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# Improvement Effect of Soft Clay using Highly Absorbent Carbonized Material

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ABSTRACT: Biochar can be used in a wide range of fields and fix $CO_2$ in the soil. In this study, a simple gasifier was developed for carbonizing various biomass such as grass clippings, waste paper, and dried livestock manure to produce high-quality carbonized materials. Geotechnical utilization of biochar is also discussed based on the cone index test results of mixture of clay and biochar. The physicochemical properties of various biomass carbonized materials produced using a newly developed self-combustion carbonization device and effect of mixing carbonized material on improving the trafficability of high-water content clay are investigated. The carbonization device can produce carbonized materials in 30 min without fossil fuels, except for the initial ignition. Grass clipping carbon (CG) has a unique honeycomb structure with many small spaces, so that carbonized grass clippings can be expected to have significant environmental and economic benefits as a recycled material for improving high-moisture clay. It is also found that a stabilizer mixture (CG-COS) developed using calcined oyster shells (COS) with the carbonized materials can be used as an alternative to traditional stabilizers for stabilizing clays with high water content.

KEYWORDS: Carbonized material, Water absorbent, Soft clay.

## 1 INTRODUCTION

In order to achieve carbon neutrality, it is necessary to reduce greenhouse gas emissions and increase absorption. For this reason, it is necessary to utilize negative emission technologies that absorb CO2 from the atmosphere and fix carbon. One such technology is the use of biochar obtained by carbonizing biomass. Although cement and other materials are generally used to improve soft ground, carbonized materials are also expected to be effective as water-absorbing materials that reduce the amount of solidification materials that emit large amounts of CO2.

Biochar is a porous material rich in carbon that has attracted considerable attention in recent years due to its potential economic and environmental benefits in soil (Dai et al, 2013). In this study, self-combustion carbonization device was developed to reduce the time and cost associated with carbonization. This device can carbonize organic waste without fossil fuels while efficiently burning the gases produced during the carbonization process, thereby reducing the thermal decomposition time and costs. Effect of mixing carbonized material on improving the trafficability of high-water content clay is investigated and physicochemical properties of various biomass carbonized materials produced using a developed self-combustion carbonization device. A stabilizer mixture developed using calcined oyster shells (COS) with the carbonized materials is also applied to improve soft clay.

## 2 SELF-COMBUSTION CARBONIZATION DEVICE AND PROPERTIES OF CARBONIZED MATERIALS

This paper introduces an overview of a simple carbonization device that burns the distillation gas generated during the pyrolysis of biomass at high temperatures to obtain high-quality carbonized material (Omine et al, 2023).

Figure 1 shows self-combustion carbonization device developed in this research. A chimney is attached to an insulated stainless steel pipe, and the dried biomass is packed into the stainless steel pipe, which is heated from below, allowing the carbonization gas to burn continuously at a high temperature. A baffle is attached inside, and the incoming air and carbonization gas swirl and mix thoroughly, resulting in almost complete combustion, and high-quality carbonized material can be obtained through self-combustion alone. This is a portable carbonization device, and since the carbonization gas is burned at a high temperature of around 1000 °C, it produces almost no smoke or soot, and produces highly absorbent and porous carbonized material.

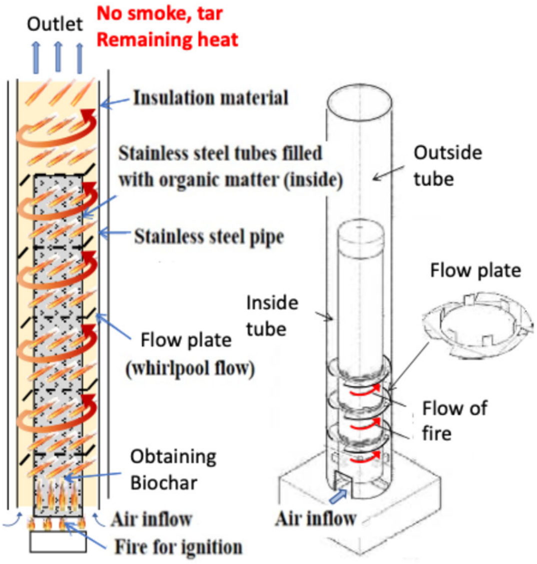



Figure 1. Self-combustion carbonization device.

