CONSTRUCTION MATERIALS STIMULATION

A Comparative Strength Properties Analysis of Machine and Manual Methods for Earth Blocks Stabilized with Unprocessed Sugarcane Bagasse

A. M. Manga[1], I. B. Muhammed[2], Y. M. Bukar[3], M. A. Abukabar[4], K. Hassan[5]

[1]Department of Agricultural and Bioresource Engineering, Abubakar Tafawa Balewa University, Bauchi State, Nigeria
[2]Department of Agricultural Engineering, Federal University Wukari, Taraba State, Nigeria
[3]Department of Agricultural Technology, Federal College of Horticulture, Gombe State, Nigeria
[4]Department of Mechanical Engineering, Nigerian Maritime University, Delta State, Nigeria
[5]Department of Building Technology, Abubakar Tafawa Balewa University, Bauchi State, Nigeria

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Abstract

The practice of earth as construction material has thrived for centuries across various parts of the world; however, challenges such as surface wear and low compressive strength continue to limit its structural application and long-term durability. This research addressed the inadequate mechanical performance of traditional earth blocks, which restricts their wider adoption as sustainable building materials. Enhancing the engineering properties of earthen materials offers a practical and energy efficient alternative to conventional construction techniques. In this study, clay soil samples were collected from Bauchi State, Nigeria. Preliminary tests, including moisture content and compaction analyses, were conducted. Blocks were produced at stabilization levels of 0%, 5%, 10%, and 15% by weight, with dimensions of 300 mm × 145 mm × 105 mm, using both manual and machine compaction methods. Scanning Electron Microscope (SEM) analysis was performed on unprocessed sugarcane bagasse to examine its textural structure. The soil exhibited a moisture content of 3.90%, while SEM results revealed a well-ordered matrix with fibrous morphology. Results showed that machine-compacted blocks absorbed 10.18% more moisture, displayed 4% higher wear resistance, and achieved 20.09% greater dry compressive strength than manually compacted. This research paper lies in the innovative use of unprocessed sugarcane bagasse as a natural stabilizing material, combined with a comparative evaluation of manual and machine compaction techniques. Providing new experimental insight into improving the mechanical properties of earth blocks through Sugarcane bagasse utilization and compaction optimization, thereby promoting sustainable and eco-friendly construction practices.

Keywords: Sugarcane bagasse; stabilized earth blocks; strength; wearing resistance; dry compressive strength

1 Research background

The manual method popularly known as the hand method is a simple and traditional approach of block fabrication in contrast, compressed method involves the use of mechanical equipment to achieve more efficient and uniform compaction (Bahar et al., 2004).

The importance of using earth as building material cannot be over emphasize since, it is readily and abundantly available, making it perhaps the most accessible and economical natural construction material (Vilane, 2010).

Development in material engineering has yet to render earth obsolete as a building material, especially in financially and resources challenged places like Nigeria.

Study has shown that low strength, wearing, wall cracking and shrinkage are the major problems of using earth as building material (Guettala et al., 2006).

Man realized that relying solely on earth for the production of durable blocks is insufficient since, the inherent cohesion found in clay emerged as an indispensable natural binder for composite materials (Binici et al., 2005). In Nigeria up to 720,000 tonnes of sugarcane bagasse also known as sugarcane fibre is being generated annually as reported by (Deboucha & Hashim, 2011). These huge amount of bagasse are carelessly disposed causes hazard to both human and animal health.

Research revealed that improper management of sugarcane bagasse results in environmental concerns, because is usually burned or dumped into landfills which contribute to increase in Green House Gas (GHG) emissions and pollute water (Turgut & Yesilata, 2008). Several studies on the utilization of sugarcane bagasse to enhance earth blocks strength properties exists (AbdulKadir and Maason, 2013 and Bock-Hyeng et al., 2016). However, findings from these studies are limited because they only investigated the viability of processed sugarcane bagasse. Therefore, this research paper make comparative evaluation of strength properties resulting from manual and machine compaction techniques in earth blocks stabilized with sugarcane bagasse. Sugarcane bagasse can be used to stabilize soil blocks and plays important role in enhancing and improving the strength of the composite materials (Jeefferie et al., 2011). Typically, findings documented in various sources indicate the feasibility of incorporating sugarcane bagasse into clay blocks, suggesting its capability to generate lightweight clay bricks characterized by enhanced strength and durability (Faria et al., 2018 and Souza et al., 2011).

