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Experimental Investigation of Soil Stabilization Using Sugarcane Bagasse Ash

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Abstract—Soil stabilization is widely adopted to improve the engineering performance of weak or unsuitable soils. This study experimentally investigates the use of sugarcane bagasse ash (SBA), an agricultural waste material, for improving the compaction characteristics of soil. Naturally available sand was used as the soil material and SBA was incorporated at 1%, 2%, and 5% by the study program. Preliminary characterization included sieve analysis, specific gravity, direct shear testing, and standard Proctor compaction testing. The specific gravity of the soil was reported as 2.68, while the natural soil exhibited an optimum moisture content (OMC) of 14% and a maximum dry density (MDD) of 1.80 g/cm³. The reported compaction results indicate that SBA addition changes both OMC and MDD. For the mixtures, the reported optimum conditions were 14% OMC and 2.015 g/cm³ MDD for 1% SBA, 16% OMC and 1.875 g/cm³ MDD for 2% SBA based on the detailed test table, and 18% OMC and 1.825 g/cm³ MDD for 5% SBA. The report identifies 2% SBA as the optimum content based on its summarized comparison and concludes that SBA can provide a cost-effective and environmentally beneficial route for soil improvement. A discrepancy between the detailed 2% SBA test table and the summary table is noted and should be resolved before journal submission.

Keywords—soil stabilization, sugarcane bagasse ash, agricultural waste, compaction, optimum moisture content, maximum dry density, geotechnical engineering

I. Introduction

Soil is one of the principal materials encountered in civil engineering construction and must possess adequate strength and stability to support foundations, pavements, embankments, and other infrastructure. Fine-grained or weak soils may exhibit undesirable engineering behavior and may require stabilization before construction. Conventional stabilization methods include cementation, bituminization, silicification, resinification, electrochemical or thermal treatment, and artificial freezing. Although effective, some conventional methods can have economic and environmental implications.

The utilization of agricultural residues in geotechnical engineering offers an alternative approach that can simultaneously address soil improvement and waste management. Sugarcane bagasse ash (SBA) is a residue generated from the combustion of sugarcane bagasse. The present experimental study examines the influence of SBA on the engineering and compaction characteristics of soil. The principal objectives are to improve soil stability and strength, compare the influence of different waste-material percentages, and identify an optimum SBA content.

II. Literature Review

Previous investigations reported improvements in the engineering behavior of soils treated with sugarcane-derived ashes and related agricultural wastes. Nethravathi et al. reported that addition of bagasse ash to expansive black cotton soil increased strength with curing period and identified 20% bagasse ash as the optimum content in their study [1]. Shimola reported reductions in plasticity

index and increases in dry density, unconfined compressive strength, and shear strength at 16% bagasse ash [2].

Prajapati reported that combinations of bagasse ash and rice straw ash increased UCS and CBR of clayey soil [3]. Reddy and Prasad observed that sugarcane straw ash improved compaction, strength, and penetration characteristics, with 20% straw ash and 1% fibre producing promising results in their investigation [4]. Osinubi reported gains in UCS and CBR with bagasse ash but concluded that bagasse ash alone may not satisfy higher-grade pavement requirements for the soil investigated [5]. Comparative work by Harun indicated that both fly ash and bagasse ash could be used for expansive soil stabilization and reported 10% as an optimum bagasse-ash content in that study [6].

The reported optimum content varies substantially among studies because soil type, ash characteristics, curing conditions, and test criteria differ. The present work therefore focuses on the experimentally observed response of the selected soil to relatively low SBA contents of 1%, 2%, and 5%.

III. Materials and Methods

3.1 Materials

Two materials were used: naturally available sand and sugarcane bagasse ash. The sand was collected from the nearby ground area and classified in the report as a well-graded sandy soil, although the particle-size discussion also describes the sand as poorly graded. SBA was used as the stabilizing agricultural waste material.

3.2 Preliminary Characterization

The preliminary testing program comprised sieve analysis, specific gravity testing, direct shear testing, and standard Proctor compaction testing. The sieve analysis reported 28.85% material retained on the 425- μm sieve, 63.35% on the 150- μm sieve, and 6.45% on the 75- μm sieve, with 1.35% in the pan. The reported specific gravity was 2.68.

