Comparison of Strength in Treated Dredged Marine Clay Using Cement and steelmaking slag

Hiroshima University Student member ○ Arlyn Aristo Cikmit
Hiroshima University Member Takashi Tsuchida, Gyeong O Kang
Kanmon Kowan Construction Co., Ltd. Yi Xin Tang
JFE Steel Corporation Member Hideki Honda

1. Introduction

Annually, numbers of wharves in Japan are under maintenance for navigable water depth which induced vast amounts of dredged marine clay. Dredged marine clay is commonly known as dredged material (DM), consists of clayey soils with shell particles and high water content. Through immense of research and field constructions, Portland Cement (PC) has been utilized as a general binder in treated dredged material for embankment raw material or other purposes. Meanwhile, million tons of steelmaking slag as an outcome of steel production process should be well organized and considered as a by-product. Therefore, by applying 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 (Japan Port and Bureau, 2006; Coastal Development Institute of Technology, 2017).

The main research purpose is to understand further the strength development comparison of steelmaking slag and cement as a binder agent in treated soft marine clay with various elapsed curing time.

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	**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
Coarse-Grained Soil (%)	9.95
Fine-Grained Soil (%)	0.50
Free CaO, f-CaO (%)	4.27

Table 2. Comparison between Cement and SMS as the binder (e.g for 1.5LL and 20% binder)

	Cement treated clay	Steelmaking slag treated clay	
Soil = 100gr			
mass (gr)	100.00	100.00	
volume (cm$^{3)}$	37.79	37.79	
Water =1.5LL			
mass (gr)	160.73	160.73	*
volume (cm$^{3)}$	160.73	156.04	
Binder =20%			
mass (gr)	25.00	122.12	**
volume (cm$^{3)}$	7.94	38.77	

*: Artificial water for steelmaking treated clay
**: Calculated using mass and volume ratio

2. Research Method

In comprehending the strength comparison of cement and steelmaking slag as a binder to treated dredged clay, the study of cement treated marine clay (CTC) which was previously performed (Kang et.al, 2017) and the new data from steel making slag treated clay (SMSTC) were evaluated by using the same dredged marine clay. A brief explanation of research methodology for steel making slag treated clay is described.

Dredged marine clay was collected from Tokuyama Port, Yamaguchi Prefecture, Japan. Steelmaking slag, less than 5mm in granular size, was provided by JFE steel company. Engineering properties of dredged marine clay and steelmaking slag are shown in Table 1. Dredged material was separated from other course particles e.g. shells or coral reef using 2 mm sieve and properly kept to avoid water loss. Steelmaking Slag was air-dried in room temperature (20^{o}C) for one day to acquire the dry surface density. Artificial seawater was prepared to accustom the field condition (3.5% salinity). Dredged material, steelmaking slag, and artificial water are manually blended using a hand mixer for 5 minutes to achieve a homogeneous mixture. Mixing proportion and curing time schedule are shown in Table 2 and 3. 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 the mixture was analyzed by conducting the laboratory vane shear test (JGS 1441-2012) and unconfined compression test (JGS 0511-2014) to obtain the early low strength and higher strength due to elapsed time, respectively.

3. Result and Discussion

It is well ascertained (shown in Figure 1.a) that by mixing dredged materials with SMS, a significant development of strength occurs on dredged material with elapsed curing time. However, the strength developed relatively low up to 5 hours of curing time, in the concrete material study, this inactive zone is commonly known as a “setting time”. Unlike steelmaking slag treated clay which shown a longer slow rate of hydration reaction, as it can be seen in

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Address: 〒739-8527 東広島市鏡山 1-4-1 広島大学大学院工学研究科 社会基盤環境工学専攻 事務室
TEL：082-424-7819・7828

Table 3. 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)

Figure 1.b, cement treated dredged clay shows almost no inactive zone (except for 1.5LL, c=10%). In later curing time, 5-72hours, both the strength increment formed linear lines and steep slopes in cement and steelmaking slag treated clay. For the similar initial water content (w_0=1.5LL), 30% addition of steelmaking slag has gained a slightly higher value of strength to 10% addition of cement. At more than 72 hours of curing time, the strength development of both CTC and SMSTC are reduced to gentler slopes comparing to 5-72 hours curing time. It is also found that the average line of both strength increment of CTC and SMSTC at >72 hours show two parallel lines which are likely implied that the pozzolanic reaction has started for both CTC and SMSTC. 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, similar behavior to cement treated dredged clay.

