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Freezing and Thawing Resistance of Hemp Fiber Reinforced Clays

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Abstract

Clays are natural soils. In geotechnical engineering, clayey soils are problematic because of their volume-change properties when they interact with water. Additionally, they may lose strength when exposed to freezing and thawing. Various soil improvement methods are used to modify the clay soil's properties. One of these methods is by adding natural fibers. The aim of the study was to investigate the strength and freezing-thawing properties of a high-plasticity clay (CH) with hemp fiber. For this purpose, fiber-reinforced clay samples were prepared by adding hemp fiber at different percentages (0.5%, 1%, and 1.5%) and different lengths (2 mm, and 5 mm) to a CH clay from Erzurum, Turkey, and the consistency, unconfined compressive strength (UCS), and freezing-thawing properties of the samples were investigated. According to the consistency limits test results, liquid limit values increased as the fiber length and the hemp fiber addition ratio increased, and the plastic limits of the specimens varied depending on the hemp fiber addition. The unconfined compressive strength of the samples increased with the increase in the hemp fiber percentage, and improvements occurred in their unconfined compressive strengths after four freezing-thawing cycles compared to unreinforced clay. According to the test results, it is thought that hemp fibers could be an alternative for improving the freezing and thawing resistance of clay soils.

1. Introduction

The clay soils frequently encountered in geotechnical engineering are problematic because they display plastic behavior and because of their water absorption, shrinkage, swelling, and settlement properties. Additionally, freezing-thawing is also an important problem, especially on the clays in cold climatic regions. After freezing-thawing cycles, due to the change in soil structure, the soil's strength decreases [1]. Eliminating the unfavorable properties of problematic clay soils and improving their engineering properties have played an important role in geotechnical engineering. For this purpose, waste materials like fly ash, silica fume, lime, red mud, ground glass, and marble powder may be used as additives to modify the engineering properties of clay soils [2], [3], [4], [5].

Other materials used to improve clay soils include natural fibers. In the past, researchers looked at how coconut coir, rice straw, and Cannabis sativa fibers could be used in the field. They found that the natural fibers made from these plants improved tensile strength [6], [7]. Prabakar and Sridhar [8] used sisal fiber at different lengths and percentages as a reinforcement material for soils and investigated the strength properties. The triaxial compression test results showed that sisal fiber improves the strength of soils [8]. Güllü and Khudir [9] have treated fine-grained soil with jute fiber, steel fiber, and lime. And it was mentioned that adding jute fiber to low-plasticity clay improves the strength behavior after freezing-thawing cycles [9]. Hemp is a natural fiber that is extracted from the stalk of cannabis plants (Cannabis sativa). Cannabis is a ligneous plant from the family of Cannabinaceae, and its annual fiber

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yield is quite high; its homeland is Asia [10]. It is an annual plant with a height of 1-5 m, having generally single and specific leaves, and it is grown in fields with a high nitrogen content [11]. Natural hemp fiber is biodegradable and widely recyclable [12]. Ammar et al. [13] and Ammar et al. [14] conducted direct shear tests and single fiber pullout tests on the hemp fiber-reinforced sandy clay soils to investigate the interface shear strength between sandy clay and natural hemp fibers. The researchers thought that hemp fibers have a high water absorption capacity, and this could affect the clay-fiber interface [13], [14]. Najjar et al. [15] have conducted unconsolidated, undrained triaxial tests on the hemp fiber-reinforced clays to improve the load response of compacted clays. According to test results, the undrained shear strength of the hemp fiber-reinforced clays increased with hemp fiber content [15]. Abou Diab et al. [16] used hemp fiber to improve the strength properties of natural clay and indicated that hemp fibers improve the shear strength of compacted clay. With the addition of hemp fibers, clay gained a ductile structure [16].

