Evaluation on the compressive strength of dredged soil-steel slag

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ABSTRACT

In order to apply the mixtures of dredged soils with slag to geotechnical field, the compressive strength characteristics should be identified. In this study, unconfined compressive strength tests for two local dredged soils mixed with three different types of slags were performed. In this study, factors affecting the compressive strength of soil-slag mixture including the types of dredged soil, types of slag, mixing ratio of soil/slag and mixing water content were investigated. Higher slag portion in the soil-slag mixture induces greater strength improvement. The increase of compressive strength in soil-slag mixture was more significant in the case of mixing with steelmaking slag than GFNS and AFNS. The sufficient fine content of dredged soil and CaO of slag was found to have a significant influence on the solidification effect. In addition, the initial mixing water content was higher, strength improvement might be limited.

Keywords: dredged soil, steel slag, unconfined compressive strength, beneficial use

1 INTRODUCTION

During the last decade dredged soils have been generated about 32 million m³ annually by port construction, coastal development and water channel maintenance works in Korea. Most of dredged soils have been disposed in containment facilities. Due to the significant amount of dredged soil, the development of sustainable application and appropriate beneficial use is an important challenge around the country. The fine-grained properties of dredged soils generally make dredged soil unattractive for earthwork or backfill materials unless it can be mixed with other cementitious materials to enhance its strength. Previous efforts on improving the geotechnical applicability of dredged soils have been carried out over the years. A few successful implementations have been reported in the literature such as the dredged soil mixed with cement and gypsum neutral stabilizer and the lightweight treated soil formed by infusing soil with air bubbles or expanded polystyrene beads (Chan et al. 2011). Important criteria for potential materials mixed with dredged soils are low cost and high abundance.

One of such materials is the slag which is by-product of metal manufacture. Slag generated more than 20 million tons a year in Korea would be possible blending materials. It is known that steel slag enables soft dredged soils to be strengthened for reusing by effectively reinforcing their characteristics such as chemical components and mechanical properties (Malasavage et al., 2012; Kikuchi and Mizutani, 2013). The free lime content in steel slag gives it the cementation effect similar to that of cement, though weaker due to other factors like the chemical composition, mineral phase and alkalinity (Altun and Yilmaz, 2002). Although significant amount of slag has been reused as construction materials such as cement raw material and road base course material, the geotechnical applications to dredged soils of slag are still required a further research to expand the reuse of slag.

The purpose of this paper is to present the experimental feasibility for geotechnical applications on mixtures of dredged soils with slag from metal manufacturing processes to expand the reuse of both dredged soils and slag. In this study, laboratory experiments including unconfined compressive strength for two local dredged soils mixed with three different types of slags were performed. Compressive strength characteristics with various curing times for different mixing ratios of dredged soils with slag were investigated. The compressive strength characteristics of soil-slag mixture depending the types of dredged soil, types of slag, mixing ratio of soil/slag and water content were investigated.
2 TEST MATERIALS AND METHOD

2.1 Materials

Dredged soils used in this study were sampled at Saemangeum and Gwangyang where are located in west and south coast of Korea, respectively.

The slag from metal manufacturing processes can be categorized into iron and steel slag and non-ferrous metal slag. In addition, depending on the cooling method used, it is classified either as air-cooled slag or granulated slag. Granulated slag is produced by rapidly cooling hot molten slag with a jet of high-pressure water. Air-cooled slag is produced by subjecting hot molten slag to air cooling and moderate water sprinkling (Horii et al. 2013). In this study, three different types of slags including steelmaking slag (SM slag), granulated ferro-nickel slag (GFNS) and air-cooled ferro-nickel slag (AFNS) were used.

The constituents and concentrations of used slag are presented in Table 2. SM slag is composed mainly of Fe₂O₃, CaO and SiO₂ while both granulated and air-cooled ferro-nickel slag (FNS) is composed mainly of SiO₂ and MgO.

The Saemangeum dredged soil(Soil A) is classified as silty sand (SM) and Gwangyang dredged soil(Soil B) is classified as silty and clayey sand (SM-SC). The basic physical properties of two dredged soils are summarized in Table 1.

Table 1. Physical properties of dredged soils.

| Soil   | SM-SC   | SM-SC   |
|--------|---------|---------|
| Location | Saemangeum | Gwangyang |
| Specific gravity | 2.65 | 2.62 |
| Liquid limit (%) | - | 26.7 |
| Plasticity Index | N.P. | 8.9 |
| Percentage of fines | 4.1 | 47.5 |
| USCS | SM | SM-SC |

The constituents and concentrations of used slag are presented in Table 2. SM slag is composed mainly of Fe₂O₃, CaO and SiO₂ while both granulated and air-cooled ferro-nickel slag (FNS) is composed mainly of SiO₂ and MgO.

