Enhancing Earth-Based Building Materials: Effect of Palm Fibre Reinforcement on Compressive Strength

ABSTRACT

The rising need foraffordable and eco-friendly housing occasioned by a surge in global population growth, the ever-increasing cost of building materials and environmental concerns has been an issue of concern over the last few decades. This has necessitated continuous research and development of affordable and eco-friendly building materials for low- and middle-income earners. This research evaluated the effect of oilpalm fibre on the compressive strength of compressed earth blocks. Oilpalm fibre was added to the soil matrix at 0%, 0.5%, 1% and 1.5% by weight of laterite. The blocks were cured for 28 days after which they were tested. The results obtained indicate that the addition of palm fibre in the matrix increased the compressive strength up to 1% where the maximum compressive strength (1.38N/mm^2) was observed. Further addition of palm fibre in the matrix resulted in a decrease of the compressive strength. An optimum reinforcement of the blocks with 1% palm fibre is recommended.

Keywords: earthen construction, palm fibre, compressive strength, compressed earth blocks, sustainable construction materials

1. INTRODUCTION

Quality housing is integral to human sustenance and well-being as shelter is one of the basic needs of man. It is not limited to the physical structure alone but includes all necessary facilities for the good health and well-being of man [1]. The surge in global population has resulted in an infrastructural deficit, especially in developing countries. About 1 billion houses will be needed worldwide by the year 2025. About 30% of the urban population in developing countries reside in slums.The urban population will continue to rise as the world continues to urbanize over the next three decades—from 56 per cent in 2021 to 68 per cent in 2050, translating into an increase of 2.2 billion urban residents, living mostly in Africa and Asia. Providing adequate infrastructure, affordable and adequate housing and addressing the challenge of slums, are expected to be the major challenges of urbanization in developing countries[2-3].

Cement products are the most commonly used building materials globally.The ever-rising price of cement and other construction materials has made construction and quality housing far from reach to low- and middle-income group urban and rural dwellers[4]. This has made building houses expensive and challenging for low-income earners (mostly peasant farmers) across the globe especially in sub-Saharan Africa. Also, environmental and ecological issues due to climate change arising from the use of cement have been at the fore in recent global discussions. The cement industry contributes about 7% to global warming due to the raw materials used and the manufacturing process.The carbon iv oxide (CO_2) emitted during cement production for example, is a major contributor to greenhouse gases which depletes the ozone layer[5-8]. This has necessitated research into greener, eco-friendly and sustainable alternatives that can be used as building materials

Earth has been employed as a building material for ages with over 30% of the global population living in earthen houses. In recent times, earth blocks have been used mainly to reduce the negative impact of buildings onthe environment. In developing economies, earthen materials were dominantly used due to theircost-effectiveness. In addition, earthen materials are eco-friendlyalternatives to high energy-intensive building materials which increase the carbon footprint of buildings. The utilization of earth for housing offers very high resistance to fire and provides a comfortably built living environment due to its high thermal and heat insulation value. It also offers other important factors that contribute to the achievement of a good house planning/design and construction solution.The addition of fibres in the production of earthen building materials improves the strength and durabilityof such materials as fibres reduce shrinkage cracking [9-12].

The effect of the use of natural and synthetic fibres to reinforce compressed earth blocks (CEBs) has been evaluated by various researchers. The effect of fibres like vetiver shoot [10], banana fibre [13-14], coconut fibre [15-16], sugarcane bagasse fibre [17-18], cogon fibre [19], jute fibre [20-21], polypropylene [22], rice straw [23], cork granules [24], sisal fibre [25-26],oil palm fibre [27-32]among others, on various properties of CEBs have been investigated.The results obtained from their investigations showed that the use of fibres in CEB production led to improved mechanical and durability properties of the blocks.

Onodagu et al [27] evaluated the effect of untreated oil-palm fruit fibre reinforcements on the density, water absorption ratio, and compressivestrength of non-fired pressed mud blocks. Palm fibre was incorporated in the matrix in proportions of 0-5%. They observed that as the proportion of fibre in the matrix increased, the density, water absorption, and compressive strengthincreased. They recommended a 3% fibre addition for optimum strength results and dissuaded the use of fibres to reinforce mud blocks in areas with high humidity.

Nafu et al [28] investigated the effect of treated palm oil mesocarp fibres on the thermal properties (thermal effusivity, volume calorific capacity, thermal conductivity, and thermal diffusivity) of cement-stabilized earth bricks. The soil was stabilized with 10% cement by mass and reinforced with fibres at 0-2.5% by mass. The results obtained revealed that the addition of palm oil mesocarp fibres increases proportionately the specific heat capacity ofthe cement stabilized earth block leading to a gradualreduction in the thermal effussivity, volume calorific capacity,thermal conductivity and thermal diffusivityof the palmmesocarp fibres cement stabilized earth bricks.

The current study investigated the effect of oilpalm fibre on the compressive strength of CEBs. Palm fibre is readily available in most parts of Nigeria as Nigeria is one of the largest producers of palm oil in the world, with an estimated production of 1.4 million metric tons in the year 2022 [33-35].

