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Carbon sequestration using biochar in cement-treated ground

Y. Kurimoto[1], Y. Yoda[2], K. Kojima[3], and Y. Asaka[4]

[1]*Research Engineer, Shimizu Corporation, Tokyo, Japan, email: yuhei.kurimoto@shimz.co.jp*

[2]*Senior Researcher, Shimizu Corporation, Tokyo, Japan, email: yoda.y@shimz.co.jp*

[3]*Manager, Shimizu Corporation, Tokyo, Japan, email: kojima_k@shimz.co.jp*

[4]*Group Manager, Shimizu Corporation, Tokyo, Japan, email: yoshiharu.asaka@shimz.co.jp*

ABSTRACT

Research and development on using carbon sequestration and low-carbon materials to mitigate climate change are advancing in the field of geotechnical engineering. This paper describes laboratory research in which biochar with carbon fixed in the natural state was added to soil-cement in a slurry state. This study also investigated the effect of biochar on strength development and hexavalent chromium elution of soil-cement for carbon neutralization of the stabilizer in cement-treated ground. Ordinary Portland cement and blast furnace cement types B and C were used as stabilizers to solidify the soil. Adding biochar with zero carbon dioxide emission to the stabilizer of the soil-cement slightly increased the uniaxial compressive strength. It also reduced the hexavalent chromium elution, regardless of the type of stabilizer used.

Keywords: Carbon sequestration, biochar, cement-treated ground, compressive strength, hexavalent chromium

1 INTRODUCTION

Construction projects are actively promoting the use of wood (e.g., Kuittinen, 2013) to increase carbon accumulation and mitigate climate change. The carbon dioxide emissions associated with building construction (embodied carbon) and demolition account for approximately 30 % of the life cycle CO_2 ($LCCO_2$) of a building (National Institute for Land and Infrastructure Management, 2008). Research and development on the utilization of carbon sequestration and low-carbon materials is also being pursued in the field of geotechnical engineering.

Geotechnical engineers in Japan are investigating wood as a means of ground improvement (Numata, 2014). Materials with fixed carbon in the natural state, such as biochar, and artificial or natural low-carbon materials, such as bio-improved soils (Terzis, 2018) are also being investigated. Biochar is environmentally friendly and has attracted attention in recent years in the fields of agriculture and geotechnical engineering. Papageorgiou (2021) assessed the environmental impacts of using biochar produced from wood waste to remediate contaminated soil. Pardo (2018) reported that biochar could increase the liquefaction resistance of sandy soil and mitigate liquefaction.

This paper describes laboratory tests in which biochar was added to ground improvement materials for cement-treated ground using the intermediate layer and deep mixing methods.

2 TEST OVERVIEW

2.1 Materials used

A soil mixture consisting of sandy and cohesive soils with a mass ratio of 8:2 was used as the original soil. Table 1 and Figure 1 show the specifications and grain size distribution curve of the soils used for ground improvement. Table 2 shows the quality of the materials used as stabilizers. Three stabilizers were used: 1) Ordinary Portland cement (symbol: OPC), 2) blast furnace cement type B (symbol: BFC-

B), and 3) blast furnace cement type C (symbol: BFC-C), each complying with Japanese Industrial Standards (JIS) specifications. BFC-C was mixed with a ratio of Ordinary Portland cement 30 % and ground granulated blast furnace slag 70 %.

Powdered biochar of grain size 5 mm or less manufactured by Nara Tanka Industries Co., Ltd. was used, as shown in Figure 2. Note that the original feedstock for biochar was sawdust produced while sawing coniferous and broad-leaved trees. Physical tests and proximate analysis revealed the basic properties shown in Figure 1 and Table 3. Biochar can be highly porous depending on the original feedstock and pyrolysis conditions (see Figure 2). The results of the water absorption tests on granular biochar with reference to the methods used JIS A 1110 (2020) are shown in Figure 3. Granular biochar was used in the water absorption tests because it was impossible to measure the water absorption of powdered biochar with the current measuring method. The water absorption of granular biochar increases with time, and its value exceeds 40 % after 24 hours.

