Research article

Changes in Physical Characteristics of Bamboo in Response to Its Degradation in Water and Soil Environments

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Abstract The utilization rate of bamboo in Japan is still very low, leading to the formation of abandoned bamboo forests. To reduce the area of abandoned bamboo forests, the use of bamboo as a construction material has been gaining attention in recent years. To use bamboo as a construction material, its physical characteristics (e.g., bending and compressive strengths) and chemical (e.g., degradation and organic matter) characteristics must be understood. Previously, the compressive strength and degradation of bamboo had been reported. To the best of our knowledge, the relation between the physical and chemical characteristics is still unclear. The first objective of this study is to clarify the degradation characteristics of bamboo in water and soil environments. Another objective of the study is to examine changes in the physical characteristics of bamboo, i.e., compressive strength, in response to its degradation in water and soil environments. Regarding the experiments performed in the laboratory, the bamboo samples with and without creosote oil treatment were placed in deionized water, soil, and ultraviolet light environments. Then, the temporal changes in mass loss on ignition, water content, and compressive strength of each sample were examined. Soil organisms were observed at the end of the experiments. The degradation of bamboo seemed to be higher in soil and UV light environments compared with its degradation in deionized water. Soil organisms and the destruction of cell walls of bamboo due to UV light may partly contribute to the higher degradation of bamboo in soil and UV light environments. It is noteworthy that the compressive strength seemed to decrease with the bamboo degradation. Fortunately, treating bamboo with creosote oil could reduce the rate of reduction in compressive strength of bamboo due to degradation. From the observation made on soil organisms, bamboo degradation could activate heterotrophic bacteria in soils, and treating bamboo with creosote oil had no negative effects on soil organisms.

Keywords bamboo, degradation, loss on ignition, compressive strength, soil organisms

INTRODUCTION

Although bamboo has been used in many different fields in Japan, the utilization rate of bamboo is still very low, leading to the formation of abandoned bamboo forests. According to a report by the Forestry Agency of Japan, bamboo forest area was approximately 1600 km^2 in 2007, which was 10% greater than in 1981. This bamboo forest area covered approximately 0.6% of the total forest area in Japan. However, 66% of the total bamboo forest area was unused. To reduce the area of abandoned bamboo forests, many countermeasures have been proposed for increasing the utilization rate of bamboo. Previously, bamboo was primarily used as a material for construction and household furniture. In recent years, bamboo has been used as a fertilizer in agriculture (Cui and Wu, 2010; Liu et al., 2014), and as an absorbent for contaminant removal (Liu et al., 2012; Mohamed et al., 2015).

It is noteworthy that when using bamboo as a construction material, the physical (e.g., compressive strength) and chemical (e.g., the degradation of organic matter) characteristics must be understood. Many studies have focused on the compression, tension, shear, and flexural strength of bamboo under different treatments (Sharma et al., 2015; Penellum et al., 2018). Because bamboo is an organic material, the degradation of bamboo produces organic acids, phenolic compounds, and heterocyclic compounds (Huo et al., 2016). Therefore, degradation of bamboo has been extensively studied (Xiao et al., 2014).

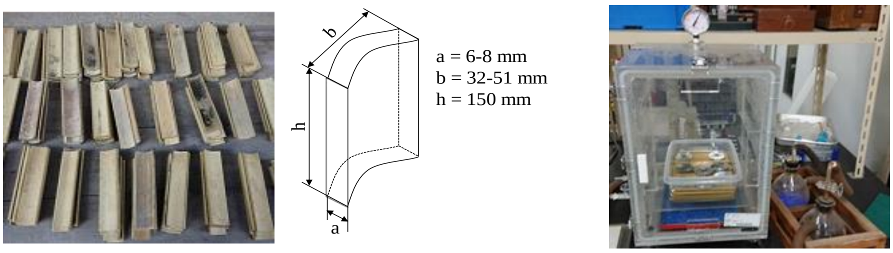
To date, degradation and physical characteristics of bamboo have been examined separately. To the best of our knowledge, changes in the physical characteristics of bamboo owing to its degradation have not yet been reported in the literature. When bamboo is used as a construction material in soil and water environments, understanding the relation between the physical and the degradation characteristics of bamboo is very important. Hence, the first objective of this study is to examine bamboo degradation in soil and water environments. The second objective is to evaluate changes in the compressive strength of bamboo owing to its degradation. In previous studies (Wang et al., 2012; Jessada, 2014), it has been reported that bamboo vinegar influences bacterial communities. Thus, the final objective of this study is to examine the effects of bamboo degradation in soil environment on soil organisms.