2. MATERIALS AND METHODS

The materials and methodology employed in this study are presented as follows

2.1 Materials

The following materials were sourced and used for this study:

2.1.1Laterite

The soil (reddish-brown laterite) used for this research was obtained from an existing borrow pit at Akpataega, Idah, Kogi State, Nigeria, at a depth of ~1.5m free from organic matter and deleterious materials. The soil index/geotechnical properties were determined by BS 1377[36] to classify the soil. The soil test was carried out at the Soil Mechanics Laboratory, Department of Civil Engineering, The Federal Polytechnic, Idah, Kogi State. The results of the sieve analysis and the soil index/geotechnical properties are presented in Table 1 and Table 2 respectively, while Figure 1 shows the particle size distribution curve.

Table 1. Sieve Analysis of the Lateritic Sample

Sieve opening (mm)	4.750	2.000	0.850	0.600	0.425	0.250	0.106	0.075	pan
Percentage passing (%)	99.6	61.5	34.7	25.0	12.7	7.9	4.9	3.3	-

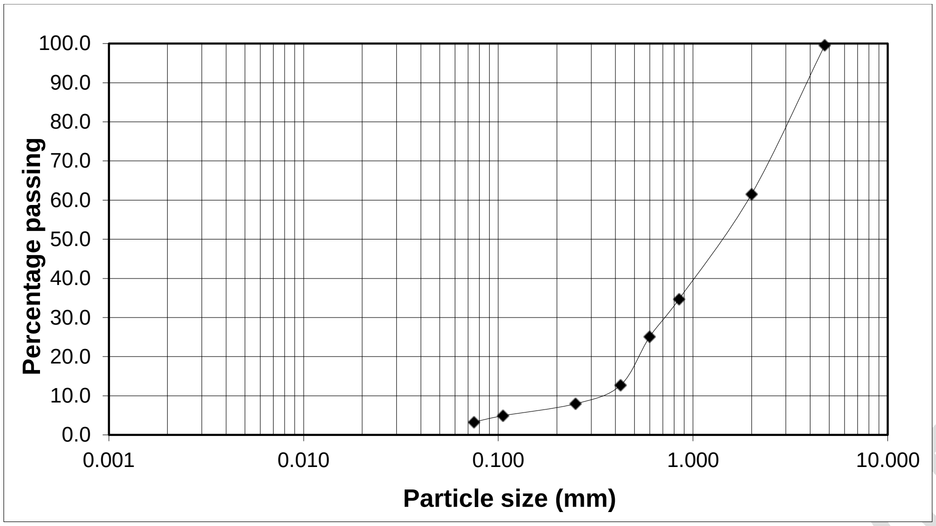

Fig 1. Particle size distribution curve

Table 2. Geotechnical Properties of the Soil

TEST	**RESULT**
Specific gravity (%)	2.61
% passing BS 200 sieve (0.075mm)	3.3
Natural moisture content (%)	10.8
Maximum dry density (kg/m^3)	2066.38
Optimum moisture content (%)	10.6
Condition of sample	Air dried
Liquid limit (%)	29
Plastic limit (%)	23
Plasticity index (%)	6
Coefficient of curvature	1.98
Coefficient of uniformity	8.82
USCS classification	ML (silty and clayey fine sand)
ASSHTO classification	A-2-4

2.1.2 Palm Fibre

The Palm fibre (PF) used for this research is the mesocarp of oil palm fruits (palm fruit bunch). It was obtained from oil palm processing mills atOgbogbo town in Idah, Kogi state. The fibre was washed with warm water to remove oil and dirt, and sun-dried before it was used. Figure 2 shows a photograph of the palm fibre used. Some of the physical and mechanical properties of the palm fibre used are presented in Table 3.

Fig. 2. Photograph of palm fibre used

Table 3: physical and mechanical properties of palm fibre used

Parameter	Value
Length	26-53 mm
Radius	0.15-90 mm
Density	524N/mm^2
Tensile strength	76N/mm^2
Young's modulus	495N/mm^2
Elongation at break	18

2.1.3 Water

Fresh, colourless, odourless and tasteless potable water that is free from injurious amounts of oils, alkalis, salts, sugar organic matter or any other substances, was used for this research.

2.2 Experimental Investigation

2.2.1Mixture Proportioning, Moulding and Testing of Blocks

The soil was reinforced with palm fibre proportions of 0%, 0.5%, 1.0% and 1.5% by weight of laterite for each mix. The mix proportion of the specimens is presented in Table 4. Block specimens of size 200 mm x 100 mm x 100 mm were moulded from the fibre-reinforced lateritic soil samples. The lateritic soil and PF were thoroughly mixed under dry conditions after which an appropriate amount of water (the optimum moisture content) was added to the mixture. A total of 20 blocks were moulded with five blocks for each set of mix and compaction was done in accordance with BS 1377[36]. Mixing of the materials, moulding and compaction of the blocks was carried out manually. The freshly moulded blocks were carefully extruded in good shape on a clean, hard and flat surface after which they were left to cure under a shade for 28 days. Water was sprayed on the blocks once every morning and evening for the 28-day curing period. The compressive strengths of the blocks were tested in accordance with BS 771-1 [37] and BS 12390-4 [38] after 28 days of curing. Figure 3 shows the freshly moulded blocks.

