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Effect of Natural Fibers on desiccation cracking in fine grained soil

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ABSTRACT: Desiccation cracking in fine-grained soils poses significant challenges to geotechnical engineering, particularly in arid and semi-arid regions, where it reduces soil strength and stability. Traditional stabilization methods have limitations, prompting the exploration of more sustainable techniques. This study investigates the use of Natural Fibers (NF) to mitigate desiccation cracking and enhance soil properties. The research involves incorporating NF to investigate the desiccation cracking of fine-grained soils. Laboratory tests were carried out to assess the mechanical response and performance of treated and untreated soil along. The results indicate that the NF adds to the mitigation of desiccation cracking substantively through the enhanced shear strength and cohesiveness of soils. The treated soil had reduced compressibility which is an indication of enhanced stability. These results demonstrate the potential of such approach in enhancing the behavior of soils and reduce risks in geotechnics. The study highlights the environmental and technical advantages of utilizing NF and offers significant shear strength, for a viable long-term foundation and pavement-building option.

KEYWORDS: Microbial induced calcite precipitation (MICP), Natural fibers, Desiccation cracking

1 INTRODUCTION

In fine grained soils the formation of desiccation cracks may cause severe problem, where they engender shear strength loss, high permeability, and potential destabilization of soil structure (Coppola et al., 2022). Such cracks are triggered by drying of the soil surface, which causes tensile stress that is larger than the tensile strength of the soil and eventually results in cracking. Desiccation cracking severely impacts ground and varies depending on many factors, including the soil type, the clay mineralogy, the environment, climatic conditions, and stress history (Maljaee et al., 2021). Severe effects of desiccation cracks are not limited to aesthetic concerns alone, but can also cause a loss of structural integrity of earthworks, embankments, and foundations (Jose et al., 2018). These cracks occur due to a complicated interaction between the soil properties, environmental conditions, and stresses. Hence it is important to learn as much as possible about relationships to prevent spelling.

This change in the hydraulic characteristics of soil due to the desiccation cracking can severely undermine the integrity and usability of any development constructed, including waste containment facilities (Zeng et al., 2019). The occurrence of such desiccation cracks increases the hydraulic conductivity of the soil being a vital parameter that can be used in several geotechnical processes as well as it affects the overall performance and stability of the soil body. Defects such as cracks in the clay-liners can lead to the migration of leachates potentially jeopardizing surrounding groundwater resources and the environment generally (Liang, Gui and van der Land, 2019). The mechanism of crack formation is highly critical in coming up with effective measures to reduce the effects of the cracks on the structures built on such soil. The effects of desiccation cracks on infrastructure may be especially extreme in areas that are subject to seasonal moisture changes, which is why efficient and sustainable soil stabilization methods must be found.

In context of quantifying the desiccation cracks image analysis is a valuable tool for established surface crack patterns on soils of cohesive types under drying situations, which is important in determining the effect of cracking on the permeability and mechanics of the soil. (Lakshmikantha, Prat and Ledesma, 2009; Wu et al., 2022).

The use of NF as reinforcement constitutes a viable and cost-efficient strategy to overcome desiccation cracking in soils as an alternative method to the present chemical stabilization techniques due to its environmental friendliness. Natural fibers obtained as a product of vegetal materials like coir, jute, and sisal come with a natural tensile strength that can enhance a better strength and ductility of soil composites. Addition of NF in soil matrices also increases tensile strength and ensures that crack propagation in soil structures is minimized and ultimately the overall strength of the soil structure is improved. The tendency of reinforcement of natural fibers is determined by some aspects, such as fiber type, length, content, orientation, and soil. (Lu et al., 2012).

The use of NF presents the synergistic solution to minimize desiccation cracking as well as overall improvement of the performance of fine-grained soils. NF contributes to the shear strength and thus lesser crack propagation and improved durability ultimately creating a stronger and greener soil stabilization solution. (Omoregie et al., 2025).

2 MATERIALS AND METHOD

2.1 *Materials properties*

Figure 1Soil and other materials, i.e. NF are shown in Figure 1. Whereas the engineering properties and physical characteristics of the soil used are presented in Table 1. Based on the Unified Soil Classification System (USCS) soil was classified as low plastic clay (CL). NF (sisal) of uniform length were utilized (Zhao et al., 2019).

