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# EFFECTS OF LIME ON BAGASSE ASH-STABILISED EXPANSIVE SOILS

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**ABSTRACT:** *Management of agricultural wastes and improvement of construction soils have become increasingly necessary for sustainable development. This study therefore stabilised selected expansive soils using bagasse ash (BA) and lime, with a view to determining the effect of lime on BA-stabilised soils. Two soil samples (identified as Sample A and Sample B) were collected from two identified locations characterised with expansive soils in Ile-Ife, Osun State, Southwestern Nigeria. Using standard procedures, the following preliminary and geotechnical tests were conducted on the soil samples in their natural state: moisture content determination, particle size analysis, specific gravity, Atterberg limits, compaction and unconfined compressive strength (UCS). BA was then introduced to the soils in 5 %, 10 % and 15 % proportions by weight of dry soil. Thereafter, Atterberg limits and UCS tests were conducted on the BA-stabilised soils. Also 2.5 % lime was introduced to each proportion of BA earlier used. Atterberg limits and UCS tests were then conducted on the BA-lime stabilised soils. Results showed that the two soils in their natural state have high plasticity and they both belong to the A-2-7 group. For both BA and BA-lime stabilised soil samples, plasticity reduced with increase in the stabilisers, which implies an improvement in the soil properties. Also, UCS of both BA and BA-lime stabilised soil samples increased with optimum values at 10 % BA content. Expectedly, addition of lime increased the values of UCS for each combination of stabilisers. It was concluded that BA could be used to improve the properties of expansive soils and that the addition of certain proportions of lime does not have a negative impact on the stabilisation properties of BA, but rather improves it.*

**KEYWORDS:** Bagasse ash, expansive soil, lime, soil strength, stabilisation.

## INTRODUCTION

Expansive soils are characterised by a cycle of swelling (during the rainy season) and shrinkage and crack (during the dry season). This characteristic has made expansive soils to be problematic for civil engineering applications (Chen, 1988). Consequently, there is the growing need to improve or stabilise expansive soils for engineering purposes.

Bagasse is an agricultural waste obtained from milling or consumption of sugarcane. The ash from bagasse has been categorised under pozzolana with about 1.78 % calcium oxide (CaO), 5.78 % iron oxide ($Fe_2O_3$), 1.23 % magnesium oxide (MgO), 65.58 % silicon oxide ($SiO_2$) and 5.78 % aluminum oxide ($Al_2O_3$) (Hailu, 2011).

The over dependence on industrially manufactured soil improving additives (such as cement, lime, etc.) has kept the cost of construction of roads and other engineering structures high. This hitherto has continued to deter the under-developed and poor nations of the world from providing sustainable infrastructure to meet the needs of their rural dwellers (mostly farmers) who constitute a large percentage of their population.

The need to bring down the growing cost of soil stabilisers and the cost of waste disposal has led to intense global research towards economic utilisation of wastes for engineering purposes. The safe disposal of industrial and agricultural waste products demands urgent and cost-effective solutions because of the debilitating effect of these materials on the environment and the health hazards that they constitute.

In order to improve the properties of deficient soils and thus make them useful and meet geotechnical engineering design requirements, researchers have focused more on the use of potentially cost-effective materials that are locally available from industrial and agricultural wastes (Osinubi, 2009). Thus, the possible use of agricultural waste, such as bagasse ash, will considerably reduce the cost of construction and as well reduce or eliminate the environmental hazards caused by such waste.

Attempts have been made to utilise waste product materials to minimise or completely eliminate the amount of money spent on lime or cement as stabilising agents (Osinubi & Thomas, 2007; Brooks, 2009; Fatahi & Khabbaz, 2012). The utilisation of the pozzolana in bagasse ash as a replacement for traditional/industrial stabilisers will go a long way in achieving the aim of scouting for cheap and readily available construction materials, in addition to achieving sustainable development and clean environment.

Wubshet and Tadesse (2014) undertook the stabilization of expansive soil using bagasse ash and lime. After the preliminary analysis and classification, the selected soil sample was stabilized using 15 % bagasse ash (BA); 3 % lime; and a combination of 15 % BA and 3 % lime, by weight of dry soil. The effect of the additives on the soil was investigated with respect to plasticity, compaction and California bearing ratio (CBR) tests. Results showed an increase in optimum moisture content (OMC) and CBR value, and a decrease in maximum dry density (MDD) and plasticity of the soil for all additives. There was also a tremendous improvement in the CBR value when the soil was stabilised with a combination of lime and BA. They concluded that BA has a great potential as admixture in lime-stabilised expansive soils.