Table 1. *Specification of sandy and cohesive soils.*

Soil classification	Origin	Soil particle density (g/cm^3)	Water content (%)
Sandy soil	Chiba, Japan	2.69	0.6
Cohesive soil	Tokyo, Japan	2.69	44

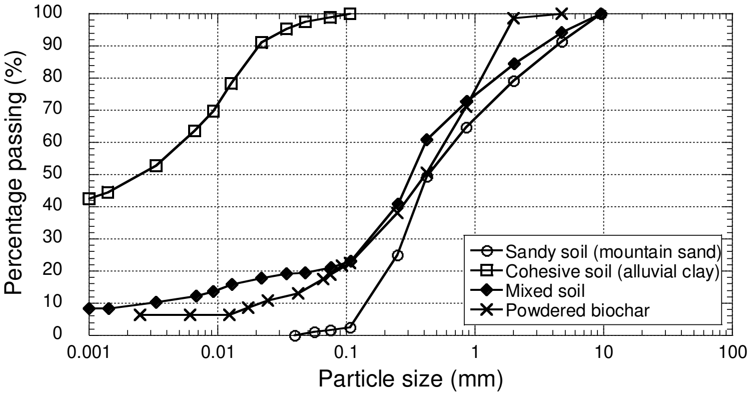

Figure 1. *Grain size distribution curve of sandy, cohesive, mixed soils, and powdered biochar.*

Table 2. *Material used as a stabilizer.*

Material	Symbol	Quality
Ordinary Portland cement	OPC	Density: 3.16 g/cm^3 Specific surface area: 3,330 cm^2/g
Blast furnace cement type B	BFC-B	Density: 3.04 g/cm^3 Specific surface area: 3,950 cm^2/g Ignition loss: 1.39 % SO_3: 2.14 % Mixing ratio of blast furnace slag: 40 %
Ground granulated blast furnace slag	BFC-C	Density: 2.90 g/cm^3 Specific surface area: 3,950 cm^2/g Ignition loss: 0.82 % SO_3: 1.98 %

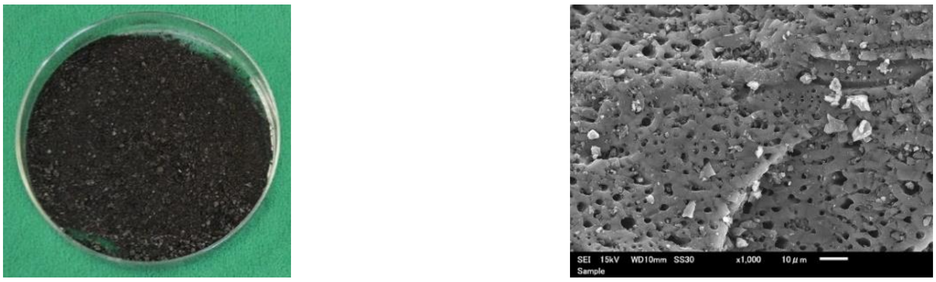

Figure 2. *Powdered biochar before mixing with mixed soil. Microstructure image of granular biochar by SEM.*

Table 3. *Specification of powdered biochar.*

Material			**Powdered biochar**
True density	g/cm^3	JIS Z 8807	1.743
Bulk density	g/cm^3	JBAS[a] 0002	0.801
Soil particle density	g/cm^3	JIS A 1202	1.636
Water content	%	JIS A 1203	13.87
Specific surface area	m^2/g	JIS Z 8830	294.884
Maximum grain size	mm	JIS A 1204	4.75
Uniformity coefficient	-	JIS A 1204	29.67
Coefficient of curvature	-	JIS A 1204	2.53
Total moisture	%	JBAS 0002	14.5
Inherent moisture	%	JBAS 0002	2.0
Ash	%	JBAS 0002	2.0
Volatile matter	%	JBAS 0002	6.1
Fixed carbon	%	JBAS 0002	89.9

[a] JBAS: Japan Biochar Association Standards.