There are scarcely any studies in the literature researching the effects of the freezing-thawing effect on the hemp fiber-reinforced clays. The aim of this study is to indicate the potential usability of natural hemp fiber in improving the freezing-thawing resistance of high-plasticity clays. In this study, natural clay from Erzurum, Turkey, was reinforced with hemp fiber in different lengths (2mm, 5mm) and percentages (0.5%, 1%, 1.5%) to show the effect of hemp fiber on the geotechnical properties of the clay. Tests of the consistency limits, unconfined compressive strength, and freezing-thawing properties were conducted on the clay specimens. Then the same tests were conducted on the clay specimens reinforced with hemp fiber. The test results obtained from the clay specimens reinforced with hemp fiber were compared with the results obtained with clay.

2. Material and Method

2.1. Clay

In the study, a clay specimen (C) from Erzurum, Turkey, was used. After the clay was brought to the laboratory, it was dried for 24 hours at 105 °C in an oven, ground in a Los Angeles abrasion device, and sieved through a number-40 sieve before being used in the tests. Some geotechnical properties of the clay are seen in Table 1, and its chemical content, determined by X-ray fluorescence (XRF) analysis, is seen in Table 2. The clay specimen's mineral content was determined to be quartz, plagioclase, clay mineral, and calcite. The clay's soil class was found to be high plasticity clay (CH) according to the Unified Soil Classification System (USCS).

Table 1. Geotechnical properties of the clay [17]

Geotechnical Properties	Clay
Clay content (< 0.002 mm) (%)	42
Specific gravity	2.64
Liquid limit (%)	60.8
Plastic limit (%)	26.5
Plasticity index (%)	34.3
Soil classification	CH
Optimum moisture content* (%)	25.5
Maximum dry unit weight* (kN/m^3)	15

*The results were obtained from samples compacted with standard proctor energy.

Table 2. Chemical composition of the clay (XRF analysis)

Item	Clay
SiO_2	59.3
Al_2O_3	16.5
Fe_2O_3	8.0
MgO	2.1
K_2O	1.6
CaO	1.5
Na_2O	1.4
TiO_2	0.6
P_2O_5	0.2
MnO	<0.1
SO_3	-
LOI	8.50

2.2. Hemp Fiber

The commercial hemp fiber (H) was supplied from a local hardware store in Erzurum. In the literature, it is seen that fibers were used in different lengths for the stabilization of soils [7], [16], [25]. In this study, hemp fiber was cut into lengths of 2 and 5 mm and used in the tests. Hemp's specific gravity is 1.50, and its moisture content is 10%. Table 3 and Table 4 list the chemical content and physico-mechanical properties of the hemp fiber, respectively. Figure 1 shows the appearance of the clay and hemp fiber used in the tests.

Table 3. The chemical composition of hemp fiber [18]

Item	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Wax (%)
Hemp	70.2-74.4	17.9-22.4	3.7-5.7	0.8

Table 4. Physico-mechanical properties of hemp fiber [19]

Properties	Values
Tensile Strength (MPa)	690
Young’s Modulus (GPa)	70
Elongation at break (%)	1.6

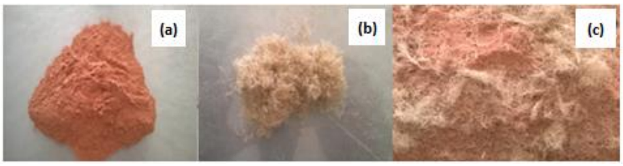

Figure 1. The materials (a) Clay, (b) Hemp fiber, (c) Hemp fiber-clay mixture

2.3. Preparation of Specimens

Cut hemp fiber was mixed with finely ground CH clay in amounts of 0.5%, 1%, and 1.5% of the weight of the clay. The mixture was then mixed evenly to make hemp fiber-reinforced clay specimens. The hemp fiber ratios have been chosen according to the literature focused on the natural fiber-reinforced clays [7], [25]. Figure 1 (c) shows the appearance of hemp fiber-reinforced clay. The addition percentages used in preparing the specimens are recorded in Table 5. Three identical specimens were prepared from each additive percentage.

