

Investigation of the Effects of Weathering and Decay on Soil Stabilized with Rice Straw Fibers

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Abstract

This study investigates the effect of varying levels of rice straw fiber (RSF) decomposition on the unconfined compressive strength (UCS) of soil stabilized with different cement contents. The evaluation was conducted using the unconfined compressive strength test (UCS) and standard compaction tests (SCT). Additionally, the effect of weathering on the weight changes of soil samples containing different percentages of fibers was examined through freeze-thaw cycle tests. The variables in this research include: Fiber content (0%, 0.25%, 0.5%, and 1%), cement content (0%, 4%, 8%, and 12%) and curing time (0, 7, 14, and 28 days). The objective of examining the effects of decomposition and weathering on natural fibers is to achieve sustainability goals in geotechnical engineering. The results indicated that as the fiber content increased from 0% to 1%, the compressive strength of both dry and wet samples decreased, while the strain at failure increased. In decomposed samples, the compressive strength and strain at failure decreased by 39.28% and 80.69%, respectively. It is noteworthy that stabilized samples containing 12% cement exhibited higher compressive strength than those with 4% and 8% cement, although their strain at failure was lower. In the freeze-thaw cycle tests, the weight loss increased with a higher percentage of fibers, especially in the cured samples. The average R^2 values of approximately 0.88 also demonstrate the effectiveness of the Response Surface Methodology (RSM) models.

KEYWORDS

Rice straw fibers, Weathering, decay, Cement, RSM

1. Introduction

Improving soil behavior can be achieved through various mechanical and chemical stabilization methods,

depending on environmental, economic, and structural considerations [1,2]. In recent years, the sustainable reinforcement of soil using natural fibers has gained attention as an eco-friendly alternative to conventional

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stabilizers such as lime and cement [3]. Synthetic fibers have been widely used to enhance soil and concrete performance [4,5]; however, several researchers have emphasized the use of natural fibers to promote sustainable geotechnical practices [6].

Among natural fibers, rice straw—an agricultural by-product abundantly available in farmlands—is an environmentally friendly material with significant potential for soil improvement [7]. The open burning of rice straw contributes to air pollution and the loss of soil organic matter, while its reuse as a reinforcing material can enhance soil strength and sustainability. Agricultural and industrial waste utilization has also become an important approach for reducing greenhouse gas emissions and promoting circular economy principles [8,9]. Bio-based materials improve the durability and strength of soils and other construction materials, with plant fibers—composed mainly of cellulose, hemicellulose, and lignin—showing strong tensile and flexural properties. Recently, numerical methods have been developed to predict laboratory data in civil engineering applications, which can be used to reduce costs and save money [10-12].

Nevertheless, biodegradability and decay remain challenges in natural fiber applications, as environmental exposure affects fiber strength and bonding. To assess these effects, degradation and freeze-thaw cycles were simulated following ASTM D560/D560M-16 standards. In this study, rice straw fibers and cement were jointly used to investigate the mechanical behavior of stabilized soil under different curing and decay conditions. Furthermore, Response Surface Methodology (RSM) was applied to develop diagnostic models and evaluate the relationships among experimental parameters [13,14].

2. Materials and Methods

The cohesive clayey soil used in this study was classified as CL according to the USCS. Rice straw fibers were collected from agricultural fields in Mazandaran Province, Iran. They had a specific gravity of 0.23, an average diameter of 0.2 cm, and were cut to 1 cm length to ensure uniform mixing with the soil. Type II Portland cement with a specific gravity of 3.0–3.25 was used at 4%, 8%, and 12% by dry weight to study the effect of cement stabilization and fiber decay. The samples were then constructed to use for various experiments like standard proctor and uniaxial compressive strength tests.

3. Discussion and Results

The compaction results showed that adding rice straw fibers reduced the maximum dry density and increased the optimum moisture content due to the lightweight and absorbent nature of the fibers. The addition of cement improved the density and bonding between soil particles

Unconfined compressive strength (UCS) tests indicated that dry samples had higher strength than wet samples. Increasing fiber content slightly decreased UCS but enhanced ductility by increasing strain at failure. However, decayed fibers led to a clear drop in both strength and strain, mainly because of the deterioration of fiber-soil bonding. Cement stabilization effectively compensated for this reduction, with 12% cement content producing up to four times greater UCS than untreated soil (Table 1). Curing time significantly influenced soil performance. Longer curing periods resulted in higher UCS and lower strain at failure, suggesting stronger yet more brittle behavior. The freeze-thaw cycle tests revealed minor weight loss and small variations in UCS, confirming that fiber inclusion helped preserve soil integrity under repeated freezing and thawing. Figure 1 illustrates the response surface modeling (RSM) results, showing the relationship between fiber percentage, cement content, and UCS. The model highlights that UCS increases with cement addition, while excessive fiber content slightly reduces overall strength due to weaker interfacial bonding. Overall, cement addition and curing duration are the key factors enhancing soil strength, while fiber inclusion mainly improves ductility. Fiber decay reduces both strength and strain, but its negative effect can be mitigated by proper cement stabilization and curing.

Table1. Changes in the compressive strength and strain at failure of the samples containing 1% fibers

Changes in strain at failure relative to the control specimen	Changes in compressive strength relative to the control specimen	Specimen containing 1% fiber	Curing (days)
34.57% increase	50% decrease	Wet	0
69.89% decrease	293.33% increase	Dry	
99.41% decrease	43.33% decrease	Wet	7
64.6% decrease	329.99% increase	Dry	
36.13% increase	0%	Wet	14
52.23% decrease	336.66% increase	Dry	
65.42% decrease	43.35% increase	Wet	28
86.52% decrease	359.99% increase	Dry	

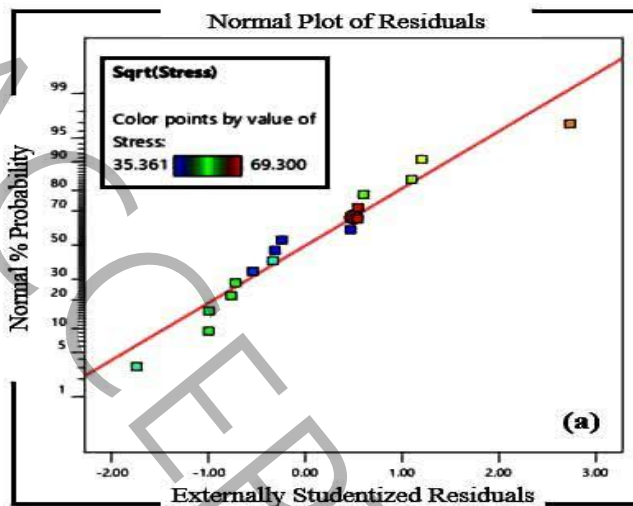


Figure 1. normal probability plots of residuals for stress parameter (RSM)

4. Conclusion

- Decay of rice straw fibers resulted in a reduction in both UCS and strain, attributed to increased porosity and the loss of tensile capacity in the fibers. Although decayed samples had higher UCS than wet ones, they exhibited brittle failure behavior. Cement stabilization, particularly with 12% cement, markedly improved UCS while reducing strain. In decayed fiber samples, cement effectively filled the voids created by fiber degradation, enhancing the overall bonding and integrity of the soil matrix.
- Mathematical models developed using the Response Surface Methodology (RSM) showed strong agreement with the experimental data ($R^2 = 0.84$ for stress and $R^2 = 0.94$ for strain), confirming that the proposed approach can reliably predict the mechanical response of fiber-stabilized soils.

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