2.2 Method

The dredged soil was mixed with slag at mass ratios of soil and slag with 8:2, 7:3 and 6:4. The soil-slag mixtures were compacted in a cylindrical plastic mold with 100mm diameter and 200mm height. The compaction of specimen was achieved by 25 times tapping each three layers. After compaction, the specimens were carefully capped, and then left to cure at a thermos-hygrostat for periods up to 28 days. At pre-determined 7 days, 14 days and 28 days curing times, specimens were extracted from the mold and trimmed for unconfined compression strength test.

3 TEST RESULTS

The results of unconfined compression test on soil B mixed with three different types of slags with curing time are shown in Figs. 2~7. Figs. 2~4 present the compressive strength of soil-slag mixture when initial mixing water content is 30%. And Figs. 5~7 show the case of initial mixing water content is 22%. Note that the selected mixing water contents are above and below liquid limit of soil B, respectively.

As expected, prolonged curing showed the increase of compressive strength might be caused by solidification. Such increases were more pronounced with higher slag portion and low initial mixing water content. In addition, the increase of compressive strength with curing time of soil-slag mixture was more significant when steelmaking slag is mixed in dredged soil, compared with the case of GFNS or AFNS. Factors affecting the compressive strength of soil-slag mixture will be presented in the following section.
DISCUSSION

4.1 Effect of soil types

The unconfined compressive strength of two dredged soils mixed with steelmaking slag at 7 days of curing time is presented in Fig. 8. The initial mixing water content was 30%. The compressive strength of soil B mixed with steelmaking slag was gradually increased with slag content. When the slag portion was increased from 20% to 40% in soil-slag mixture, the compressive strength increased from 30 kPa to 50 kPa. The increase of compressive strength with steelmaking slag implies that the solidification was developed by the reaction between free lime in steelmaking slag and soil minerals. However, the compressive strength of soil A mixed with steelmaking slag was not increased by slag addition. It is noted that the fine content of soil A is 4.1% while the fine content of soil B is 47.5%. The low fine contents of soil A did not enhance the solidification by free lime of steelmaking slag.

4.2 Effect of slag types

Fig. 9 presented the 28 days compressive strength of soil B mixed with three different types of slags. The compressive strength of soil B at water content of 22% was 22.3 kPa. The compressive strength was
significantly pronounced with increased slag portion. The increase of compressive strength with slag portion in soil-slagn mixture was more significant in the case of mixing with steelmaking slag than GFNS and AFNS. When the steelmaking slag portion was increased from 0% to 40% in soil-slagn mixture by weight, the compressive strength showed remarkable departure from 22.3 kPa to 239.2 kPa. In the case of GFNS and AFNS, the compressive strength showed 95 kPa and 86 kPa for slag portion of 40%, respectively.

Such results might be caused by the difference of CaO concentration in slags which can make solidification of soil-slagn mixture. Steelmaking slag contains CaO of 33.8% while CaO concentration in GFNS and AFNS is 0.56% and 0.55%, respectively. This indicates that the free lime in steelmaking slag gives the cementation effect on soil-slagn mixture and consequently it results in the significant increase of compressive strength with slag addition in soil.

4.3 Effect of water content

Fig. 10 shows the 28 days compressive strength of soil B with steelmaking slag with different initial mixing water content of 22% and 30%, respectively. It is noted that the water content of 30% was the value above the liquid limit of soil B. At lower water content, it resulted in significantly higher strengths at all slag portions and plotting out an upward trend with increased slag portion. The compressive strength of soil-slagn mixture at water content of 22% was significantly increased with slag portion up to 239.2 kPa at the slag portion of 40%. However, in the case of water content of 30%, the compressive strength of soil-slagn mixture was slightly increased and the maximum compressive strength showed 68.7 kPa at the slag portion of 40%. When the initial mixing water content was higher, strength improvement might be limited for the stabilized material. Such result indicates that it should be considered the appropriate amount of mixing water content for optimum solidification in soil-slagn mixture.

5 CONCLUSIONS

In order to evaluate the factors affecting the compressive strength of soil-slagn mixture, unconfined compressive strength tests for two local dredged soils mixed with three different types of slags were performed in this study.

Higher slag portion in the soil-slagn mixture induces greater strength improvement. The increase of compressive strength in soil-slagn mixture was more significant in the case of mixing with steelmaking slag than GFNS and AFNS. The sufficient fine content of dredged soil and CaO of slag was found to have a significant influence on the solidification effect. In addition, the initial mixing water content was higher, strength improvement might be limited. The appropriate water content should be found for enhancing the solidification effect in soil-slagn mixture.

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