Table 4. Mix proportion of the specimen

Mix ID	PF (Kg/m^3)	Laterite (Kg/m^3)
C (control)	0.00	20.63
P1	0.10	20.52
P2	0.21	20.42
P3	0.31	20.32

Fig.3.Photograph showing freshly moulded block specimen

3. RESULTS AND DISCUSSIONS

The average compressive strength of the blocks produced is shown in Table 5 and Figure 4. When compared to the control mix, it was shown that adding PFto each matrix resulted in a significantincrease in the compressive strength of the blocks. The compressive strength of the blocks increased as the amount of PFin the matrix increased. However, the addition of PF in the matrix beyond 1% resulted in a decrease in the compressive strength.The results obtained align with the findings of previous studies carried out by [27, 29, 31] which show that the compressive strength of CEBs increased with the addition of palm fibre at proportions between 1-5% in the matrix.

The increase in the compressive strength of the blocks may be attributed to the strength and toughness of the fibres, while the decrease in the compressive strength with a 1.5% PF proportion in the matrix can be attributed to the increase in the volume of pores in the matrix. This is justified byMostafa and Uddin [14]andDanso et al [39] who opined that the development of strength properties of soil-fibre mixes mostly depends on the formation of fibre-matrix, matrix-matrix and fibre-fibre bonds. The creation of an isotropic matrix between the soil mix and the fibre network results in a strength increase as such a matrix opposes the movement of particles thereby creating stability in the matrix. They further stated that these bonds can be affected by the quantity of fibre present.Anincrease in fibre content results in a decrease in fibre-matrix and matrix-matrix bonds, and a reduction in the cohesion of the fibre with the soil due to knotting and overlapping of the fibres, resulting in a reduction of the compressive strength of the blocks

Table 5. Average Compressive Strength of Blocks

MIX ID	PF (%)	Average Compressive Strength (N/mm^2)	Change in Compressive Strength (%)
C (control)	0.0	0.97	0.00
P1	0.5	1.23	26.80
P2	1.0	1.38	42.27
P3	1.5	1.13	16.49

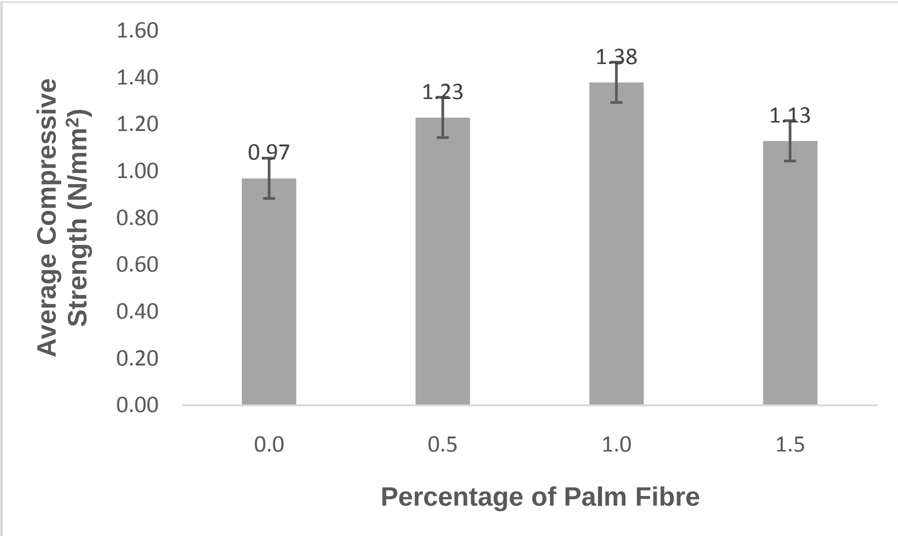

Fig. 4.Average Compressive Strength of Blocks

4. CONCLUSION

Compressed earth blocks reinforced with palm fibre (0-1.5%) by weight of laterite were produced and tested for their compressive strengths after 28 days of curing. The compressive strength of the blocks increased with the addition of palm fibre to the matrix. From the observations of this investigation, the following conclusions were made

1. The blocks reinforced with palm fibre had better performance in their compressive strengths as compared to the unreinforced blocks.
2. The addition of palm fibre to the soil matrix led to an increase in the compressive strength of the blocks.
3. When compared with the control mix, the addition of 0.5%, 1.0% and 1.5% of palm fibre resulted in a 26.80%, 42.27% and 16.49% increase in the compressive strength respectively.
4. An optimum reinforcement of the blocks with1% palm fibre is recommended.
5. Palm fibre can be used to improve the properties of CEBs for affordable eco-friendly housing in developing countries and low-income earners.

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