As a result, it is essential to explore potential methods for enhancement, and the utilization of unprocessed sugarcane bagasse in stabilization. This paper will make contribution to academic value by generating experimental evidence and technical data on the performance of earth blocks stabilized with unprocessed bagasse, establishing a low-cost and eco-friendly alternative to conventional stabilizers, and promoting sustainable construction practices in developing regions. The aim of this study is to develop and evaluate compressed earth blocks stabilized with unprocessed sugarcane bagasse to improve their strength, durability, and sustainability for affordable construction.

2 Materials and methods

2.1 Soil sample

The clay soil employed in this research was collected from Sabon Kaura in the vicinity of Bauchi State, located in Northern Nigeria. This site was primarily designated for block molding purposes

2.2 Sugarcane bagasse

The sugarcane bagasse which was collected around Bauchi state, was sun-dried to reduce its moisture content. The unprocessed sugarcane bagasse's morphological texture was then observed using a scanning electron microscope (SEM)

2.3 Experimental design and data analysis

This study was conducted to examine the influence of unprocessed sugarcane bagasse on the mechanical properties of Earth blocks. Four stabilization levels (0%, 5%, 10%, and 15% by dry weight) were selected to represent a practical range of additive incorporation. The 0% level served as the control to establish the baseline properties, while 5% and 10% were selected to evaluate the initial

and intermediate effects of stabilization. The 15% level was included to assess the upper limit, beyond which further addition of the stabilizer may reduce workability or produce marginal strength gains, as observed during preliminary compaction and mixing trials. The selected range aligns with existing literature on agro- waste-based soil stabilization and allows for meaningful comparison and interpretation of results. All laboratory tests were performed under controlled environmental conditions. For each stabilization level, five replicate specimens were prepared to enhance result reliability and reduce experimental uncertainty. All specimens were cured uniformly before testing. The measured data for each parameter were expressed as mean values with their corresponding standard deviations (SD).

ANOVA was performed to determine whether significant differences existed among the stabilization levels ($p < 0.05$). Tukey's (HSD) test was used for post-hoc pairwise comparisons.

2.4 Preparation of sample

The soil sample and unprocessed sugarcane bagasse were collected and thoroughly mixed. Water was added and the mixture was worked on by treading barefooted and turning it with a spade until it became homogeneous and plastic, with all lumps broken up. The water content used was the optimum moisture content (OMC).

2.5 Earth block production

The process involved the use of a pressure gauge block-making machine and manual compaction molding. Rectangular-shaped molds were utilized for all tests.

To prevent the molded blocks from adhering to the sides of the hand mold, sand was sprinkled on the inner surfaces, and occasionally, the mold was dipped in water. The earth blocks, due to their naturally rough surface, facilitated a strong bond between the blocks and mortar. Additionally, for the pressure gauge block-making machine, oil was applied to prevent earth from sticking to the mold.

2.6 Earth block drying

The research utilized the sun-dried method, a common practice among traditional farmers, for 21 days to dry the blocks.

2.7 Moisture content determination

Three weighing containers were cleaned and weighed to the nearest 0.001 g using the electronic weighing balance of 0.001 g accuracy. The sample were collected freshly then crumbled and placed loosely in the containers and the containers with the sample were weigh to the nearest 0.001 g before placing in an oven and dry at 105 -110 oC for 24 hours. The containers and the samples were remove and weigh to the nearest 0.001 g. The moisture content of a soil were determined in accordance with BS 1377-2:1990 (clause 3.2) and calculated using Equation (1):

$$M = \frac{W_w}{W_s} \times 100\% \quad (1)$$

where W_w = weight of water lost and W_s = weight of dry soil (solid).