OBJECTIVE

To examine the points as follows: 1) degradation of bamboo in soil and water environments; 2) the changes in the compressive strength of bamboo owing to its degradation; and 3) the effects of bamboo degradation on soil organisms.

METHODOLOGY

Bamboo Used for the Experiments



(a) Bamboo specimens (b) Creosote oil treatment

Fig. 1 Bamboo specimens and creosote oil treatment (JIS A 9002)

Bamboo (*Phyllostachys bambusoides*) sample used for the experiments was cut from a bamboo forest located in Kozaki-Machi (Chiba Prefecture, Japan). The bamboo was cut into several pieces of 150 mm in height each to make the bamboo specimens used for the experiments as shown in Fig. 1a. Two kinds of specimens were prepared, i.e., those with and those without creosote oil treatment (JIS A 9002). During the creosote oil treatment, the specimens were placed in a container filled with 800 mL of creosote oil (Fig. 1b). Then, the container was placed in AS ONE vacuum desiccator (VLH). To enhance the penetration of creosote oil into the bamboo specimens, the desiccator pressure was decreased to approximately 40 kPa for 5 h. This process for pressure decrease was performed in duplicate repetition.

Experimental Procedures and Measurements

The bamboo specimens with and without creosote oil treatment were placed in different containers (360 mm × 510 mm × 290 mm) that contained black soil (Emata, Kurotuti) and deionized water.

(a) Black soil environment (b) Deionized water environment (c) Ultraviolet light environment

Fig. 2 Bamboo specimens with/without creosote oil treatment in different environments

(a) Specimen species (b) Compressive strength measurement

Fig. 3 Specimen species for water content, LOI, and compressive strength measurement

Furthermore, the specimens were placed in a plate and kept under ultraviolet (UV) light (AS ONE, TY-33N) environment, as shown in Fig. 2c. When using black soil, the outer side of the bamboo specimen was made to get in contact with soil. The inner side of the bamboo was exposed to either air or UV light. When using deionized water, the specimens was submerged in water.

At the 1st, 2nd, 3rd, and 4th week after starting the experiments, some specimens were taken out from each container to measure mass loss on ignition (LOI), compressive strength, and water content. Each specimen was sliced into small pieces (Fig. 3a) and heated at 100°C for 24 h (Advantec, FS-605) to measure water content; the specimen was also heated at 800°C for 1 h (Advantec, KL-420) to measure LOI. The compressive strength was measured using an unconfined compression apparatus (Maruto, S56A) based on JIS Z 2101 (Fig. 3b).

On week 4 after starting the experiments, soil organisms were observed using the colony count method. Briefly, 1 g of surface soil was randomly extracted from the container, and it was then mixed with 100 mL of deionized water. The mixed sample was filtrated using 1.2 µm-membrane (Whatman, GF/C). The colony count plates (3M Health Care, Petrifilm^{TM} Aqua 6457 for coliform bacteria, Petrifilm^{TM} Aqua 6450 for heterotrophic bacteria, and Petrifilm^{TM} Aqua 6408 for yeast and mold) were made to get in contact with the filtrates of the samples, placed in 35 ± 1°C for 24 ± 2 h in the cultivation of coliform bacteria, 35 ± 1°C for 48 ± 3 h in the cultivation of coliform heterotrophic bacteria, and 20-25°C for 3 to 5 days in the cultivation of yeast and mold.

