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# Improvement of mechanical behavior of cemented soil reinforced with waste cornsilk fibers

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## HIGHLIGHTS

- The addition of cornsilk fibers in cemented soil increases compressive and splitting tensile strength.
- A strong linear relationship between compressive strength and splitting tensile strength is given.
- Models for estimating the compressive and splitting tensile strength are proposed.
- Cement content is the most effective parameter on compressive and tensile strength followed by curing time and fiber content.

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## ABSTRACT

This study focused on exploring the effects of cornsilk fibers on mechanical properties of cemented soil by conducting compaction, compression, and splitting tension tests. The influences of fiber content (0%, 0.25%, 0.5%, and 1% by weight of dry soil), cement content (4%, 8%, and 12% by weight of dry soil), and curing time (7, 14, and 28 days) were investigated in the present work. The multiple nonlinear regression models following the parameters including curing time, fiber content, and cement content for predicting compressive strength as well as tensile strength were established. The effective degree of each parameter on compressive and tensile strength was also evaluated. The experimental results revealed that the addition of cornsilk fibers in cemented soil improved the compressive and splitting tensile strength. The fiber contents of 0.25%–0.5% are recommended to use in cemented soil reinforced by cornsilk fibers. Splitting tensile strength equals to 0.148 times of compressive strength for both cemented soil and fiber-cement stabilized soil. The compressive and tensile strength could be predicted following the regression models with high accuracy. Based on the proposed model and sensitivity analysis, the cement content is the most effective parameter affecting on compressive strength and splitting tensile strength followed by curing time and fiber content.



## 1. Introduction

The building materials (steel, concrete, burnt brick, etc.) are considered as embodied carbon of construction materials because their manufacturing processes cause the release of pollutants (carbon dioxide, carbon monoxide, particulate matter, etc.) into the atmosphere [1,2]. Currently, the use of earth as a construction or building material to produce rammed earth, adobe block, or adobe brick has been paid more attention due to its cost-effectiveness and negligible effects on natural environment [3,4]. In addition, [5,6] mentioned that the population of the world still living in the earthen structure is about 30%. As a result, earth is still a necessary and sustainable building construction material. However, an earthen material such as Adobe has low mechanical properties [4,7] (compressive strength, tensile strength, durability, etc.) as compared to modern construction materials (concrete, steel, etc.). In order to improve the mechanical properties of the earthen material, researchers have proposed to use many kinds of stabilizer such as cement, lime, etc. [5,8–11]. In these stabilizers, cement is widely used to improve soil's strength properties [12–16]. However, cement is one of many reasons causing the $CO_2$ emissions mentioned in Ref. [17]. As a result, cemented soil reinforced with fibers has received more attention. The addition of fibers in cemented soil makes contribution to not only the improvement in mechanical properties [4,17–20] but also the reduction in the amount of used cement leading to the decrease of $CO_2$ emissions. In this method, although many kinds of fiber including natural and synthetic fibers [21–24] have been used in earth stabilization; from the viewpoints

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of sustainable development and cost-effectiveness, natural fibers should be used in earth stabilization. Cornsilk, an abundant fiber material, is a by-product from corn which is the third most cultivated crop in the world and is cultivated in many countries over the world such as South America, India, China, etc. [25]. In addition, there are limited studies on the influences of cornsilk on earth stabilization, typically the effects of fiber content or curing time on mechanical properties of fiber-cement stabilized earth. Therefore, the earth stabilization by cornsilk fibers and cement should be concerned.

The study aims to investigate the effects of waste cornsilk fibers on mechanical properties such as dry unit weight, optimum water, compressive strength, splitting tensile strength of cemented soil with variations of fiber content, cement content, and curing time. In order to understand the mechanical properties of cemented soil reinforced by cornsilk fibers, the compaction, compression, and splitting tension tests were performed. From the experimental data, the relationship between compressive strength and tensile strength is also established. In addition, the paper also proposes some models for predicting compressive and tensile strength as a function of curing time, fiber content, and cement content based on multiple regression analysis.

## 2. Materials and methods

### 2.1. Materials

The soil material used for the experiments consists of 8% clay (<5 μm), 84% silt (5μm–75 μm), and 8% sand (75 μm–2000 μm) in accordance with ASTM D422. The properties of soil are shown in Table 1. In addition, grain particle size is also shown in Fig. 1.

Stabilization materials used in this study include cement and cornsilk fibers. The used cement was GEOSET 200 provided by Taiheiyo Cement Corporation, Japan. The compositions of cement are shown in Table 2. Fiber material was made of raw cornsilk fibers which were provided by Thanh Binh Company. At first, raw cornsilk fibers were washed and cut into a segment of 10 mm approximately. After that, they were dried in the drying machine at 40 °C for 2 days to obtain fiber material (Fig. 2). The average diameter, water absorption, specific gravity, and tensile strength of cornsilk fibers are approximately 0.3 mm, 4 cc/g, 0.94 and 8.3 MPa, respectively.

