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Effect of fibre aspect ratio on mechanical properties of soil building blocks

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HIGHLIGHTS

- Most fibres will produce increasing block strength with increasing fibre length.
- Some fibres have an optimal aspect ratio when used in soil blocks.
- Natural fibres continue to hold blocks together after failure of the soil matrix.
- The effect of fibre aspect ratio is similar in magnitude to effect of fibre content.

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ABSTRACT

Inclusion of fibres in soil blocks has been shown to enhance strength development. This study investigates the effect of aspect ratio of coconut, bagasse and oil palm fibres on the mechanical properties of soil blocks. Experiments were conducted on soil blocks with fibre aspect ratios (25–125) to determine the compressive and tensile strength of the blocks. Blocks with coconut and oil palm fibres showed increasing strength with increase aspect ratio, while bagasse fibres showed an initial increase followed by a decline at higher aspect ratio. The study concludes that generally longer aspect ratios produce better mechanical properties of soil blocks.

1. Introduction

Enhancement of the engineering properties of soil blocks with agricultural waste fibres has potential to produce more robust and resilient homes for some poorest communities in Less Economically Developed Countries (LEDCs). A range of fibres such as chopped barley straw, processed waste tea, vegetal, oil palm empty fruit bunches, lechuguilla, pineapple leaves, cassava peel and hibiscus cannabinus have been investigated as stabilisers to enhance the properties of soil blocks/bricks by Bouhicha, Aouissi [1], Demir [2], Achenza and Fenu [3], Kolop, Haziman [4], Juárez, Guevara [5], Chan [6], Villamizar, Araque [7] and Millogo, Morel [8], respectively. In all these studies, there were improvements in the engineering properties of the stabilised soil blocks/bricks over the unstabilised with compressive strength, for example, showing improvements varying from 4% to 117% (median of 26%) [9]. This makes natural fibres an attractive low cost stabilising material for soil blocks. Besides the structural benefits, they also have economic, environmental and social significance when used to stabilise soil blocks for earthen construction. Thou the moisture uptake of natural fibres is high [10], the use of the fibres has generated much interest due to their low cost, low density, biodegradability, renewability and abundance [11].

The energy requirement and the processes involved in manufacturing soil blocks are less intensive than for cement, sandcrete blocks and burnt brick production and therefore soil blocks have a less environmental impact [12–15]. Furthermore, soil is locally available and abundant which makes it easy and affordable to obtain [6], therefore, people in the low-income bracket can afford to acquire their own houses. In addition, instead of burning agricultural waste which contribute to carbon emissions and air pollution, wastes may be used to produce enhanced soil blocks. Socially, earth construction uses existing local or easily transferable skills, avoiding the need for costly training, reducing displacement of labour and reducing societal or cultural disruption especially in

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LEDCs. Understanding of how agricultural waste fibres enhance soil block properties is therefore important to practitioners of earth construction to maximise the performance and sustainability advantages compared with binders.

There are two important parameters that contribute to strength development of fibre enhanced blocks. These are; fibre content (the fraction of fibre in the soil) and the fibre aspect ratio (the ratio of length to diameter of the fibre). Most studies on the use of natural fibres for enhancement of soil blocks have focused on the fibre content, with few incorporating fibre lengths in their experimental design [1,5,16,17]. There is therefore a need to determine the aspect ratio of fibres that will produce the optimum strength when used for stabilising soil blocks. Fibre aspect ratio is the ratio of length to diameter of a fibre and is usually expresses as a single number greater than 1. This study therefore investigates the effect of aspect ratio of three different natural fibres derived from agricultural waste (coconut, bagasse and oil palm) on the mechanical properties of soil blocks.

2. Materials and methods

An experimental study was conducted by using agricultural waste (coconut husk, bagasse and oil palm fruit) fibres as stabilising materials in the production of soil blocks. For this purpose, a local soil obtained from Sunyani town of Brong Ahafo region in Ghana was used for the production of the blocks. The properties of the soil are reported in Table 1.

The soil has a liquid limit of 13.3% and a plasticity index of 13.9% and hence could be classified as low plasticity clay soil (CL) according to BS1377 [18]. The optimum moisture content (OMC) for the soil without stabilisation was obtained by using a Standard Proctor mould [18] and was 18%, the maximum dry density (MDD) was 1.78 mg/m^3. The particle size distribution curve is shown in Fig. 1. The soil has pH value of 7.33 which means the soil is neutral (between acidic and alkaline) according to Soil survey division staff 'Soil survey manual' [19]. Chemical element/composition of the soil was determined through inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis method and the result is presented in Table 2.