Table 1: Direct Shear Test Results Reported for the Soil

State	Relative density	Unit weight (kN/m^3)	ϕ (deg)
Loose	30%	15.3	33
Medium dense	59%	16.5	37
Dense	80%	17.5	40

3.3 Standard Proctor Test

Standard Proctor compaction tests were performed using light compaction to determine OMC and MDD. The mould diameter and height were 10 cm and 12.7 cm, respectively, with a reported mould volume of 981.25 cm^3 . For the natural soil, the maximum dry density was reported as 1.80 g/cm^3 at an OMC of 14%.

3.4 SBA Treatment Program

SBA was incorporated at 1%, 2%, and 5% in the experimental program. For each mixture, a series of water contents was used in the Proctor test to obtain the corresponding dry-density curve and identify the reported OMC and MDD.

Table 2: Summary Of Compaction Results

SBA Content	OMC (%)	MDD (g/cm^3)	Increase in MDD (%)
0%	14	1.800	—
1%	14	1.875	4.17
2%	16	2.089	16.06
5%	18	1.825	1.39

IV. Results and Discussion

The experimental results demonstrate that the incorporation of sugarcane bagasse ash (SBA) significantly modifies the compaction characteristics of the soil. The untreated soil exhibited an optimum moisture content (OMC) of 14% and a maximum dry density (MDD) of 1.80 g/cm^3 . With the addition of SBA, the OMC and MDD varied depending on the percentage of ash incorporated. The soil containing 1% SBA exhibited an OMC of 14% and an MDD of 1.875 g/cm^3 as shown in Fig 1, while the mixture containing 2% SBA attained an OMC of 16% and the highest MDD of 2.089 g/cm^3 as shown in Fig 2. At 5% SBA, the OMC increased further to 18%, whereas the MDD decreased to 1.825 g/cm^3 .

The variation in MDD indicates that the addition of SBA initially improves the packing characteristics of the soil, with the maximum improvement occurring at 2% SBA. The MDD increased from 1.80 g/cm^3 for the untreated soil to 2.089 g/cm^3 at 2% SBA, corresponding to an improvement of approximately 16.06%. However, further addition of SBA to 5% resulted in a reduction in MDD to 1.825 g/cm^3 . This indicates that the beneficial effect of

SBA is not proportional to its percentage and that an optimum content exists for achieving maximum compaction.

