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Evaluation of Sawdust Ash-Stabilised Lateritic Soils for Low-Cost Urban Road Construction and Sustainable Cities

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Abstract: *The increasing demand for sustainable and affordable urban road infrastructure has heightened interest in alternative soil stabilization materials made from waste products. Lateritic soils are commonly used as subgrade materials in tropical areas; however, their high plasticity, moderate strength, and moisture sensitivity often limit their performance. This study assesses the effectiveness of sawdust ash (SDA) as an environmentally friendly stabilizing agent for lateritic soils used in low-cost urban road construction. To achieve this, lateritic soil samples were collected from selected borrow pits in Ile-Ife, Osun State, southwestern Nigeria. Standard procedures were used to perform preliminary and geotechnical tests on the natural soil samples. SDA was added to the soil samples at 3%, 6%, and 9% by weight of dry soil to identify the optimal stabilization level. The treated soil samples then underwent CBR testing. Results indicated that adding SDA reduced soil plasticity, signifying decreased swelling potential and better workability. The addition of SDA also increased CBR values, with the highest results at the optimal stabilization levels, indicating improved load-bearing capacity. This enhancement is due to pozzolanic reactions between silica-rich SDA and calcium compounds in the soil, resulting in the formation of cement-like products that strengthen the soil. The findings demonstrate that SDA is a practical and environmentally sustainable stabilizer for lateritic soils. Reusing SDA not only improves geotechnical performance but also supports waste management and reduces environmental pollution. This study advocates for the use of SDA stabilization in sustainable urban road development.*

Keywords: California Bearing Ratio, road construction, sawdust ash, sustainable cities, urban development

INTRODUCTION

The shift from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs) has significant effects on urban and regional planning, especially regarding sustainable infrastructure and material use (UN- Habitat, 2020). Although MDGs mainly focused on reducing poverty and providing basic services, they did not sufficiently address the environmental impacts of rapid urban growth and construction activities. In contrast, the SDGs offer a more integrated planning framework that connects spatial development with environmental sustainability, particularly through SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (United Nations, 2015; Sachs *et al*., 2021).

Sustainable cities are fundamental to contemporary urban and regional planning as they aim to balance environmental protection, economic development, and social equity. Key elements of sustainable cities include efficient land-use planning, integrated transportation systems, resource efficiency, and inclusive governance (Beatley, 2012). Compact urban form and mixed land use help reduce urban sprawl, promote walkability, and improve access to services and employment opportunities (Newman and Kenworthy, 2000).

Green infrastructure such as urban forests, green roofs, and sustainable drainage systems enhances environmental resilience and improves urban liveability (Gill *et al*, 2007). Additionally, participatory planning and community engagement ensure that development decisions reflect local needs and promote social inclusion (Campbell, 2016). Recent studies emphasise the role of smart technologies and climate-responsive planning in improving urban sustainability and resilience (UN-Habitat, 2022). Integrating these elements within urban planning frameworks is essential for achieving long-term sustainable development and improving the quality of life in rapidly growing cities.

Sustainable cities also consist of sustainable infrastructure. Sustainable infrastructure development requires environmentally responsible materials capable of delivering adequate engineering performance. Lateritic soils are commonly used for road subgrades in tropical regions, yet their high plasticity and moisture sensitivity often necessitate stabilisation (Ogunribido, 2012). Traditional stabilisers such as cement and lime are effective but associated with high energy consumption and carbon emissions. Consequently, recent research has focused on alternative binders derived from agricultural and industrial wastes.

Sawdust ash, a by-product of timber processing, contains reactive silica and alumina that promote pozzolanic reactions when combined with soil (Edeh *et al*, 2014). These reactions form cementitious compounds that enhance soil strength and reduce plasticity (Koteswara Rao *et al*, 2012). Studies indicate that SDA improves the engineering characteristics of lateritic soils by reducing plasticity index and increasing shear strength (Ogunribido, 2012).

Environmental sustainability is a major motivation for adopting waste-based stabilisers. Brown & Johnson (2019) emphasised that eco-friendly stabilisation methods significantly reduce environmental impact compared to conventional cement-based techniques. Similarly, Roberts and Harris (2018) highlighted the importance of integrating sustainability principles into geotechnical engineering practice. The mechanical performance of SDA-treated soils has been evaluated in several laboratory studies. Turner (2019) observed improved compaction behaviour and moderate increases in maximum dry density at optimum ash content. Roberts (2020) reported enhanced compressive strength and reduced compressibility in SDA-stabilised soils. Davis (2021) further demonstrated that pozzolanic reactions between SDA and soil calcium compounds increase cohesion and structural integrity.