Table 5. Additive percentages

Sample	Hemp fiber (%)	
	2 (mm)	5 (mm)
C	-	-
H1	0.5	-
H2	1	-
H3	1.5	-
H4	-	0.5
H5	-	1
H6	-	1.5

2.4. Testing Procedures

Liquid limit, plastic limit, unconfined compressive strength, and freezing-thawing tests were conducted on the clay and hemp fiber-reinforced clay samples. Liquid limit tests were conducted on the specimens through the fall cone method according to BS 1377, Part 2 [20]. Plastic limit tests were conducted on the samples according to ASTM D 4318 [21].

Unconfined compressive strength and freezing-thawing tests were conducted on 35 mm diameter and 70 mm height reinforced clay samples taken from specimens compacted under standard Proctor energy at the optimum moisture content of the clay specimens according to ASTM D 2166 [22]. In the freezing-thawing tests, to protect the water content of the prepared samples, the samples were wrapped in aluminum foil before they were put into the automatic freezing-thawing cabin. Additionally, vaseline has been used to prevent aluminum foil from adhering to samples. The number of cycles in the freezing-thawing tests was four, the temperature values were -20 °C for freezing and +25 °C for thawing, and the time interval selected for each process was six hours [23], [24]. The unconfined compressive strength values after freeze-thaw cycles were determined on the specimens taken from the cabin after the freezing-thawing cycles.

3. Results and Discussion

3.1. The Results of Consistency Limits Tests

Hemp fiber has a high water absorption capacity [13]. Table 6 shows the values of the liquid limits of the hemp fiber-reinforced clay specimens as measured by the increase in hemp fiber percentage. Liquid limit values increased as the fiber length (2 mm and 5 mm) and the hemp fiber addition ratio increased. It is thought that the increase in the liquid limit with the increase in fiber length and percentage is due to the high absorption capacity of hemp fiber. Due to the higher absorption capacity of hemp fiber, hemp fiber-reinforced clay specimens absorb more water, and the liquid limit values are increased. Furthermore, the plastic limits of the specimens varied depending on the hemp fiber addition. The consistency limits test results showed that the CH soil classification of clay changed to MH with hemp fiber addition according to USCS (Table 6).

Table 6. Consistency limits test results of specimens

	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Soil Classification
C	60.8	26.5	34.3	CH
H1	67.8	39.1	28.7	MH
H2	68.8	41.2	27.6	MH
H3	71.2	35.8	35.4	MH
H4	69.2	36.0	33.2	MH
H5	70.8	39.2	31.6	MH
H6	71.3	42.3	29.0	MH

3.2. The Results of UCS Tests

Figure 2 shows the values measured for UCS in the hemp fiber-reinforced clay specimens with the increase in hemp length and hemp percentage. The specimens conducted to unconfined compression strength tests have been presented in Figure 3.

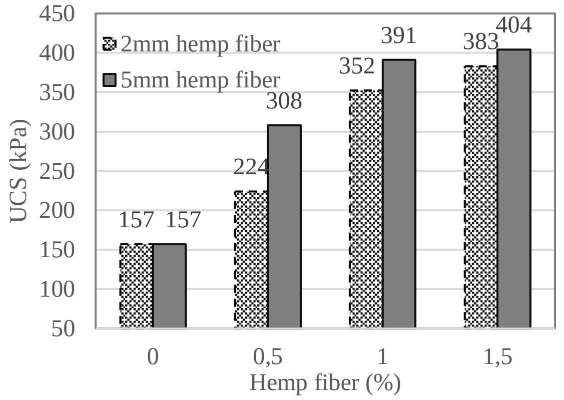

Figure 2. UCS values measured in the hemp fiber-reinforced clay specimens with increases in hemp length and hemp percentage

Figure 2 shows that the 2-mm hemp fiber-reinforced clay's unconfined compressive strength increased by 42.6%, 124%, and 144% when the hemp ratio was 0.5%, 1%, and 1.5%, respectively, compared to the clay's UCS (when the hemp ratio was 0%). The 5-mm hemp fiber-reinforced clay's UCS increased by 96%, 149%, and 157% compared to the clay's UCS when the hemp ratio was 0.5%, 1%, and 1.5%, respectively (Figure 2). The increase in strength with increasing hemp fiber percentage and hemp fiber length means there is good interaction between clay and hemp. The hemp fiber structure prevents the fiber from slipping into the clay, which increases its strength. Similarly, Sharma et al. [7] demonstrated that fibers increased the compressive strength of soils, and they attributed that behavior to better soil-fiber interaction and the resultant bond that did not allow slippage of fibers over each other.

