Experimental study on mechanical characteristics of composite geo-material for recycling dredged soil and bottom ash

L'étude expérimentale sur les Caractéristiques Mécaniques de Géo-matière Composite pour Recycler le Sol Dragué et les Cendres lourdes

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ABSTRACT

The experimental results of composite geo-material indicated that the stress-strain relationship and the unconfined compressive strength are strongly influenced by mixing conditions such as air-foam content and bottom ash content. Maximum compressive strength of CGM increased with an increase in cement content, but decreased with an increase in air-foam content. Most of the failure types of specimens were general shear failure. Bulging failure, however, was shown in the specimen with high air-foam content. It was observed that the compressive strength as well as the stiffness of composite geo-material increased by adding bottom ash due to angular shape of bottom ash and the pozzolanic reaction in the mixture. The 28-day strength of composite geo-material was 1.5~2.3 times higher than the 7-day strength. The moist unit weight strongly depended on air-foam content as well as bottom ash content added to the composite geo-material. In composite geo-material, secant modulus (E_{50}) also increased as its compressive strength increased due to the inclusion of bottom ash. Secant moduli of CGM were in the range of 185 to 480 times the value of unconfined compressive strength. The stiffness of CGM was greater than that of unreinforced lightweight soil due to the reinforcing effect of bottom ash.

RÉSUMÉ

Les resultants expérimentaux de géo-matière composite ont indiqué que le rapport d'effort de tension et la force ouverte de compresseur sont fortement sous l'influence des conditions se mélangeant comme le contenu de mousse aérienne et le contenu de cendres lourdes. La force maximum de compresseur de CGM a augmenté avec une augmentation dans le contenu de ciment, mais a diminué avec une augmentation dans le contenu de mousse aérienne. La plupart des types d'échec d'exemplaires étaient l'échec de tondage général. L'échec étant gonflé, pourtant, a été montré dans l'exemplaire avec le haut contenu de mousse aérienne. Il a été remarqué que la force de compresseur aussi bien que la raideur de géo-matière composite augmentée en ajoutant des cendres lourdes en raison de la forme angulaire de cendres lourdes et de la réaction pozzolanic dans la mixture. La force de 28 jours de géo-matière composite était 1,5-2,3 fois plus haut que la force de 7 jours. Le poids d'unité moite a fortement dépendu du contenu de mousse aérinne aussi bien que le contenu de cendres lourdes ajouté à la géo-matière composite. Dans la géo-matière composite, le module secant (E50) a aussi augmenté comme sa force de compresseur a augmenté en raison de l'inclusion de cendres Lourdes. Les modules sécants de CGM étaient dans la gamme de 185 à 480 fois la valeur de force ouverte de compresseur. La raideur de CGM était plus grande que ce de sol léger non renforcé en raison de l'effet renforçant de cendres lourdes.

Keywords : Recycling, Dredged soil, Bottom ash, Composite geo-material

1 INTRODUCTION

Recycling industrial wastes and by–products has been one of most important subjects in sustainable construction applications for past few decades. Examples of most commonly recycled wastes include old tire, dredged material, and fly and bottom ash. The appropriate use of recyclable wastes in construction not only provides an environmentally friendly practice, but also brings a cost saving element to a project.

Recently in Korea, during construction of large-scale ports and harbors such as Busan New Port, a large amount of soft soil has been dredged from construction sites in order to remove siltation in navigation channel or restore marine environment (Kim et al., 2008). Most of the dredged material is clayey soil with high water content which normally is too soft to be reused for backfilling material without proper treatment. In practice, the dredged soil has been dumped in waste disposal sites in the sea. This practice, however, is not environmentally friendly, and therefore there has been increasing social demands to reuse the dredged soil in construction projects.

A number of studies and applications have been conducted on reusing dredged soil as a construction material. Lightweight soil is one example of recycled dredged soils that the research focus has been given to until recent days (Tsuchida, 1995; Tsuchida et al., 1996; Otani et al., 2002; Tsuchida and Kang, 2002; 2003; Watabe et al., 2004).

