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EFFECT OF SUGARCANE BAGASSE FIBER AND LIME ON THE SHRINKAGE BEHAVIOR OF SOFT SOIL

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ABSTRACT

This study evaluates the shrinkage behavior of high-water-content soft soil stabilised with lime and sugarcane bagasse fibre (SBF). Soft soil samples were treated with a uniform lime content of 10% and varying SBF proportions (0%, 1%, 1.5%, and 2% by dry weight) and cured 28 days as the ongoing studies. Linear shrinkage tests were conducted under controlled drying conditions to investigate the effects of lime and SBF on soil shrinkage characteristics. Results reveal that lime significantly reduced shrinkage by stabilizing the soft soil matrix, while SBF further enhanced shrinkage resistance by disrupting soil particle alignment and interlocking within the matrix. Optimal performance was observed at 1.5% SBF content, where shrinkage was reduced by 38% compared to untreated soil. These findings provide insights into sustainable approaches for improving shrinkage behavior in soft soils.

KEYWORDS: *Sugarcane Bagasse Fibre, Lime Stabilisation, Shrinkage Behavior, Soft Soil, Sustainable Geotechnics*

1. INTRODUCTION

Soft soils are widely regarded as problematic in geotechnical engineering due to their high-water content, low strength, and significant volume changes during wetting and drying cycles [1], [2], [3], [4], [5], [6]. Shrinkage behavior, particularly during drying, is one of the most critical challenges associated with soft soils, often resulting in cracks that compromise the integrity of infrastructure built on such soils [7], [8], [9]. These shrinkage-induced cracks are primarily driven by the soil's plasticity and expansive clay mineral composition, making stabilisation essential for improving its engineering properties [9], [10], [11].

Lime stabilisation is a well-established method for controlling shrinkage in expansive and soft soils. Lime alters the soil's physico-chemical properties through pozzolanic reactions, reducing plasticity and forming a cementitious matrix that resists shrinkage[12], [13], [14], [15], [16], [17]. However, lime-treated soils often exhibit brittleness, which limits their ability to resist cracking during drying [18], [19].

Sugarcane bagasse fibre (SBF), an agricultural by-product, offers a sustainable alternative for enhancing the shrinkage resistance of lime-stabilised soils. Natural fibres like SBF increase soil ductility, disrupt particle alignment, and reduce shrinkage potential by providing mechanical reinforcement within the soil matrix [9], [20], [21], [22]. While studies have shown the benefits of natural fibre reinforcement in reducing shrinkage [9], [23], [24], the combined effects of lime and SBF on shrinkage behaviour have not been extensively investigated, particularly for soft soils with high water content.

This study evaluates the effects of lime and SBF on the shrinkage behaviour of soft soil. By examining the linear shrinkage of soil treated with 10% lime and varying SBF contents (0%, 1%, 1.5%, and 2%), this research aims to provide insights into sustainable soil stabilisation practices.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Soft Soil

The soft soil was collected from Zhenjiang, China, and classified as high-plasticity clay (CH) under the Unified Soil Classification System (USCS)[25]. The soil exhibited a liquid limit (LL) of 52%, a plastic limit (PL) of 28%, and a natural moisture content of 63.1% [26] and [27] respectively. The properties are detailed in table 2-1.

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Table 2-1: Physical and mechanical properties of natural soil

Properties	Quantity
Sand proportion (diameter 0.006<D<2mm), %	1.5
Clay/silt proportion (D< 0.002mm, %)	98.5
Natural moisture, w_n (%)	63.1
LL (%)	52.6
PL (%)	27.2
PI (%)	25.4
USCS	CH

Figure 2-1: **Natural Soft Soil**

2.1.2 Lime

Hydrated lime, containing 90% calcium hydroxide, was used as a stabiliser. Lime content was fixed at 10% by dry weight of the soil, based on previous studies suggesting this as an optimal proportion for stabilising soft soils [28]. The lime was sourced locally from Lime Materials Factory supplier, Nanjing, China

Figure 2-2: Lime

2.1.3 Sugarcane Bagasse Fibre (SBF)

SBF was sourced from local sugarcane mills in Zhenjiang. The fibres had a diameter range of 0.3 mm to 3.1 mm and lengths of 0.3 mm to 13.8 mm, with a specific gravity ranging from 1.25 to 1.55. The fibres were air-dried, sieved, and mixed with soil in varying proportions (0%, 1%, 1.5%, and 2% by dry weight) [29]. The SBF utilised in this research were sourced from Agricultural Inputs and Logistics Services in Nanjing, China.

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Figure 2-3: SBF

2.2 Sample Preparation

The air-dried soil was sieved to remove particles larger than 2 mm. Lime and SBF were added to the soil in the specified proportions, and distilled water was mixed to achieve the soil's optimum moisture content (32%). Thorough mixing ensured uniform distribution of lime and fibres within the soil matrix.