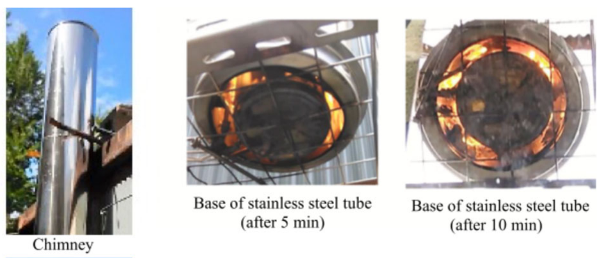



Figure 2. combustion state of the carbonized gas.

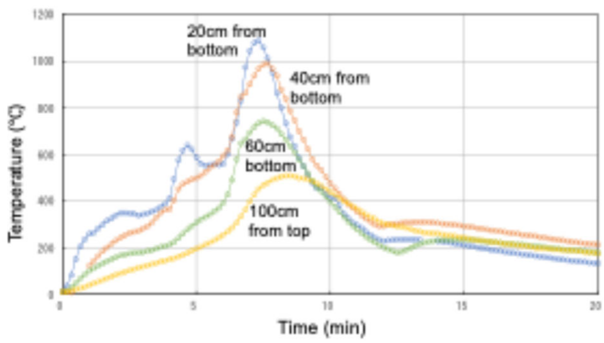
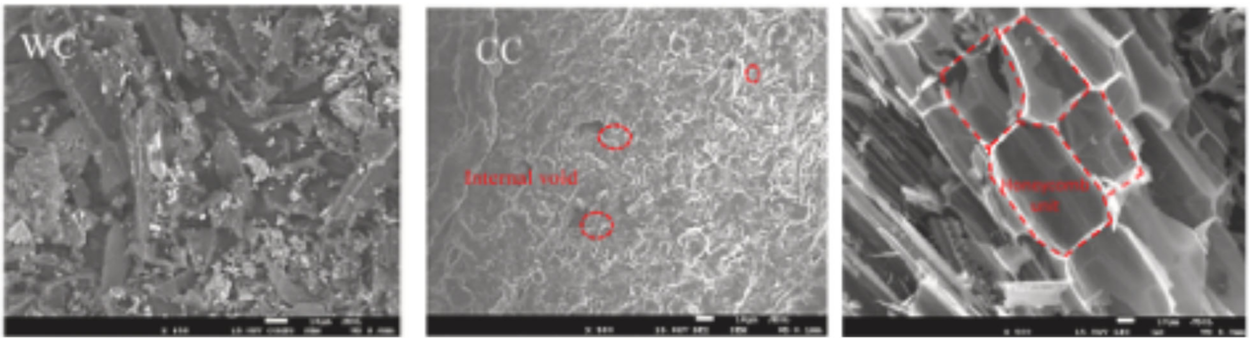



Figure 3. change in the combustion temperature of the carbonized gas over time.




(a) Wood charcoal (b) Carbonized cow dung (c) Carbonized Grass

Figure 4. SEM image of carbonized materials.

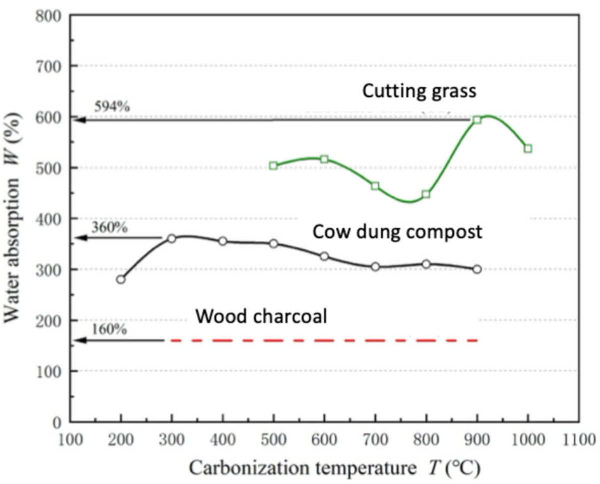



Figure 5. Relationship between water adsorption and carbonization temperature.

The stainless steel container used for carbonization is approximately 2.5 L (diameter 60 mm, height 900 mm) or approximately 4 L (diameter 106 mm, height 455 mm), with an outer stainless steel pipe of approximately 120 mm or 150 mm in diameter . By increasing the insulation effect, the combustion temperature can reach a maximum of 1200 °C. Figure 2 shows the combustion state of the carbonized gas, and Figure 3 shows the change in the combustion temperature of the carbonized gas over time. For the first few minutes, the carbonized gas is ignited using a portable stove, and after 5 to 10 minutes the temperature rises rapidly and a strong updraft is generated, maintaining a state of almost complete combustion with no smoke or soot. Carbonization is completed in approximately 20 minutes.