In addition, coal ash is a by-product from the combustion of coal for power generation. The amount of the production of coal ash has risen at fast rate because the demand for energy has been increasing due to economic growth and industrial development. During the combustion process, different types of coal ash, fly and bottom ashes, are produced. Bottom ash remains at the bottom of the coal-fired boiler after coal combustion; fly ash is transported from the combustion chamber by exhaust gases. Bottom ash is a coarse, granular material in contrast to the very fine structure of fly ash. In was reported that, in general, approximately 8 to 9 % of the total ash generated is bottom ash (Sell et al., 1989). 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 (Ghafoori and Buchloc, 1996; Churchill and Amirkhanian, 1999; Andrade et al., 2007; Bouvet et al., 2007; Pan et al., 2008). Kumar and Stewart (2003) conducted laboratory tests to investigate the geotechnical engineering characteristics of

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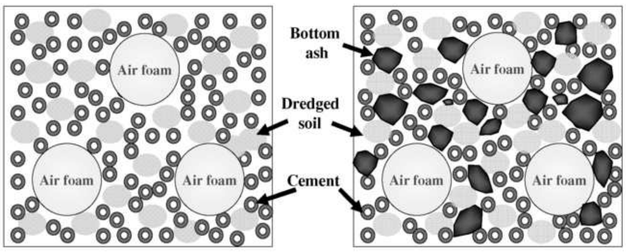
bottom ash–bentonite mixtures. Bottom ash mixtures can also be applied to highway embankment as construction materials (Kim et al., 2005).

This paper investigates the mechanical characteristics of composite geo-material (CGM) which was developed to reuse both dredged soil and bottom ash at the same time. Composite geo-material is one of cement-treated lightweight soil with a light unit weight and high shear strength. A composite geo-material used in this experiment consists of dredged soil, cement, air-foam and bottom ash. Dredged soil was taken from construction site of Busan New Port and bottom ash was a by-product generated at the Samchunpo thermal power plant, Korea. Several series of laboratory tests were performed to investigate behavior characteristics of composite geo-material, in particular the reinforcing effect by mixing bottom ash.

2 COMPOSITE GEO-MATERIAL (CGM)

Lightweight soil usually consists of dredged clayey soil, cement, and lightening material, as illustrated in Figure 1 (a). The unit weight of lightweight soil is very low, typically 6 to 15 kN/m^3, due to incorporation of air-foam into soil mixtures, while maintaining required shear strength. Because of its characteristics, lightweight soil makes a useful backfilling material regardless of its cost. Lightweight soil is relatively homogeneous compared to natural soil and its density can be adjusted by varying the amount of air-foam mixed with soil. However, the proper density may not be achieved due to defoaming of the air-foam before hardening or the water pressure during underwater curing (Tsuchida and Egashira, 2004). The shear strength of lightweight soil greatly depends on the amount of cementing agent added. The more cementing agent that is added to the mixture, the greater its unconfined compressive strength (q_u) is (Tsuchida and Egashira, 2004). In order to increase the shear strength of lightweight soil, bottom ash is added as shown in Figure 1 (b) resulting in the CGM composed of dredged soil, cement, air-foam and bottom ash.



(a) Lightweight soil (b) Composite geo-material

Figure 1. Conceptual diagrams of lightweight soil and composite geo-material

3 EXPERIMENTAL PROGRAM

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	2.60	81.2	CL

As a cementing material, ordinary Portland cement was used in this study. The protein type of the foaming agent was used as a lightening material. The bottom ash was added into lightweight soil 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. It is noted 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 49.8 % SiO_2, 18.2 % Al_2O_3, 10.4 % Fe_2O_3, and 13.9 % CaO.

Table 2 shows mixing conditions of experimental tests. The bold number in the Table represents the reference mixing condition. In order to observe the effect of content of air-foam, or bottom ash on the characteristics of the CGM, each admixture content was modified to the value specified in the table during mixing stage while keeping other admixtures contents as the reference values. 20% cement was uniformly added into the soil mixture. The water content was 120 %. The air-foam content varied from 0 to 3 %. To evaluate the reinforcing effect by bottom ash on the strength of CGM, bottom ash was uniformly mixed at five different contents (0, 25, 50, 75 and 100 %). All the values of admixture contents presented represent the ratio of the weight of corresponding admixture to the dry weight of untreated soil. To investigate bulk unit weight, stress-strain behavior, compressive strength and secant modulus under each mixing condition, each specimen was cured for 7 or 28 days and analyzed through laboratory tests. For curing, the slurried mixture was placed into a mold with a diameter of 72 mm and height of 148 mm and cured for specified period at a temperature of 20±2°C.