2.2 *Methodology*

To study the response of soil unconfined compression strength (UCS) tests were conducted along with the crack image analysis to study the cracking pattern. UCS tests were performed in accordance with ASTM D2166.

Soil samples were prepared using percentage of NF being maintained as 0.3%, 0.6%, 0.9% and 1.2%. Samples were tested for UCS and crack analysis at 14 days of curing.

2.3 *Sample Preparation*

Soil used in this study was collected from KPK region of Pakistan. Soil collected from field was dried in the oven at 105 ± 5 °C and then crushed and sieved to gain uniformity. To avoid material loss and dust, the soil with the natural moisture content of 5% (soil) combined with NF for 5 minutes. The mixture was then kept in the plastic bags overnight to absorb moisture and to improve its cohesion. The other moisture i.e. the difference between the optimum moisture content (OMC) and the natural moisture content (OMC - w_n) was subsequently added. The contents were then kneaded to get uniform material matrix. Samples were prepared by compacting the soil in a Proctor mold at 600 kN-m/m^3 energy. Prepared samples were allowed to dry air for 24 hours. Hydraulic sample extruder was used to extract samples from compacted soil to acquire specific sized sample for unconfined compression strength (UCS) testing.

3 RESULTS AND DISCUSSION

The stress–strain behavior of treated and untreated soil specimens is illustrated in **Figure 3**, highlighting the influence of varying natural fiber (NF) contents on the unconfined compressive strength (UCS) and ductility of the soil. The untreated specimen, with a UCS of approximately 40 kPa, exhibits a distinctly brittle response, characterized by the lowest strain at failure. Such behavior indicates minimal deformation capacity, making the soil highly susceptible to sudden fracture under applied loads.

In contrast, specimens treated with increasing NF contents (0.3%, 0.6%, 0.9%, and 1.2%) demonstrate a progressive improvement in UCS. The highest fiber content (1.2%) achieves a UCS of approximately 170 kPa and exhibits substantially greater strain at failure, signifying enhanced ductility. This improvement is attributed to the fiber-reinforced soil matrix, where NF bridges soil particles, redistributes stresses, and delays crack propagation. Even at lower dosages, NF contributes to improved performance; for example, the 0.3% NF specimen reaches a UCS of ~110 kPa, though with limited ductility (~6% strain), still reflecting a relatively brittle nature.

Curing duration also influences the mechanical response. Cementation during curing enhances stiffness and strength but can reduce deformation capacity, promoting brittleness. NF addition counteracts this effect, restoring flexibility through its tensile bridging mechanism.

The effect of NF on cracking behavior during moisture fluctuations is presented in **Figure 4**, which shows the crack surface ratio (Rsc) for untreated and treated specimens subjected to wetting–drying (W–D) cycles. The untreated specimen consistently records the highest Rsc values, reaching 6.186 mm² after the third drying cycle (3D), indicative of severe cracking and low resistance to deformation.

NF-treated specimens exhibit significantly lower Rsc values, confirming improved resistance to desiccation cracking. The most effective performance is observed in the 0.3% NF specimen (**Figure 5**), which records an Rsc peak of only 0.913 mm² after the third wetting cycle (3W). This demonstrates that even minimal fiber inclusion can stabilize the soil and prevent excessive crack formation. Specimens with 0.6% and 0.9% NF achieve comparable results, with peak Rsc values of approximately 0.977 mm²—far lower than untreated conditions.

These findings collectively indicate that NF addition, even at low dosages, substantially enhances both mechanical strength and crack resistance in fine-grained soils. The combination of increased UCS, improved ductility, and reduced Rsc supports NF as a sustainable, cost-effective, and environmentally compatible soil stabilization technique, particularly suited for arid and semi-arid regions subject to repeated wetting–drying cycles.

These findings indicate that the incorporation of NF decreases the crack surface area, significantly, at the time of the stress of wetting-drying. The treated samples also show better crack resistance values than untreated soil demonstrating the potential of NF processes to improve soil strength.