Figure 4 shows SEM images of three types of carbonized materials (CG: carbonized grass clippings, CC: carbonized cow manure compost, WC: wood charcoal). It can be seen that the carbonized grass clippings has larger gaps than the charcoal and cow manure carbonized materials.

In addition, to examine the tendency of water absorption rate depending on the temperature during carbonization, cow manure compost and grass clippings were carbonized for one hour in a small electric furnace and compared. The water absorption rate was calculated based on the standard coarse aggregate water absorption rate test (JISA1110), by soaking the samples in water for 24 hours, wiping off the surface moisture with a damp cloth to represent the surface dry state, and then calculating (mass after water absorption/mass before water absorption x 100).

Figure 5 shows the results of the water absorption test. The water absorption rate of carbonized cow manure compost did not vary significantly with temperature, ranging from 300 to 350% . Grass clippings carbonized at 900 °C had the highest water absorption rate of 594 %. The reason for this large difference in water absorption rate is thought to be the difference in pores. As shown in the SEM image in Figure 4, there are not many pores in the carbonized cow manure compost material, but pores can be seen here and there in the carbonized grass clippings material. The carbonized grass clippings material has a honeycomb structure with many gaps. We also measured the water absorption rate of commercially available charcoal, which was 160%, lower than the other two samples (Li et al, 2023) .

## 3 SAMPLES AND EXPERIMENTAL METHODS

Currently, grass clippings cannot be burned in the field, and the disposal of the large amounts of grass clippings generated during the maintenance of river levees has become a problem throughout the country as shown in Fig.6. The grass clippings mentioned above were generated on river levees in Nagasaki. The cow manure compost and charcoal were commercially available products purchased from a home center.

Figure 6. Grass clippings on river levee.

We investigated to what extent trafficability could be improved by mixing these carbonized materials with high water content clay to reduce the apparent water content. As shown in Table 1, in Series 1, specimens were prepared by mixing various carbonized materials with kaolin clay with a water content of 70% (liquid limit 41.1%). The amounts of carbonized materials added were 100, 200, and 300 kg/$m^3$ . Meanwhile, in Series 2, specimens were prepared using carbonized grass clippings with different clay water content and amounts of carbonized materials added. Simple cone penetration tests were conducted on these specimens to measure the cone index.

When improving high water content clay using only carbonized materials, the amount of additive is thought to be quite large. Therefore, in this study, we also examined conditions in which calcined oyster shells (COS) were used in combination. The oyster shells used were from Omura Bay,

Table 1. Mixing condition of Kaolin clay and carbide.

| Series | Water content of clay *w* (%) | Amount of carbides *C* (kg/m³) | | |
|---|---|---|---|---|
| | | CG (Carbonized grass) | CC (Carbonized cow dung) | WC (wood charcoal) |
| 1 | 70 | 100, 200, 300 | - | - |
| | 70 | - | 100, 200, 300 | - |
| | 70 | - | - | 100, 200, 300 |
| 2 | 70 | 100, 200, 300 | - | - |
| | 50 | 100, 150, 200 | - | - |
| | 30 | 40, 80, 120 | - | - |

Table 2. Mixing condition of Kaolin clay with carbide and COS.

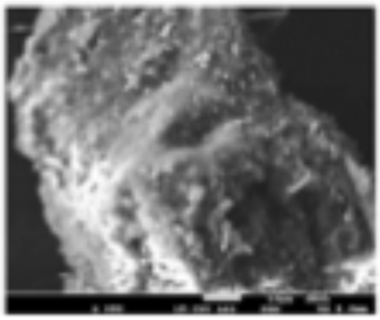
| Water content of clay *w* (%) | Amount of carbides *C* (kg/m³) | | | Content of COS |
|---|---|---|---|---|
| | CG | CC | WC | *S* (kg/m³) |
| 70 | 30, 60, 90, 120 | - | - | 30 |
| | - | 30, 60, 90, 120 | - | 30 |
| | - | - | 30, 60, 90, 120 | 30 |

Nagasaki Prefecture. The oyster shells were dried, crushed into powder, and sieved through a 2 mm mesh. The oyster shell powder was then calcined in an electric furnace at 1000 °C for 2.5 hours. The yield after calcination was about 45%, and it is believed that most of the material had been converted to calcium oxide. Mixing condition of Kaolin clay with carbide and COS is shown in Table 2.

