IMPROVEMENT IN THE MECHANICAL PROPERTIES OF COHESIVE SOILS BY MIXING CARBIDE POSSESSING WATER ABSORPTION PROPERTY

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ABSTRACT

In order to improve the mechanical properties of volcanic cohesive soils, they are usually stabilized by adding cement or lime. However, this method has certain drawbacks such as insufficient hardening or the leaching of hexavalent chromium from cement. Each year, a large amount of mown grass is generated from embankments and river areas. Most of this grass is either burnt in a field or disposed, while a part of it is used in composting. A technique for the carbonization of mown grass has been developed. Carbide is a porous material with a high capacity for water absorption. Therefore, the mown grass carbide can be used for water purification and soil improvement. In this study, the strength and leaching properties of cement-treated soils mixed with charcoal are investigated by performing unconfined compression and by conducting leaching tests. Furthermore, a cone penetration test is performed on the volcanic cohesive soils using carbide from the mown grass and lime, and the improvement in the trafficability is clarified.

Key Words: Volcanic Cohesive Soils, Carbide, Cone Penetration Test, Trafficability

1 INTRODUCTION

Several types of volcanic cohesive soils are found in the Kyushu region of Japan. Although these soils are stabilized by adding hardening agents such as cement or lime for improving their mechanical properties, the trafficability of those soils is insufficient in usual amount of hardening agents. Some cohesive soils are not suitable for soil stabilization or require a large amount of hardening agents. This often causes problems such as increase in construction cost and leaching of hexavalent chromium from cement. A large amount of mown grass is generated from embankments and river areas; most of it is either burnt or disposed. The transportability of mown grass improves by compression and molding. A technique for carbonizing the compressed mown grass has been developed. Since the mown grass carbide has a high capacity for water absorption, it can be used for water purification, soil improvement, as a deodorant, etc. The effect of immobilization due to charcoal mixing has also been investigated.

In this study, strength improvement and immobilization of heavy metals in charcoal mixed cement-treated soils are investigated by unconfined compression and the leaching tests. Furthermore, a cone penetration test is performed on the volcanic cohesive soils using carbide from the mown grass and lime, and the improvement in the trafficability is clarified.

2 IMPROVEMENT IN THE CEMENT-TREATED SOIL AFTER MIXING CHARCOAL

2.1 Samples and test method

In order to investigate the fundamental improvements due to carbide mixing, the unconfined compression and leaching tests were performed on cement-treated soils mixed with charcoal. Used charcoal was prepared according to the following procedure. Disposable chopsticks were wrapped in an aluminum foil, and the charcoal was obtained by carbonizing at a temperature of 400°C for approximately an hour in a table electric furnace. The obtained charcoal was crushed to a size of less than 2mm.

Kaolin clay ($I_r = 50.6, w_r = 31.0\%$) in 100% water content was used as a soil sample. A prescribed amount of charcoal was mixed with the clay in a slurry form for about 5 min followed by the addition of 200 kg/m³ Portland cement. The slurry was stirred for about 5 min. Specimens were made by pouring the slurry into a mold to diameter 50 mm and height 100 mm. They were cured at a temperature of 20°C in a humidity room for 7
or 28 days. The unconfined compression test was then performed on the specimens.

In order to clarify the adsorption effect of charcoal, the charcoal mixed cement-treated soil was crushed to a size of less than 2 mm. The leaching test was then performed according to Notification No. 46 of the Japan Environmental Agency. The test fluid was prepared with a solid-liquid ratio of 1:10 and agitated for 6 h to leach the contaminants in the specimen. The mass of the hexavalent chromium released from cement was measured.

2.2 Test results

The relationship between the compressive stress and the axial strain of the cement-treated soils for different charcoal contents is shown in Fig. 1. Two types of charcoal contents are defined, as indicated in this figure. One is a dry weight ratio of charcoal and clay (%), and the other is the dry weight of charcoal per unit volume of the specimen (kg/m³). The maximum stress of the treated soil increases with an increase in the charcoal content, and the residual stress increases by mixing charcoal. Figure 2 shows the variation in the strength ratio \( R = \frac{q_{sw}}{q_{ul}} \), where \( q_{ul} \) is the strength of the treated soil without charcoal mixing. The strength ratio increases with the charcoal content, and the increase for a curing time of 7 days is significantly higher than that for 28 days.

