Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-601

Basic characteristics of environment-friendly soil-cement material with added biochar

Caractéristiques de base d’un matériau sol-ciment écologique avec biochar ajouté

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ABSTRACT: This paper describes research in which carbon-rich biochar is added to a soil-cement slurry in the laboratory with the purpose of offsetting the carbon emissions of the stabilizer used in cement-treated soil. The effect of the biochar on strength development and resistance to material separation is investigated. Blast furnace cement type B is used as the stabilizer, which is added to solidify the soil. Specimens with five different ratios of stabilizer relative to the volume of the soil-water mixture are tested (40, 80, 120, 150 and 300 kg/m^3) and different proportions of biochar are added to offset and more than offset the CO_2 emissions of the stabilizer. The assumed CO_2 sequestration resulting from biochar addition is 2.51 kg-CO_2/kg, based on methodologies used for the addition of biochar to mineral soil in cropland/grassland. The unconfined compression strength of the soil-cement with biochar after curing for 28 days tends to be higher than that of the material without biochar, except for the 40 kg/m^3 cases. The maximum ratio of increase in unconfined compression strength is 1.04, 1.43, 1.37, 1.36 and 1.16 for the 40 to 300 kg/m^3 cases. The material segregation resistance of the soil-cement is also improved when the amount of biochar added exceeds 30 kg/m^3, regardless of the amount of stabilizer added.

RÉSUMÉ: Cet article décrit des recherches dans lesquelles du biochar riche en carbone est ajouté à une boue sol-ciment en laboratoire dans le but de compenser les émissions carbone du stabilisateur utilisé dans le sol traité au ciment. L’effet du biochar sur le développement de la résistance mécanique et sur la résistance à la séparation des matériaux est étudié. Du ciment de haut fourneau de type B est utilisé comme stabilisateur, qui est ajouté pour solidifier le sol. Des échantillons avec cinq ratios différents de stabilisateur par rapport au volume du mélange sol-eau sont testés (40, 80, 120, 150 et 300 kg/m^3) et différentes proportions de biochar sont ajoutées afin de compenser et faire plus que compenser les émissions de CO_2 du stabilisateur. La séquestration de CO_2 supposée résultant de l’ajout de biochar est de 2,51 kg-CO_2/kg, sur la base des méthodologies utilisées pour l’ajout de biochar à un sol minéral dans des terres cultivées/prairies. La résistance à la compression monoaxiale du sol-ciment avec biochar après 28 jours de durcissement tend à être supérieure à celle d’un matériau sans biochar, à l’exception des cas à 40 kg/m^3. Le ratio d’augmentation maximum de la résistance à la compression monoaxiale est de 1,04, 1,43, 1,37, 1,36 et 1,16 pour les cas allant de 40 à 300 kg/m^3. La résistance à la ségrégation des matériaux du sol-ciment est également améliorée lorsque la quantité de biochar ajoutée dépasse 30 kg/m^3, indépendamment de la quantité de stabilisateur ajoutée.

Keywords: Carbon sequestration; biochar; cement-treated soil; unconfined compression strength; bleeding.

1 INTRODUCTION

The building and construction industry accounts for around 37% of global energy usage and process-related CO_2 emissions (UNEP, 2022). Emissions from the manufacture of concrete, aluminium and steel used in the construction of buildings are estimated to represent around 2.3 Gt-CO_2 globally. Other materials used in the construction of buildings, such as bricks and glass, are estimated to account for a further 1.2 Gt-CO_2 of emissions globally. NILIM (2008) reported that CO_2 emissions associated with construction (embodied carbon) and demolition account for approximately 30% of the life cycle CO_2 emissions of a building. Meanwhile, research and development related to carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS) is being pursued in the field of geotechnical engineering. Furthermore, both artificial and natural low-carbon building materials, such as recycled concrete fines and bio-improved soils, are being investigated. The use of wood in construction projects is also being actively promoted (e.g., Kuittinen, 2013) to increase carbon accumulation and mitigate climate change. Moreover, carbon-rich materials, such as wood and biochar, have attracted attention in recent years not only in the agriculture field but also among geotechnical engineers. Biochar is a solid material generated by heating biomass to a temperature in excess of 350°C under conditions of controlled and limited oxidant concentration to prevent combustion. Senadheera (2023) summarized comprehensively the physicochemical properties of biochar when added to cementitious materials, considering both the environmental and economic impact.

