

# Effects of Using Sawdust Ash as a Stabilizer for Expansive Soils

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**Abstract.** Expansive soils are known to swell and shrink with moisture content changes, rendering them unsuitable for construction without proper stabilization. Cement and lime have conventionally served as common additives for soil stabilization. However, in Uganda, the escalating costs of these additives accentuate the need for alternative solutions. Therefore, this research attempts to investigate the viability of sawdust ash, an affordable agricultural waste, as an effective stabilizer for expansive soils. Through systematic experimentation, various percentages of sawdust ash (ranging from 0% to 10%) were introduced into the soil matrix. The objectives of the study were achieved through a series of laboratory tests, including gradation analysis, Atterberg limit determination, compaction, and California Bearing Ratio (CBR) test. The findings revealed the soil is clay with high plasticity, emphasizing the need for stabilization. Importantly, the addition of sawdust ash resulted in a substantial reduction in the plasticity index, from 35% to 16%, at 0% and 10% sawdust ash content, respectively. Furthermore, the incorporation of sawdust ash led to an increase in the maximum dry density and a reduction in the optimum moisture content as its proportion was augmented. Notably, with 6% sawdust ash content, the CBR value reached its highest point at 14.4%. These outcomes reveal the potential of sawdust ash as an economically attractive alternative to traditional stabilizers such as cement and lime. This research contributes valuable insights to the field of soil stabilization and offers a sustainable solution that addresses both economic and environmental concerns in construction practices.

## 1 Introduction

Expansive soils are highly plastic clays with a significant mineral composition of montmorillonite and illite [1]. They tend to swell when moistened and soften or shrink and develop cracks as they dry [2-4]. The expansive nature of these soils has led to significant damage to buildings and infrastructure. For example, in the United States alone, expansive soils annually cause destruction exceeding 15 billion dollars [5]. Due to the potential for property loss, it is essential to stabilize expansive soil before using it in the construction of buildings and roads.

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Soil stabilization involves modifying the properties of the soil using additives to improve its bearing capacity and resistance to physical and chemical stresses over the engineered facility's service life [6]. Various methods are employed globally to stabilize expansive soils, such as chemical stabilization using cement and lime. Nowadays, industrial by-products like fly ash, blast furnace slag, and agricultural wastes like sawdust ash, rice husk ash, etc., have replaced expensive stabilizers (lime or cement) [7-9]. For example, Rathan et al.'s [9] research focused on studying the effects of soil stabilization with rice husk ash. Laboratory tests demonstrated that as the percentage of rice husk ash increased, both the liquid limit and free swell index decreased. Additionally, the tests revealed that the maximum dry density (MDD) increased from 16.39 kN/m<sup>3</sup> to 20.95 kN/m<sup>3</sup> with an increase in the rice husk ash percentage.

Nowadays, by-products such as fly ash, rice husk ash, etc. have replaced expensive stabilizers like lime or cement [7-9]. For instance, Rathan et al.'s [9] research was about studying the effect of stabilizing soil with rice husk ash. The laboratory tests carried out showed that with an increase in rice husk ash percentages, liquid limit and free swell index reduced. The tests also showed that maximum dry density (MDD) increased from 16.39 kN/m<sup>3</sup> to 20.95 kN/m<sup>3</sup> with the increase in rice husk ash percentage.

Zi-ru & Xing [4] conducted research on the impact of using lime and fly ash as stabilizers for expansive soil. Laboratory tests indicated that adding lime increased the plastic limit of the soil, while the addition of fly ash decreased the liquid limit. Consequently, the plasticity index decreased when either lime or fly ash was introduced to the soil. Furthermore, the tests showed that the MDD and free swell of the soil decreased with an increase in the percentages of fly ash and lime.

Current research endeavors in the construction industry are increasingly focused on harnessing the potential of cost-effective, locally available materials, including agricultural waste products such as sawdust ash, rice husk ash, and sugarcane bagasse ash [10]. Sawdust, a byproduct of wood log processing, is one such resource, and its incinerated counterpart, known as sawdust ash (SDA), has demonstrated promise in enhancing the properties of construction materials. The utilization of SDA in construction is not a novel concept and has been explored in previous studies to enhance the characteristics of both concrete and soil [8, 11]. Noteworthy contributions have been made by researchers such as Ikeagwuani et al. [12], Elahi et al. [13], Owamah et al. [14], and Butt et al. [7], who have investigated the potential of sawdust ash as an additive for soil improvement. However, within the context of Uganda, limited research has been conducted to explore the feasibility and advantages of incorporating cost-effective agricultural waste materials, like sawdust ash, into construction practices. It is in this context that the current research aims to investigate the effects of utilizing sawdust ash as a stabilizing agent for expansive soils. This endeavor encompasses a comprehensive evaluation of the chemical properties of sawdust ash and a thorough analysis of the engineering properties of both stabilized and non-stabilized soils. By doing so, this study seeks to contribute valuable insights to sustainable construction practices and promote eco-friendly solutions tailored to the specific needs of Uganda's construction industry.

