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EFFECT OF PLANTAIN FIBRES IN COMPRESSED STABILIZED EARTH BLOCKS

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ABSTRACT

Compressed Stabilised Earth Blocks (CSEB) are building materials made from damp soil, stabiliser and water, compressed at high pressure to form blocks. They are primarily made in situ, making them a relatively cheap and available building material. This study was done to determine the effect of plantain fibre in compressed stabilised earth blocks. Both laterite and plantain stems were sourced locally, and the fibre was extracted from the plantain stem. A hydro form compaction machine extruded the blocks following ASTM C-62 Standard. A total of 450 samples were made. The compressive strengths of the samples were obtained using a Universal Testing Machine (OKH-600). A moisture absorption test was also carried out on all the samples, and a scanning electron microscopy image of the selected sample was obtained. Design Experts 7 statistical software was used to analyse the CSEB variance and optimise the compressive strength. The maximum compressive strength of 2.934±0.17 was obtained at an 8% cement ratio and 15g of plantain fibre for a block of 5kg, and the lowest compressive strength obtained after 28 days of curing was 1.230±0.05 at a 2% cement ratio and 5g of fibre. The analysis of variance for the response surface cubic model shows that the model is significant if the cement ratio is squared and if the cement ratio is raised to the power of three. From optimisation, the cement ratio of the range 5.47-5.57% has a desirability of 0.812, all having plantain fibre of 5g each. The optimum cement-plantain fibre stabilised mix ratio was obtained at 5.53% cement and 5g of plantain fibre for every 5kg of block produced.

Keywords: Compressed Stabilised Earth Blocks, Plantain fibre, Compressive strengths

INTRODUCTION

Compressed Stabilised Earth Blocks (CSEBs) are gaining popularity as an alternative to traditional building materials because of their low production costs, environmental friendliness, and easy access to raw resources. According to Mostafa and Uddin (2015), they are primarily formed of damp soil, stabiliser, and water compacted under high pressure to create blocks. Compressed Earth Blocks (CEBs), Pressed Earth Blocks, and Compressed Soil Blocks are some of the names given to CSEBs in the literature.

CSEBs are environmentally friendly alternatives to conventional building materials that are both cost-effective and sustainable. They have been employed in several construction projects worldwide, from high-end design to affordable housing (Alonso-Marroquin *et al.,* 2019). CSEBs have received a lot of attention in recent years in the field of building construction due to their properties, such as their thermal insulation, durability, and fire resistance, making them suitable for various applications (Bartelt *et al.,* 2018).

However, recently, more studies have concentrated on finding new methods to improve the mechanical properties of CSEBs, such as their tensile, flexural, and compressive strengths. One method that has been demonstrated to enhance the blocks' characteristics is using natural fibres (Mostafa and Uddin, 2015). Due to its accessibility, affordability, and superior mechanical qualities, plantain fibres have been identified as one of the most promising natural fibre options (Garca-Segura *et al.,* 2021).

Therefore, this study aims to determine whether it is feasible to use plantain fibres to reinforce compressed earth blocks stabilised with cement for the construction of low-cost buildings. The study will examine the durability and moisture resistance of the blocks as well as the impact of various fibre contents on their compressive strength and other mechanical parameters. The results of this research will aid in creating affordable and environmentally friendly building materials for low-cost housing and other construction projects.

MATERIALS

The materials used to produce Compressed Earth Stabilized Blocks include sun-dried clay (laterite soil), Ordinary Portland Cement, plantain fibres and water.

Plantain fibre extraction

Plantain stems were obtained from the university farm and manually processed into fibre using a roller to press out the water in the stems and a comb-like tool to remove the fibre by combing it against a flat surface. Before being further processed into the desired lengths, the fibre was sun-dried.

Laterite sampling:

Laterite was procured from the Federal University of Agriculture, Abeokuta. Samples were used to get some physical properties of the soil, such as moisture content, Atterberg limits, specific gravity, compaction, and grain size distribution.

Block production:

The blocks were produced within the university using the Hydraform Compaction machine, and 25 mix ratios were used in making the block in which varying quantities of plantain fibres were used as reinforcement. The blocks were dried in a cool environment.

