Strength Characteristics of Stabilized Dredged soil and Correlation with Index Properties

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SYNOPSIS : A geo-composite soil (GCS) is a stabilized mixture of bottom ash, cement and dredged soil. Various samples with different mass ratios of mixtures were tested under curing time of 7 and 28 days to investigate physical properties and compressive strength. This paper focused on the effect of bottom ash on the strength characteristics of Busan marine dredged soil. Cement has been added as an additive constituent to enhance self-hardening of the blended mixture. The unconfined compressive strength of GCS increases with an increase in curing time due to pozzolanic reaction of the bottom ash. The strength after 28 days of curing is found to be approximately 1.3 to 2.0 times the strength after 7 days of curing, regardless of mixture conditions. The secant modulus of GCS is in the range of 55 to 134 times the unconfined compressive strength. The correlation of unconfined compressive strength with bottom ash content and initial void ratio are suggested.

Keywords : Mixture, bottom ash, correlation, initial void ratio.

1. Introduction

Recently, recycling of dredged soil and bottom ash becomes an important issue for building a sustainable society. Dredged soil, which has obviously very low strength and high compressibility, are generated from restoring under water environment in costal and low-land regions. Bottom ash remains approximately 8 to 9 % of the total ash at the bottom of the coal-fired boiler after coal combustion (Sell et al., 1989). There is a lot of studies on the soil stabilization by using cement (Feng et al., 2001, Udin et al., 1997). It is more resonable to use a less cement content for stabilization of dredged soil due to its high cost. In order to improve the strength of stabilized soil, a good way is to add bottom ash into mixtures (Kim et al., 2009). Bottom ash has been reused as replacements to various construction materials such as cement binder, aggregate, natural sand, and road construction material because of its particle size distribution characteristics.

In this study, geo-composite soil (GCS) consists of dredged soil, bottom ash, cement which can improve the mechanical characteristics of natural dredged soils. The first part of this paper concentrates on the strength characteristics of stabilized dredged soil in term of recycling bottom ash and dredged soil. Secondly, a correlation of unconfined shear strength with bottom ash content and initial void ratio of mixtures is suggested.

2. Experimental Program

2.1 Material for testing

The geotechnical properties of the dredged soil, taken from the construction site of Busan New Port, Korea, are shown in Table 1. The natural water content of the dredged soil is 54.7 % and its plasticity index about 20.7. The dredged soft clay is mostly classified as CL according to the Unified Soil Classification System.

Table 1. Properties of dredged soil

Water content (%)	Liquid limit (%)	Plastic Limit (%)	Specific Gravity	Percent passing No. 200 sieve (%)	USCS
54.7	39.2	18.5	2.7	81.2	CL

As an additive agent, ordinary Portland cement was used in this study. The bottom ash was added into soil mixture in an attempt to increase shear strength. It was taken from a power plant in Samchunpo, Korea and the particles of gravel size were screened through a standard No. 4 sieve. The particle - size distribution of bottom ash, cement and dredged soil are presented in Fig. 1.