## **2 Materials and Methods**

### **2.1 Materials**

The current study employed expansive soil and sawdust ash (SDA). A thorough description of these materials is presented as follows:

### 1) Expansive soil

Soil sample was obtained from Kitgum in the Acholi sub-region in Northern Uganda. The soil sample was then transported using trucks to the International University of East Africa (IUEA) laboratory in Kampala, where it was tested.

### 2) Sawdust ash

The sawdust utilized in this study was sourced from a local carpentry workshop in Kampala. It originated from eucalyptus wood and underwent incineration, reaching temperatures within the range of 320 to 350 °C, resulting in the production of ashes.

## 2.2 Methods

The objectives of this study were successfully achieved through a series of comprehensive laboratory experiments. Sawdust ash was meticulously incorporated into the soil at varying percentages: 0%, 2%, 4%, 6%, and 10%. These specific percentages were chosen with consideration of prior research conducted by Venkatesh & Reddy [15], where sawdust ash (SDA) proportions of 0%, 2%, 6%, and 8% were employed. Subsequent laboratory tests were conducted on both the expansive virgin soil and the soil that had been stabilized with sawdust ash. These tests encompassed: Sieve analysis, employed to ascertain particle size distribution, Atterberg limit determination using Casagrande's apparatus, which provided data on liquid limit (LL), plastic limit (PL), and plasticity index (PI), Compaction testing to establish the optimum moisture content (OMC) and maximum dry density (MDD), and California Bearing Ratio (CBR) testing to assess the soil's load-bearing capacity.

These meticulous tests conducted in accordance to specific standards (see Table 1) collectively facilitated a comprehensive assessment of the characteristics of the soils, enabling a thorough evaluation of the effectiveness of sawdust ash as a stabilizing agent.

**Table 1.** Laboratory test standards.

Laboratory test	Designation
Particle size distribution	B.S. 1377: Part 2: 1990
Atterberg limit	AASHTO T-89
Compaction test	BS 1377 part 4: 1990
California Bearing Ratio	BS 1377: Part 4: 1990

## 3 Results and Discussions

This section shows a presentation of the results and their interpretation. The chemical properties of sawdust ash, the geotechnical and mechanical properties of both stabilized and non-stabilized soil are presented.

### 3.1 Chemical properties of sawdust ash

The chemical composition analysis of SDA, as presented in Table 2, demonstrates that SDA exhibits a substantial content of silica (58.21%), ferric oxide (8.03%), and alumina (8.60%), establishing it as a viable pozzolanic material. In accordance with ASTM C 618–15 guidelines [16], materials are classified as pozzolans when the total percentage of silica, ferric oxide, and alumina exceeds 70%. In the context of this study, the cumulative percentage of

these constituents amounts to 74.28%. This characterization firmly establishes SDA as a pozzolanic material, indicative of its potential utility in soil stabilization.

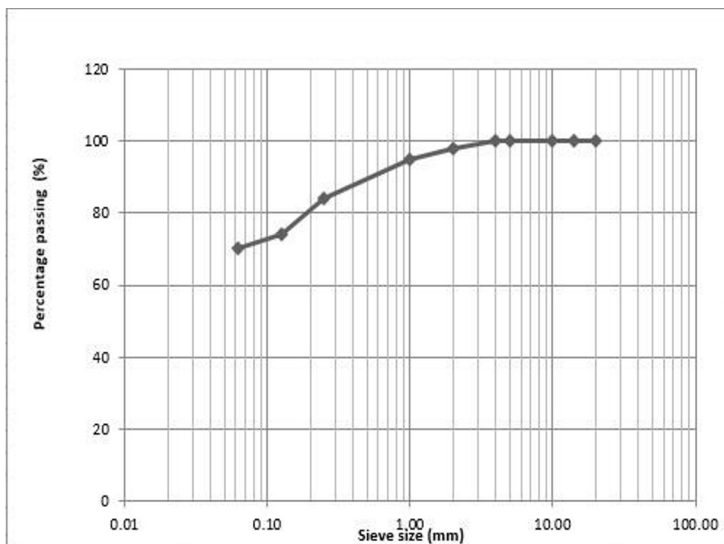
**Table 2.** Chemical properties of sawdust ash.