Dang *et al*. (2016) attempted the enhancement of engineering properties of expansive soil using bagasse ash and hydrated lime. The preparation of stabilised soil specimens was conducted by


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changing the bagasse ash contents from 0 to 25 % by weight of expansive soil along with an increase in hydrated lime. Linear shrinkage and CBR tests were conducted on the stabilised expansive soil after various curing periods of 3, 7 and 28 days. Results revealed that the additions of hydrated lime and bagasse ash improved the strength and bearing capacity of stabilised expansive soil remarkably, while significantly reducing the linear shrinkage of the soil. The authors concluded that the application of hydrated lime and bagasse ash as reinforcing material does not only enhance the engineering properties of expansive soil, but also facilitates sustainable development by using sugarcane waste (by-product) to improve unusable clay material (soil) in road construction.

Hasan *et al.* (2016a) used bagasse ash and lime to stabilise highly expansive soil. Different ratios of lime to bagasse ash were applied to optimise the amount of bagasse ash for treatment of the expansive soil. They observed significant improvement in the CBR values when 18.75 % bagasse ash was added to soil when the ratio of lime to bagasse ash was 1:3 at 28 days of curing time under both unsoaked and soaked conditions. Also, it was found that when bagasse ash (18.75 %) was added to lime (6.25 %) treated soil, the linear shrinkage and free swell ratio were significantly reduced, in comparison with those of the natural soil. They concluded that the outcome of the study provides an eco-friendly opportunity in the road subgrade stabilisation application.

Hasan *et al.* (2016b) also carried out the remediation of expansive soils using agricultural waste (bagasse ash) and lime. Hydrated lime was mixed in varying proportions (0 %, 6 %, 10 %, 18 % and 25 % by weight of dry soil) with selected black soil samples. The stabilised samples were cured for 3, 7 and 28 days, and an unconfined compressive strength (UCS) test was conducted on the stabilised soil samples. From the results, it was concluded that stabilisation of expansive soils using bagasse ash and hydrated lime not only improves the strength of soil but also helps to cope with environmental concerns through the management of sugar industry waste.

Srinivasa and Sai (2017) carried out the stabilisation of expansive soil using bagasse ash. Bagasse ash was used to stabilize the soil sample using varying proportions – 2 %, 4 %, 6 %, 8 % and 10 %. The performance of bagasse ash was evaluated using physical and strength performance tests, namely, compaction and unconfined compressive strength. It was observed that BA led to the improvement of properties of the expansive soil. They therefore concluded that BA could be employed in the stabilisation of expansive soils.

Saini *et al.* (2019) stabilised black cotton soil using bagasse ash (BA). The soil was treated with varying proportions (2.5 %, 5 %, 7.5 %, 10 %, 12.5 %) by weight of dry soil. For the treated soil, liquid limit, plastic limit, plasticity index, differential free swell index, swelling pressure, compaction, CBR and UCS tests were performed and compared with the natural soil. They concluded that BA improved the engineering properties of the cotton soil and reduced the swelling potential, with the optimum impact obtained at 5 % BA.

Studies have shown that engineering properties of soils are commonly altered (improved) when agricultural wastes (such as bagasse ash, groundnut shell ash, banana leaf ash, etc) are used to stabilise soils (Amu *et al.*, 2011; Ajala *et al*., 2020; Daramola *et al*. 2021; Adunoye *et al*., 2022; Adunoye *et al.*, 2023). More efforts have also been made at studying the effects of chemical admixtures (such as lime and cement) as admixtures in stabilisation of soils with agricultural


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wastes (Hanna *et al.*, 2021). This study therefore set to contribute to existing knowledge on the effects of lime on BA-stabilised soils.

## MATERIALS AND METHODS

### Materials and Equipment

The materials used for the study are: lateritic soil samples, bagasse and lime. The lateritic soil samples were collected from two identified locations (in Ile-Ife, Osun State, Nigeria) characterised with expansive materials. Bagasse was obtained from a sugar cane depot, while lime was purchased from the open market.

The following equipment and apparatus were used: moisture content apparatus, a set of British Standard (BS) sieves and mechanical sieve shaker, pycnometer, Casagrande apparatus, compaction apparatus, and UCS machine.

### Soil Sampling and Preparation

Two samples of expansive soil were collected from two identified borrow pits (one sample from each borrow pit) within Ile-Ife, Osun State, Southwestern Nigeria. The first borrow pit is located at the back of the Faculty of Environmental Design and Management, Obafemi Awolowo University (OAU) campus. The sampling point at this borrow pit is named Sample A and has a geographic positioning system (GPS) description of N7$^0$31’31.9”; E4$^0$31’34.8”). The second borrow pit is at Damico Estate, Ile-Ife. The sampling point at this second borrow pit is referred to as Sample B and has a GPS description of N7$^0$30’0.36”; E4$^0$30’21.1”.