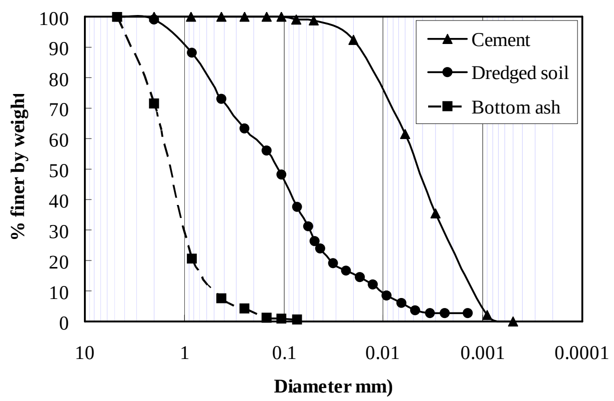

Fig. 1. Grain size distribution of material used

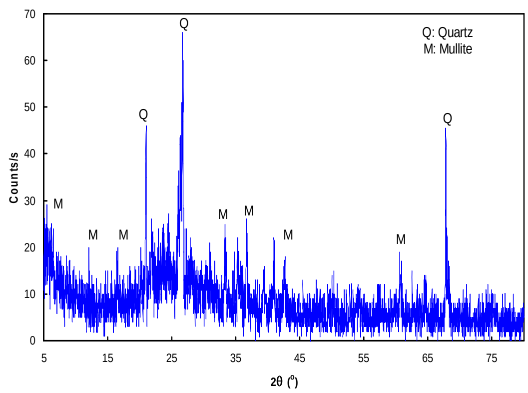

Fig. 2. X-Ray Diffractogram of bottom ash

It is found that the characteristics of the particle - size distribution of the bottom ash appear as poorly graded sand. The specific gravity of bottom ash was determined to be approximately 2.0. As of the chemical composition, the bottom ash contains 59.48 % SiO_2, 20.49 % Al_2O_3, 8.96 % Fe_2O_3, and 4.69 % CaO as shown in Table 2. The X-ray diffractogram of bottom ash was also conducted and the results are presented in Fig. 2. The figure shows the presence of a mica phase with major crystalline phases of quartz at intensity of $2\Theta = 27°$, secondary glassy phase is mullite at $2\Theta = 32°$ where Θ represents the angle of the incident X-ray to atomic planes (Mitchell, 1993).

Table 2. Chemical composition of cement and bottom ash

Oxide component (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Na_2O	SO_3
Cement	20.9	5.67	2.74	62.5	3.36	0.5	1.05	0.14	2.34
Bottom ash	59.48	20.49	8.96	4.69	3.48	1.51	0.86	0.56	0.31

2.2 Specimen preparation and testing

To evaluate the effect of bottom ash content on the strength of mixture, test specimens were prepared at 5 different percentage of bottom ash contents (i.e. 0 to 100% at 25 % intervals) while water content and cement content are fixed as shown in Table 3.

Table 3. Mixing ratio

Mixing condition	Cement (%)	Water content (%)	Bottom ash (%)	Curing time (days)
Content (%)	20	120	0, 25, 50, 75, 100	7, 28

With this water content, the mixture has a reasonable workability with the flow value in range of 20±5cm (Kim et al., 2009), each specimen can be poured into PVC mold with the 50mm diameter and 100mm height without compaction effort. The mold together with specimen was wrapped to prevent moisture loss, and then placed for curing inside the room having a temperature of 20±5°C for 7 and 28 days. After curing, each specimen was removed from its mold, carefully checked the unit weight and then was subjected to unconfined compression test with strain rate of 1.0 mm/min.

3. Experimental results and discussion

3.1 Initial void ratio of mixtures (e_{0m})

The initial void ratio for mixture after curing time can be expressed as follows:

$$e_{0m} = \frac{G_{s,m}(1+w_m)\gamma_w}{\gamma_m} - 1 \qquad (1)$$

Where $G_{s,m}$ = the specific gravity of mixture; γ_m = unit weight of mixture; w_m = water content of mixture after curing

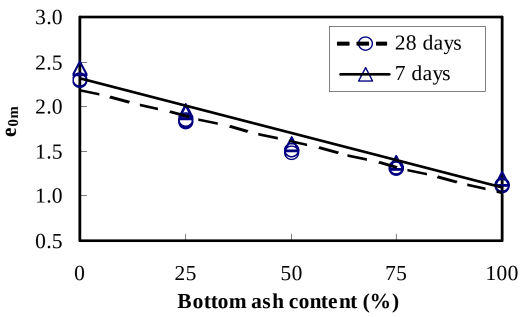

Fig. 3. Change of e_{0m} with BA and curing time

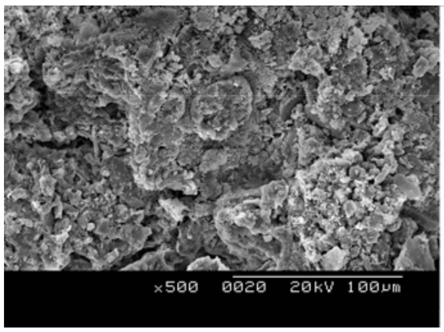

Fig. 4. SEM photos of BA=100% at 28 days

Fig. 3 shows that initial void ratio of the mixture significantly decreases with increasing bottom ash content and slightly decreases with curing time. This can be seen in Fig 4, in which SEM photos shows the good evidence for the increase of bond strength due to the positive effect of pozzolanic reaction with curing time when more bottom ash is used.