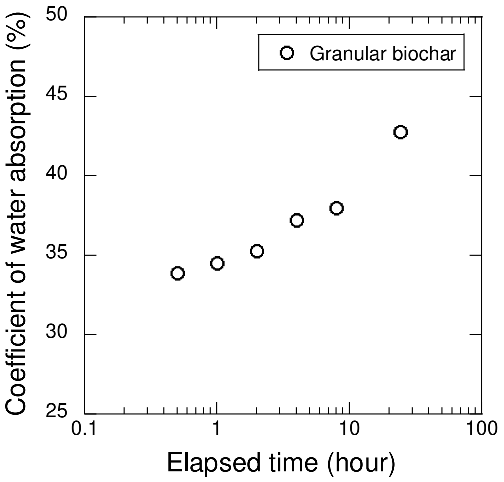

Figure 3. *Variation of coefficient of water absorption of granular biochar with elapsed time.*

2.2 Mix proportions and production of soil-cement samples

Three amounts of stabilizer—125 kg/m^3, 160 kg/m^3, and 180 kg/m^3—were used relative to the volume of the soil mixture. Table 4 shows the material composition of the soil-cement. The target uniaxial compressive strength was set to 1-3 N/mm^2. Test IDs were described by "type of stabilizer – amount of stabilizer added – presence or absence of biochar." For example, "BFC-B-160-B" is used for a case in which the stabilizer is blast furnace cement type B (BFC-B), the amount of stabilizer added is 160 kg/m^3, and biochar was added.

The CO_2 emissions inventory data of the materials used are summarized in Table 5. Based on the inventory data and the content of each material, the amount of biochar used was adjusted so that the CO_2 emissions of the materials was zero (see Table 4). The biochar was added as a percentage of the materials at the beginning of mixing. The CO_2 sequestration quantity of biochar was assumed to be the organic carbon content factor of biochar produced by pyrolysis (0.77) × fraction of biochar carbon remaining after 100 years (0.89) × 44/12 = 2.51 (g-CO_2/g), based on the computational method for application of biochar to farmland (J-Credit Scheme). Considering the CO_2 emissions in the manufacturing and transport processes of biochar, the minimum amount of CO_2 fixation to the soil-cement was estimated to be 88.8-126.3 kg-CO_2/m^3 for OPC, 53.3-75.8 kg-CO_2/m^3 for BFC-B, and 26.6-38.0 kg-CO_2/m^3 for BFC-C (see Table 4).

The soil-cement was prepared by kneading for 3 minutes using a Hobart mixer. After confirming that no bleeding occurred, the mixture was poured into a dedicated mold 50 mm in diameter and 100 mm in height. During pouring, the mold was tapped to eliminate air bubbles sufficiently. The prepared test pieces were immediately sealed with wrap and cured without demolding in a room at a constant temperature of 20±2 °C.

Table 4. *Material composition of soil-cement.*

Test ID	Addition amount (kg/m^3)			W/C (%)	CO_2 emissions of stabilizer (kg/m^3)	Powdered biochar (kg/m^3)	Minimum CO_2 fixation (kg-CO_2/m^3)
	Stabilizer	Water	Mixed soil				
OPC-180	180	342	1,564	190	135.6	55.5	126.3
BFC-B-180	180	342	1,564	190	83.1	33.3	75.8
BFC-C-180	180	342	1,564	190	43.7	16.7	38.0
OPC-160	161	354	1,546	220	121.5	49.8	113.3
BFC-B-160	161	354	1,546	220	74.4	29.9	68.0
BFC-C-160	161	354	1,546	220	39.2	14.9	33.9
OPC-125	126	378	1,513	300	95.1	39.0	88.8
BFC-B-125	126	378	1,513	300	58.3	23.4	53.3
BFC-C-125	126	378	1,513	300	30.7	11.7	26.6

Table 5. *Inventory data for the materials used.*

Material	CO_2 emissions (kg/t)	Reference
Ordinary Portland cement	757.9	Japan Society of Civil Engineers, 2002
Blast furnace cement	24.1	Japan Society of Civil Engineers, 2002
Biochar	-2,513	J-Credit Scheme

2.3 Uniaxial compressive strength and hexavalent chromium elution tests

The prepared test pieces were demolded at the age of 28 days. The pieces were then tested for shear wave velocity (JGS 0544, 2020) and uniaxial compression (JIS A 1216, 2020). The molds and test specimens were cut to a target height of 100 mm, and the end faces were smoothly polished. Figure 4 shows an example of the test specimens with and without biochar. The shear wave velocity and uniaxial compressive strength results were the average values of three test specimens.

The hexavalent chromium is one of the major sources of soil pollution. After the uniaxial compression test, the hexavalent chromium elution in the soil-cement was verified using diphenylcarbazide absorptiometry (JIS K 0102, 2016) as described in Notification No.46 of the Ministry of the Environment.

