Effect of Different Grain-sizes in Soft Soil Stabilization Using Basic Oxygen Furnace (BOF) Slag

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1. Introduction

In Japan, utilizing the BOF slag (a by-product of steel manufacturing) to stabilize soft soils often confronts problems such as an inconsistency of strength between laboratory result and the field construction. This is due to the different grain-sizes between the sample in the laboratory and the field. This study aims to comprehend the effect of different grain-sizes of BOF slag in the stabilization of soft soils.

Physical properties of both soft soil and BOF slag were initially investigated. Two types of strength test were conducted on the BOF slag-treated soft clay with various grain-size distributions (GSD); an unconfined compressive (UC) test and a laboratory vane shear (LVS) test. Also, the unit weight of the stabilized soft soil was recorded.

The results indicated that the unit weight of the stabilized soil was drastically increased due to the high relative density of the BOF slag. The different GSD caused a significant effect on the strength development of BOF slag, the strength ratio of the stabilized soil with GSD less than 4.75 mm (commonly used in laboratory) and less than 37.5 mm (commonly used in a field construction), ($S_{u(4.75)}/S_{u(37.5)}$) is 3.6.

Table 1. Physical properties of the soft soil and the BOF slag

Property	Value
Liquid limit, (w_L) %	107.2
Plastic limit, (w_P) %	38.6
Plastic index, (*PI*) %	68.5
Particle density, (*Gs*) g/cm^3	2.65
Coarse-grained Soil (>75 μm), %	9.9
Fine-grained size (<75 μm), %	90.0
Unified Soil Classification System (USCS)	CH-OH
pH	7.2
Ignition loss, (*LOI*) %	8.2
Basic Oxygen Furnace slag	**Value**
Initial moisture content, %	8.4
Average of specific gravity, g/cm3	3.15
Specific gravity of coarse aggregate <4.75 mm	2.96
Specific gravity of fine aggregate <4.75 mm	3.23
Largest size of aggregate, mm	37.5
Coarse-grained size (>75 μm), %	89.5
Fine-grained size (<75 μm), %	10.5
Free CaO, (f-CaO), %	8.49

Table 2. Curing time and mix proportion of the study.

Normalized clay water content (w/w_L)	R_{BOF} (%)	Maximum particle size	Curing Time
1.5 (160.72%)	20, 30	<0.89mm, <2mm, <4.75mm, <9.5mm	0.5h, 2, 5, 7, 10, 15 (hours) 1, 2, 3, 7, 28, 90 (days)
1.5 (160.72%)	20, 30	<37.5mm	0.5h, 2, 5, 7, 10, 15 (hours) 1, 2, 3, 5, 7, 14, 28, 90 (days)
1.5 (160.72%)	30	0.85-9.5mm, 2-9.5mm, 4.5-9.5mm 9.5-37.5mm	1, 3, 7, 28, 90 (days)

2. Research Method

The soft clay used in this study was drawn from Tokuyama Port, Yamaguchi Prefecture, Japan. The Basic Oxygen Furnace (BOF) slag was provided by JFE steel company with a particle size less than 37.5 mm. The physical properties of the soft clay and the BOF slag are summarized in Table 1.

The soft clay was sifted using 2 mm sieve to eliminate the coarse particles.

BOF slag was air-dried in room temperature (20^{o}C) for one day. The grain size distribution (GSD) of BOF slag was arranged by sieving into the ranges shown in Table 2.

Artificial seawater with 3.5% salinity was prepared to acquire the 1.5 w_L of clay initial water content.

The soft clay, the BOF slag, and artificial water were mixed for 5 minutes using a heavy-duty mixer. Mixing proportion 20-30% shown in Table 2 was determined using Equation 1 below:

$$R_{BOF} = \frac{V_{BOF}}{V_{soil} + V_{water} + V_{BOF}} \times 100 \qquad (\%) \qquad \text{(Eq.1)}$$

where V_{BOF} is the solid volume of BOF slag, V_{soil} is the solid volume of soil, and V_{water} is the volume of water.

3. Result and Discussion

The unit weight of soft soil was significantly increased by mixing with the BOF slag. The rate addition of 20-30% increased the unit weight of the stabilized soil to 16.4-18.72 kN/m^3. The different GSD exhibited the different unit weight where the smaller maximum size produced a less heavy unit weight. The unit weight ratio between 30% and 20% of BOF addition rate, $\gamma_{(RBOF=30)}/\gamma_{(RBOF=20)}$ is 1.1 for every type of GSD.

Keywords Dredged material, soft clay, steelmaking slag, strength development, Soil improvement
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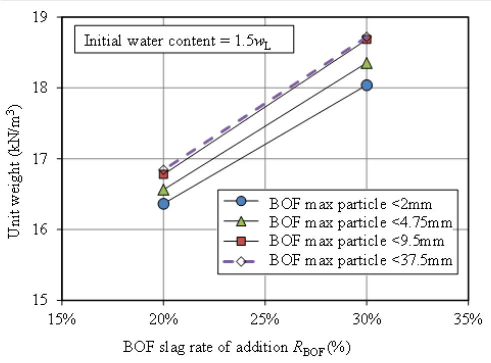

Figure 1. Unit weights of the stabilized soil with different grain size distributions (GSD).