3.2 Stress-strain behaviors of unconfined compression test

The stress-strain behaviors of samples cured at 7 and 28 days are presented in Fig. 5. In this figure, the symbols with the same shape correspond to specimens with the same bottom ash content, and the filled and unfilled symbols mean 7 days, and 28 days of curing time, respectively.

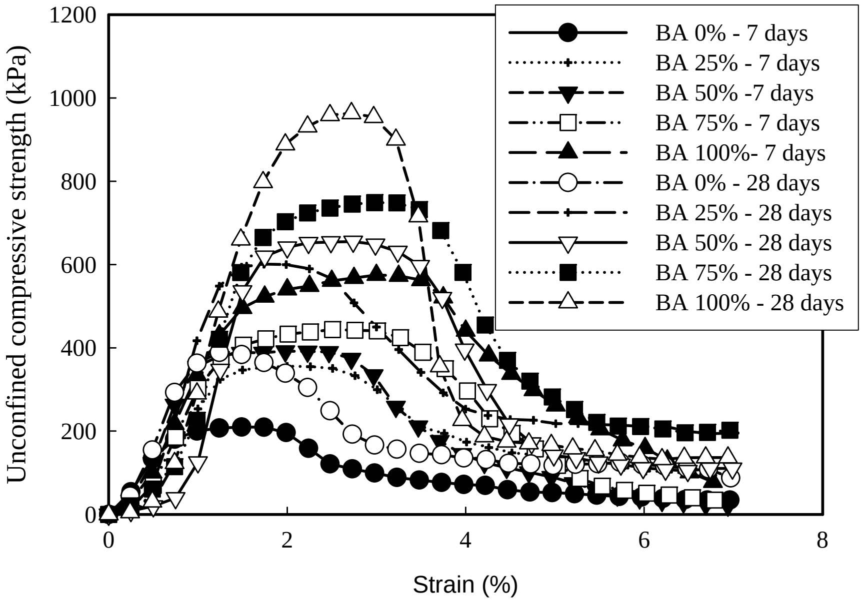

Fig. 5. Stress-strain relationship with various bottom ash contents and curing time

As observed in the figure, the maximum compressive strength of GCS increases with increase in bottom ash content. These results are similar to results of Kim et al. (2009). The increase in shear strength due to addition of bottom ash can be explained mainly by two mechanisms. First, frictional resistance between granular materials in the soil mixture can cause a greater resistance against shear. Second, the pozzolanic reaction in the mixture can mobilize more bond strength.

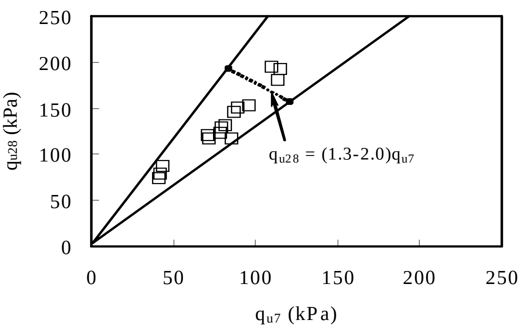

Fig. 6. Normalized compressive strength (q_{u28}/q_{u7}) as a function of curing time

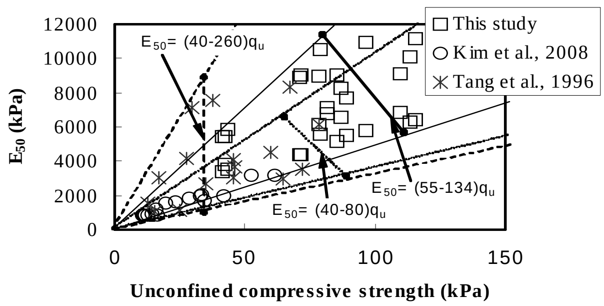

Fig. 7. Relationship between the secant modulus and unconfined compressive strength

The relationship between unconfined compressive strengths after 7 and 28 days of curing time, q_{u28} and q_{u7} is shown in Fig. 6. The unconfined compressive strength after 28 days of curing is 1.3 to 2.0 times the strength after 7 days of curing, regardless of mixing conditions. This trend is consistent with the results of laboratory tests conducted by Kim et al. (2008) on the lightweight soil with bottom ash added.