In pavement engineering applications, California Bearing Ratio (CBR) and unconfined compressive strength (UCS) values are critical performance indicators. Edeh *et al* (2014) documented significant improvements in CBR values of lateritic soils treated with SDA. Smith (2017) reported that agricultural waste ashes improve load distribution capacity and durability of subgrade materials.

Kumar and Singh (2022) confirmed that waste ash stabilisation enhances pavement subgrade performance under repeated loading. The reduction in plasticity characteristics is consistently reported across studies. Ogunribido (2012) noted that increasing SDA content reduced plasticity index, thereby decreasing swelling potential. Ali and Hassan (2023) observed that sustainable binders derived from waste materials effectively improve consistency limits and mechanical stability of tropical soils. Beyond technical performance, circular economy principles encourage the reuse of waste materials in infrastructure projects. Nguyen and Tran (2024) highlighted that recycling industrial and agricultural by-product in geotechnical applications promotes resource efficiency and environmental protection. Zhang *et al.* (2018) emphasised the chemical mechanisms underlying pozzolanic stabilisation using waste-derived binders.

Despite promising findings, determining optimum SDA dosage remains essential. Excessive ash content may reduce density and limit strength gain due to incomplete reaction (Roberts, 2020). Therefore, controlled laboratory evaluation is necessary to establish appropriate stabilisation levels for specific soil types.

Overall, previous studies have shown that SDA is a viable, sustainable stabiliser for lateritic soils. The integration of engineering performance evaluation with environmental considerations supports its application in low-cost urban road construction. Also, the use of alternative construction materials, such as SDA becomes especially relevant for urban and regional planning. It supports resource-efficient land use, lowers the ecological footprint of building and road production, and encourages circular economy principles in city systems (Akinyemi *et al*., 2021; Olofinnade *et al*., 2022).
This study contributes to existing knowledge by experimentally assessing the influence of SDA on lateritic soils to identify optimum stabilisation content for sustainable infrastructure development.

MATERIALS AND METHODS

Materials and equipment

The materials used for this study are lateritic soil samples and sawdust.
The tools and equipment used are: hand auger (for soil sampling); equipment for the determination of soil moisture content, particle size distribution, specific gravity, Atterberg's limits; compaction apparatus; unconfined compressive strength (UCS) machine, and California Bearing Ratio (CBR) machine.

Soil sampling and preparation

Lateritic soil samples were collected from two identified locations (borrow pits) in Ile-Ife, Osun state, Southwestern Nigeria. About 25 kg of each sample was collected (using a disturbed sampling method) using a hand auger. The samples were kept in waterproof bags, properly sealed, labelled (samples from the first and second locations were labelled as Sample A and Sample B respectively) and immediately transported to the Geotechnical Engineering Laboratory (referred to as the Laboratory) of the Department of Civil Engineering, Obafemi Awolowo University (OAU), Ile-Ife. At the Laboratory, representative samples were immediately taken for the determination of natural moisture content, while the rest of the soils were air-dried for subsequent analyses.

Preparation of sawdust ash (SDA)

Sawdust was obtained from a nearby Saw Mill, transported to the Laboratory and burnt to ash in the furnace at a temperature of about 600°C. The SDA obtained was allowed to cool, sieve through a BS sieve size 450 micron and the content passing was kept in a air-tight container for subsequent analyses.

Preliminary and geotechnical tests on natural soils

The following preliminary and geotechnical tests were conducted on soil samples in their natural state: natural moisture content, particle size distribution, specific gravity, Atterberg limits, compaction, and California Bearing Ratio (CBR}. The tests were conducted using standard procedure as outlined in BS 1377 (1990).

Engineering tests on soils stabilised with SDA

The soil samples were stabilised by adding SDA in varying proportions of 3 %, 6 % and 9 % by weight of dry soil. Subsequently, CBR test were conducted on the stabilised soil samples, in accordance with BSI 1377 (1990).

RESULTS AND DISCUSSION

Results of preliminary and geotechnical tests on natural soils

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

The natural moisture content values obtained for Sample A and Sample B were 26.70 % and 21.80 %, respectively. The void ratio of lateritic soils is the predominant factor that affects the moisture content of the soils. 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.