In this paper, the effect of adding biochar to soil-cement used as a material for backfilling, earth retaining and ground improvement is studied through laboratory tests.

2 TEST OVERVIEW

2.1 Materials

A soil-water mixture consisting of silica sand in air-dried condition, a 1:1 mix of Kibushi clay and Kaolin clay by mass, and water with a mass ratio of 4:1:2.15 was used as the original mud. Blast furnace cement type B (symbol: BB) complying with the Japan Industrial Standard (JIS R 5211, 2019) was used as the stabilizer; its characteristics are density 3.04 g/cm^3, specific surface area 3950 cm^2/g, ignition loss 1.39%, SO_3 2.14%, and addition ratio of blast furnace slag 40%. The cement used was of the type generally distributed in Japan with ingredients stipulated by JIS, bearing in mind that cement ingredients differ among countries.

Biochar was used as an admixture to improve the segregation resistance of the soil-cement material. It was manufactured by Nara Tanka Industries Co., Ltd. and had been sieved to a grain size of 5 mm or less. The original feedstock for this biochar is sawdust produced while cutting coniferous and broad-leaved trees. The sawdust is compression-molded into briquettes, then carbonized, pulverized, and sieved for use as biochar. Biochar can be highly porous depending on the original feedstock and pyrolysis conditions, and the specific surface area differs by three orders compared to the stabilizer. The water absorption of the biochar is 21-25%. Other basic physical properties of the biochar are available in Kurimoto (2023).

2.2 Mix proportions

Five amounts of stabilizer (40, 80, 120, 150 and 300 kg/m^3) were used relative to the volume of the soil-water mixture. The target water content of both the soil-water mixture and the soil-cement was 43%. The target unconfined compression strength of the soil-cement was set to 100-3000 kPa.

Based on the CO_2 emissions inventory data of the stabilizer (MLIT, 2017), the amount of biochar used was adjusted to offset the CO_2 emissions of the stabilize or more than offset them. Note that the amount of CO_2 sequestration by the biochar was assumed to be the ratio of organic carbon content for this type of biochar (0.77) × fraction of biochar carbon remaining after 100 years (0.89) × relative molecular mass ratio of carbon dioxide to carbon (44/12) = 2.51 kg-CO_2/kg, based on methodologies used in regard to biochar addition to mineral soil in cropland/grassland (J-Credit Scheme, 2023). Biochar was added as a material percentage at the beginning of mixing. In this experiment, CO_2 emissions related to the manufacture and transport of the biochar were not considered.

2.3 Mixing and testing

The soil-cement material was prepared by kneading for three minutes in a small mixer. Details of the process are given in Kurimoto (2023). Immediately after kneading, the temperature, density, flow, and bleeding characteristics of the soil-cement in a slurry state were measured. Test specimens were prepared with a size of 50 mm in diameter and 100 mm in height and these were demolded at the age of 28 days. The specimens were then tested for shear wave velocity and unconfined compression. Sher wave velocity was measured by bender element test. Shear wave velocity and unconfined compression strength results are the averages of three test specimens.

3 EXPERIMENTAL RESULTS

Table 1 shows the physical properties and unconfined compression strength of the soil-cement specimens. Test IDs consist of “type of stabilizer - amount of stabilizer added - ratio of CO_2 fixation in biochar to CO_2 emissions of stabilizer.” For example, “BB-80-1” represents the case in which the stabilizer is blast furnace cement type B, the amount of stabilizer added is 80 kg/m^3, and biochar is added to exactly offset the CO_2 emissions of the stabilizer. Figures 1 to 4 show the results for all test specimens. The vertical axes in Figure 1 and Figure 2 are normalized by the value for the soil-cement without biochar in each case.

Table 1 and Figure 1 show that, although there is no effect of adding biochar on the density of the soil-cement after kneading, the flow and bleeding tend to decrease as the amount of biochar increases, except for BB-40-0 to BB-40-3. In other words, the material segregation resistance of the soil-cement is improved when the amount of biochar added exceeds 30 kg/m^3, regardless of the amount of stabilizer added.

