SMS to dredged material, the flow test value is decreasing, in contrary, the higher initial water content will increasing the flow value.

4. Conclusion

Steelmaking slag addition gives a significant strength development to dredged material, both a decreasing initial water content and a chemical reaction are found to be the reasons. Three stages are presumed to be part of the SMSTC strength development due to elapsed curing time, a “setting time” which shown a very slow rate of increment, a “high acceleration” stage which is presumed to be derived from the hydration reaction and a “moderate acceleration” stage from the pozzolanic reaction.

An equation for secant modulus determination from q_u is proposed, which apparently, prior to 30% volume addition of SMS, qu/E_{50} development is not affected significantly by SMS addition and level of initial water content.

Flow value of SMSTC is decreased by increasing the volume of steelmaking slag and followed by decreasing the initial water content at the early curing time.

Reference

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Technical manual of steelmaking slag treated soil for Harbour, Airport, and Coastal construction projects, 2017. (In Japanese)

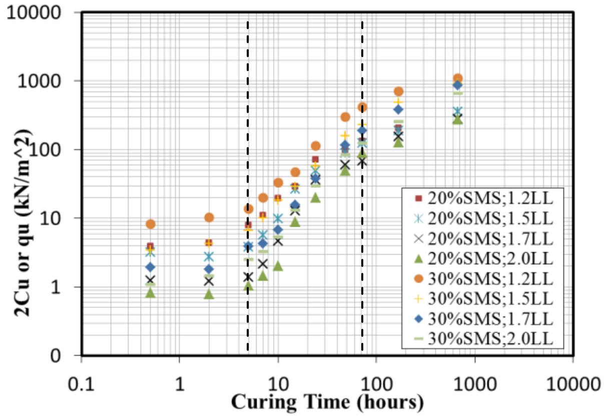

Fig. 1. Compression strength in elapsed curing time

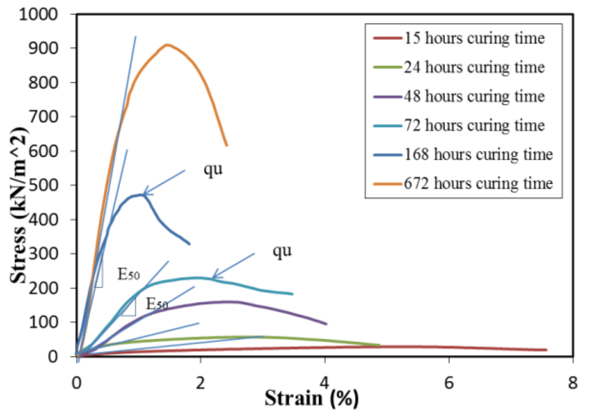

Fig.2. Typical stress-strain of mixed material in elapsed time

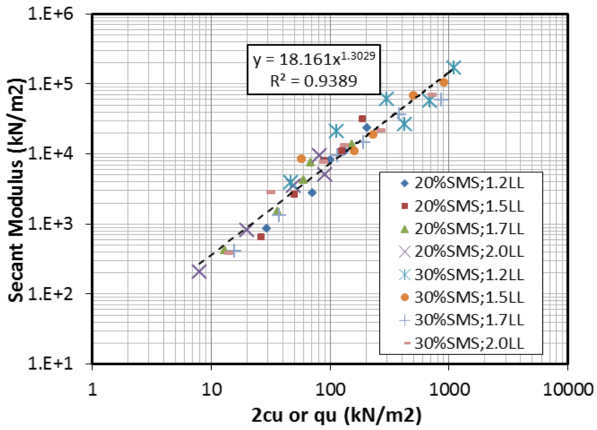

Fig.3. Secant Modulus development in elapsed time

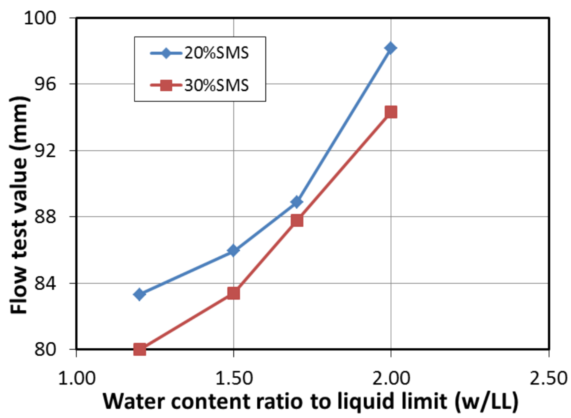

Fig.4. Flow test value to various of initial water content.