Parameter	Composition (%)
Calcium Oxide (CaO)	10.90
Alumina (Al <sub>2</sub> O <sub>3</sub> )	8.60
Potassium Oxide (K <sub>2</sub> O)	8.94
Sodium Oxide (Na <sub>2</sub> O)	3.05
Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	8.03
Silicon dioxide (SiO <sub>2</sub> )	58.21

### 3.2 Geotechnical and mechanical properties of non-stabilized soil

#### 3.2.1 Particle Size Distribution

The test results, depicted in Figure 1, revealed that the soil exhibits a uniform grading. Analysis of the soil composition indicated the following percentages for different soil types: Gravel = 0%, Sand = 25.05%, and Silts and Clays = 74.95%. The predominant components in the gradation are silts and clays, as evidenced by the notably high percentage.

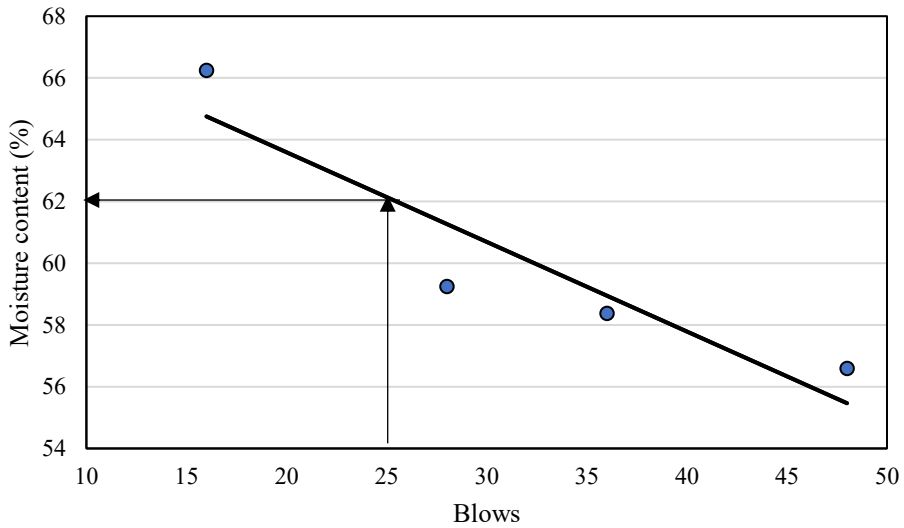


**Fig. 1.** Particle size distribution of soil.

#### 3.2.2 Atterberg Limit

The liquid limit of the non-stabilized soil was found using Casagrande. The liquid limit was obtained at 25 blows, as observed in Figure 2. The plastic limit was 27%. The plasticity index, which is the difference between LL and PL, was determined to be 35%. The plasticity chart showed that the soil has high plasticity. This analysis reveals that the soil exhibits a notably

high degree of plasticity. Given the plasticity index of 35%, it is evident that the soil's potential for swelling is extremely high, consistent with the findings presented by Chen [17].



**Fig. 2.** Determination of liquid limit.

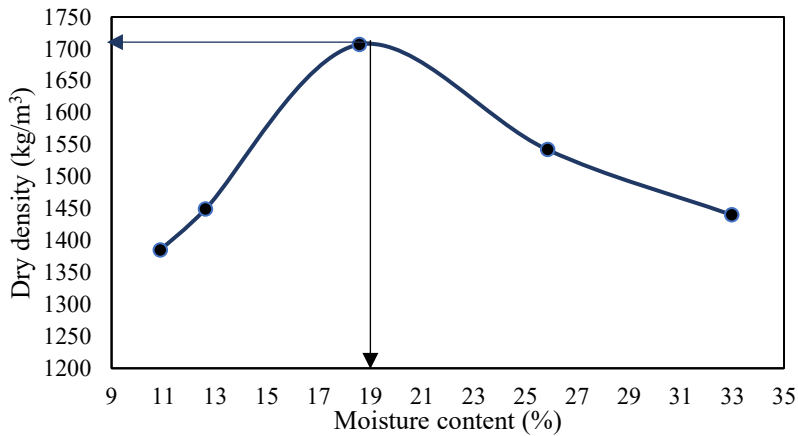
Based on the results from particle size distribution and Atterberg tests, the soil was identified as A-7-5 using the American Association of State Highway and Transportation Officials (AASHTO) and clay of high plasticity (CH) using the Unified Soil Classification System (USCS). The geotechnical properties of the soil that formed the basis of classification are summarized in Table 3.