Table 1 and Figure 2 demonstrate that the unconfined compression strength of the soil-cement without biochar in five cases is 169-2695 kPa, which satisfies the target strength. By contrast, the unconfined compression strength of the soil-cement with biochar is

Table 1. Physical properties and unconfined compression strength of the soil-cement material.

Test ID	**Biochar (kg/m^3)**	**CO_2 emissions of stabilizer (kg/m^3)**	**CO_2 fixation in biochar (kg/m^3)**	**Density (g/cm^3)**	**Flow (mm)**	**Bleeding (%)**	**Unconfined compression strength (kPa)**
BB-40-0	0	20	0	1.77	254	1.19	169
BB-40-0.5	4	20	10	1.78	234	1.17	149
BB-40-1	8	20	20	1.77	235	1.21	154
BB-40-1.5	12	20	30	1.78	249	1.18	161
BB-40-2	16	20	40	1.78	260	1.47	141
BB-40-2.5	20	20	50	1.77	263	1.39	159
BB-40-3	24	20	60	1.79	261	1.20	158
BB-40-3.5	28	20	70	1.80	237	0.84	162
BB-40-4	32	20	80	1.79	240	0.70	175
BB-80-0	0	40	0	1.77	238	0.75	223
BB-80-0.5	8	40	20	1.77	264	0.85	238
BB-80-1	16	40	40	1.76	240	0.48	259
BB-80-1.5	24	40	60	1.77	229	0.34	266
BB-80-2	32	40	80	1.78	198	0.23	269
BB-80-2.5	40	40	100	1.79	185	0.49	286
BB-80-3	48	40	120	1.79	198	0.41	298
BB-80-3.5	56	40	140	1.80	198	0.26	314
BB-80-4	64	40	160	1.78	197	0.28	320
BB-120-0	0	60	0	1.78	264	0.81	465
BB-120-0.5	12	60	30	1.79	221	0.22	486
BB-120-1	24	60	60	1.79	241	0.57	481
BB-120-1.5	36	60	90	1.78	223	0.43	456
BB-120-2	48	60	120	1.78	232	0.32	504
BB-120-2.5	60	60	150	1.79	200	0.19	499
BB-120-3	72	60	180	1.80	200	0.28	525
BB-120-3.5	84	60	210	1.78	198	0.13	639
BB-120-4	96	60	240	1.80	174	0.00	536
BB-150-0	0	75	0	1.76	270	0.79	744
BB-150-0.5	15	75	37	1.76	265	0.72	817
BB-150-1	30	75	75	1.78	250	0.51	781
BB-150-1.5	45	75	112	1.78	242	0.33	855
BB-150-2	60	75	150	1.78	216	0.17	947
BB-150-2.5	75	75	187	1.78	207	0.21	975
BB-150-3	90	75	225	1.76	190	0.05	950
BB-150-3.5	105	75	262	1.77	183	0.00	1015
BB-150-4	120	75	300	1.77	169	0.00	1001
BB-300-0	0	150	0	1.71	254	0.01	2695
BB-300-0.5	30	150	75	1.73	264	0.00	2570
BB-300-1	60	150	150	1.75	247	0.00	2722
BB-300-1.5	90	150	225	1.75	234	0.00	2836
BB-300-2	120	150	300	1.76	206	0.00	2981
BB-300-2.5	150	150	375	1.74	209	0.00	2781
BB-300-3	179	150	450	1.75	186	0.00	3127
BB-300-3.5	209	150	525	1.75	171	0.00	3015
BB-300-4	239	150	600	1.77	156	0.00	3126

slightly higher, except for BB-40. The maximum ratio of unconfined compression strength increase in each case is 1.04 for BB-40, 1.43 for BB-80, 1.37 for BB-120, 1.36 for BB-150 and 1.16 for BB-300. This slight increase in strength is because the highly porous biochar absorbs water over time, thereby reducing the water-cement ratio of the soil-cement (Kurimoto, 2023). On the other hand, the water-cement ratio of the soil-cement in BB-40 is larger than in the other cases; consequently, the water absorption of biochar has little effect on strength of the soil-cement. Figure 3 shows that when the unconfined compression strength of the soil-cement is in range of 141-3127 kPa, the corresponding deformation modulus is in the range 26-712 MPa. The ratio of the deformation modulus E_{50} and the unconfined compression strength q_u is in the range 180-260. The unconfined compression strength exhibits a unique relationship with shear wave velocity

