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学 位 論 文 要 旨
Dissertation Summary

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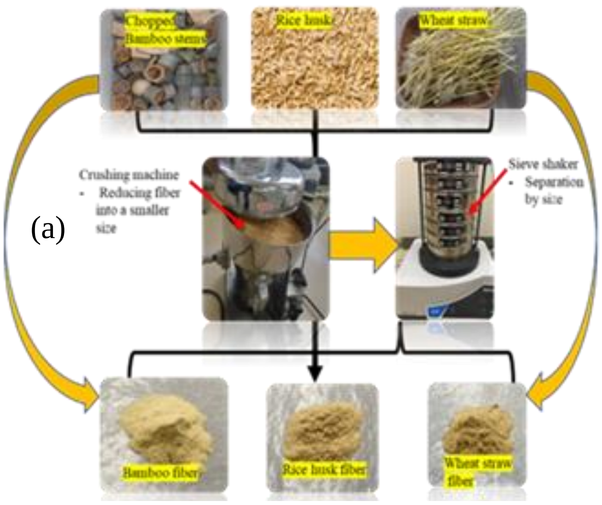
論　文　名：OPTIMIZATION OF PHYSICAL AND STRENGTH PERFORMANCE OF EXPANSIVE SOIL STABILIZED WITH CELLULOSE-BASED FIBER ADDITIVES
(Dissertation Title)

Soil is one of the most important and widely used building materials in the world. It has been effectively used for a variety of purposes, such as building social infrastructures, growing agricultural products, and performing several other important activities that can be useful for human life. The nature of soil varies from place to place due to its physical, chemical, and mechanical properties. Expansive soil is one of the different types of soils known as geotechnically problematic soils, and it represents a significant challenge for both civil engineering and geotechnical applications. Its fundamental problem is mainly related to the variation of moisture content, and it has shrinkage and swelling behavior during dry and wet seasons. It causes enormous damage to the infrastructure such as buildings, roads, pipelines, and other facilities that are built on the expansive soil. Figure 1 shows that the cobbled pavement failed due to the failure of the subgrade.

Figure 1 Behavior of the expansive soil and collapsed road section due to the unstable subgrade soil

This study investigated the existing and new mechanisms to mitigate the problem of expansive soils. Stabilizing expansive soils to improve the engineering properties of the soil has been an important technique used for many years. The purpose of soil stabilization is to improve bearing capacity, reduce permeability, reduce compressibility, and improve the soil's overall physical and mechanical performance. Despite environmental concerns and cost issues, traditional soil stabilizers such as cement, lime, fly ash, bitumen, etc. have been effectively used to improve the engineering properties of soil. Nowadays, using sustainable and environmentally friendly materials for soil stabilization is attracting a lot of attention worldwide. The use of agricultural waste resources for stabilizing problematic soils is one of the areas of interest for geotechnical engineers, researchers, and practitioners. Agricultural waste by-products, such as cellulose-based fiber additives, are sustainable, environmentally friendly, and locally available. They are also cost-effective materials. It is clear that not all agricultural by-products are suitable for soil stabilization, but there are some criteria to consider from selection to application as soil stabilizers.

This study had three main objectives. First, the selection of agricultural waste by-products as cellulose-based fiber additives for soil stabilization was carried out. Many attempts have been made to select suitable cellulose-based fibers from agricultural waste resources. In the selection of cellulose-based additives, their strength, water absorbency, chemical composition, and cellulose content are considered. Therefore, three suitable candidates such as bamboo fiber, rice husk fiber, and wheat straw fiber were selected based on the test results. The result shows that bamboo fiber has high cellulose content and high-water absorption capacity, while wheat straw has high water absorbency with relatively low cellulose content. Rice husk has low water absorbency and moderate cellulose content. Based on these parameters, it was proved that bamboo fiber, rice husk fiber, and wheat straw fiber are suitable for the stabilization of expansive soils. The preparation process of the cellulose-based fiber additives from agricultural waste is shown in Figure 2 (a), and Figures 2 (b) and (c) describe the water absorption test and the evaluation of the cellulose content for the cellulose-based fiber additives.