2.8 Scanning electron microscope (SEM)

The image of the morphological structure of the unprocessed sugarcane bagasse were captured using a JSM-6100 scanning microscope at 500x magnification.

The texture was examined using a backscatter electrons detector (BSD) to emphasize the higher atomic number of the element and the contrast between the atomic numbers of the elements being compared, which affects the probability of backscattering and the resulting image.

2.9 Water absorption determination

The test was carried out according to the ARS 683: 1996 as presented in Figure 1. The specimens of blocks were preventively dried at open air for 21 days. After the specific curing days the blocks were weighed and recorded as (M1). Then, the blocks were partially immersed on 5mm height in a metal tray, the 5mm was kept constant during the test. The bottom face of each block were put on the level guides on steel rod placed into the metal tray in their normal position, portable drinking water at room temperature was put in the pan to immerse the blocks on 5mm depth for the blocks to absorb that water by capillarity absorption.

The water level was kept constant during the test up to the saturation of the blocks. The mass of wet blocks was recorded after 10 minutes as (M2). The test was repeated for all the different percentages of stabilizer and the water absorption coefficient was computed using Equation (2):

$$C_B = \frac{100(M_2 - M_1)}{S\sqrt{T}} \quad (2)$$

where C_B = water absorption coefficient; M_1 = mass of the earth block after drying (g); M_2 = mass of the earth block after 10 min wetting (g); S = surface area of the submerged face (cm^2); and T = duration of immersion (min).



Figure 1. Water absorption test.

2.10 Wearing resistance determination

The tests were carried out in accordance with (ARS 683: 1996) following the specific curing age. Both unstabilize and stabilized compressed earth blocks underwent mechanical erosion, applied by brushing with a metal brush at a constant pressure over a designated cycle. The brushing targeted the sides of the blocks, which serve as the visible facing, i.e., stretches. During this test, the mass of the block was determined by weighing and recorded as M1.

The block was then positioned on a horizontal work surface for brushing. The surface underwent forward and backward motions for 60 cycles per minute, using a wire brush with a width of 25mm and a weight of 3kg placed upon it. The brushing covered the entire length of the block.

Upon completion of brushing, the eroded loose matter was cleaned from the block, and the block was re-weighed as M2. The brushed surface area was calculated using Equation (3), and the abrasion coefficient using Equation (4).

$$S = L \times W \tag{3}$$

where S = surface area of brushing (cm^2), L = length of the brushed face of the block (cm) and W = width of the brush (cm). The abrasion coefficient (C_a, cm^2/g) is the ratio of the brushed surface to the mass of material detached by brushing:

$$C_a = \frac{S}{M_1 - M_2} \tag{4}$$

2.11 Dry compressive strength determination

The test was carried out following the British Standard Institute BS EN 772:1 (2011) guidelines, using a CONTROLS 50-C46G2 testing machine with a maximum capacity of 2000kN. The blocks were subjected to loads applied at a rate of 0.05 N/mm2/s until failure occurred (Gaw, 2011).

3 Results and discussion

3.1 Moisture content

The result shows that the soil average moisture content was found to be 3.90% which presents the summary results of the moisture content of the soil samples prior to blocks fabrication. The natural moisture content of the soil served as one of the important engineering properties. Also, the factors which affect the dry density of compacted soil include moisture content, amount and type of compaction and type of soil (Ramamurthy and Sitharam, 2005).

3.2 SEM of unprocessed sugarcane bagasse

Figure 2 shows the micrograph structure of unprocessed sugarcane bagasse has smoother texture. The result is in agreement with the finding reported by (Saha et al., 2018) that Scanning Electron Microscope (SEM) of raw sugarcane bagasse showed lamellar and smooth surface. It was (Grimaldi et al., 2015). Furthermore, in the research reported by (Kerrou et al., 2021) shows that SEM of sugarcane bagasse has a fibrous structure, each elementary fibre has a compact structure that is aligned in the direction of the fibre axis, and it has a smooth and continuous surface.