**Table 3.** Geotechnical properties of expansive soil.

Property	Value
Liquid limit	62%
Plastic limit	27%
Plasticity index	35%
Linear shrinkage	9%
AASHTO	A-7-5
USCS	CH

### 3.3 Compaction test

This test was performed to obtain the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. MDD was determined to be 1707 kg/m<sup>3</sup> while OMC was 19%, as shown in Figure 3.



**Fig. 3.** Determining OMC and MDD.

### 3.4 California Bearing ratio (CBR)

This test was carried out in accordance with BS 1377: Part 4: 1990. The sample was first soaked for four days before the test was carried out. The CBR value of the non-stabilized soil was found to be 9.6%. The CBR swelling after four days was found to be 22.05%.

### 3.5 Geotechnical and mechanical properties of soil stabilized with SDA

#### 3.5.1 Atterberg Limits

Table 4 shows the values of liquid limit (LL), plastic limit (PL), shrinkage limit (SL) and plasticity index when different percentages of SDA were added to the soil. The findings presented reveal a notable reduction in the liquid limit, decreasing from 62% to 52% as the proportion of SDA increased from 0% to 10%. This decline can be attributed to the reduced water affinity exhibited by SDA [2, 3], resulting in diminished soil plasticity. Consequently, the observed decrease in the liquid limit signifies a substantial mitigation of the compressibility and swelling characteristics of the soil.

**Table 4.** Atterberg limit with different SDA percentages.

SDA (%)	LL (%)	PL (%)	PI (%)	SL (%)
0	62	27	35	9
2	64	31	32	8
4	63	40	22	6
6	53	35	18	3
10	52	37	16	2

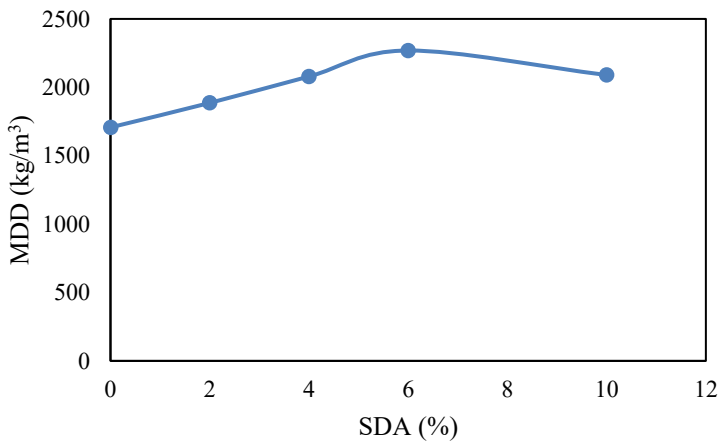
The plasticity index reduced from 35% to 16% when SDA was increased from 0% to 10%. A similar phenomenon was observed by Ogunribido [18] when SDA was added to lateritic soil. The results showed a decrease in plasticity index when SDA percentages were increased.

### 3.5.2 Compaction test for the stabilized soil

The dry density values of the soil samples, with varying percentages of SDA stabilizer ranging from 0% to 10%, are as follows: 1707 kg/m<sup>3</sup>, 1886 kg/m<sup>3</sup>, 2079 kg/m<sup>3</sup>, 2269 kg/m<sup>3</sup>, and 2090 kg/m<sup>3</sup>, respectively. This trend demonstrates a consistent increase in soil density as the SDA content increases. However, for the 10% SDA mixture, a decrease in dry density is observed, as depicted in Figure 4. Additionally, it is noteworthy that the Optimum Moisture Content (OMC) decreased with the increasing proportion of SDA, as summarized in Table 5.

**Table 5.** The changes of OMC and MDD with SDA addition.

SDA (%)	MDD (kg/m <sup>3</sup> )	OMC (%)
0	1707	19
2	1886	18
4	2079	17
6	2269	12
10	2090	13



**Fig. 4.** Variation of MDD with SDA.

MDD increases with increase in SDA because SDA fills the voids that exist between soil particles and, in turn, block the water to flow. These findings contrast with the results obtained by Rai [19], where the opposite trend was observed. With increase in SDA, dry density decreased with the lowest dry density achieved being 15.79 kN/m<sup>3</sup> with 25% SDA.

### 3.5.3 California Bearing Ratio (CBR)

CBR value of the non-stabilized soil was 9.6%, while the highest CBR achieved was 14.4% at 6% of SDA, as seen in Figure 5. However, there was a drop in CBR when 10% of SDA was added. Based on the CBR values observed, it can be noted that the optimum percentage of SDA to be used as a stabilizer is 6%. This increase in CBR may be because of the pozzolanic properties of SDA, and the reduction in CBR credited to the low strength of SDA.