The method of sampling used was disturbed sampling. About 25 kg of each soil sample was collected with the aid of hand auger, placed in plastic bags, sealed, labelled and transported immediately to the Geotechnical Engineering Laboratory (referred to as the Laboratory), Department of Civil Engineering, OAU, Ile-Ife. At the laboratory, the natural moisture content was determined for the soil samples before spreading (for air-drying) for subsequent analysis. The already air-dried soil samples were slightly pulverised with minimal pressure to break up lumps which were formed during storage.

### Preparation of Bagasse Ash

Bagasse was obtained from the sugarcane depot at Sabo, Ile-Ife. After collection, the bagasse was spread on a sack and air-dried at room temperature. Thereafter, bagasse ash (BA) was prepared by burning the bagasse at the furnace situated at the laboratory of the Department of Materials Science and Engineering, OAU, Ile-Ife. It was burnt to ash at a temperature of 800$^o$C. The BA was then taken to the Laboratory and sieved through 75 µm BS sieve to get the fine ash to be used for the stabilisation.

### Geotechnical Tests on Soil Samples in Their Natural State

The following preliminary and geotechnical tests were conducted on the soil samples in their natural state: specific gravity, particle size analysis, Atterberg limits, compaction, and UCS. The tests were conducted using standard procedures as outlined in BS 1377 (1990).


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**Stabilisation of Soil with Bagasse Ash and Lime**

Bagasse ash (BA) was added to the soil samples at 5 %, 10 % and 15 % proportions by weight of soil. Atterberg limits, compaction and UCS tests were conducted on the various proportions of the soil-bagasse ash mixture.

Subsequently, bagasse ash (BA) and lime were added to the soil samples in the following proportions by weight of dry soil: 5 % BA with 2.5 % lime, 10 % BA with 2.5 % lime, and 15 % BA with 2.5 % lime. Thereafter, Atterberg limits, compaction, and UCS tests were also conducted on the various proportions of the soil-bagasse ash-lime mixture.

## RESULTS AND DISCUSSION

### Results of Geotechnical Tests on Natural Soil Samples

The results of geotechnical tests on the soil samples in their natural state are shown in Table 1.

The void ratio of lateritic soil is the predominant factor that affects the moisture content of the samples. The higher the void ratio of a soil, the higher its moisture content. Therefore, it is generally accepted that the lower the moisture content the better the soil (Jackson & Ravindra, 1996). Therefore, Sample B (with lower natural moisture content) is expected to have a lower void ratio.

The specific gravity of the solids making up a given soil sample is useful mainly for deriving other needed properties of soil in that it is used to check for the phase relationship between matters (Gidigasu, 1971). The values of the specific gravity of the soils (see Table 1) indicate that the degree of laterisation is high in the soil samples.

According to Das (2006), a soil is said to be clayey if it has a plasticity index greater than or equal to 11 %. With the values of Atterberg limits (Table 1), it could be deduced that both Sample A and Sample B have relatively high clay content (11<25.1, 11<24.65). Also, according to Whitlow (1995), a soil having a liquid limit between 50 % and 70 % has high plasticity. Soil samples A and B each have their liquid limits between 50 % and 70 %, and therefore have high plasticity.

**Table 1: Index and Geotechnical Properties of Natural Soils**

| Property | Sample A | Sample B |
|---|---|---|
| Natural moisture content (%) | 14.19 | 28.26 |
| Specific gravity | 2.71 | 2.62 |
| Liquid limit (%) | 64.50 | 59.40 |
| Plastic limit (%) | 28.35 | 25.75 |
| Plasticity index (%) | 36.15 | 33.65 |
| Percentage passing sieve No. 200 (fines) | 0.70 | 2.10 |
| Percentage passing sieve No. 40 | 34.11 | 47.91 |
| AASHTO classification | A-2-7 | A-2-7 |
| Optimum moisture content (%) | 17.30 | 25.70 |


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| | | |
|---|---|---|
| Maximum dry density (kg/m$^3$) | 1630.00 | 1420.00 |
| Unconfined compressive strength (Kpa) | 57.13 | 34.96 |

From the results of Atterberg limits test and grain size analysis (Table 1), using American Association of State Highway and Transport Officials (AASHTO) classification system, it was found that the two soil samples belong to the A-2-7 category (Table 1).