Table 2-2: **Sample Preparation with Different Dosages of Lime and Bagasse Fiber.**

Samples	Lime dosage (%)	SBF dosage (%)
S	0	0
S-L10	10	0
S-SBF1	0	1
S-SBF1.5	0	1.5
S-SBF2	0	2
S-L10-SBF1	10	1
S-L10-SBF1.5	10	1.5
S-L10-SBF2	10	2

Note: **S** refers to pure soft soil, **L** refers to lime, **SBF**, refers to sugarcane bagasse fiber. The percentages in dosage are by weight of dry soil.

2.3 Testing Procedures

2.3.1 Linear Shrinkage Test

The shrinkage behavior was evaluated using linear shrinkage tests. In this investigation, a portion of soil weighing at least 200 g was obtained from material passing the 425 µm sieve. The soil was air-dried until it became friable, allowing the crumbling of soil aggregates. The preparation of the disturbed soil samples followed the guidelines outlined in ASTM D4318 for Atterberg limits testing. Linear shrinkage values for both untreated and treated soft soil specimens were subsequently determined in accordance with ASTM D4943, which specifies the procedure for evaluating soil shrinkage behavior. The sample is prepared in a compacted in a mold, cured and specimens were subjected to drying in a controlled environment at 20°C and 50% relative humidity until no further change in length was observed. Linear shrinkage (LS) was calculated as:

$$\text{Linear Shrinkage (\%)} = \frac{\text{Initial Length} - \text{Final Length}}{\text{Initial Length}} \times 100\% \qquad (2\text{-}1)$$

3. RESULTS AND DISCUSSION

3.1 Effect of Lime on Shrinkage Behavior

Lime-treated soil samples exhibited a significant reduction in linear shrinkage compared to untreated soil. The untreated soil had a linear shrinkage of 22.64%, which decreased to 18.34% with lime treatment. The reduction is attributed to lime's ability to stabilise clay particles by forming a cementitious matrix that resists volumetric changes during drying [9], [10].

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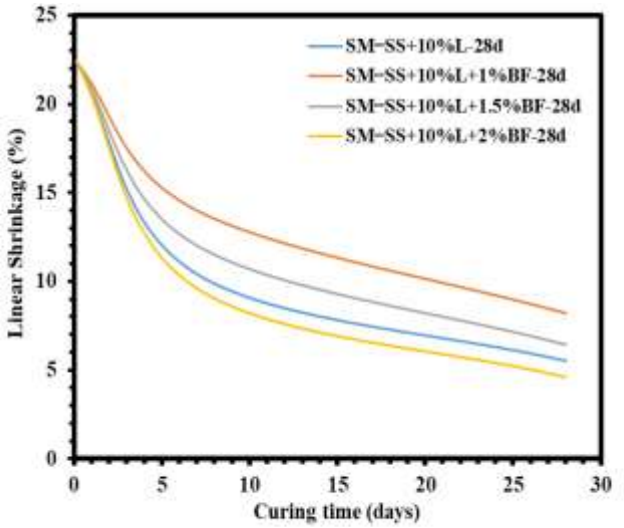

Figure 3-1: Variation of Linear shrinkage with SBF contents at 28d of curing

Figure 3-2 shows how adding lime-SBF affected the LS of soft soil after the 28 days of curing. There are comparable tendencies in the LS of fiber -reinforced soft soil, as shown in Figure 3-2. Linear shrinkage decreases as the content of fiber increases, and the 10% lime for instance, treated soft soil had a LS decrease of about 65%. Soft soil treated with a mixture of 10% lime and 2% bagasse fiber showed a linear shrinkage reduction of nearly 80% compared to untreated soft soil. In agreement with Dang (2018), it is worth noting that Figure 3-1 and 3-2 show that lime and SBF combinations reduced linear shrinkage more than SBF-reinforced soft soil alone. Similar results were observed by some researchers [30], [31].

3.2 Effect of SBF on Shrinkage Behaviour

The impact of adding SBF on linear shrinkage (LS) with varying curing durations are shown in figure 3-2. It is worth mentioning that as the curing period rose, the linear shrinkage decreased significantly for SBF content levels ranging from 0% to 2%. In particular, as compared to virgin soil specimens, reinforced soft soils with 2% SBF added after 3 hours of curing exhibit negligible reductions in linear shrinkage.