In order to determine the reason for strength improvement by charcoal mixing, the unconfined compression test was performed by mixing the cement-treated soil with Toyoura sand. The test results are shown in Fig. 3. There is no increase in the strength of the sand mixed cement-treated soils, because the water absorption capability of sand is very low as compared with that of charcoal. Another test result confirmed that there is no increase in strength of treated soils mixed with humid charcoal. From these test results, it is concluded that the apparent water-cement ratio in the treated soil decreases due to the absorption by charcoal, thereby improving the strength.
Figure 4 shows the total mass of hexavalent chromium Cr(IV) released, during the leaching test on the treated soils mixed with charcoal. The concentration of Cr(IV) decreases with an increase in the charcoal content, and its value is below the value set by the environmental quality standards (0.05 mg/l). This suggests that the charcoal has a possibility of adsorption for Cr(VI). Thus, the amount of Cr(IV) released from the cement-treated soil can be minimized by mixing charcoal.

3 IMPROVEMENT IN TRAFFICABILITY OF VOLCANIC COHESIVE SOILS BY MIXING MOWN GRASS CARBIDE

3.1 Physical properties of volcanic cohesive soils

In this section, carbide obtained from mown grass is used instead of charcoal. Samples of volcanic cohesive soils are used, which are surplus soils at construction sites in the Oita prefecture, Kyushu, Japan. A schematic diagram of the geologic stratum of the volcanic cohesive soils is shown in Fig. 5. Loam (upper) is the topmost layer followed by pumice soil, loam (lower), and Haido (volcanic clay). The physical properties of these layers are also shown in Table 1. The cone penetration test was performed on pumice soil, loam (lower) and Haido because they exhibit insufficient trafficability. In addition, since the particles of the pumice soil are porous and contain a large amount of water, they can be crushed easily to obtain fine particles.

3.2 Characteristics of the mown grass carbide

The mown grass carbide is obtained by the following procedure. Naturally dried mown grass is molded and compressed into a cylindrical form of diameter 2-3 cm and height 1-10 cm. Carbide is then produced by carbonizing the compressed mown grass.

\[ A_r: \text{Carbide content}, \ A_i: \text{Lime content (Unit: kg/m}^3\text{)} \]

The weight of the mown grass is reduced to 30%. Photo 1 shows a mown grass carbide. Its specific gravity is approximately 0.3, and its water absorption ratio is about 90%. The water absorption ratio is measured by the following procedure: 1) the carbide is submersed into water for a day, 2) it is then taken it out and the surface water is removed by wiping, and 3) its water content is measured after drying in an oven.
3.3 Test methods

Based on the standards of Japanese Geotechnical Society, specimens were prepared by the compaction of stabilized soil. Carbide or lime was mixed with a soil sample and the resulting mixture was cured for a day. After compaction using a mold of diameter 10 cm and a rammer weighing 2.5 kgf, the cone penetration test was performed on the compacted samples based on the standards of the Japanese Geotechnical Society for the cone index test of compacted soil. The conditions for the cone penetration test are listed in Table 2. The mown grass carbide crushed to a size of less than 19mm was used, and its shape is shown in Photo 2. The mixing conditions of the carbide and lime are listed in Table 3. Additive content is represented by kg/m$^3$, where "kg" is the mass of carbide and lime and "m$^3$" is calculated from a wet unit weight of in-situ original soil. The specimens were prepared according to three different mixing conditions: Case-1: the carbide only ($A_c$: kg/m$^3$), Case-2: lime only ($A_l$: kg/m$^3$), and Case-3: both carbide and lime ($A_{c+l}$: kg/m$^3$) at the same weight ratio (1:1).

3.4 Test results

3.4.1 Compaction of soil samples at natural moisture content

The original volcanic cohesive soils were compacted at the natural moisture content followed by the cone penetration test. Figure 6 shows the relationship between cone index and compaction number obtained from the cone penetration test on four types of volcanic cohesive soils. With the exception of Haido, the cone index of all the other types of volcanic cohesive soils decreases with an increase in the compaction number; This clearly indicates that overcompaction has occurred. In particular, the cone index of the pumice soil reduces suddenly and becomes almost zero after 15 times the compaction number. In addition, the cone index of Haido at the natural moisture content condition is very low for each compaction number. It is known that the volcanic cohesive soils are geomaterials that are difficult to compact.

At the road construction site, a swamp bulldozer has been used as a surface compaction machine and the required cone index was $q_c = 300$ kN/m$^2$. Only the topmost loam (upper) layer satisfies this cone index value, since pumice soil, loam (lower), and Haido are investigated as objective materials.