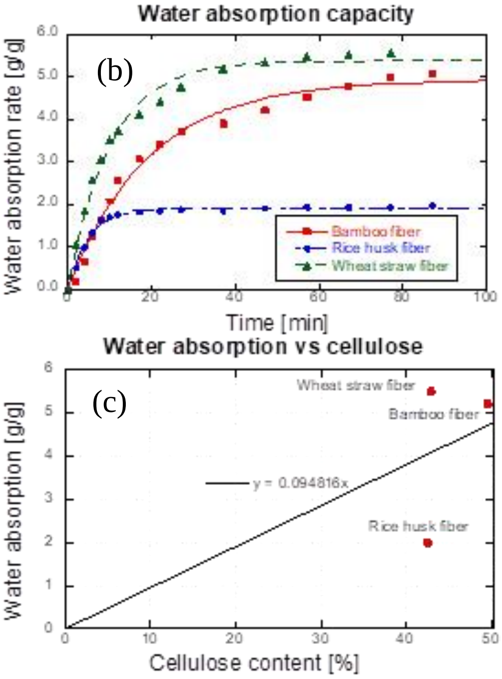


Figure 2 Process of reducing the raw agricultural into cellulose-based fiber additives (a) and evaluation of cellulose-based fibers (b) and (c)

The second objective of the study was to create a pseudo-expansive soil (PES) from a combination of clay soils like Kunigel V1, Kasaoka clay, and Tochi clay soils. Various types of geotechnical test methods were used to experimentally evaluate the replication of the expansive soil using the combination of the different soil types. The proportion by weight of KunigelV1 (21.8%), Kasaoka clay (39.1%) and Tochi clay (39.1%) was used for the replication of the expansive soil with the aim of achieving similar properties to the original expansive black cotton soil. The presence of expansive soil in Japan is rare, and the possibility of obtaining the expected properties of expansive soil is limited. Therefore, creating a pseudo-expansive soil by combining clay soils is an essential part of the study. Engineering properties such as Atterberg limits, free swell ratio (FSR), maximum dry density (MDD), optimum moisture content (OMC), and UCS values were compared with expansive soil properties. Recorded test results indicated a 101.2% liquid limit, 1.70 free swelling ratio, 1.41g/cm3 MDD, 26 percent OMC, and 110kPa UCS for the pseudo-expansive soil, and a 106.8 percent liquid limit, 1.94 free swelling ratio, 1.38g/cm3 MDD, 29.5% OMC, and 84kPa UCS for the original expansive black cotton soil. Figure 3 (a), (b), and (c) shows the comparison of some geotechnical and microstructural properties for the pseudo-expansive soil and the original expansive soil.

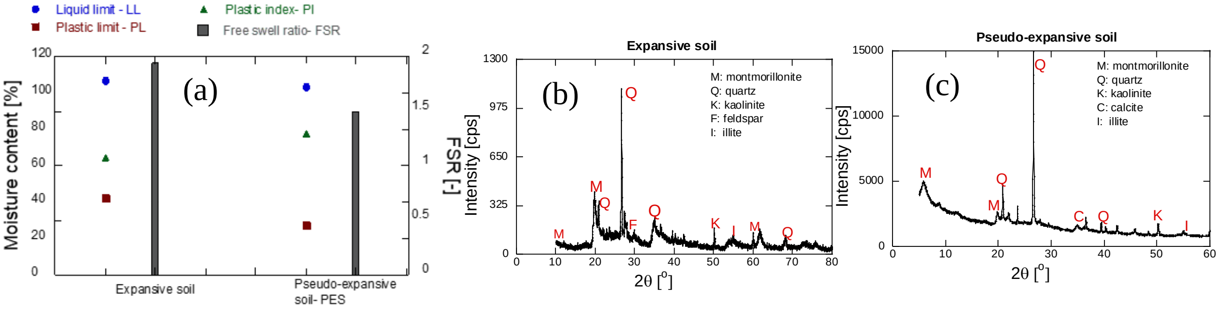
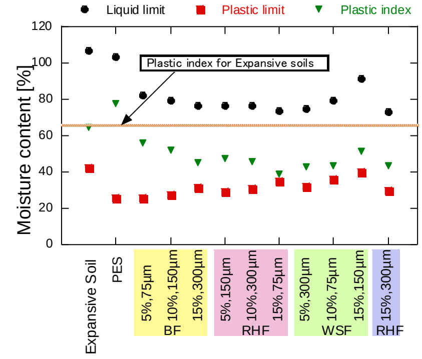
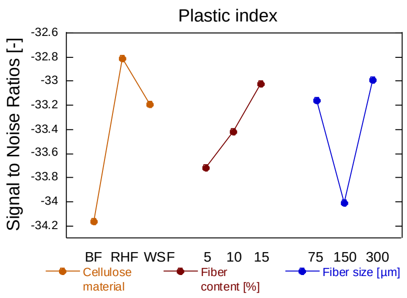