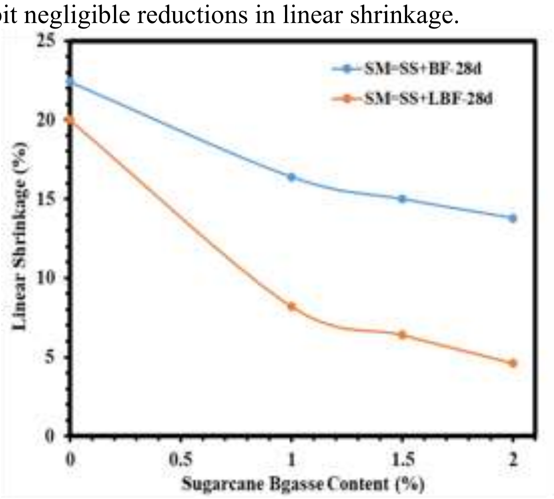

Figure 3-2:Variation of Linear shrinkage with SBF contents at 28d.of curing

The LS of SBF-reinforced soft soil falls dramatically by the end of the 7d of curing period, showed minimal changes with subsequent days of curing, over the whole 28-day curing period. Adding SBF further enhanced shrinkage resistance. The linear shrinkage of lime-stabilised soil decreased to 16.02% with 1% SBF and to 14.02% with 1.5% SBF—a 38% reduction compared to untreated soil. However, at 2% SBF, the shrinkage has diminishing decrease to 15.25%, likely due to excessive fibre content disrupting the soil matrix and reducing compaction efficiency [21], [22]. This indicates that the majority of the shrinkage resistance improvement occurred within the initial curing phase, likely due to the rapid development of stabilisation mechanisms such as fibre-soil interlocking and moisture redistribution, which stabilised the soil matrix early in the curing process.

3.3 Combined Effects on Shrinkage Resistance

As observed from Figure 3-1, the combined treatment of lime and SBF demonstrates a synergistic effect on shrinkage resistance. Lime reduced soil plasticity and created a stabilised matrix, while SBF provided mechanical reinforcement that disrupted particle alignment and reduced volumetric changes. The optimal combination (10% lime and 1.5% SBF) achieved the best performance, balancing shrinkage resistance and soil stability. This behavior is in consistent with other reported results [6], [8], [32]. Furthermore, the rationale for this noticeable enhancement in LS could be due to the presence of free lime, which induces the flocculation and aggregation of clay particles. Consequently, this reduces their surface area, resulting in a coarser and less pliable texture. As the concentration of additives increased, there was a significant decrease in linear shrinkages. This decrease may have been caused by the substitution of finer with coarser clay particles. In addition, the incorporation of BF reinforcement to lime-treated soft soils produced a further reduction in LS. This phenomenon may occur due to the gradual formation of connections within bagasse fiber-soil matrix, resulting in a potentially advantageous strengthening of the fiber -reinforced soil.

4. CONCLUSION

This study highlights the combined effects of lime and sugarcane bagasse fibre on the shrinkage behaviour of soft soil. Lime reduced shrinkage by stabilising the clay matrix, while SBF further enhanced shrinkage resistance by providing mechanical reinforcement and reducing crack formation. The optimal performance was observed at 1.5% SBF content, achieving a 38% reduction in shrinkage compared to untreated soil. The synergistic effect of soft soil treated with a mixture of 10% lime and 2% bagasse fiber showed a linear shrinkage reduction of nearly 65% compared to untreated soft soil.
These findings demonstrate the potential of lime and SBF as sustainable materials for improving the shrinkage behaviour of soft soils in geotechnical applications.

Practical Implications

The application of lime and sugarcane bagasse fibre (SBF) as stabilizing agents offers an environmentally friendly and cost-efficient approach to reducing the shrinkage behaviour of high-water-content soft soils in geotechnical engineering. This technique minimizes dependence on traditional cement-based stabilisers, promoting environmental sustainability. It is particularly suitable for practical applications such as road subgrades, embankments, and construction fill materials, where shrinkage resistance is critical for structural stability.

Recommendations for Future Work

- Further investigations should evaluate the scalability of lime-SBF stabilisation in field applications, focusing on different soil types and environmental conditions.
- Research into the long-term performance of lime-SBF-treated soils under cyclic loading and environmental stressors is essential to assess their durability and resilience.
- Exploring the inclusion of other natural fibres or recycled materials may enhance the stabilisation effectiveness and further promote sustainable construction practices.
- Further studies should explore the long-term performance and durability of fibre-reinforced soft soils, particularly under extended drying conditions of more than 28 days.

This study lays the groundwork for integrating lime and sugarcane bagasse fibres into geotechnical engineering applications. The findings demonstrate their potential to improve soil shrinkage behaviour while aligning with sustainable development goals in the construction industry.

Author Contributions

Laber and Ebongas jointly contributed to the development of the study design and preparation of the initial manuscript draft. Banda and Iradukunda critically reviewed the draft, providing valuable insights and revisions. All authors collaborated on subsequent revisions and collectively reviewed and approved the final manuscript before submission.

Competing Interests

The authors declare no conflicts of interest related to this research.

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