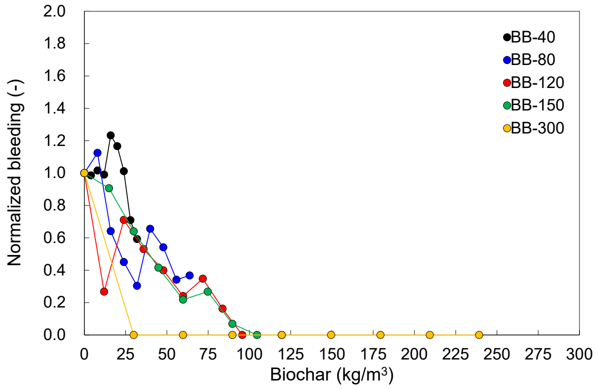

Figure 1. Normalized bleeding results.

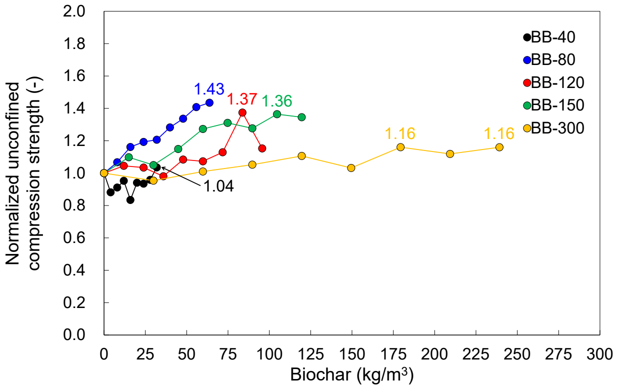

Figure 2. Normalized unconfined compression strength results.

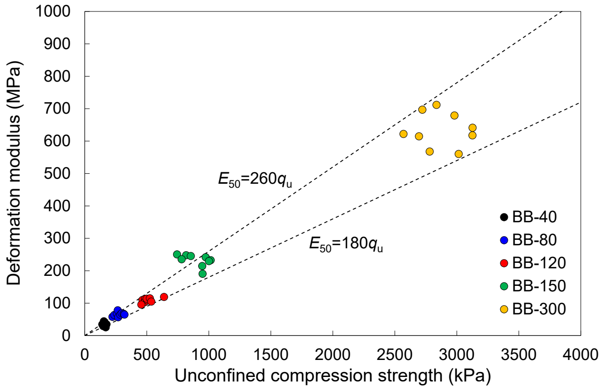

Figure 3. Relationship between deformation modulus and unconfined compression strength.

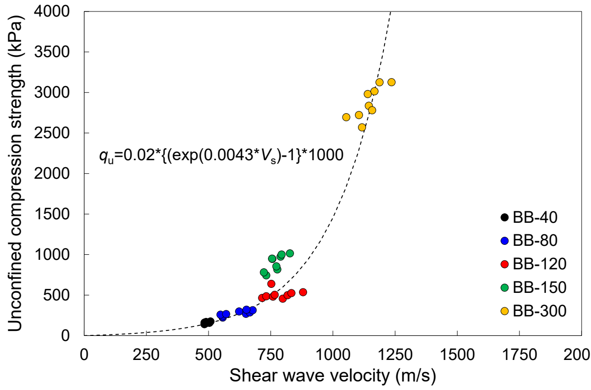

Figure 4. Relationship between unconfined compression strength and shear wave velocity.

regardless of the presence or absence of biochar and can be expressed as an exponential of the shear wave velocity, as shown in Figure 4. This relation is very similar to a description by Asaka (2011).

4 CONCLUSIONS

Biochar was used as an admixture to sequester the CO_2 in the soil-cement, and its effect on the physical and mechanical properties of the soil-cement was evaluated by laboratory tests.

As a result of adding biochar to reduce the emissions resulting from the soil-cement stabilizer, the unconfined compression strength of the material increased with the amount of stabilizer (80, 120, 150 and 300 kg/m^3) while material segregation resistance improved when the amount of biochar added exceeded 30 kg/m^3. Additionally, it was found that the relationship between the unconfined compression strength, deformation modulus and shear wave velocity was not affected by the addition of biochar.

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