Table 1: Geotechnical properties of soil samples in their natural state

Properties	Sample A	Sample B
Natural moisture content	19.12	17.75
Specific gravity	2.56	2.84
Liquid limit (%)	46.69	52.83
Plastic limit (%)	26.67	27.69
Plasticity index	23.02	25.14
Percentage passing sieve no. 200	31.65	29.3
Percentage passing sieve no. 40	1.2	0.15
AASHTO classification	A – 2 – 7	A – 2 – 7
MDD (kg/m^3)	1782.5	1690
OMC (%)	17	21.3
CBR (%)	4.26	5.63

The Specific gravity of the solids making up a given soil sample is useful mainly for deriving other needed properties of soil Gidigasu, (1969). It is generally accepted that the specific gravity of lateritic soils is very high. These high values are generally associated with the gravel fraction in which the iron oxides tend to be concentrated. According to Lamber and Whiteman (1969), the specific gravity of most lateritic soil falls within the ranges of 2.65 - 2.85. The specific gravity values for the two samples (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 soil if it has a plasticity index greater than or equal to 11. Therefore, from the obtained values of plasticity index (Table 1), It was obvious that the tested soil samples were clayey soils. Given the results of index property tests (Table 1), the two soil samples were identified as A – 2 – 7. Hence, the samples are granular lateritic in nature. The detailed analysis of the sieve analysis for lateritic soil, according to American Association of State Highway and Transportation Officials (AASHTO) classification.

Engineering properties of stabilised soils

Figure 1 shows the variation of CBR values with the introduction of SDA in varying proportions (3 %, 6 % and 9 %) It was observed that the CBR of the soil samples increased considerably with the addition of SDA reaching optimum at ^ % SDA content (Sample A) and increasing to 9 % SDA content (Sample B). The improvement in the engineering property (CBR) is as a result of the pozzolanic reaction between the SDA and the lateritic soil samples, i.e. the formation of cementitious compounds upon the reaction of SDA and Calcium hydroxide present in the soil, which helps to improve the soil properties. The decrease in the CBR at some percentages of SDA can be attributed to the excess SDA which was not mobilised in the reaction due to the small amount of Calcium hydroxide present in the soil.

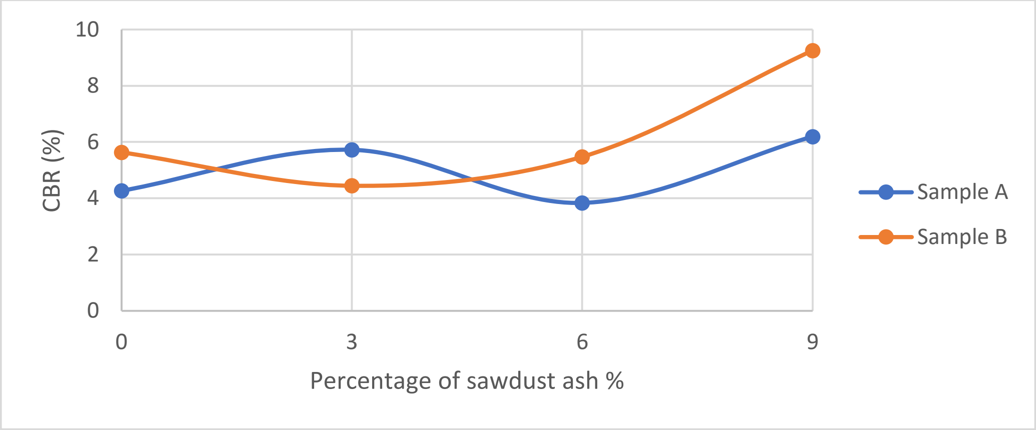

Figure 1: Values of CBR of soils with varying proportions of SDA

CONCLUSION

This study evaluated the suitability of SDA as a stabilising material for lateritic soil intended for sustainable road construction in sustainable cities. Laboratory results showed that the addition of SDA significantly influenced the geotechnical properties of the treated soils. The treated soils exhibited reduced plasticity and improved strength characteristics, particularly in terms of California Bearing Ratio and compaction behaviour at optimum ash content. These improvements are attributed to the pozzolanic reactions between the silica-rich ash and soil minerals, which enhance bonding within the soil matrix. The findings indicate that SDA can serve as an effective and environmentally friendly stabilising agent. Its utilisation not only improves subgrade performance but also promotes sustainable waste management and cost-effective road construction practices.

The finding is in agreement with Scrivener *et al*. (2018), Miller *et al*. (2020) and IPCC (2022) that, from a planning standpoint, adoption of SDA can be incorporated into development control regulations, housing policies, and sustainable urban infrastructure strategies, particularly in fast-growing regions where construction demand is high and waste management issues are common. Additionally, reducing reliance on carbon-intensive cement supports climate mitigation efforts in urban areas, aligning planning decisions with global sustainability goals.

Therefore, this research is essential for advancing modern urban and regional planning by connecting material innovation with spatial policy, ultimately fostering the development of resilient, low-carbon, and inclusive cities in line with the SDG agenda.

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