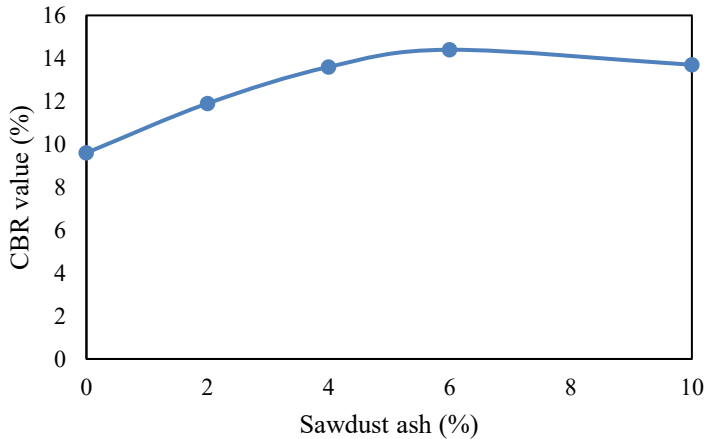


Fig. 5. California bearing ratio.

When CBR values are compared with research done by Mishra [20], lime was used as a stabilizer of black cotton soil. The optimum value of CBR was 9.52% when 5% lime was added which is less than the 14.4% CBR value obtained with 6% SDA. Therefore, SDA has shown the potential to be a stabilizer of expansive soil.

#### 3.5.4 California Bearing Ratio (CBR) swell

When utilizing the California Bearing Ratio (CBR) instrument, the test results indicated a progressive reduction in the swelling percentage of soil samples with increasing percentages of the SDA stabilizer, ranging from 0% to 10%. Specifically, the swelling percentages were recorded as follows: 22.05%, 9.45%, 4.8%, 3.15%, and 3.15% for the respective SDA proportions. This observed trend of decreasing swelling with higher SDA content is visually represented in Figure 6. A similar trend was noted in the study conducted by Niyomukiza et al. [3], where *Keruing* sawdust was employed as a stabilizing agent for expansive soil.

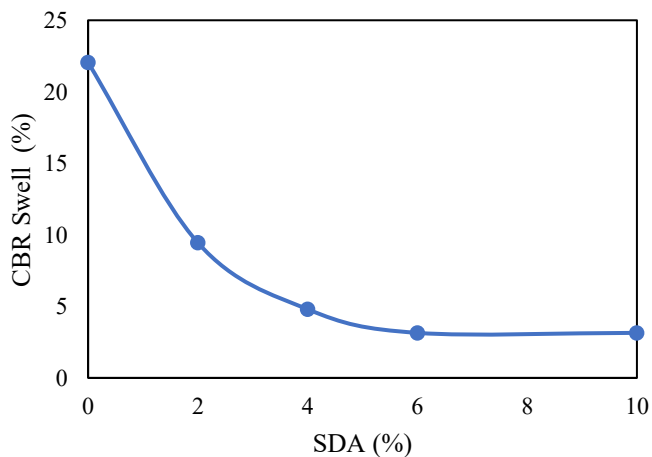


Fig. 6. California bearing ratio swell.

## 4 Conclusions

This study investigated the impact of SDA on the engineering properties of expansive soil. Based on findings, the soil was categorized as A-7-5 under the AASHTO, thus possessing poor engineering properties.

The test results consistently demonstrated a reduction in the plasticity index as the proportion of sawdust ash (SDA) in the soil increased. Notably, the optimum plasticity index of 16% was achieved when 10% SDA was incorporated. Similarly, the shrinkage limit exhibited a decreasing trend with the addition of higher percentages of SDA, reaching its lowest point of 2% when 10% SDA was employed.

Furthermore, there was a concurrent increase in maximum dry density (MDD) and a reduction in optimum moisture content (OMC) as the proportion of SDA in the soil matrix increased. The highest recorded MDD value reached 2269 kg/m<sup>3</sup> when 6% SDA was introduced.

In terms of California Bearing Ratio (CBR), a consistent rise in values was observed with increasing percentages of SDA, culminating in the highest CBR value of 14.4% when 6% SDA was utilized. Based on these findings, the optimal SDA content for soil stabilization in the Kitgum region of Uganda is determined to be 6%. Consequently, it can be concluded that sawdust ash presents a cost-effective and practical solution for enhancing the properties of expansive soils, making it a promising stabilizer option for soil improvement.

Nevertheless, it is recommended that further studies be conducted to explore the potential use of SDA in stabilizing expansive soil, particularly with different wood types. This research would provide insights into the impact of SDA on the various properties of expansive soils, contributing to a more comprehensive understanding of its applicability.

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