Figure 3 Atterberg limit values (a) and XRD analysis for expansive black cotton soil (b) and pseudo-expansive soil (c)

Third, the pseudo-expansive soil was stabilized with cellulosic fiber additives to further improve the engineering properties of the soil. Bamboo fiber, rice husk fiber, and wheat straw fiber were used to stabilize the pseudo-expansive soil composed of kunigelV1, Kasaoka clay, and Tochi clay soils. This part of the study presents a comprehensive study aimed at optimizing the physical and strength performance of cellulose-based fiber additives, namely bamboo fiber (BF), rice husk fiber (RHF), and wheat straw fiber (WSF), for stabilizing expansive soils. Various factors of cellulose-based fibers, such as cellulose content, water absorbency, fiber content and size, and fiber reinforcement mechanism, were studied to investigate their suitability as soil stabilizers. In this experiment, fiber dosages of 5%, 10%, and 15% and fiber sizes of 75 µm, 150 µm, and 300 µm were used in different combinations to achieve the optimum condition. The experiment was designed using the Taguchi method of signal-to-noise ratio approach to optimize the experimental conditions in terms of the Atterberg limit test, free swell ratio, linear shrinkage, and unconfined compressive strength as the main response factors. The result indicated that the RHF fiber dosages of 5% and 15% with a fiber size of 300 µm, as well as the WSF fiber dosage of 15% with fiber sizes of 75 µm and 150 µm, significantly improved the physical performance of the stabilized soil, while the BF fiber dosage of 15% with a fiber size of 300 µm was found to be an effective cellulose-based fiber additive for achieving the desired mechanical performance. Figure 4 and Figure 5 show some of the improved engineering properties such as Atterberg limit and UCS values of the stabilized soil by using cellulose-based fiber additives.





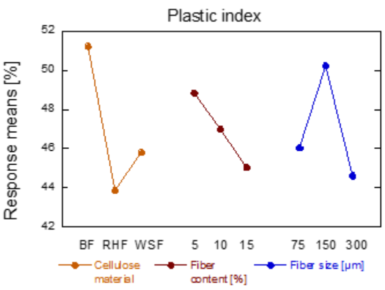


Figure 4 Atterberg limit values (a) and XRD analysis for expansive black cotton soil (b) and pseudo-expansive soil (c) by using the Taguchi method

