Research article

Strength Characteristics of Stabilized Soils Containing Bamboo Fiber Extracted by Steam Explosion

FUTOSHI KANAWA*
Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan
Email: fk205262@nodai.ac.jp

Received 10 February 2018 Accepted 18 May 2018 (*Corresponding Author)

Abstract Construction work and materials depend mostly on earth resources. A sustainable recycling-oriented society becomes possible only when technologies for recycling as well as for energy conservation in construction are disseminated and when untapped natural resources are effectively utilized. In this paper, applicability of natural fibers for the soil stabilization technique was examined. Especially, this paper focuses on bamboo fiber extracted by steam explosion, which technique is capable to produce thin and flexible fibers from raw bamboo. In order to understanding the mechanical properties of soil mixed with bamboo fiber produced by steam explosion, unconfined compression tests were conducted. As a result of unconfined compression tests, following findings are obtained. (1) The addition of bamboo fiber to cohesive soil helps to increase the unconfined compression strength of the soil. Moreover, the addition of bamboo fiber to soil helps to increase the toughness of the soil. (2) An increase in the mix ratio of bamboo fiber results in a change in the failure mode of test specimens. In addition, at a mix ratio by weight of 0.4% or higher, specimens did not occur shear failure, but instead broke such as to become barrel-shaped. (3) The deformation coefficient of the soil mixed with bamboo fiber is similar to the deformation coefficient of cohesive soil containing no bamboo fiber. The addition of bamboo fiber does not affect deformation properties.

Keywords bamboo fiber, steam explosion, soil stabilization, unconfined compressive test

INTRODUCTION

Construction work and materials depend mostly on earth resources. A sustainable recycling-oriented society becomes possible only when technologies for recycling as well as for energy conservation in construction are disseminated and when untapped natural resources are effectively utilized. The effective utilization of soft soil in situ and of soil generated as a byproduct of construction is realized by adding short-fiber materials to such soil in order to improve its mechanical properties (Gowthaman, 2018). This soil stabilization technique differs from those that utilize solidifying material, in that the addition of short-fiber materials has little effect on drainage and plant growth. Thus, this technique is expected to be applied to vegetation beds (Miki, 1994; Masuysms, 2012). It is known that mixing of polyester, polypropylene, polyethylene or vinylon fibers with soil helps to improve the toughness, strength and erosion resistance of the soil. Those reinforced soils have been already applied to materials that cover embankment slopes and to roadbeds on soft ground. For example, Sato et al. (1998) examined the applicability of vinylon fiber as material for subgrade soil improvement. That research found the following: Adding fiber materials to subgrade soil increased the unconfined compression strength, California Bearing Ratio and resilient modulus; the effectiveness of soil improvement varies depending on the type and moisture content of the subgrade soil as well as on the shape of fibers; and long, thin fibers are effective when fiber is added to soft subgrade soil. As mentioned above, the majority of the research on improving slope stability and bearing capacity addresses chemical fibers, and research utilizing natural fibers is limited (Dipika, 2016). For example, Otsubo et al. (2014) examined the erosion resistance of a revegetation bed on a slope to which bamboo fiber was applied. The

© ISERD

findings of that research included the benefits and application methods of bamboo fiber, but no mechanical assessment of bamboo fiber application was conducted.

Bamboo has been utilized as a useful natural resource in Japan. However, because bamboo has been increasingly replaced by plastic, demand for domestic bamboo has significantly declined and many bamboo forests have been left unmanaged. Bamboo grows fast and is expected to be used as a renewable resource. Techniques for the effective use of bamboo need to be developed. Bamboo is known for its high tensile strength. In the past, concrete reinforced with bamboo members was developed. Bamboo-reinforced concrete is drawing renewed attention as a material for aseismic reinforcement (Terai, 2012). The use of bamboo as a construction material has also been examined.

In this paper, applicability of natural fibers for the soil stabilization technique was examined. Especially, this paper focuses on bamboo fiber extracted by steam explosion, which technique is capable to produce thin and flexible fibers from the raw bamboo. In order to understanding the mechanical properties of soil mixed with bamboo fiber produced by steam explosion, unconfined compression tests were conducted.