Testing:

The cellulose, hemicellulose and lignin content of the plantain pseudo-stem fibre was determined based on proximate analysis (Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL)). The average results of the duplicates/triplicates for each parameter are shown as a percent. The compressive strengths of the samples were obtained using equation 1, where a Universal Testing Machine (OKH-600) measured the crushing load after 7, 14, 21, and 28 days of curing. Moisture absorption tests were also carried out on all the samples. It involved immersing the Compressed earth stabilised blocks in water for 24 hours, measuring the weight difference before and after immersion, and then using equation 2 to calculate the Relative water absorption. Scanning electron microscopy (SEM) images were produced for selected samples.

$$Compressive\ strength = \frac{crushing\ load\ (kN)}{area\ (m^2)} \quad 1$$

$$Relative\ water\ absorption\ (R.W.A)$$

$$= \frac{chang\ \ in\ weigh}{Dry\ weigh} \times 100\% \quad 2$$

Statistical analysis

Design Experts 7 statistical software was used to analyse variance and optimise the results obtained from the compressive strength test. The analysis of variance for the response surface cubic model shows that the model is significant if the cement ratio is squared and if the cement ratio is raised to the power of three. From optimisation, the optimum cement-plantain fibre stabilised mix ratio was obtained.

Energy utilisation

The energy used in the extraction of the plantain fibre from the pseudo stem was obtained from the individual operations where the number of persons involved (N_p) in the operation and the time taken (t_p), fuel consumption for transportation of laterite to the block production site (W_p), calorific values of the fuels used, the quantity of plantain fibre produced and the fuel used for the production of the blocks were all taken into consideration. Dimensionless analysis was used to determine that for processes requiring energy from the use of thermal fuel to power an internal combustion engine, the energy utilised (E_{tp}) was directly proportional to the quantity of fuel used (W_p), that is,

$$E_{tp} \propto W \Rightarrow E_{tp} = C_p W_p \qquad 3$$

Where C_p is the constant of proportionality, which represents the fuel's calorific value. The average power of a normal human labour is 0.075kW. It was observed that the energy derived from manual human labour (E_{mp}) was proportional to the number of persons and the time taken to complete the operation.

$$E_{mp} \propto N_p t_{\ p} \Rightarrow E_{mp} = nN_p t_p \qquad 4$$

Where n is the average power of a normal human labour kW

$$\therefore E_{mp} = 0.075 N_p t_p \qquad 5$$

Therefore, the total energy requirement for excavation of the laterite soil and transportation to the block production site and the production of the Compressed Earth Stabilised Blocks, according to Jekayinfa and Bamgboye (2007), is given by equation 6.

$$E_p = 3.6\left(0.075 N_p t_p\right) + W_p C_p \qquad 6$$

Where E_p is the total energy used for extracting the plantain fibre.

RESULTS AND DISCUSSION

Chemical and Mechanical Characterization of Plantain Fibre:

Plantain fibre, obtained from the pseudo stem of the plantain plant (*Musa paradisiaca*), was subjected to chemical and mechanical tests to evaluate its potential as a reinforcing material in compressed stabilised earth blocks (CSEBs). Chemical analysis revealed that the fibre contains 29.33% cellulose, 28.67% hemicellulose, and 8.67% lignin, as shown in Table 1. A comparison with literature values for banana fibre showed that plantain fibre has a lower cellulose content but a similar hemicellulose and lignin content. From Table 1, the lignin content was low compared to that obtained by (Manilal and Sony, 2011) for banana pseudo-stem, (Omotoso and Ogunsile, 2010) reported that this is an indication of easy delignification, low chemical composition and short pulping cycle.

Mechanical tests were conducted to determine the tensile properties of the fibre. Using a Universal Testing Machine, the average tensile strength, strain, and Young's modulus of elasticity were found to be 132.708 MPa, 0.130 MPa, and 1022.991 MPa, respectively as shown in Table 2. These results indicate that plantain fibre has high tensile strength and stiffness, which could make it a suitable reinforcement material for CSEBs.

The jaws move in a way that the sample is being extended at the speed of 0.01 kN/s. The load developed in the sample was measured, and the measured parameters were recorded as shown by the electronic panel attached to the Universal Testing Machine (UTM).

Table 1: Chemical properties of extracted plantain fibre

Sample	%ADF	%ADF	Cellulose	Hemicellulose	Acid detergent lignin
S1	38	68	30	30	8
S2	36	66	26	30	10
S3	40	66	32	26	8
Mean	38	66.67	29.33	28.67	8.67

Table 2: Tensile properties of manually extracted plantain fibre.

Sample	Max. Force (KN)	Tensile strength (Mpa)	Strain	Young modulus (Mpa)
Trial 1	10.08	128.37	0.1413	908.493
Trial 2	10.43	132.74	0.1468	904.223
Trial 3	10.7	136.22	0.1264	1077.690
Trial 4	10.49	133.5	0.1044	1278.736
Mean	10.425	132.708	0.130	1022.991

Physical properties of the soil used in the extrusion of the blocks:

Table 3 provides results obtained from the physical properties test of the laterite soil. The moisture content of the laterite soil is within the typical range for stabilised earth block production. However, the liquid and plastic limits indicate that the soil has low plasticity, which may affect its workability during production. The plasticity index of 11.69 is relatively low, which may also affect the strength of the compressed earth blocks.