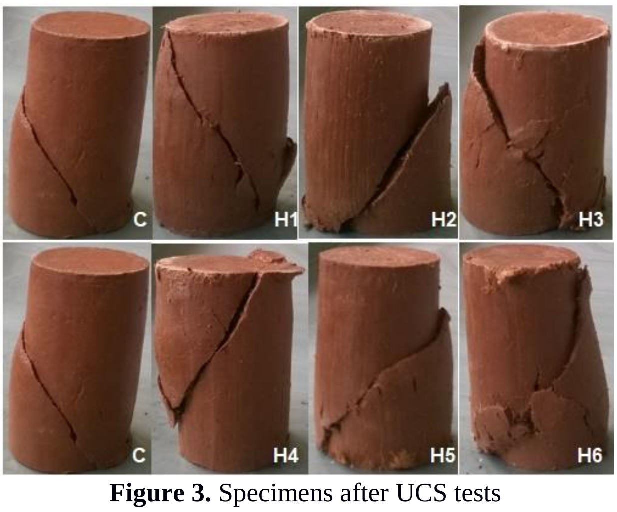

Figure 3. Specimens after UCS tests

The failure plains of samples have been obtained along the shear planes at an angle because of the ductility of hemp fiber (Figure 3). Similarly, Güllü and Khudir [9] found that the failure planes in the specimens reinforced with jute fiber have been obtained along the shear planes at an angle varying from 0 to 70° due to the ductility of jute fiber. Additionally, they thought that jute fiber being stretched still provides resistance; hence, post-peak strength retention is also increased.

3.3. The Results of Freezing-Thawing Tests

Figure 4 illustrates the variations that occurred in the UCS of hemp fiber-reinforced clay specimens after freezing-thawing tests. According to Figure 4, the UCS of the hemp fiber-reinforced clay specimens after freezing and thawing increased with increasing fiber percentage. The UCS values after freezing-thawing cycles of the 2-mm hemp fiber-reinforced clay increased by 20%, 178.8%, and 208.2% compared to the clay when the hemp fiber ratio was 0.5%, 1%, and 1.5%, respectively. Similarly, the UCS values after freezing-thawing cycles of 5-mm hemp fiber-reinforced clay increased by 144.7%, 183.5%, and 193% compared to the clay when the hemp fiber ratio was 0.5%, 1%, and 1.5%, respectively.

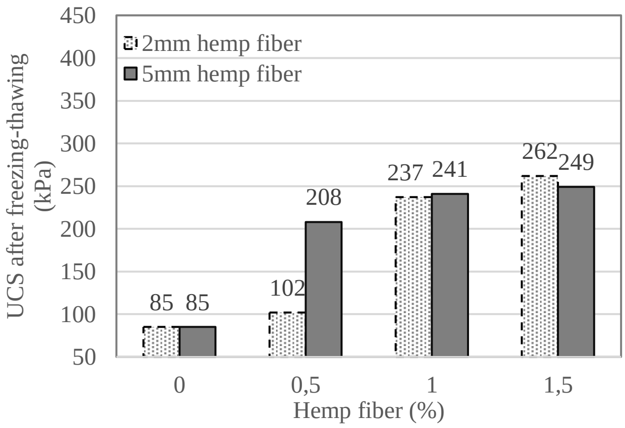

Figure 4. UCS values of the hemp fiber-reinforced clay specimens after freezing-thawing tests

In comparisons of the UCS of the hemp fiber-reinforced clay specimens (Figure 2) with their UCS after freezing-thawing tests (Figure 4), it is obvious that the UCS after freezing-thawing was lower. The clay specimen lost 45.8% of its strength after freezing-thawing cycles. The 2-mm 1.5% hemp fiber-reinforced clay specimen lost 31.6% of its strength after freezing-thawing cycles, and the 5-mm 1.5% hemp fiber-reinforced clay specimen lost 38.4%. The specimens subjected to the UCS tests after freezing-thawing cycles have been presented in Figure 5. It is seen that with freezing and thawing, the failure mechanisms of samples have changed. Wei et al. [27] indicated that with freezing and thawing, the failure patterns of soils transformed from brittle failure to plastic failure, and the cracks were thin and short. Additionally, it is thought that freezing and thawing cycles can reduce the bonding and interlocking force between soil particles, and the stress-strain behaviors of soil have changed [27].