METHODOLOGY

Production of Bamboo Fiber

Bamboo fiber was extracted by steam explosion. This technique is said to have been developed by Mason in the 1920s for producing pulp used for wood fiberboard. In this technique, material is steamed by using high-temperature, high-pressure saturated water vapor in a pressurized vessel for a given length of time. When the steamed material is suddenly re-exposed to air at normal atmospheric pressure, condensed moisture in the material evaporates to cause explosive volumetric expansion. As a result, the material is crushed. This fiber extraction technique has the following characteristics: The material structure can be crushed from within; the technique utilizes water vapor alone and no chemicals, so no wastewater disposal is required; and mechanical crushing and chemical treatment by steaming can be done simultaneously. The steam explosion machine used in this study is shown in Photo 1. When bamboo fibers are extracted, the properties of the fibers vary depending on the predetermined conditions of steam explosion. The length and flexibility of fibers need to be considered when bamboo fibers are extracted for mixing with soil. In this study, the steam pressure was 1.5 MPa, the steaming time was 30 minutes, and the fiber length was 25 mm. On the basis of the preliminary test results, these steam explosion conditions were determined to ensure the production of bamboo fibers flexible enough to be easily mixed with soil. The fiber length was adjusted by cutting the raw bamboo to a predetermined length. Photo 2 shows the bamboo fiber that was created by steam explosion in this study.

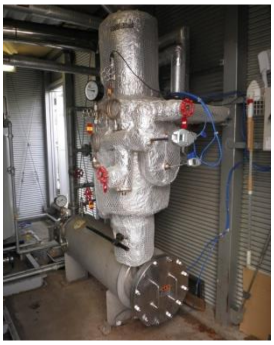


Photo 1 Steam explosion machine

Photo 2 Bamboo fiber obtained by steam explosion

Water Absorption Test for Bamboo Fiber

Soil strength properties vary according to the moisture content of soil. Because bamboo has a high water absorption rate, the production of specimens for unconfined compression tests needs to take the water absorption rate into account. For this purpose, water absorption tests of bamboo were conducted. The water absorption rate was defined as the ratio of the absorbed moisture to the dry mass of bamboo. In a water absorption test, a specimen was immersed in water for a predetermined period of time. Then the bamboo surface was wiped with a cloth, and the bamboo mass was measured. This process was repeated until the bamboo mass reached a predetermined value. When the predetermined bamboo mass was obtained, the specimen was oven-dried and its dry mass was measured. The water absorption test was conducted six times. The test results indicate that bamboo fiber absorbs water immediately upon immersion in water and that prolonged immersion does not significantly increase the bamboo mass thereafter. The mean value of water absorption rate for the bamboo used in this study was 42.2%, and the variation coefficient was 8.00%. Based on the water absorption rate of 42.2%, the water content of the soil used in the tests described below was adjusted.

Soil Properties and Unconfined Compression Test

The soil for stabilization in the tests is a cohesive soil called “Kanto loam”, which is a kind of volcanic ash soil. With the aim of understanding the physical properties of the cohesive soil, a sieve analysis test, a density test of soil particle, a compaction test, a liquid limit test, and a plastic limit test were performed. Each of these soil tests was conducted in accordance with *The Japanese Geotechnical Society: Soil Tests* (JGS, 2010). The tests found the fine fraction content to be 46.0%, the soil particle density to be 2.70 g/cm^3, the liquid limit to be 68.5 %, and the plastic limit to be 56.7%. Fig.1 shows a moisture density curve. The maximum dry density of the cohesive soil ρ_{dmax} is 1.35 g/cm^3, and the optimum water content w_{opt} is 34.6%.