### 2.2. Sample preparation

In order to investigate the effects of cornsilk fibers on strength properties of cemented soil, a wide range of cement content (4%, 8%, and 12% by weight of dry soil) and fiber content (0%, 0.25%, 0.5%, and 1% by weight of dry soil) was considered in the present work. Therefore, there are 12 mixing conditions in total in the investigation as shown in Table 3. For each mixing condition, the mixture was prepared according to the optimum moisture content and compacted until obtaining maximum dry unit weight. In the beginning, the soil was mixed with cement and fibers by hand to get the homogeneous mixtures. Then, water was added and mixed again by the mixing machine to obtain the uniform mixtures. Finally, the specimens were made by compacting the fiber-cement-soil mixture into 4 layers in the standard

**Table 1**
Soil properties.

| Soil properties | Values |
|---|---|
| Physical properties | |
| Specific gravity | 2.47 |
| Atterberg limits | |
| Liquid limit | 46.1 (%) |
| Plastic limit | 29.4 (%) |
| Plasticity index | 16.7 (%) |
| Chemical properties | |
| Compound | |
| $SiO_2$ | 72.58 (%) |
| $Al_2O_3$ | 17.28 (%) |
| $Fe_2O_3$ | 4.11 (%) |
| CaO | 1.30 (%) |
| MgO | 0.60 (%) |
| MnO | 0.04 (%) |
| $Na_2O$ | 1.68 (%) |
| $K_2O$ | 2.55 (%) |

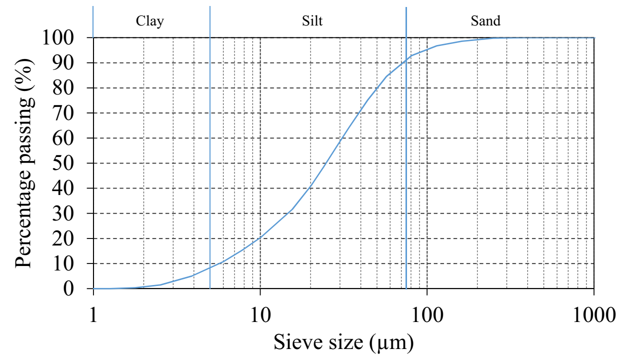


**Fig. 1.** Particle size distribution of soil.

mold with 50 mm in inside diameter and 100 mm in height. After compacting process, samples were wrapped by the plastic firm and cured in the chamber of 20 °C at different ages (7, 14, and 28 days) before subjecting to compression and splitting tension tests. In this investigation, three samples were made for each mixture to control the accuracy of the result.

### 2.3. Testing apparatus and procedure

Compaction test was conducted according to ASTM D 698 [26]. The fiber-cement-soil mixture was compacted by rammer having the weight of 2.5 kg and the falling height of 300 mm in the mold having 127 mm in height and 100 mm in inside diameter. The optimum moisture content and dry unit weight corresponding to each mixing condition were determined from this test.

The procedures of unconfined compression and splitting tension tests were carried out according to ASTM D 1633 [27] and ASTM C496 [28], respectively. The Shimazu compression machine with a maximum load sensor of 50 kN and an axial displacement rate of 0.15 mm/min was used for both these tests as Fig. 3. Before subjecting the specimens into these tests, the bearing surface of cylindrical specimens with 100 mm in height and 50 mm in diameter was polished to achieve smooth surface to ensure that the surface of testing specimens was perpendicular to the applied axial load.

## 3. Regression models and sensitive analysis

In order to propose the models for predicting compressive and splitting tensile strength of fiber-cement stabilized soil, the regression analysis was considered in the investigation. This method is a general technique and has been used for investigating the relationship or establishing the model of effective variables on some problems such as seepage velocity and piping resistance in Refs. [29,30], compressive and tensile strength in Ref. [31], or shear strength in Ref. [32]. The form of regression model as shown in Eq. (1) was considered in the present work.

$$y = k_0 + k_1x_1 + k_2x_2 + k_3x_3 + k_4x_1^2 + k_5x_2^2 + k_6x_2^2 + k_7x_1x_2 + k_8x_1x_3 + k_9x_2x_3 \quad (1)$$

where y is dependent variables or output variables (compressive strength ($\sigma_c$) and splitting tensile strength ($\sigma_t$)); $x_1$, $x_2$, and $x_3$ are the independent variables or input variables with respect to curing time (*D*), cement content (*C*), and fiber content (*F*); and $k_0$ to $k_9$ are the regression coefficients. The regression coefficients were determined by writing the independent variables and the dependent variable into matrix form and solving this matrix. The competence of developed models was examined according to the coefficient of determination $R^2$ and P-values of each variable in the developed models. In which, $R^2$ indicates the relationship between observed data and predicted data and the P-values of coefficients ($k_1$–$k_9$) associated with each variable in Eq. (1) should be less than 0.05 to provide strong evidence against the null hypothesis ($k_1 = k_2 = \ldots = k_9 = 0$). After the regression models were developed, these models were used to evaluate the effective degree or sensitivity of