3.4.2 Trafficability improvement by mixing only the mown grass carbide

Figure 7 shows the relationship between the cone
index and the carbide content of the volcanic cohesive soils determined by mixing only carbide at 25 times the compaction number. The cone index of each volcanic cohesive soil increases gradually with the carbide content, thereby improving the trafficability. When the target value of the cone index in the laboratory mixing test is $q_c = 400 \text{ kN/m}^2$ (after considering safety factor), the required carbide content is $A_C = 100 \text{ kg/m}^3$ for loam (lower), 150~200 kg/m$^3$ for Haido, and 200 kg/m$^3$ for pumice soil. Photo 3 shows the status of pumice soil compacted at the natural water content, and Photo 4 shows the status of the compacted pumice soil with a carbide content of 150 kg/m$^3$.

3.4.3 Trafficability improvement by mixing both mown grass carbide and lime

The cone penetration test was performed on the volcanic cohesive soils at three different mixing conditions: Case-1: carbide only ($A_C$), Case-2: lime only ($A_L$), and Case-3: both carbide and lime ($A_C + A_L$). The test results for pumice soil, loam (lower) and Haido are shown in Figs. 8-10, respectively. As shown in Fig. 8, the cone index increases gradually by mixing only the carbide; the increase is more significant beyond 150 kg/m$^3$. On the other hand, in Case-2 and Case-3 (using lime), the cone index obtained by using lime increases sharply when the carbide content exceeds 100 kg/m$^3$. The additive content required for satisfying the cone index of $q_c = 400 \text{ kN/m}^2$ is $A_C = 200 \text{ kg/m}^3$ for Case-1, $A_L = 100−150 \text{ kg/m}^2$ for Case-2 and $A_C + A_L = 150 \text{ kg/m}^3$ for Case-3. These results indicate carbide is effective in improving the trafficability. As shown in Fig. 9, the cone index $q_c = 200 \text{ kN/m}^2$ for loam (lower) is obtained at the natural water content without carbide or lime addition. Therefore, the trafficability of loam can be improved by a small additive content as compared with that for pumice soil. On the other hand, as shown in Fig. 10, the additive content of Haido for
satisfying the cone index of \( q_c = 400 \text{ kN/m}^2 \) is approximately \( A_C = 150-200 \text{ kg/m}^3 \) when only carbide is mixed (Case-1). However, the trafficability is improved remarkably by mixing only lime (Case-2) or both the carbide and lime (Case-3).

Thus, the improvement in trafficability by mixing carbide depends upon the type of soil and the combination of additives.

### 3.4.4 Reduction in lime content by mixing carbide

In order to clarify the reduction in lime content to carbide mixing, the relationship between cone index and lime content in Case-2 and Case-3 for pumice soil, loam, and Haido is shown in Figs. 11-13, respectively. As mentioned earlier, Case-2 and Case-3 involve the mixing of lime only and the mixing of both lime and carbide, respectively. Therefore, the difference in the lime content between Case-2 and Case-3 at the same cone index represents the reduction in the quantity of lime by the mixing of the carbide. As shown in Fig. 11 (pumice soil), it is possible to reduce the lime content for obtaining the same cone index by mixing both lime and carbide. The reduction in the quantity of lime increases with the lime content. On the other hand, as shown in Figs. 12 and 13, the reduction in the lime content of loam and Haido is not noticeable at smaller lime contents. Thus, the reduction in lime content also depends on the mixing ratio of lime and carbide.

### 4 CONCLUSIONS

In this study, the improvement in the strength of cement-treated soil and trafficability of volcanic cohesive soils by mixing charcoal or mown grass carbide are investigated by performing the unconfined compression and cone penetration tests. The property of charcoal to adsorb hexavalent chromium is also confirmed. The main conclusions are summarized as follows:

1) It is observed that the unconfined compressive strength of cement-treated soil increases by mixing charcoal that exhibits a high capacity for water absorption. Furthermore, the amount of Cr(IV) released from the cement-treated soil can be minimized by mixing the charcoal.

2) Several volcanic cohesive soils such as pumice soil, loam and Haido, have exhibit insufficient trafficability. However, their cone indexes can be increased by mixing mown grass carbide.

3) Trafficability of volcanic cohesive soils can be improved effectively by mixing both carbide and lime. This implies that it is possible to reduce the lime content for obtaining the same cone index by mixing both lime and carbide.

### REFERENCES