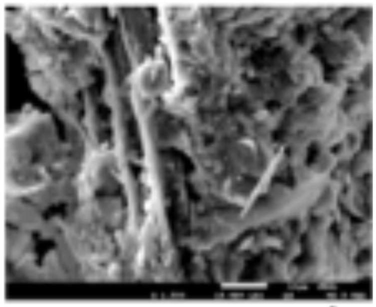
## 4 TEST RESULTS AND DISCUSSION

Figure 7 shows SEM images of the mixture of carbonized material and clay. As shown in Fig. 7 (a) , even when 200 kg/m$^3$ of charcoal was added, a thin layer of clay particles was attached to the surface of the CC particles, and there was no significant change in the sample structure, so the impact on the strength of the clay is considered to be relatively small. It can be seen that the clay particles are not effectively attached due to the blocky structure of CC. On the other hand, as shown in Fig. 7 (b), in the case of kaolin clay mixed with CG, it is presumed that high strength can be obtained because the clay particles are entangled with CG. The special structure of CG increases the contact area and attachment points of soil particles, increasing the possibility of contact between particles and promoting effective adhesion between clay and carbonized material particles. In addition, CG has a high water absorption capacity, so it is considered to have a significant impact on the strength of the sample.

As shown in Fig. 8, when the amount of carbonized material mixed is increased to 200 kg/m$^3$, an "active boundary" exists. The boundary line indicates that the stability of the clay is significantly improved as the carbonized material gradually increases from the inactive zone to the active zone, and a clear stability difference exists among the three samples. When CG is added, the cone index is higher than that of the other two carbonized materials (CC and WC). This is mainly due to the strong water absorption of CG, which greatly reduces the free water in the clay and makes the particle arrangement denser. When further carbonized material is added to the clay, the cone index exceeds 200 kN/m$^2$ when the amount of CC mixed in the clay reaches 300 kg/m$^3$. This indicates that the main effect of the carbonized material in improving the clay properties is to



(a) Kaolin + CC 200kg/m$^3$



(b) Kaolin + CG 200kg/m$^3$

Figure 7. SEM of carbonized material added to Kaolin clay.

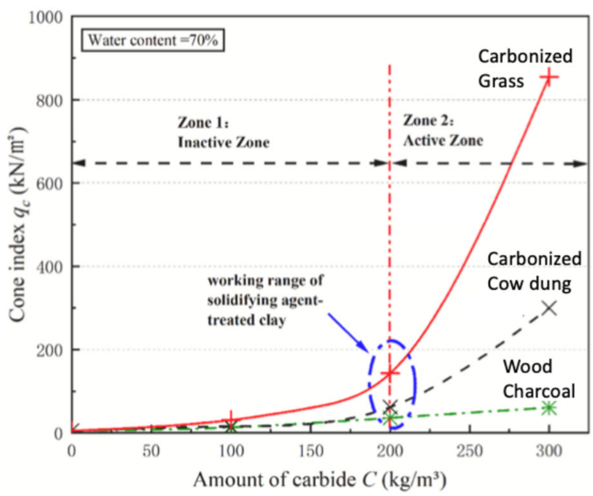



Figure 8. SEM of carbonized material added to Kaolin clay.

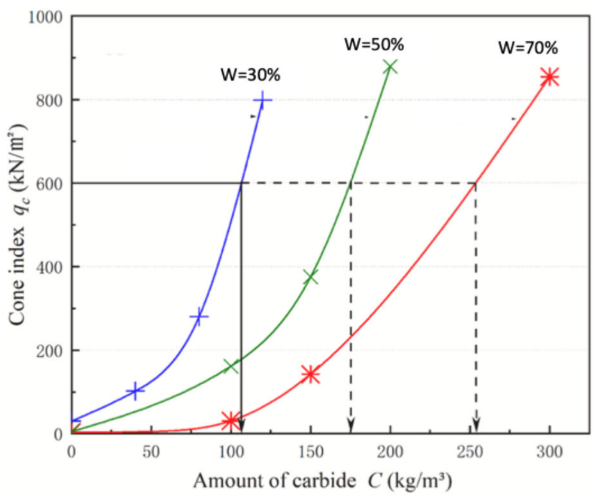



Figure 9. Relationship between cone index and CG content of clay in different initial water content.

fix the moisture in the clay. The clay treated with 300 kg/m$^3$ of CG has a cone index of over 800 kN/m$^2$, which is significantly higher than the other samples. It is believed that almost all of the moisture in the sample was absorbed, and at the same time, the CG structure in the sample contributed to the overall strength, resulting in a higher cone index.