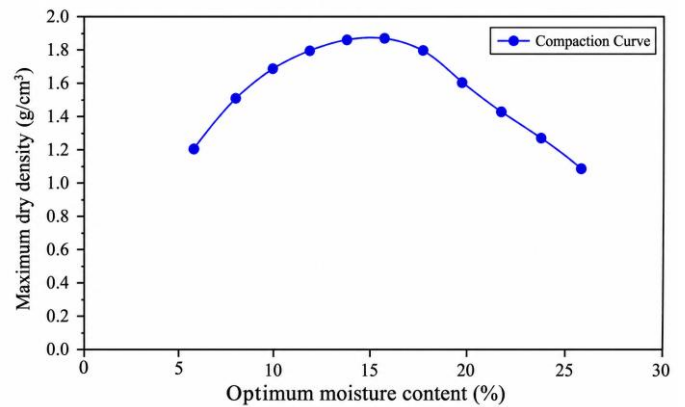


Figure 1. Compaction Curve for soil with 1% SBA

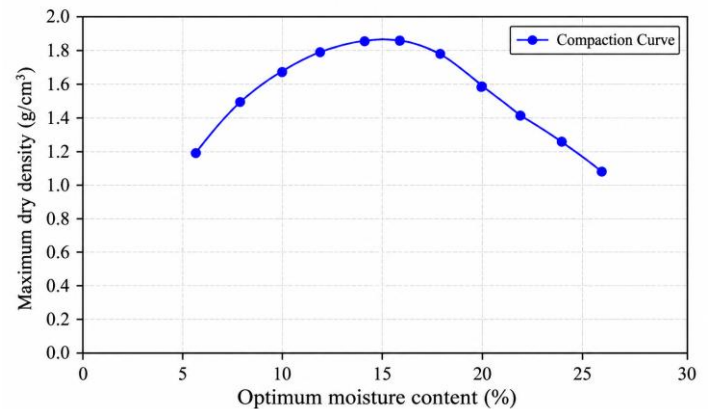


Figure 2. Compaction Curve for soil with 2% SBA

The OMC shows a different trend, increasing from 14% for the untreated soil to 16% at 2% SBA and 18% at 5% SBA. The increase in optimum moisture requirement with increasing SBA content indicates that higher quantities of ash require additional moisture to achieve the corresponding maximum dry density. This behavior may be associated with changes in particle arrangement, surface characteristics and water demand following the incorporation of SBA.

The observed variation in MDD can be explained in terms of particle packing and void filling. At an appropriate SBA content, the ash particles can modify the arrangement of the soil particles and contribute to a denser packing structure. The increase in dry density up to 2% SBA suggests that the addition of ash at this percentage produces a more favourable particle arrangement. Beyond the optimum content, the excess ash may increase the volume of finer particles and water demand, resulting in a reduction in the achievable dry density.

The results therefore indicate that 2% SBA is the optimum content based on the maximum dry density criterion. Compared with the untreated soil, the MDD increased from 1.80 to 2.089 g/cm^3 at 2% SBA. At 1% and 5% SBA, the corresponding MDD values were 1.875 and 1.825 g/cm^3 , respectively. The reduction in MDD beyond 2% demonstrates that increasing the ash content beyond the optimum does not necessarily result in further improvement in compaction characteristics.

4.1 Engineering Basis of SBA Stabilization

The effectiveness of soil stabilization can be interpreted using the principles of soil compaction. During compaction, the application of mechanical energy rearranges soil particles and reduces the volume of air voids. As water content increases, water facilitates particle rearrangement and allows the soil to attain progressively higher dry densities until the optimum moisture content is reached. Further addition of water beyond this condition does not result in a corresponding increase in dry density because the additional water occupies the void spaces.

The dry unit weight can be expressed as

$$\gamma_d = \frac{\gamma}{1 + w}$$

where γ_d is the dry unit weight, γ is the bulk unit weight and w is the water content expressed in decimal form.

The zero-air-voids condition can theoretically be represented by

$$\gamma_d = \frac{G_s \gamma_w}{1 + w G_s}$$

where G_s is the specific gravity of soil solids and γ_w is the unit weight of water. This relationship represents the limiting dry density corresponding to complete saturation without air voids and can be used to assess the physical consistency of compaction data.

In the present investigation, the addition of SBA changes the particle composition of the soil and consequently influences its packing behaviour and moisture requirement. The increase in OMC from 14% for untreated soil to 18% at 5% SBA indicates an increasing moisture requirement with ash content. The increase may be associated with the characteristics and finer nature of the added ash particles. However, the exact stabilization mechanism cannot be established from compaction data alone.

At 2% SBA, the highest MDD of 2.089 g/cm³ was obtained. This suggests that this percentage provided a favourable combination of soil and ash particles for compaction. At 5% SBA, the MDD reduced to 1.825 g/cm³ despite the increase in OMC to 18%. Thus, excessive addition of SBA does not necessarily improve density and may adversely affect the packing structure beyond the optimum content.

V. Conclusion

An experimental investigation was conducted to assess the use of sugarcane bagasse ash as a stabilizing material for soil. The study included sieve analysis, specific gravity, direct shear testing, and standard Proctor compaction testing. The natural soil had a reported specific gravity of 2.68, OMC of 14%, and MDD of 1.80 g/cm³. SBA addition altered the compaction characteristics, with the reported OMC increasing to 18% at 5% SBA. The report concludes that SBA can be used as a cost-effective and environmentally beneficial soil-improvement material and identifies 2% SBA as the optimum content. Nevertheless, the detailed 2% Proctor table does not support the summary MDD value quoted for 2% SBA. The original laboratory calculations and graphs should therefore be rechecked, and the corrected values should be used consistently throughout the final manuscript.

Future work may investigate the effect of SBA on strength, durability, CBR, UCS, and shear parameters, as well as the influence of additional additives or treatment methods intended to improve long-term performance.

VI. References

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