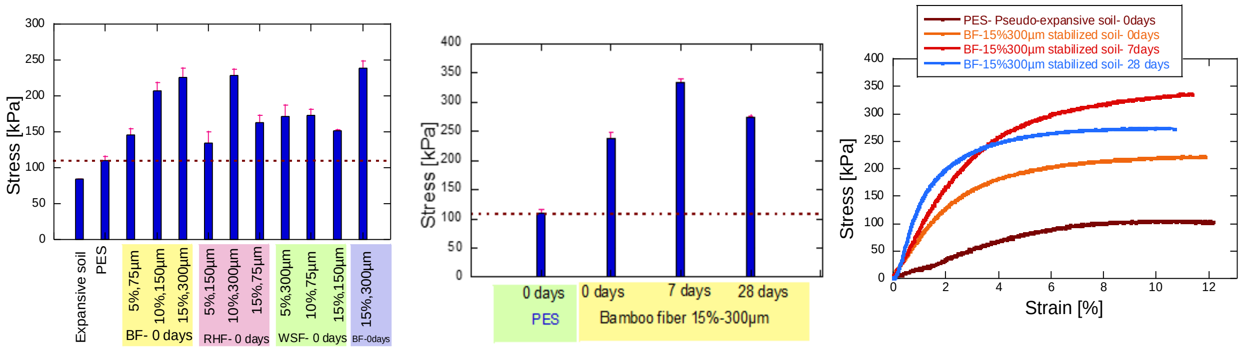
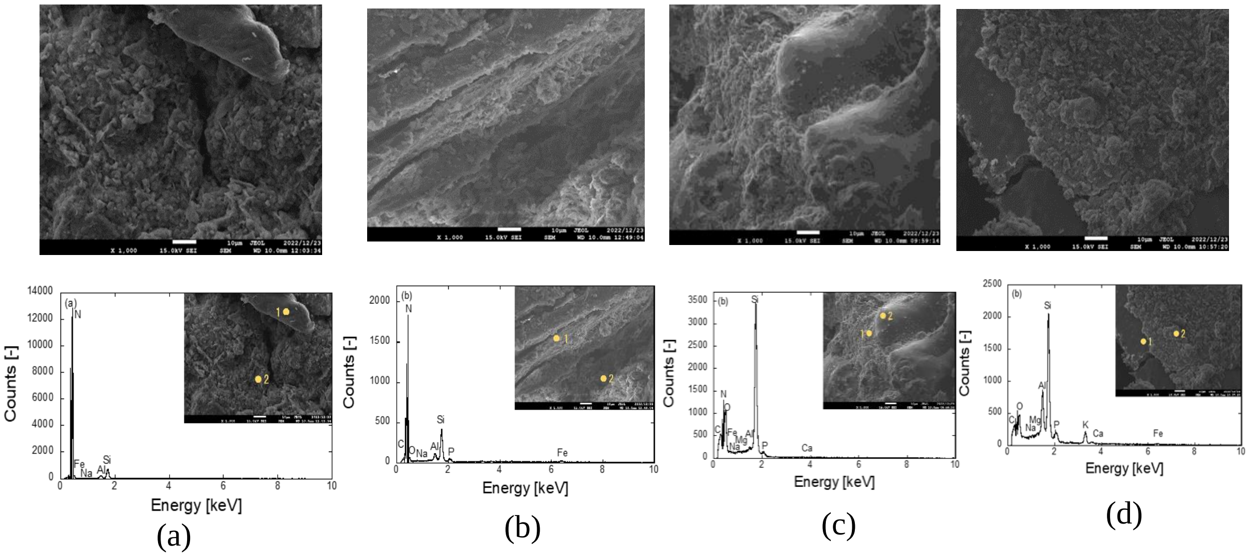


Figure 5 UCS values for expansive soil stabilized with cellulose-based additives

In addition, the microscopic analysis was carried out by SEM-EDX to observe the fiber reinforcement interaction with the stabilized soil. The SEM image shows that bamboo fiber is uniformly mixed with soil and strongly attached to the stabilized soil surface. A similar phenomenon was observed for the soil stabilized with wheat straw fiber. In the case of the rice husk-stabilized soil, the rice husk was completely mixed with the soil, and an ash-like surface was observed. This is because the length of rice husk fiber is much smaller than bamboo and wheat straw fiber materials. Besides surface morphology, chemical element composition was also observed by SEM-EDX image analysis. The main elements identified for pseudo-expansive soil were C, O, Si, and Al. In each case, liquid nitrogen was used for EDX observation and detector cooling, hence the high amount of N detected at 0.4 keV, as observed in all EDX analyses. The elements C and O were observed in the fiber materials since C and O are the main constituents of the cellulose fibers ($C_6H_{10}O_5$). As shown in Figure 6, the SEM-EDX analysis for the soil stabilized with cellulosic fibers is presented in the form of pictures.



(a) (b) (c) (d)

Figure 6 SEM-EDX analysis for pseudo-expansive soil (a), bamboo fiber stabilized soil (b), rice husk fiber stabilized soil (c) and wheat straw fiber stabilized soil (d)