The specific gravity of 3.05 indicates that the soil is relatively dense, which can be a favourable characteristic for compressed earth block production.

Table 3: Physical properties of the laterite.

Moisture content (%)	20.92
Liquid limit	43.25
Plastic limit	31.56
Plasticity index	11.69
Specific gravity	3.05

However, other factors such as soil particle size distribution and clay mineralogy can also affect the quality of the blocks.

Compressive Strength of the Compressed Stabilized Earth Blocks

This study investigated the compressive strength characteristics of compressed stabilised earth blocks (CSEBs) containing plantain fibre as a reinforcement material. The compressive strength of control samples without plantain fibre was also evaluated. The samples were tested after 7, 14, 21 and 28 days of curing, and the mean compressive strength and standard deviations were calculated. The results showed that the compressive strength of the CSEBs varied depending on the cement-fibre mix ratios and the curing time. The control samples without plantain fibre reinforcement had a compressive strength range of 1.533 MPa (2% cement) to 4.831 MPa (10% cement) at 28 days of curing.

Among the plantain fibre stabilised CSEBs, the block containing the mix ratio of 4% cement and 25g of plantain fibre gave the highest compressive strength of 2.769 ± 0.17 MPa at 14 days of curing. At 28 days of curing, the block with the mix ratio of 8% cement and 15g of plantain fibre had the highest compressive strength of 2.604 ± 0.11 MPa, while the block with the mix ratio of 2% cement and 5g of plantain fibre had the lowest compressive strength of 1.230±0.05 MPa. Interestingly, the compressive strength of the CSEBs containing plantain fibre did not increase much after 28 days of curing, which is consistent with the literature. The optimal cement-fibre mix ratio for achieving high compressive strength varied depending on the curing time. Overall, the results suggest that plantain fibre can be a promising reinforcement material for improving the compressive strength of CSEBs.

Water Absorption properties:

The study investigated the effect of plantain fibre reinforcement on the water absorption characteristics of CESBs containing different cement-fibre mix ratios. The water absorption test was conducted on the CESBs after 28 days of curing. The results showed that the average water absorption rate decreased with increasing cement and plantain fibre content in the CESBs. Among the cement-plantain fibre reinforced CESBs, the block with the lowest average water absorption rate was the one containing the mix ratio of 8% cement and 25g of plantain fibre, with a water absorption rate of 18.539%. The highest water absorption rate was obtained from the block containing the mix ratio of 10% cement and 15g of plantain fibre, with a water absorption rate of 24.226%.

In contrast, the control blocks without plantain fibre reinforcement showed higher water absorption rates. The block with a mix ratio of 8% cement and 0g of plantain fibre had the highest water absorption rate of 34.603%. In comparison, the block containing the mix ratio of 10% cement and 0g of plantain fibre had the lowest water absorption rate of 17.762%. These findings suggest that plantain fibre reinforcement can improve the water resistance of CESBs, and the optimal mix ratio for achieving low water absorption rates is 8% cement and 25g of plantain fibre.

Analysis of Variance for Compressive Strength:

Based on the results from the Analysis of Variance (ANOVA) using a response surface cubic model, the data obtained from 28 days of curing was analysed. The table shows the sum of squares, degree of freedom, mean square, F-value, and p-value of each factor, including the model, cement ratio, plantain fibre, and their interactions. From Table 4, it can be observed that the model was significant as the p-value is less than 0.05. The result indicates that the model is a good fit for the data. However, the cement ratio and plantain fibre were insignificant as their p-values exceeded 0.05. Interestingly, when the cement ratio was squared, the model became significant, and when the cement ratio was raised to the power of three, the model was also significant. This suggests that the relationship between the cement ratio and the compressive strength of the blocks is not linear but instead shows a curvilinear trend.

The R-squared value of 0.7122 obtained indicates that the model can explain 71.22% of the variation in the response variable, which is relatively high. Additionally, the Adeq Precision value measures the signal-to-noise ratio, with a ratio greater than 4 being desirable.

From the Table 4, it can be observed that the Adeq value is greater than 4, which indicates that the model is precise and can be used to make accurate predictions.

The results suggest that the model is a good fit for the data, and the cement ratio significantly affects the compressive strength of the blocks when squared or raised to the power of three. The plantain fibre, however, does not have a significant effect.