Due to the fact that the hemp fiber structure prevents the fiber from slipping in the clay, the UCS values of fiber-reinforced clay specimens exposed to freezing-thawing cycles are increased with the increase in hemp fiber percentage and hemp fiber length. Similarly, Zaimoglu et al. [26] investigated the effects of randomly distributed polypropylene fibers with different fiber lengths on soil and obtained that the peak stress value of the reinforced soil increases with the increase in fiber length. They demonstrated that randomly distributed fibers act as a bridge between soil grains which improves the load-deformation behavior. Ammar et al. [14] indicated that hemp fibers have a high water absorption capacity that may affect the fiber-clay interface interaction. According to this, it is thought that the structure of hemp fiber, which interacts with water, could be decomposed with freezing-thawing cycles. Due to the decomposition of hemp fiber, with increasing percentages of hemp fiber, unconfined compression strength values after freezing-thawing cycles of 2 mm and 5 mm hemp fiber lengths are close. When the hemp fiber percentage is 1.5%, the UCS after freezing-thawing cycles of a 5mm-long hemp fiber-reinforced clay sample is 5% lower than a 2mm-long hemp fiber-reinforced clay sample.

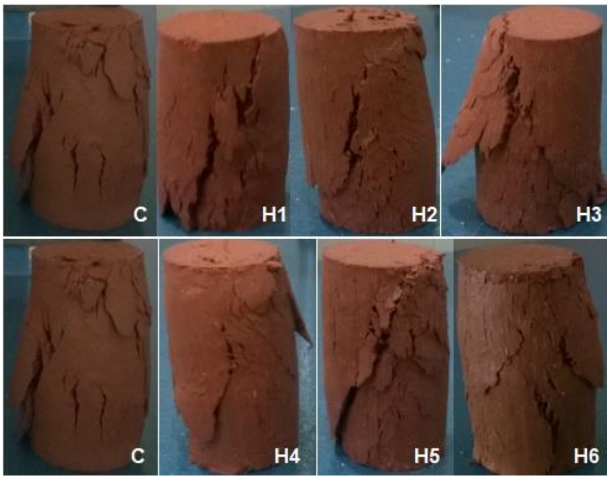

Figure 5. The specimens subjected to the UCS tests after freezing-thawing cycles

4. Conclusion and Suggestions

In this study, the potential usability of natural hemp fiber to improve the freezing-thawing resistance of high-plasticity clay has been investigated. The results obtained are listed below:

- The liquid limit values increased when fiber length and fiber percentage increased, and the plastic limits and plasticity indexes varied depending on the fiber additions.
- UCS tests conducted on the hemp fiber-reinforced clay specimens showed that UCS increased with increasing fiber percentage. The UCS of 5-mm hemp fiber-reinforced clay specimens was higher than that of 2-mm hemp fiber-reinforced clay specimens.
- Four-cycle freezing-thawing tests were conducted on the hemp fiber-reinforced clay specimens. The UCS of fiber-reinforced specimens after freezing and thawing was higher than the UCS after freezing and thawing of the clay alone.
- In the fiber-reinforced clay specimens, the UCS after freezing and thawing increased for the ratios of 0.5% and 1% of fiber but decreased by 4.9% for the ratio of 1.5%.

The addition of a natural hemp fiber increased CH clay's unconfined compressive strength both before and after freezing and thawing. As a contribution to the literature, it is thought that hemp fiber can be used as an alternative material, especially in cold climates, for reducing the effects of freezing and thawing on clay soils.

Contributions of the authors

Author 1: Methodology, writing, supervising, reviewing and editing.
Author 2: Experimental study.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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