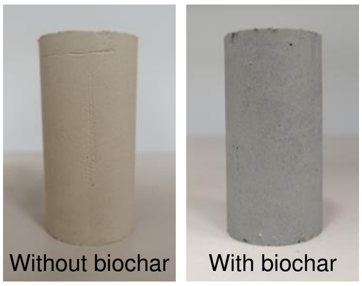

Figure 4. *An example of the difference in test specimens with and without biochar.*

3 RESULTS AND DISCUSSIONS

Figures 5 to Figure 7 show the results for the test specimens. The uniaxial compressive strength of the soil-cement without biochar after curing for 28 days was 0.81-2.34 MPa for OPC, 1.82-3.52 MPa for BFC-B, and 1.99-3.39 MPa for BFC-C. On the other hand, the uniaxial compressive strength of the soil-cement with biochar showed slight increases, except in the cases of BFC-B-160-B and BFC-C-160-B. The maximum value of the ratio of increase in uniaxial compressive strength was found with 125 kg/m^3 of stabilizer and was 1.31 for OPC, 1.06 for BFC-B, and 1.19 for BFC-C. This slight increase in strength was likely caused by the porous biochar (see Figure 2 and Pardo, 2018) absorbing water over time, as shown in Figure 3, and by the decreased W/C ratio of the soil-cement. The uniaxial compressive strength showed a clear relationship with the shear wave velocity regardless of the type of stabilizer and the presence or absence of biochar. This relation is very similar to a description by Asaka (2011) that the uniaxial compressive strength may be expressed by the exponential equation of the shear wave velocity. The elution quantity of hexavalent chromium in soil-cement using ordinary Portland cement exceeded the environmental quality standard for soil pollution of 0.05 mg/L prescribed by the Minister of the Environment of Japan, regardless of the presence or absence of biochar. However, the elution quantity of hexavalent chromium was slightly reduced by the addition of biochar. Hexavalent chromium elution was less than the lower limit of quantitation of 0.02 mg/L for the soil-cement using blast furnace cement types B and C.