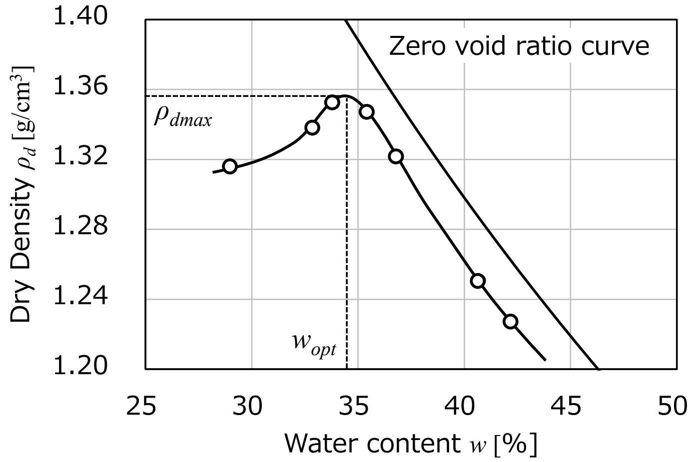


Fig. 1 Moisture density curve

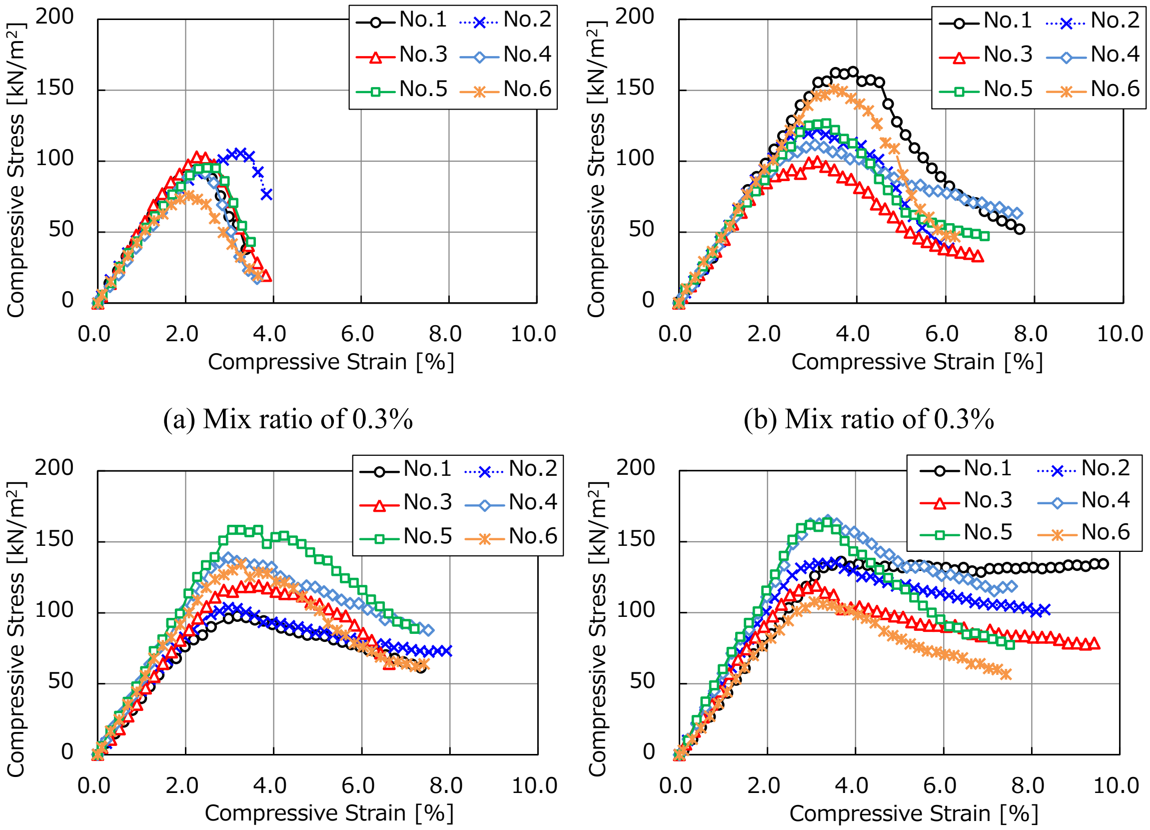
The unconfined compression test was conducted by using specimens whose moisture content was adjusted to be optimum moisture content (w_{opt}). The mix mass ratios of bamboo fibers were 0%, 0.3%, 0.4%, and 0.5%. Six specimens were used for each mix ratio. The unconfined compression test was performed with reference to *The Japanese Geotechnical Society: Soil Tests* (JGS, 2010).

RESULTS AND DISCUSSION

Figure 2 shows the test results in terms of compressive stress-strain curves. These curves demonstrate that after a unconfined compressive strength has been attained, compressive stress is maintained for soil that contains bamboo fiber, while that is not the case for soil containing no bamboo fiber. This result suggests that the addition of bamboo fiber to soil helps to increase the

© ISERD

toughness of the soil. It is also seen that the toughness of soil increases with increase in the mix ratio of bamboo fiber.



(a) Mix ratio of 0.3% (b) Mix ratio of 0.3%

(c) Mix ratio of 0.4% (d) Mix ratio of 0.5%

Fig. 2 Compressive stress-strain curves

Table 1 shows the test results in terms of the unconfined compressive strength and deformation modulus. As shown in Table 1, the unconfined compressive strength increases from the addition of bamboo fiber to soil. The variation coefficient of unconfined compression strength is 11.0% when the mix ratio is 0.0%, while the variation coefficient at other mix ratios is 18.0%. This result likely owes to the heterogeneous property of the soil mixed with bamboo fiber, which points to the need for examining methods of mixing bamboo fiber with soil more uniformly. The deformation coefficients calculated by using the data shown in Fig.2. As shown in Table 1, the deformation coefficient for the soil mixed with bamboo fiber is similar to the deformation coefficient for the original soil containing no bamboo fiber. This result suggests that the uniformity in mechanistic deformation is ensured in the soil mixed with bamboo fiber. Thus, it is not necessary to give special consideration to the possible effects of bamboo fiber on deformation when designing the earth structure.