RESULTS AND DISCUSSION

Bamboo Degradation in Soil, Water, and UV Light Environments

Herein, the degradation (decaying) characteristics of bamboo are discussed based on the change of their LOI (Fig. 4). Figure 4 shows the LOI of each specimen increased in comparison with the LOI of bamboo used. After 4 weeks, the increase in LOI of the specimens without creosote oil treatment were 2.0%, 1.2%, and 0.8% for soil, water, and UV light environments, respectively (Fig. 4a). The reason behind the increase in LOI may be partly due to the decay of bamboo. Interestingly, for the specimens with creosote oil treatment, the increase in LOI was 1.3%, 0.7%, and 0.3% for soil, water, and UV light environments, respectively (Fig. 4b). The reduction in LOI increase was confirmed with creosote oil treatment, which indicates that creosote oil treatment can retard the decay of bamboo.

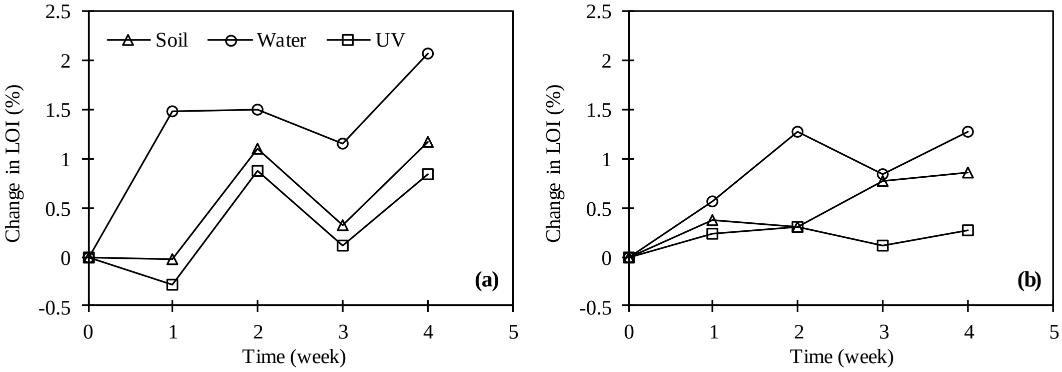


Fig. 4 LOI Change of the specimens (a) without and (b) with creosote oil treatment

Another important fact that should be noted here is the variation trend of LOI. In Fig. 4a, large temporal variations in LOI were confirmed in the soil and UV light environments compared with those in the water environment. This ensured that the decay of bamboo was activated in the soil and UV light environments than in the water environment. It is thought that soil organisms and the destruction of cell walls of bamboo by UV light play an important role in the bamboo decay process. The increase in LOI of the specimens in the UV light environment was lower than in the soil environment (Fig. 4a). It is evident that the decay of bamboo was enhanced in the UV light environment. In addition, the temporal changes in LOI seemed to be restrained by creosote oil treatment (Fig. 4b). This implies that creosote oil treatment can retard the decay of bamboo.