Table 4: Analysis of Variance for Compressive Strength

Source	Sum of squares	df	Mean square	F Value	p-value prob > F
Model	3.82	9	0.42	4.12	0.007 significant
A-Cement ratio	0.19	1	0.19	1,88	0.1906
B-Plantain Fibre	0.021	1	0.021	0.20	0.6603
AB	0.027	1	0.027	0.26	0.6144
A^2	1.22	1	1.22	11.86	0.0036
B^2	1.252E-004	1	1.252E-004	1215E-003	0.9726
A^2B	0.25	1	0.25	2.41	0.1412
AB^2	0.12	1	0.12	1.17	0.2962
A^3	0.63	1	0.63	6.07	0.0263
B^3	0.014	1	0.014	0.14	0.7151
Residual	1.55	15	0.10		
Cor Total	5.37	24			

Optimisation of results of the cement-plantain fibre-reinforced blocks

An optimisation was also carried out for the compressive strength with the optimisation goal to maximise the compressive strength. The cement ratio and plantain fibre percentages were left in range, while the compressive strength was maximised. The numerical optimisation of the results showed optimum values for compressive strength at a cement ratio of 5.53 % and plantain fibre 5 g with a desirability factor of 0.812. It was selected, and that gave a compressive strength of 2.61346 MPa. The following desirable selection was at cement ratio of 5.57 % and plantain fibre 5 g, as shown in Table 5. Figure 2 shows the relationship between plantain fibre, cement ratio and compressive strength. It is observed from the plot that the effect of plantain fibre at lower levels of cement ratio is very gentle, as represented by the slight curve, but distortion to the curve is observed as the plantain fibre increases with almost an inverse effect where it is observed that higher percentages of plantain fibre gave higher values of compressive strength as the cement ration increased as opposed to plantain fibre providing lower valves for compressive strength for lower values of cement ratio.

Table 5: Desirability test on the cement-plantain fibre reinforced blocks

Solutions Number	Cement ratio	Plantain fibre	Compressive strength	desirability	
1	5.53	5.00	2.61346	0.812	Selected
2	5.57	5.00	2.61337	0.812	
3	5.47	5.00	2.61323	0.812	
4	5.78	5.00	2.60929	0.810	
5	10.00	25.00	2.56357	0.783	

Scanning Electron Microscopy Test

Besides standard and non-standard tests, scientific tests were also performed on samples of compressed stabilised earth blocks using optical microscopy to analyse the obtained microstructure using SEM (Scanning Electron Microscopy). Generally, the untreated compressed stabilised earth blocks exhibited various shapes and formed irregular aggregations, forming a microstructure with cracks and pores.

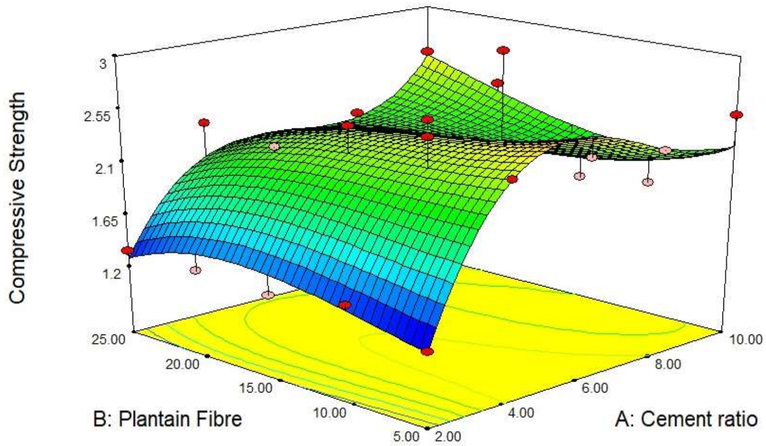
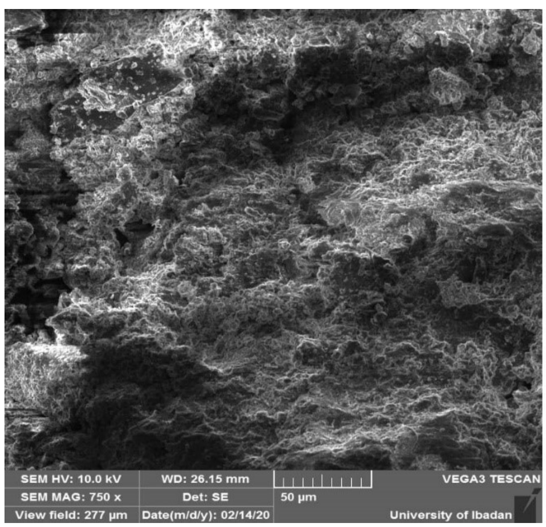
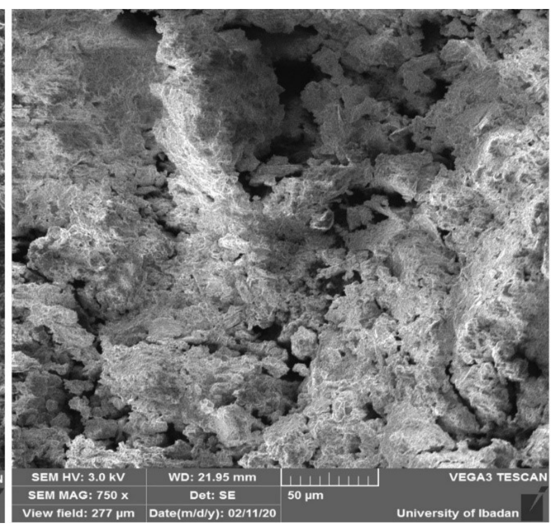