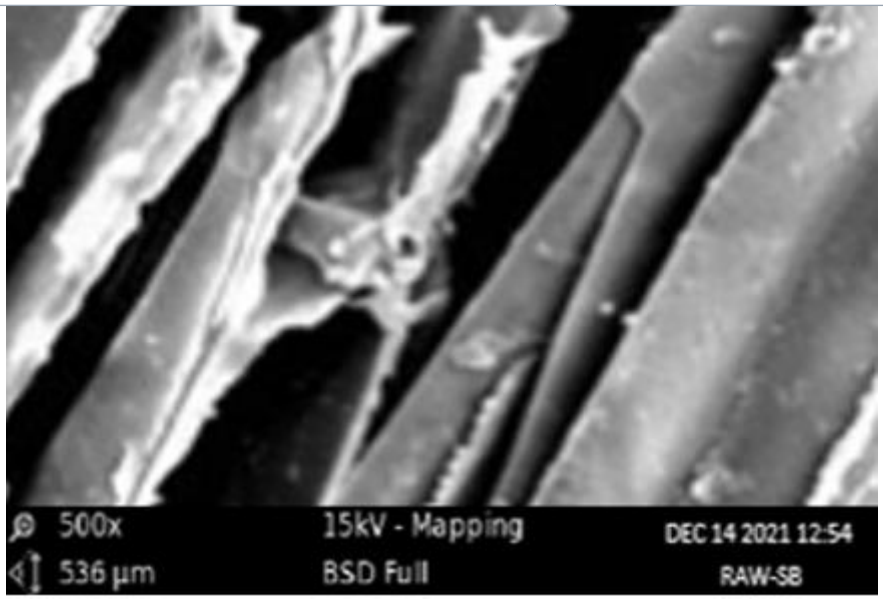


Figure 2. Micrograph of unprocessed sugarcane bagasse.

3.3 Effect of sugarcane bagasse on water absorption

Figure 3 illustrates that the water absorption of stabilized earth blocks increased progressively with higher proportions of unprocessed sugarcane bagasse. This behavior can be attributed to the hygroscopic nature of cellulose within the bagasse, which readily absorbs moisture, as well as the presence of internal voids and porous structures formed by the biomass. According to (Zievie and Yalley, 2016), the fibrous composition of sugarcane bagasse enhances capillary pathways within the matrix, thereby facilitating greater water uptake. Tukey's HSD test indicated that water absorption increased significantly ($p < 0.05$) with higher inclusion levels for both compaction methods. Machine compacted blocks consistently exhibited higher water absorption values than manually compacted blocks, with differences being statistically significant at 5%, 10%, and 15% stabilization levels ($p < 0.05$, *$p < 0.01$, **$p < 0.001$) The control (un-stabilized) blocks exhibited the lowest water absorption, with values of 4.748% and 3.801% for machine and manual compaction, respectively, indicating superior resistance to moisture penetration. In contrast, the highest water absorption was recorded at 15% stabilization level for both compaction methods, reaching 13.971% and 13.571%, respectively.

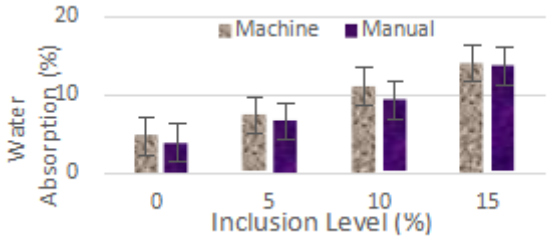


Figure 3. Effect of sugarcane bagasse on water absorption.