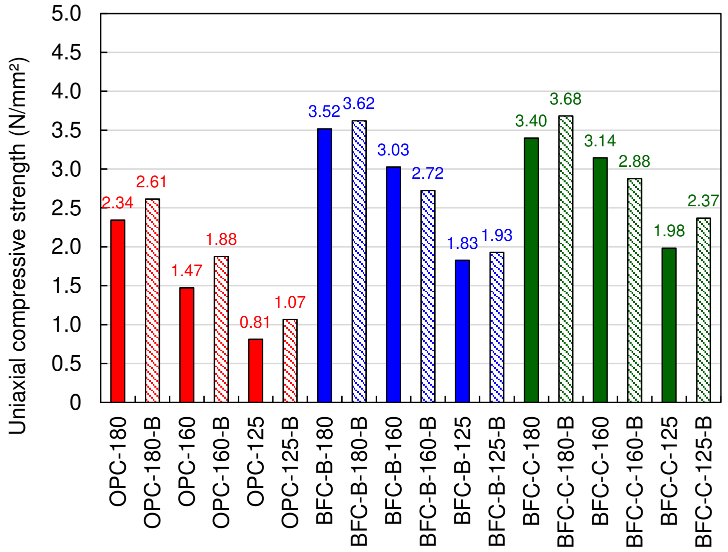

Figure 5. *Uniaxial compressive strength results.*

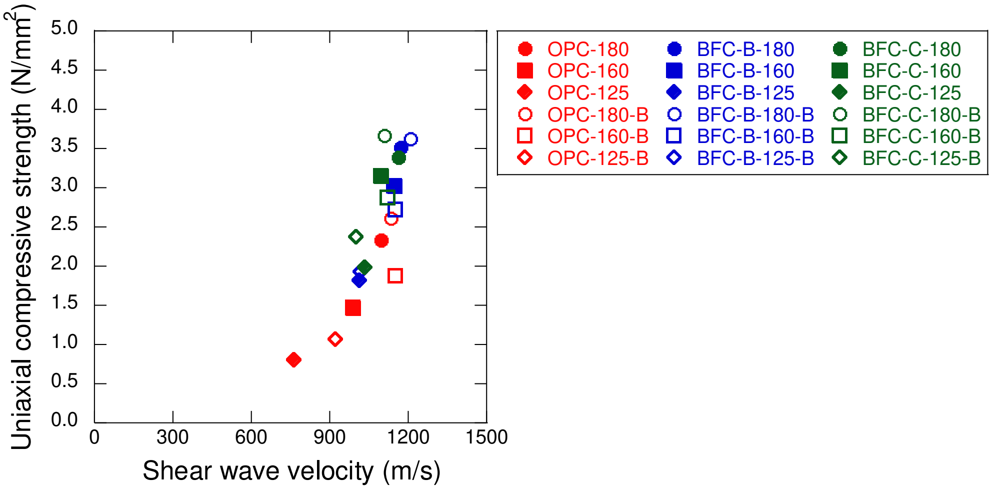

Figure 6. *Relationship between uniaxial compressive strength and shear wave velocity.*

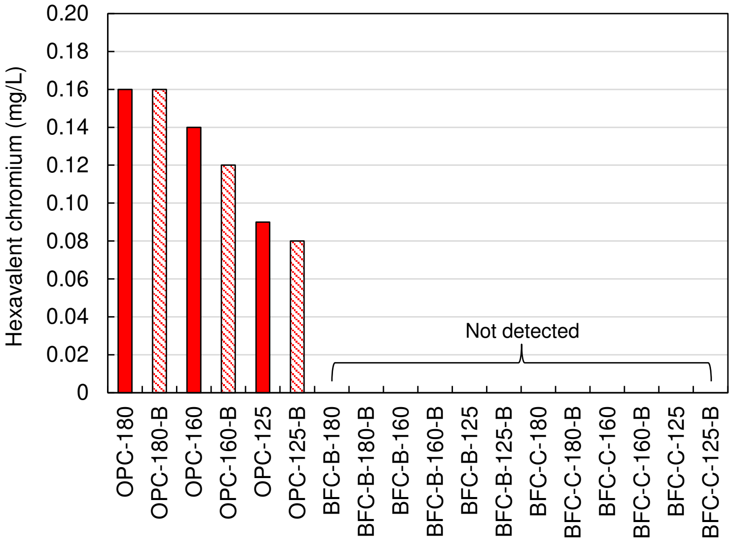

Figure 7. *Hexavalent chromium elution test results.*

4 CONCLUSIONS

The usefulness of adding biochar to soil-cement was verified by investigating the effect of biochar on strength development and hexavalent chromium elution of soil-cement in the laboratory. As a result of adding biochar with zero CO_2 emission to the stabilizer of soil-cement, the uniaxial compressive strength increased slightly, and the hexavalent chromium elution was suppressed regardless of the type of stabilizer. Further laboratory experiments would be required to understand the mechanical properties of soil-cement in varying amounts of biochar added.

REFERENCES

Asaka, Y., & Abe, T. (2011). Non-destructive technique for assessing cement-treated ground. Proceedings of the Institution of Civil Engineers - Ground Improvement, 164(3), 179-187.

Japan Society of Civil Engineers. (2002). Concrete engineering series, (44), 1-26. (in Japanese)

J-Credit Scheme. Biochar addition to mineral soil in cropland/grassland (AG-004). (in Japanese)

Kuittinen, M., Ludvig, A., & Weiss, G. (2013). Wood in carbon efficient construction: Tools, methods and applications. CEI-Bois.

National Institute for Land and Infrastructure Management. (2008). Project Research Report, (21). (in Japanese)

Numata, A., Miwa, S., Tsutsui, M., Hara, T., Mimura, K., & Ikeda, H. (2014). Use of wood for countermeasures against liquefaction. World Conference on Timber Engineering.

Pardo, G. S., Orense, R. P., & Sarmah, A. K. (2018). Cyclic strength of sand mixed with biochar: Some preliminary results. Soils and Foundations, 58(1), 241-247.

Papageorgiou, A., Azzi, E. S., Enell, A. & Sundberg, C. (2021). Biochar produced from wood waste for soil remediation in Sweden: Carbon sequestration and other environmental impacts. Science of the Total Environment, 776, 145953, 1-13.

Terzis, D., & Laloui, L. (2018). 3-D micro-architecture and mechanical response of soil cemented via microbial-induced calcite precipitation. Scientific Reports, 8(1), 1-11.

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