Figure 2a. shows that four levels of the initial water content 1.2-2.0LL and additional 20-30% of steelmaking slag are possibly represented by one trendline which is indicated that the strength/secant modulus (q_u/E_{50}) development is not significantly affected by initial water content and the additional of SMS. Similar to Steelmaking Slag treated clay, in figure 2.b qu/E50 development for cement treated dredged clay is also not affected by variation of initial water content and cement addition.

Using combined data from figure 2a (steelmaking slag treated clay) and figure 2b (cement treated clay), the secant modulus (E_{50}) of Portland cement and steelmaking slag as the binder to treated dredged clay varies with the strength of dredged materials. It could be delineated as a red dashed line, as shown in figure 3. Based on the result, the relationship between 2cu or qu and secant modulus can be written in equation (1).

$$E_{50} = 28.36\, q_u^{\ 1.18} \qquad (1)$$

where,
E_{50}: Secant modulus of PC or SMS treated clay (kN/m^2)
q_u: Compression strength of each binder treated clay (kN/m^2)

4. Conclusion

Similar to Cement treated clay, Steelmaking Slag addition also gives a significant strength development to dredged marine clay, 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. Meanwhile, in CTC, there are only two stages i.g. early and later stages of curing time.

An equation for secant modulus determination from q_u is proposed, which apparently, prior to 30% volume addition of SMS, qu/E_{50} development shows a similar development to cement treated dredged clay.

Reference

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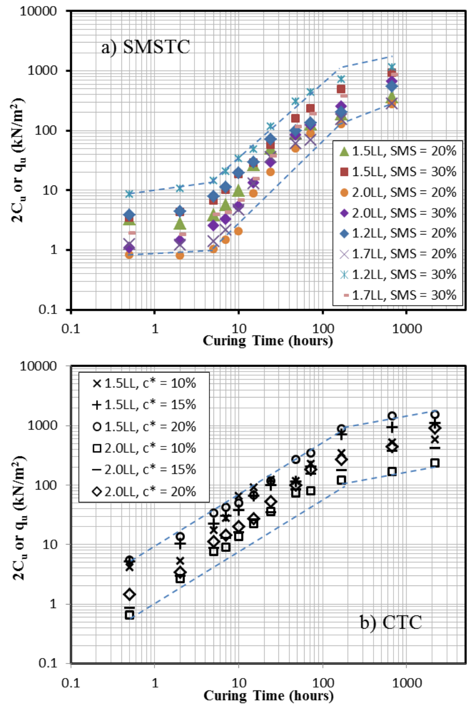

Figure 1. Strength comparison between a) Steelmaking slag treated clay and b) Cement treated dredged clay.

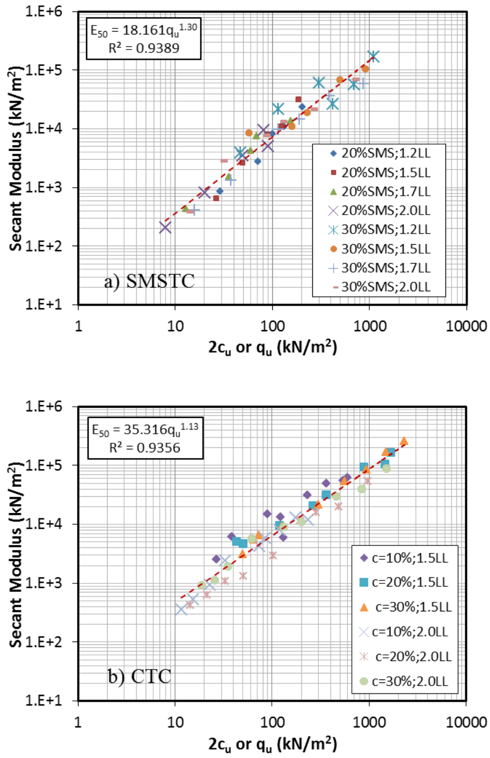

Figure 2. Relationship between $2c_u$ or q_u with secant Modulus a) SMSTC and b) CTC

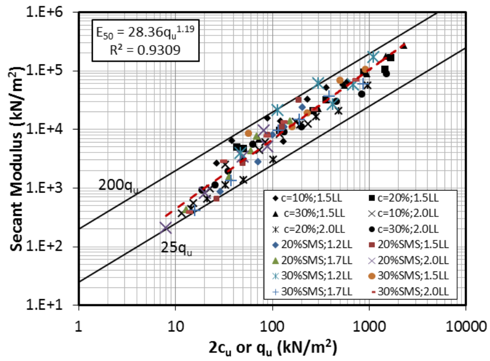

Figure 3. Secant modulus of SMSTC and CTC combination