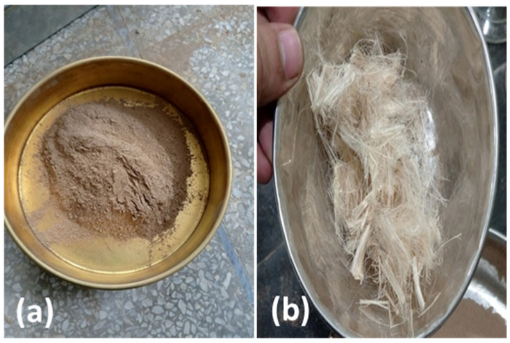

Figure 1. Material utilized in current study (a) Soil (b) NF

Table 1. Geotechnical characteristics of selected soil

Test/System	Value	Unit
USCS Classification System	*CL*	NA
Unconfined compression strength, q_u	*58.34*	kPa
Maximum dry unit weigh	*16.46*	kN/m^3
Optimum water content, OMC	*17.5*	%

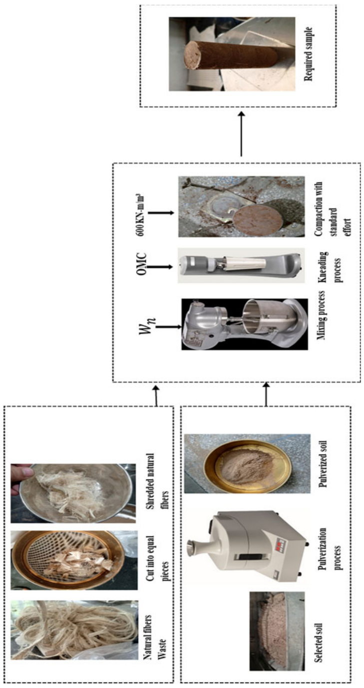

Figure 2. Samples Preparation Technique.

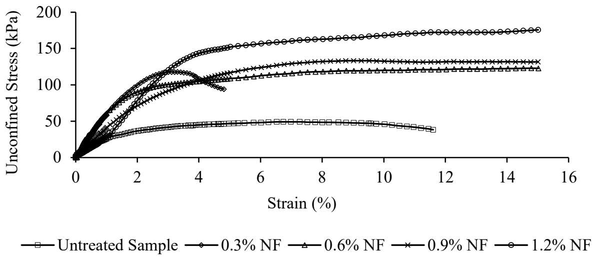

Figure 3. UCS results for Untreated and NF Treated Soil.

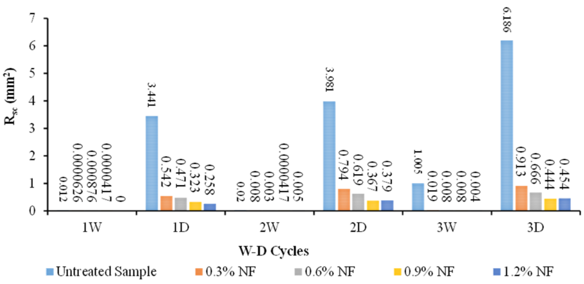

Figure 4. R_{sc} Values for W-D Cycles and SE (Bar Chart).

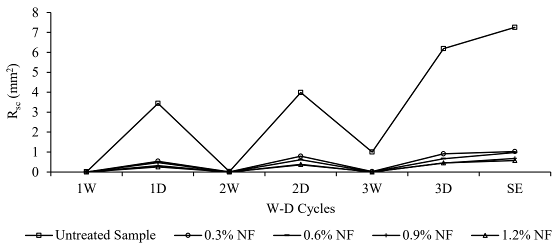

Figure 5 R_{sc} Values for W-D Cycles and SE (Line Chart).

4 CONCLUSIONS

This study demonstrates that NF provides an effective and innovative approach to mitigating desiccation cracking in fine-grained soils. Desiccation cracking, common in arid and semi-arid regions, leads to structural weakness, reduced durability, and higher maintenance costs in geotechnical applications. Experimental results revealed that NF addition markedly enhances the tensile strength and ductility of soil, thereby suppressing crack initiation and propagation during drying. The fibers act as micro-reinforcing elements, bridging soil particles and redistributing stresses more uniformly, which delays failure and improves deformation capacity. In addition to controlling cracking, NF-treated soils exhibited a notable increase in shear strength, indicating improved resistance to both tensile and shear loading conditions. The observed effects were synergistic, as the combined improvements in mechanical properties contributed to enhanced stability and integrity of soil structures. Given its natural origin, NF offers a sustainable, low-cost, and environmentally friendly alternative to conventional soil stabilization techniques. These attributes make it particularly suitable for infrastructure projects in climates prone to extreme moisture fluctuations. Future investigations should focus on evaluating the long-term performance, scalability, and environmental impact of NF treatments under realistic field conditions, as well as their adaptability to different soil types for broader engineering applications.

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