3.4 Effect of sugarcane bagasse on wearing resistance

Figure 4 presents the effect of sugarcane bagasse on wearing resistance. The wearing resistance of the earth blocks increased with the addition of unprocessed sugarcane bagasse, attaining an optimum value at 5% stabilization before declining at higher contents. Statistical analysis showed a

significant improvement ($p < 0.05$) in wearing resistance with the inclusion of bagasse. Machine compacted blocks exhibited superior performance compared to manually compacted, with wearing resistance coefficients of 2.143% and 2.059%, respectively, indicating that mechanical compaction provides better surface durability and structural integrity. The improvement in wearing resistance observed with increasing sugarcane bagasse content up to 5% aligns with the findings of (Cirillo et al., 2008), who reported that the incorporation of fibrous additives enhances surface cohesion and reduces material degradation under abrasive forces.

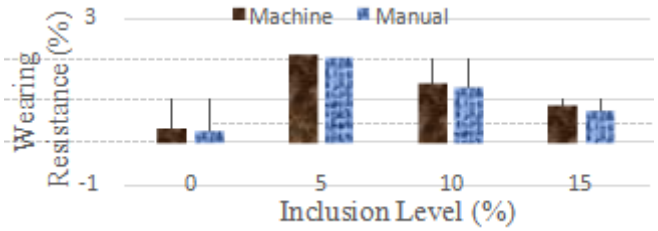


Figure 4. Effect of sugarcane bagasse on wearing resistance.

3.5 Effect of sugarcane bagasse on dry compressive strength

Figure 5 shows the effect of sugarcane bagasse on dry compressive strength. The results revealed that both stabilization level and compaction method had a significant effect ($p < 0.05$) on the dry compressive strength of the stabilized earth blocks. However, the interaction between the two factors was not statistically significant ($p > 0.05$), indicating that the influence of sugarcane bagasse content was consistent across both compaction methods.

Tukey's HSD analysis indicated that 10% sugarcane bagasse produced significantly higher compressive strength compared to other stabilization levels. The machine compacted blocks exhibited greater strength (2.481 N/mm^2) than those produced manually (2.028 N/mm^2), confirming that mechanical compaction enhances particle interlocking and reduces voids, thereby improving load-bearing capacity. As reported by (Karim et al., 2011) that incorporating natural fibers or agricultural residues into soil blocks improves strength up to an optimal point, beyond which excess fibers weaken the matrix due to poor bonding and increased voids.

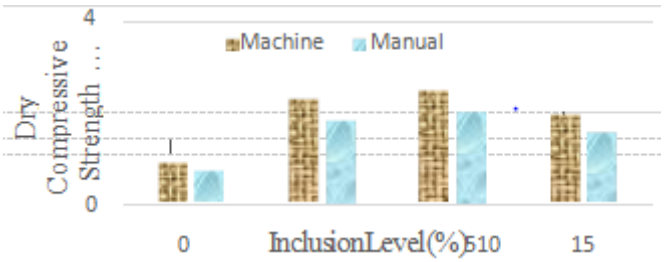


Figure 5. Effect of sugarcane bagasse on dry compressive strength.

4 Conclusion

The use of unprocessed sugarcane bagasse as a stabilizing agent in clay soil demonstrates promising potential for producing lightweight and sustainable earth blocks. The sugarcane bagasse particles likely act as pore formers within the soil matrix, reducing density while maintaining structural integrity. The highest dry compressive strength of 2.481 N/mm^2 and wearing resistance coefficient of 2.143% were obtained for machine compacted blocks at 10% and 5% stabilization, respect-

ively.These results indicate that mechanical compaction significantly enhances the bonding and strength characteristics of the blocks compared to manually pressed counterparts.

However, this study was limited to laboratory scale production and focused solely on unprocessed sugarcane bagasse as the stabilizer.

Future research should investigate the effects of chemical pre- treatment of sugarcane bagasse, long-term durability under varying environmental conditions, and thermal insulation behavior to better establish its applicability for large-scale construction.

Conflict of interest

The authors declared that there is no conflict of interest.

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