Table 1 The results of unconfined compression tests

Mix mass ratios of bamboo fibers [%]	0.0	0.3	0.4	0.5
The unconfined compressive strength q_u [kN/m^2]	94.6	129.1	125.2	137.8
Failure strain [%]	2.4	3.3	3.2	3.3
Deformation modulus E_{50} [MN/m^2]	4.9	4.9	4.8	5.1

© ISERD

Photo 3 shows the failures of the specimens after the tests. The specimens whose bamboo fiber mix ratio was 0.0% or 0.3% were occurred shear failure, and specimens whose bamboo fiber mix ratio was 0.4% or 0.5% were occurred breakage that produced barrel-shaped specimens. The shear failure surface of a specimen containing bamboo fiber at a mix ratio of 0.3% is shown in Phot. 4. In the photograph, a bamboo fiber spans the shear failure surface. No bamboo fibers were broken during the tests. Thus, it is said that the pull-out resistance of bamboo fibers works against shear failure and helps to prevent brittle failure. In the case of higher bamboo fiber content (e.g., 0.4% or 0.5%), it is presumed that the large failure resistance caused the failure mode to be barrel-shaped failure instead of shear failure. This suggests that the toughness of subgrade soil increases from the addition of bamboo fiber. It can be said that soil mixed with bamboo fiber is adequate as a soil improvement material that is applicable to pavement subgrade which needs to have good bearing capacity and durability.

(a) Shear failure (b) Barrel-shaped failure

Photo 3 Failure of specimens after the compression test

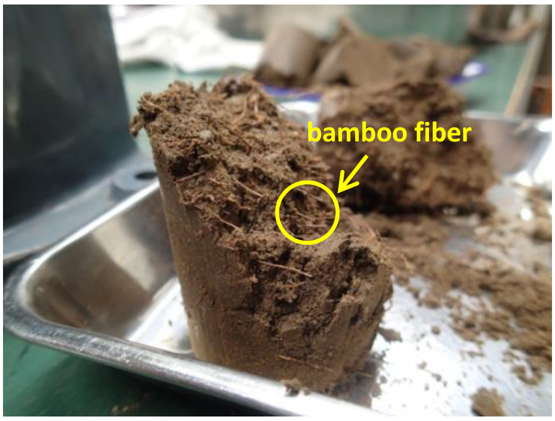


Photo 4 Shear failure surface of a specimen containing bamboo fiber

CONCLUSION

In this study, applicability of bamboo fibers extracted by steam explosion for the soil stabilization technique was examined. In order to understanding the mechanical properties of soil mixed with bamboo fiber produced by steam explosion, unconfined compression tests were conducted. The major findings of this study are as described below.
(1) That the addition of bamboo fiber to cohesive soil helps to increase the unconfined compression strength of the soil. Moreover, the addition of bamboo fiber to soil helps to increase the toughness of the soil.
(2) An increase in the mix ratio of bamboo fiber results in a change in the failure mode of test specimens. Then, at a mix ratio by weight of 0.4% or higher, specimens did not occur shear failure, but instead broke such as to become barrel-shaped.
(3) The deformation coefficient of the soil mixed with bamboo fiber is similar to the deformation coefficient of cohesive soil containing no bamboo fiber. The addition of bamboo fiber does not affect deformation properties. Thus, uniformity of mechanical deformation is ensured.

REFERENCES

Dipika, D. and Boken, J. 2016. Shear strength behaviour of bamboo fiber reinforced soil. International Research Journal of Engineering and Technology, India, 3, 433-437.
Gowthaman, S., Nakashima, K. and Kawasaki, S. 2018. A State-of-the-Art review on soil reinforcement technology using natural plant fiber materials, Past findings, present trends and future directions. Materials, 11, 553.
Mason, W.H. 1926. Process and apparatus for disintegration of wood and the like. US Patent: 1578609, USA.
Masuysms, H., Saito, Y., Ishihara, M., Sasaki, T. and Mori, H. 2012. Experimental study of erosion

resistance and applicability to vegetation of short fiber reinforced soil mixture. Journal of Japan Society of Civil Engineers. Ser. B1, Hydraulic Engineering, 68, 4, I_1129-I_1134.

Miki, H., Hayashi, Y., Mori, K. and Katsu, N. 1994. Development of fiber-Reinforced soils and its application to practical use. Soil Mechanics and Foundation Engineering, 42, 11-16.

Outsubo, M., Sugimoto, H., Furuno, H. and Higashi, T. 2014. Resistance to erosion of bamboo fiber as a slope greening substrat. Sci. Bull. Fac. Agr., Kyushu Univ., 69, 47-54.

Sato, H., Kuriyagawa, Y. and Akiba S. 1998. Evaluation applicability of fiber as subgrade improving material. Journal of Pavement Engineering, 3, 129-138.

Terai, M. and Minami, K. 2012. Research and development on bamboo reinforced concrete structure. Proceedings of 15th WCEE.

The Japanese Geotechnical Society, 2010, Soil test. Maruzen, Japan.

© ISERD