Changes in Compressive Strength Owing to Bamboo Degradation

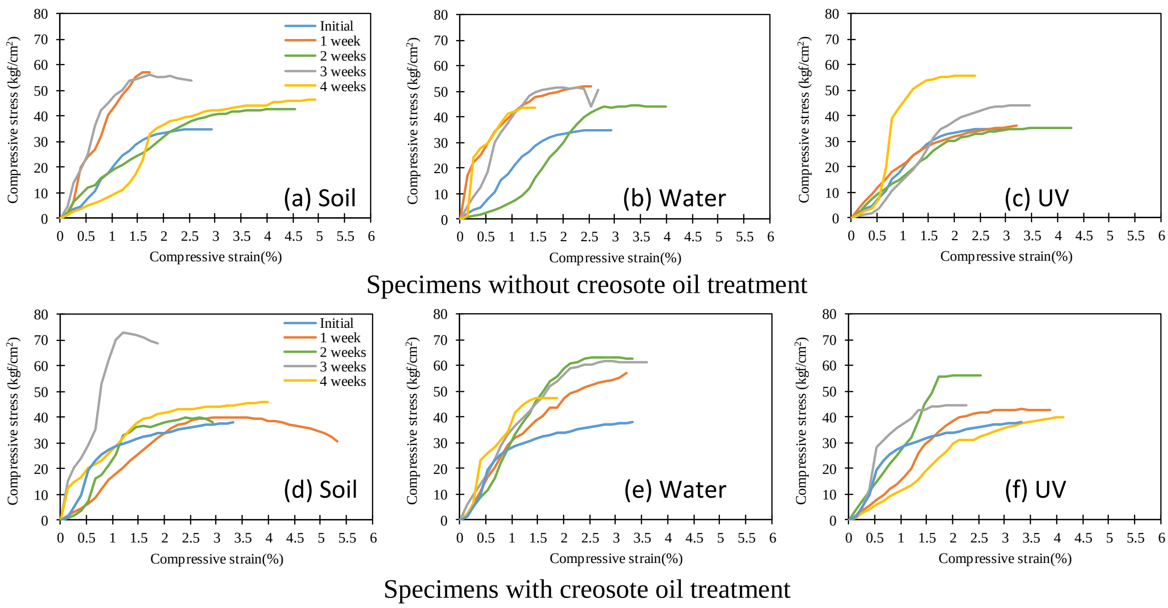


Fig. 5 Temporal changes in compressive stress

From Fig. 4, it can be seen that the degradation of bamboo in the soil environment was higher than that in the water environment. In addition, creosote oil treatment could retard bamboo degradation. It is expected that the compressive strength of bamboo decreases due to bamboo degradation. In other words, the compressive strength of bamboo in the water environment is expected to be higher than in the soil environment.

Figure 5 shows the temporal changes in the compressive stress of the specimens with and without creosote oil treatment in soil, water, and UV light environments. As the water content of specimens in the UV light environment was very low compared to the water content of the specimens when placed in other environments (Fig. 6), only the results regarding when the specimens placed in soil and water environments would be discussed. As expected, the compressive stress of the specimens in the water environment seemed to be higher than its value when the specimen was placed in the soil environment at 4th week (Fig. 5a&b). This suggests that the compressive strength of bamboo becomes smaller as the degradation of bamboo advances.

Moreover, the compressive stress of the specimens with creosote oil treatment in the water environment seemed to be higher than those without creosote oil treatment. It can be said that the retardation of bamboo degradation using creosote oil treatment can improve the decreasing compressive strength of the bamboo due to degradation. Unfortunately, a clear difference in the compressive stress between the specimens with and without creosote oil treatment in the soil environment was not verified.

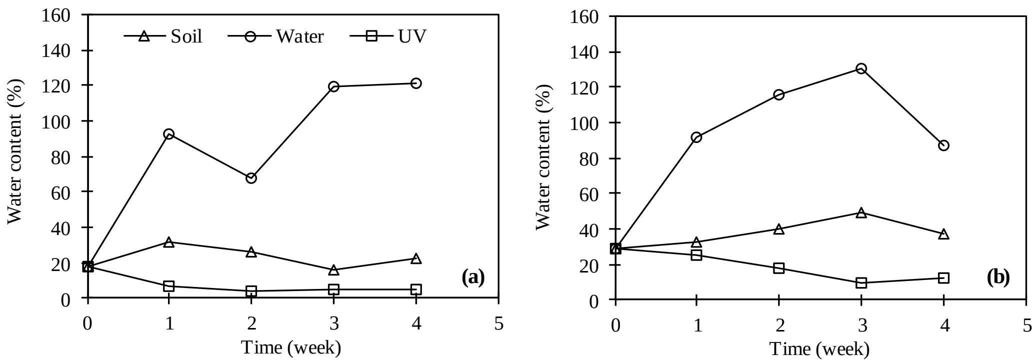


Fig. 6 Water content of the specimens (a) without and (b) with creosote oil treatment