Figure 9 shows the relationship between the initial water content of clay and the cone index of CG mixed soil. The $q_c$ value of untreated clay without carbonized material is about 3 to 7kN/m$^2$. Increasing the amount of CG added increases the overall strength of the samples. However, as the initial moisture content of the clay increases, the amount of CG required to achieve the same strength increases significantly. As a result, the improvement becomes less pronounced as the moisture

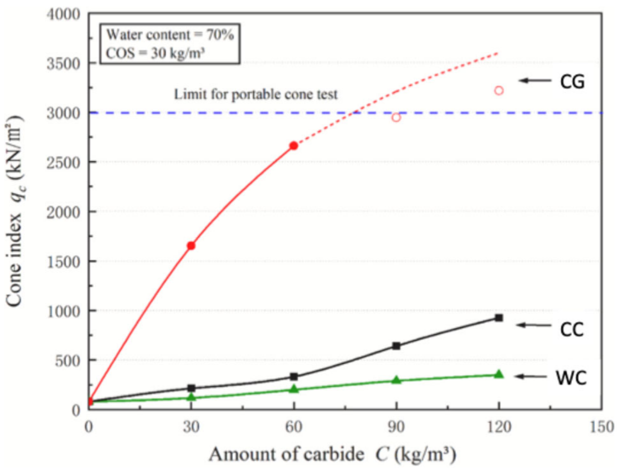



Figure 10. Effect of carbide content on COS-stabilized clay.

content increases. Conversely, decreasing the moisture content of the clay shortens the distance between particles or particle clusters, making it easier for particles in the clay to adhere directly to the CG surface. This strengthens the bonding strength between particles in the clay and the charcoal.

Previous studies have shown that the addition of COS improves the strength and stability of clay. This is because COS reacts with water to produce calcium hydroxide ($Ca(OH)_2$), which forms a robust gel-like structure when mixed with clay, improving soil strength (Bell, 1996). During this process, the high pH environment decomposes the silicates and aluminates on the clay surface, forming gel crystalline phases such as calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH), and calcium aluminum silicate hydrate (CASH). These gel phases bind clay particles to minerals. Although COS is beneficial for clay, its preparation requires long-term high-temperature firing, which increases carbon dioxide emissions. Therefore, replacing some COS with carbonized materials may be effective to address environmental and cost-related challenges (Li et al, 2023).

In this study, we investigated the effect of adding different amounts of carbonized materials (CG, CC, WC) and a certain amount of COS (30kg/m$^3$) to high water content clay. As shown in Fig. 10, the $q_c$ of clay stabilized with CG-COS increased most rapidly with increasing carbonized material content. When the CG content of CG-COS reached 30kg/m$^3$, the qc increased to 800kN/m$^2$, and is classified as Type 2 improved soil based on the "standard for use of surplus soil" in Japan. When the CG content in CG-COS increases to 90kg/m$^3$, the cone index exceeds 3000kN/m$^2$ , exceeding the limit of the portable cone test. Therefore, a prediction line based on the qc of specimens with CG contents of 30kg/m$^3$ and 60kg/m$^3$ is drawn. This indicates that CG plays a role in promoting hydration between COS and clay particles, improving strength. It also suggests that this may be related to the unique structure of CG and its strong water absorption.

## 5 CONCLUSIONS

In this study, we investigated the use of carbonized materials produced by a simple carbonization apparatus for improving high water content clay. The main conclusions obtained are as follows.

1) Self-combustion carbonatization device was developed that can produce carbonized materials in 30 min without fossil fuels, except for the initial ignition. The device reduced smoke emissions by fully burning the pyrolysis gas, and significantly reduced the time required for the material to carbonize.

2) Grass clipping carbon (CG) has a unique honeycomb structure with many small spaces, and therefore exhibits much stronger water absorption than other charcoal or carbonized cow manure compost , reaching a peak water absorption rate of 594%.

3) When the amount of carbonized material mixed with high water content clay and grass clippings exceeded 200 kg/m³, the cone index increased rapidly, demonstrating a significant improvement effect.

4) The qc of clay stabilized with CG-COS mixed with burnt oyster shells and carbonized grass clippings increased rapidly as the carbonization content increased. When the CG content of CG-COS reached 30kg/m$^2$, the qc was 800kN/m$^2$ and can be an alternative to conventional amendments for stabilizing clays with high moisture content.

Thus, carbonized grass clippings can be expected to have significant environmental and economic benefits as a recycled material for improving high-moisture clay. Additionally, this approach contributes to a noteworthy reduction in greenhouse gas emissions. Therefore, recycling cutting grass for CG preparation as a substitute for conventional soil stabilizers emerges as a green and viable method.

## 6 ACKNOWLEDGEMENTS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