**Effects of Bagasse Ash (BA) on the Geotechnical Properties of Soil**

The effects of BA on the plasticity and UCS of the soil samples are presented in Figures 1 and 2 respectively. It was observed that the addition of bagasse ash in varying proportions (5 %, 10 % and 15 %) to the soil samples led to a reduction in the plasticity of the soils (Figure 1), which translates to improvement in the properties of the soils.


**Figure 1: Variation of plasticity index with bagasse ash**

Also, addition of BA led to increase in UCS with optimum value obtained at 10 % BA content, for both samples (Figure 2). The decline in the UCS of the soils, after attaining maximum value at 10 % BA content, could be due to excess BA that was not mobilised in the reaction, which consequently occupied spaces within the soil samples. Since an increase in UCS is an indication of soil improvement (Craig, 2004), it could be said that addition of GSA to the soils led to their improvement, with 10 % optimum BA content. The improvement could be attributed to the pozzolanic reaction that improved the strength properties (Adun0ye *et al.*, 2022).

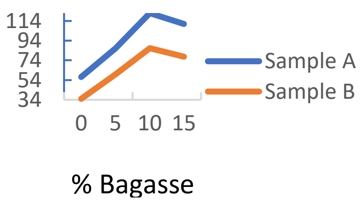


**Figure 2: Variation of UCS with bagasse ash**


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**Combined Effects of BA and Lime on Soil Samples**

Figures 3 and 4 present the variations in the plasticity and UCS of the soils with the addition of BA and lime. It was observed that addition of BA and lime led to reduction in plasticity, for both samples (Figure 3), implying an improvement in the soil properties. It was also observed that the UCS value of the soil samples increased considerably with increase in BA and lime, for both samples (Figure 4). As in the case of BA stabilization alone, optimum value of UCS was obtained at 10 % BA-2.5 % lime stabiliser content. However, expectedly, the presence of lime gave lower plasticity and higher values of UCS for each BA content.

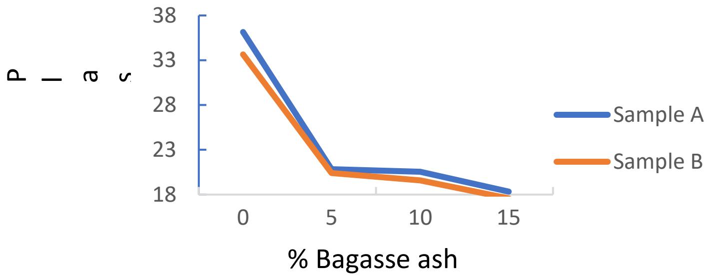


**Figure 3: Variation of plasticity index with BA + lime**

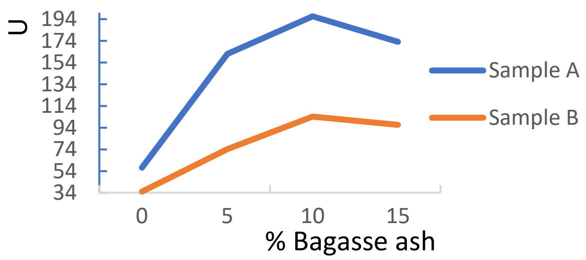


**Figure 4: Variation of UCS with BA + lime**

For both BA and BA-lime stabilisation, the decrease in plasticity and increment in the UCS values could be attributed to the gradual formation of cementitious (Calcium Silicate ($CaSiO_3$)) compound between the BA, lime and Calcium Hydroxide ($Ca(OH)_2$) present in the soil. Expansive soils are known to contain a very high percentage of $Ca(OH)_2$ and when this combines with about 50% $SiO_2$ content present in BA, it produces $CaSiO_3$.


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$CaSiO_3$ has chemical properties very similar to cement and because of this similarity, $CaSiO_3$ can be used as a stabilising agent (see Equation 1). It is primarily used in ceramics and tile factories (Mohanalaksh *et al.*, 2016).

$$SiO_2 + Ca(OH)_2 \longrightarrow CaSiO_3 + H_2O \qquad (1)$$

## CONCLUSION

Effects of lime on bagasse ash-stabilised expansive soils have been studied. The selected soils, in their natural state, belonged to A-2-7 class; they have high plasticity, which implies a need for improvement for engineering applications. The introduction of BA led to a reduction in plasticity and increase in UCS, with optimum value at 10 % BA content. Addition of a constant amount (2.5 %) of limit led to further improvement in the properties and strength of the soils. Therefore, introduction of BA led to a considerable improvement in the properties and strength of the soil samples. Also, the addition of lime did not have any adverse effect on the stabilising property of BA but rather improved it.

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