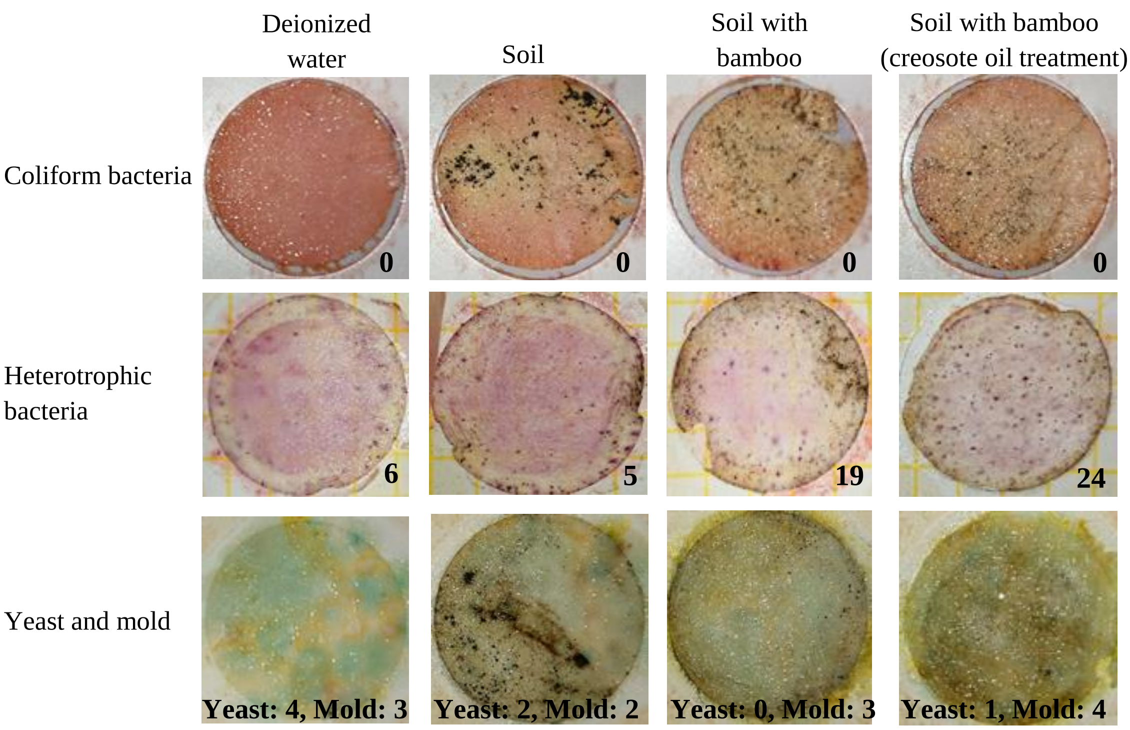


Fig. 7 Comparison of soil organisms (Number refers to the cell abundance of the organism)

Effects of Bamboo Degradation on Soil Organisms

Figure 7 depicts the observations on the effects of bamboo degradation on soil organisms. The number in the figure refers to the cell abundances of the organisms. As can be seen from the figure, coliform bacteria were not observed, suggesting that coliform bacteria do not exist in the black soil used in the experiments. For yeast and mold, the cell abundances were almost of the same order, which ensures that bamboo degradation and creosote oil treatment had no negative effects on the inhabitation environment of yeast and mold.