3.3 Secant modulus (E_{50})

As observed in Fig. 7, E_{50} of the stabilized soils for all mixtures was markedly improved with curing time. An increase in deformation modulus with curing time implies that the soils with high plasticity were changed into materials with high rigidity. For example, with 100% bottom ash content at 28 days, the mixture could obtain greater E_{50} value of approximately 11.000kPa, which was equivalent to dense sand, because of the roughness of large particle size of bottom ash. The results of this study present that E_{50} = (55 -134)q_u, which is greater than those previously suggested by Kim et al. (2008) and within that of Tang et al. (1996). It could also be concluded that E_{50} was developed similarly to strength development for the addition of bottom ash.

4. Correlation with bottom ash content and initial void ratio

The essential role of initial void ratio (e_{0m}) and bottom ash content (BA_i, %) will be emphasized on the strength development of GCS. Lorenzo and Bergado (2004) found a good relationship for cement-admixed Bangkok clay based on ratio of after-curing initial void ratio to cement content for all curing times. But in this study, it is found that with the addition of bottom ash content, the strength of mixture is significantly enhanced with bottom ash content as well as curing time. The relationship at each curing time is established as shown in Fig. 8 and equation 2:

$$q_u(kPa) = \begin{cases} -0.032\left(\frac{BA_i}{e_{0m}}\right)^2 + 6.46\left(\frac{BA_i}{e_{0m}}\right) + 237.04 & at\ 28 days \\ -0.012\left(\frac{BA_i}{e_{0m}}\right)^2 + 6.61\left(\frac{BA_i}{e_{0m}}\right) + 439.71 & at\ 7 days \end{cases} \quad (2)$$

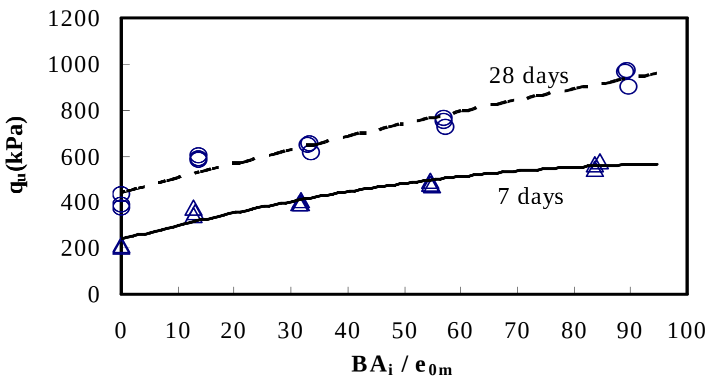

Fig. 8. Relationship between q_u and BA_i/e_{0m} with curing time

It is apparent that strength increases as a value of BA_i/e_{0m} ratio increases. Based on the curve fitting by the method of least squares, the data for mixtures at specified curing times of 7 days agree well with the polynomial functions while the correlations of mixtures cured at 28 days can be either linear or polynomial function. It can be implied that, for the long-term of curing time, the strength increase significantly with the pozzolanic reaction due to the addition of bottom ash.

5. Conclusion

1. Initial void ratio decreases with increases of bottom ash and curing time because the more pozzolanic reaction was formed with more bottom ash.

2. The unconfined compressive strength of GCS increases with increase in bottom ash content and curing time. The strength after curing 28 days is found to be approximately 1.3 to 2.0 times the strength after 7 days of curing, regardless of mixing conditions. The increase in shear strength is caused by the development of the friction at the interface of mixture component and the bond strength due to pozzolanic reaction of bottom ash.

3. The secant modulus of GCS is in the range of 55 to 134 times the unconfined compressive strength. The increase in deformation modulus with curing time implies that the soils with high plasticity were changed into materials with high rigidity due to the reinforcing effect of bottom ash.

4. The prediction on strength could be accomplished using the proposed correlations with the predetermined bottom ash content at the mixing condition, accompanied with the initial void ratio checked after curing (e_{0m}). This relationship shows a good way to characterize the strength of stabilized dredged soil in terms of bottom ash content and initial void ratio, which is similar to the approach of Lorenzo and Bergado (2004).

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