Figure 2: 3-Dimensional graph of optimisation of the blocks

Two micrographs displaying the controlled compressed stabilised earth blocks and the plantain fibre reinforced compressed stabilised earth blocks are shown in Plate 1 B shows the pores present in the block sample that had the highest compressive strength of 2.931 MPa, and Plate 1 A shows the image of the control block sample that had the highest compressive strength of 4.831 Mpa which is the sample containing the cement mix of 10% cement and 0 g of plantain fibre.





A **B**

Plate 1: A: Image of SEM of control block sample magnification 750x

B: Image of SEM of plantain fibre CESB sample magnification 750x

Data collection and calculation of the extraction of the plantain fibre

The data collected for the extraction of plantain fibre is represented in Table 6. It took one person, and the time for each processing was recorded. The extracted fibre was dried and taken to the block making site. Due to the closeness of the extraction point to the block making site, the use of a vehicle was not required. The type of energy used for the extraction was manual.

Table 6: Measured quantities for plantain fibre extraction

Vehicle	Fuel Type	Mode of Excavation	Time (min)	Weight (kg)	Number of Workers	Quantity of Fuel
-	-	Manual	240	2.84	1	-
-	-	Manual	150	1.61	1	-
-	-	Manual	180	1.83	1	-
Total			570	6.28		

From the quantities obtained in Table 6, the energy required to extract the plantain fibre is calculated to be 42.75 kJ, which gives approximately 6.799 kJ/kg using Equation 5. The final production of the CSEB is the result of combining the individual operations. According to the results, the energy consumption for the separate operations of material mixing and block compaction was 5.575 kJ/kg and 1686.022 kJ/kg, respectively. It was determined that 1.692 MJ/kg of total embodied energy was consumed in the manufacturing of CSEB.

CONCLUSIONS AND RECOMMENDATION

Conclusions

Compressed earth blocks stabilised with plantain fibre were created, and the blocks' compressive strength and water absorption rate were assessed. Because of its high tensile strength and stiffness, plantain fibre has the potential to be used as a reinforcement material for compressed stabilised earth blocks (CSEBs). When the chemical makeup of plantain fibre was examined, it was found that it included less cellulose, hemicellulose, and lignin than banana fibre. According to the study, the curing period impacted the ideal cement-fibre mix ratio for achieving high compressive strength. The ideal plantain fibre-cement stabiliser ratio was 5.53 % cement and 5 g of plantain fibre per 5 kg of produced blocks. The addition of plantain fibre reinforcement increased the water resistance of CSEBs, and an ideal mix ratio of 8% cement and 25g of plantain fibre is required to achieve low water absorption rates. The workability of the soil during block manufacture may be impacted by the study's laterite soil's low plasticity, though. Overall, the research points to the possibility of using plantain fibre as a reinforcement material to enhance the mechanical and water absorption capabilities of CSEBs.

Recommendation

Additional research should be carried out to improve the compressive strength of fibre reinforced compressed stabilised earth blocks. Furthermore, the strengths of plantain and banana fibres used as reinforcement in compressed stabilised earth blocks should be compared. Additionally, additional research is advised to examine other mechanical qualities and durability traits of the plantain fibre reinforced CSEBs and to optimise the mix ratio for various curing durations. This information may benefit the creation of eco-friendly and affordable building materials for construction applications.

Declaration of Competing Interest

Authors declare that they have no competing interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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