Interestingly, large differences in the cell abundance of heterotrophic bacteria were observed. The cell abundances in deionized water and soil environments were 6 and 5 cells, respectively. On the other hand, the cell abundance in the soil environment with bamboo was found to be 19 cells (24 cells when using the bamboo with creosote oil treatment). It can be said that bamboo degradation can activate heterotrophic bacteria in soils. Moreover, the cell abundance when using bamboo with creosote oil treatment was higher than that without creosote oil treatment. This further strengthens the fact that creosote oil treatment has no negative effects on soil organisms.

CONCLUSION

In this study, experiments were conducted to examine the degradation (decay) of bamboo in soil, water, and UV light environments. Changes in the compressive strength of bamboo owing to its degradation, and the effects of bamboo and creosote oil treatment on soil organisms were also examined. A large variation in LOI in the soil and UV light environments were observed, indicating that soil organisms and the destruction of cell walls of bamboo due to UV light play an important role in enhancing bamboo degradation. The compressive stress of bamboo in the soil environment seemed to be lower than when placed in the deionized water environment, suggesting that the compressive strength of bamboo decreases as the bamboo decays. Furthermore, the cell abundance of heterotrophic bacteria was higher when in contact with decaying bamboo, which implies that bamboo degradation can activate heterotrophic bacteria in soils. The cell abundance of soil organisms (heterotrophic bacteria, yeast, and mold) was of the same order when the experiments were conducted using bamboo with and without creosote oil treatment. This means that creosote oil treatment has no negative effects on soil organisms.

REFERENCES

Cui, Y. and Wu, L.R. 2010. Present situation and prospect of bamboo vinegar study in China. J. Bamboo Res., 29 (1), 11-16.

Huo, Y., Liu, Z., Xuan, H., Lu, C., Yu, L., Bao, W. and Zhao, G. 2016. Effects of bamboo vinegar powder on growth performance and mRNA expression levels of interleukin-10, interleukin-22, and interleukin-25 in immune organs of weaned piglets. Anim. Nutr., 2, 111-118.

Jessada, R. 2014. Effects of dietary bamboo charcoal powder including bamboo vinegar liquid supplementation on growth performance, fecal microflora population and intestinal morphology in Betong chickens. J. Poult. Sci., 51 (2), 165-171.

Liu, Z.X., Cui, Y., Huo, Y.J., Yu, L.H., Bao, W.B. and Xu, Z.H. 2014. The comparison of the physicochemical property of two different types of bamboo vinegar powder as feed additive. J. Bamboo Res., 33 (3), 27-31.

Liu, Y., Gan, L., Chen, Z., Megharaj, M. and Naidu, R. 2012. Removal of nitrate using *Paracoccus* sp. YF1 immobilized on bamboo carbon. J. Hazard. Mater., 229, 419- 425.

Mohamed, I., Zhang, G., Li, Z., Liu, Y., Chen, F. and Dai, K. 2015. Ecological restoration of an acidic Cd contaminated soil using bamboo biochar application. Ecol. Eng., 84, 67-76.

Penellum, M., Sharma, B., Shah, D.U., Foster, R.M. and Ramage, M.H. 2018. Relationship of structure and stiffness in laminated bamboo composites. Constr. Build. Mater., 65, 241-246.

Sharma, B., Gatóo, A. and Ramage, M.H. 2015. Effect of processing methods on the mechanical properties of engineered bamboo. Constr. Build. Mater., 83, 95-101.

Wang, H.F.,Wang, J.L.,Wang, C., Zhang, W.M., Liu, J.X. and Dai, B. 2012. Effect of bamboo vinegar as an antibiotic alternative on growth performance and fecal bacterial communities of weaned piglets. Livest.

Sci., 144, 173-180.
Xiao, X., Bian, J., Li, M.F., Xu, H., Xiao, B. and Sun, R.C. 2014. Enhanced enzymatic hydrolysis of bamboo (*Dendrocalamus giganteus* Munro) culm by hydrothermal pretreatment. Bioresour. Technol., 159, 41-47.