Table 2. Mixing and testing conditions

Admixture	Content (%)
Cement content, Ci	**20**
Water content, Wi	**120**
Air foam content, Ai	0, 1, **2**, 3
Bottom ash content, BAi	0, 25, 50, 75, **100**

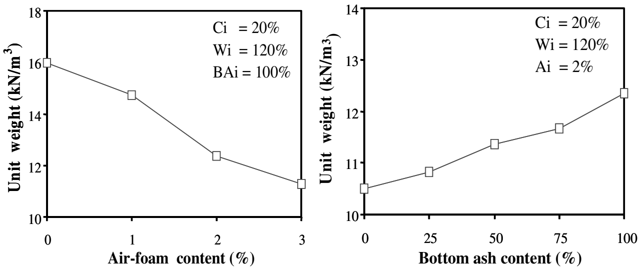
4 EXPERIMENTAL RESULTS

4.1 *Bulk unit weight*

Figure 2 shows the bulk unit weight of CGM as a function of the percentage of admixtures. Test results in Figure 2 show that the value of the bulk unit weight greatly decreases from 16.0 to 10.7 kN/m^3 while air-foam content changes from 0 to 3 % because small content (in weight) of air-form generates considerable volume of void. However, the value of the bulk unit weight increases from 10.5 to 12.4 kN/m^3 for bottom ash content increasing from 0 to 100 %. Experimental results indicated that the bulk unit weight of CGM strongly depends on the air-foam content of the soil mixture. The bulk unit weight can also be affected much by bottom ash because the range of the bottom ash content tested (or applicable in practice) is wide considering it is a by-product.

4.2 *Stress-strain behavior*

The stress-strain behaviors and failure types of CGM specimens with various admixture conditions are presented in Figure 3. The compressive stress of CGM tends to increase with increase in axial strain up to a peak. After reaching the peak stress, strain softening occurs that the unconfined compressive stress decreases with increasing axial strain.

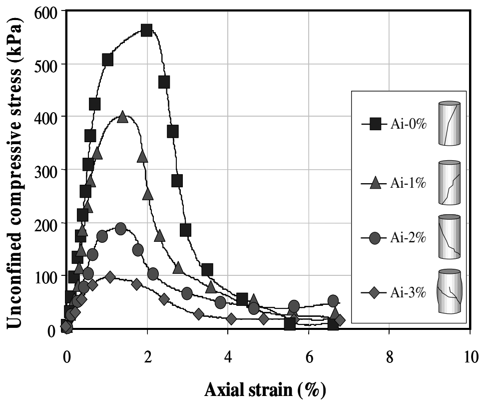


(a) Air foam content (b) Bottom ash content

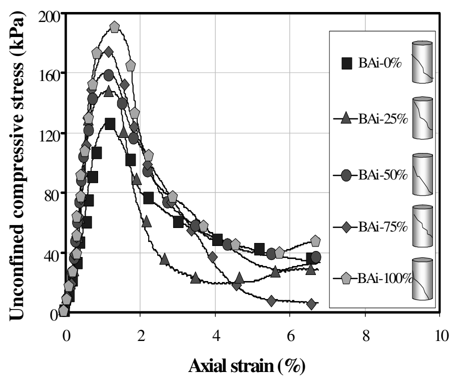
Figure 2. Bulk unit weight with various mixing conditions

From Figure 3(a), it can be observed that both the unconfined compressive strength and the initial slope of stress-strain curve of CGM decrease with increases in air-foam content. Most of the specimens experienced general shear failure which is common for cement-treated soil. However, buldging failure was observed for the specimen with high air-foam content as illustrated in the figures.

Figure 3(b) shows stress-strain relationships and failure types of CGM specimens with various bottom ash contents. All the specimens had general shear failure in this case. As observed in the figure, the maximum compressive strength of CGM increases with increase in bottom ash content. The increase in shear strength due to addition of bottom ash can be explained mainly by two mechanisms. First, the development of friction between granular materials in the soil mixture can mobilize better resistance against shear. Second, the pozzolanic reaction in the mixture can cause more bond strength.