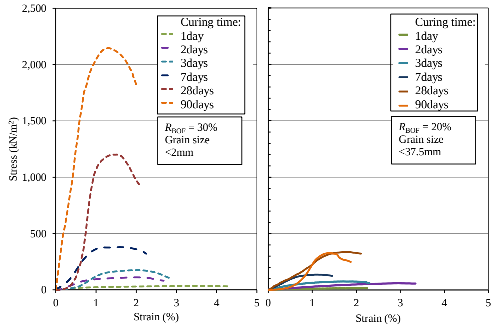

Figure 2. Stress-strain curves of the stabilized soil with GSD 2 mm and 37.5 mm (UC tests).

The stress-strain curves of stabilized soil obtained using UC test at 0.5 h - 90 d of curing time are shown in Figure 2. The nature of stabilized soil with GSD 2 mm changed with time; at the early curing time the stabilized soil behaved similar to soft soil, later, at 28 and 90 d of curing time, the stabilized soil behaved close to stiff soil behavior. Figure 3 shows the strength of stabilized soil with different grain size distribution (0-2, 0-0.89, 0-4.75, 0-10, and 0-37.5 mm) as a function of curing time. Despite the different GSD, the strength development of stabilized soil can be de divided into three zones of strength increment; an inactive zone (0-10 h), high accelerated zone (10 h-7 d) and moderate accelerated zone (more than 7 days). The results agreed with previous study[1].

The strength of stabilized soils with BOF slag was significantly affected by the different grain-sizes distribution. Figure 4 shows the stress strength of stabilized soil with the 30% BOF addition rate as a function of different maximum grain-sizes. At 7 d curing time the stabilized soil with GSD 0.89, 2, 4.75, 10, and 37.5 mm had 761.6, 369.3, 340, 341, and 136.4 kN/m^3 stress strength, respectively. At 28 d curing time the stabilized soil with GSD 0.89, 2, 4.75, 10, and 37.5 mm had 1884, 1163.7, 1093.7, 1083.6, and 338.4 kN/m^3 stress strength, respectively. At 90 d the strength of stabilized soil with GSD 0.89, 2, 4.75, 10, and 37.5 mm increased to 2449.3, 2015.2, 1838.6, 1886.6, and 477.5 kN/m^3, respectively. These results suggest that a smaller max GSD produced higher stress strength of soil mixture.

Figure 5 shows the relationship between stress strength of the stabilized soil and its secant modulus of elasticity. Data of various initial content and free lime were also included in the analysis. From the results, the secant modulus (E50) of stabilized soil can be predicted by the stress strength obtained from UC test as $E_{50} = 88.5q_u$, despite the free lime content of BOF slag, clay initial water content or BOF grain-size distribution.

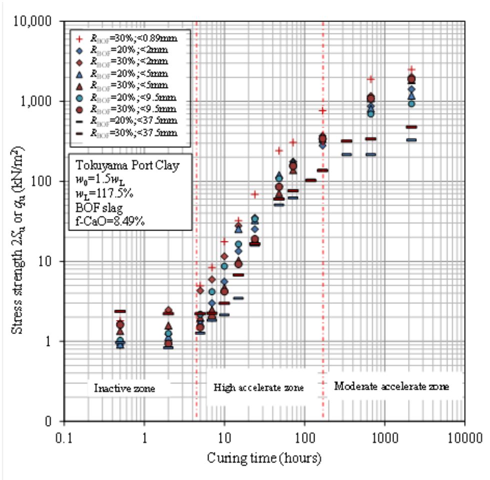

Figure 3. Strength development of the stabilized soils with different GSD.

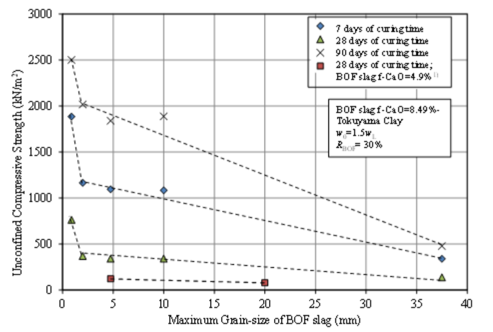

Figure 4. Stress strength of the stabilized soils as a function of various grain-size distributions at 7, 28 and 90 days of curing time.

4. Conclusion

Despite the different GSD in this study, the strength development was found to be similar to the previous study[1]. Our results indicated that the different grain-size distribution affected the unit weight, the stress-strain behavior, strength development of the stabilized soil with BOF slag. The stabilized soil with smaller GSD produced higher strength than the larger GSD; this is probably due to the different surface area owned by each GSD.

The secant modulus of stabilized soil can be predicted as $E_{50} = 88.5q_u$ from the UC test.

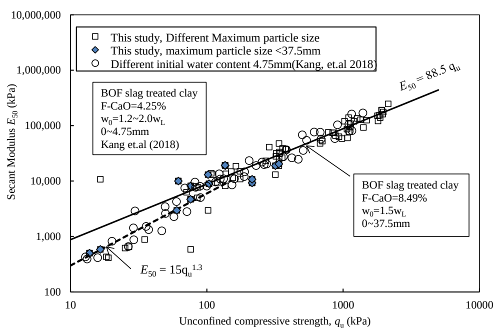

Figure 5. the relationship between qu from UC test and secant modulus of stabilized soils with various initial water contents, free lime contents, and GSD

Reference

[1]Sato, H., Nishimura, S., Toda K., Sato, S., Arai, Yu. (2016). “Characteristic and Interpretation of Development of Strength and Stiffness for Early-Age Calcia-Stabilized Dredged Soils”. Hokkaido Site Engineering Society, Technical report No.56, pp 15-20.

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