(a) Air foam content



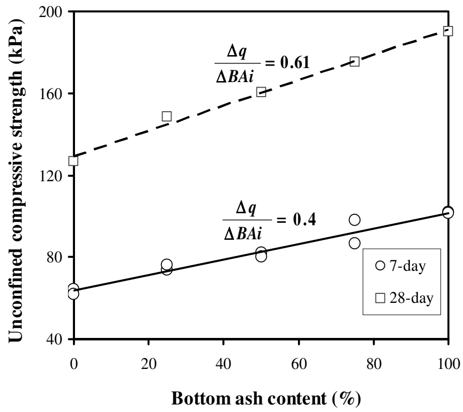
(b) Bottom ash content

Figure 3. Stress-Strain relationship with various mixing conditions

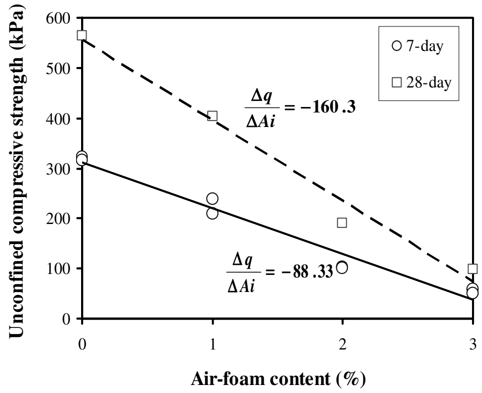
4.3 *Unconfined compressive strength*

The relationship of unconfined compressive strength (q_u) and admixture contents can be found in Figure 4 with curing time of 7 and 28 days. Figure 4(a) show the variation of unconfined compressive strength with respect to bottom ash content. Unconfined compressive strength of CGM linearly increases with increases in bottom ash content. It is worth to note that inclusion of bottom ash into soil admixture gives benefits of increasing shear strength as well as chance to recycle bottom ash. On the other hand, as shown in Figure 4(b), the unconfined compressive strength of CGM decreases with increases in air-foam content and the strength of CGM remarkably is affected by air-foam content. Simple linear relations of unconfined compressive strengths and admixture contents are made in in Figure 9, which would be valid for the range of admixture contents considered in this study.

The relationship between unconfined compressive strengths after 7 and 28 days of curing time is shown in Figure 5. The unconfined compressive strength after 28 days of curing is 1.5 to 2.3 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 reinforced with waste fishing net.



(a) Bottom ash content



(b) Air foam content

Figure 4. Change in compressive strength with respect to admixture

4.4 *Secant modulus*

The relationship between secant modulus (E_{50}) and unconfined compressive strength (q_u) of CGM is presented in Figure 6. Kim et al. (2008) reported that E_{50} of lightweight soil without bottom ash ranges 44 to 80 times q_u . Tang et al. (1996) also observed that E_{50} is about 40 to 260 times q_u and tends to decrease as the total confining pressure increases. The results of this study present that E_{50} of CGM is in the range of 185 to 480 times q_u which is greater than those previously suggested by Kim et al. (2008) and Tang et al. (1996). By comparing the moduli of CGM and lightweight soil, it is indicated that the stiffness of CGM is slightly greater than that of lightweight soil due to the reinforcing effect of bottom ash.

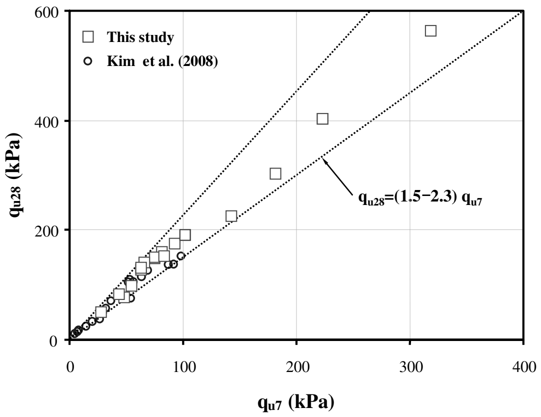


Figure 5. Comparison of compressive strength at curing time of 7 and 28 days

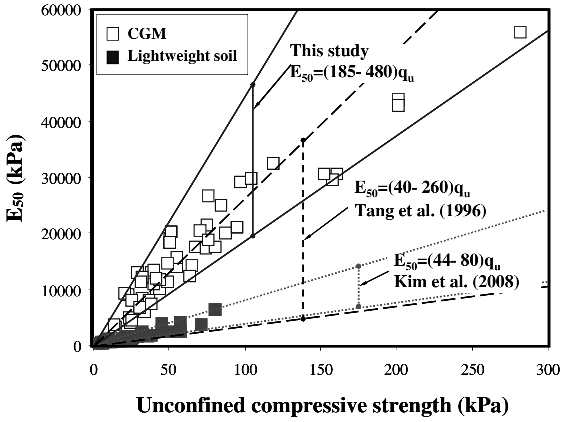


Figure 6. Relationship between secant modulus and unconfined compressive strength

5 CONCLUSIONS

In this paper, several series of laboratory tests were performed to evaluate mechanical behaviors of composite geo-materials (CGM) and unreinforced lightweight soils. Composite geo-material consisted of dredged soil, cement, air-foam and bottom ash. From this experimental study, the following conclusions were found.

The moist unit weight strongly depended on air-foam content as well as bottom ash content added to the composite geo-material

Stress-strain behaviors of composite geo-material depended on various mixing conditions. Unconfined compressive strength and the stiffness of CGM increased with an increase in bottom ash content due to angular shape of bottom ash and the pozzolanic reaction in the mixture.

Unconfined compressive strength of CGM increased with an increase in curing time. The 28-day strength of composite geo-material was approximately 1.5~2.3 times the 7-day strength.

Secant moduli of CGM were in the range of 185 to 480 times q_u . The stiffness of CGM was greater than that of unreinforced lightweight soil due to the reinforcing effect of bottom ash.

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