Bagasse fibre was obtained from sugar cane residue at a local sugarcane alcohol distillery mill in Somanya, the coconut fibre was obtained from the husk of coconut fruit from coconut vending points at Cape Coast and oil palm fibre was obtained from a palm oil extraction plant in Kumasi, Ghana. The by-products were soaked in water for at least 48 h, mechanically beaten and the fibres extracted and dried. The images of the fibres and SEM of each fibre type is shown in Fig. 2. SEM images of single fibre were determined with JSM-6100 scanning microscope at 35× magnification for each fibre type (Fig. 2).

One hundred fibres (from each type) were randomly selected for determining the length and diameter. A compound light Microscope (Leitz HM-LUX3) of 25× magnification with a graticule eye piece was used for the measurement of diameter while a steel rule was used to measure the length. The fibre diameter was measured at five points evenly along each length. The distribution of the measurements are shown in Fig. 3 and display a generally normal distribution with only the oil palm displaying any marked tapering. The nominal diameter determined by taking the mean of these measurements for each fibre type and required fibre lengths were obtained by multiplying the nominal diameter by the required aspect ratio. These are shown in Table 3. It should be noted that, as there are a range of diameters of fibre present in each block, the corresponding aspect ratio will also vary with the same relative standard deviation as quoted for diameter.

Table 1
Properties of soil.

Properties	Values
Proctor test	
Optimum moisture content (%)	18.0
Maximum dry density (mg/m^3)	1.78
Atterberg limits	
Liquid limit LL (%)	13.3
Plastic limit PL (%)	17.2
Plasticity index PI (%)	13.9
Particle size distribution	
Gravel (>2 mm) (%)	12
Sand (2–0.063 mm) (%)	46
Silt (0.063–0.002 mm) (%)	28
Clay (<0.002 mm) (%)	14
Organic content	
Content (%)	1.8
pH	
Value	7.33

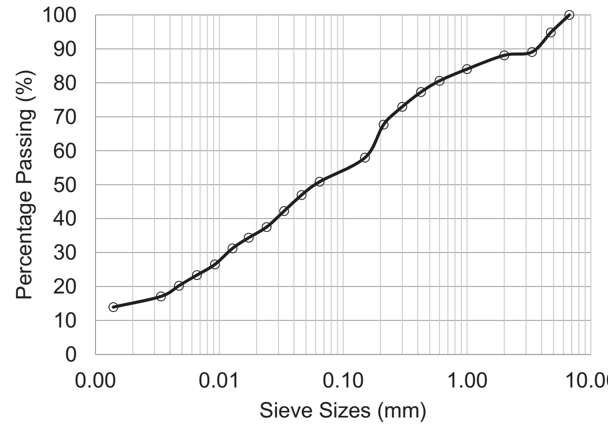

Fig. 1. Particle size distribution of the experimental soil.

Table 2
Chemical composition of soil.

Element/compound	Concentration (mg/kg)
Al^{3+}	0.06
Ca^{2+}	44.0
SiO_2	0.06
K	3.88
Zn	0.86
Pb	0.10
Fe^{2+}	1.038
Mg^{2+}	14.8
Cl^-	18.99
PO_4^{3-}	6.17
SO_4^{2-}	20.0

Enhanced soil blocks of 290 × 140 × 100 mm were made with soil and 1% fibre by weight as this was the maximum fibre content recommended by previous studies [8,20,21]. The fibres were cut to aspect ratios of 25, 50, 75, 100 and 125, which was limited by the fibre lengths available. The required quantity of the materials (soil, fibres and water) were weighted. The soil was first spread on a platform, then the fibre was spread on soil and turned over and over till a uniform mixture was obtained. Water was sprinkled on the soil-fibre mixture and turned over and again to obtained uniform mix. The blocks were made with pressure gauge hydraulic block making machine with a constant pressure of 100 bars. The blocks were sun dried at an average temperature of 27 °C and relative humidity of 72% for 21 days (Fig. 4) before testing.

Compressive and tensile splitting tests were conducted to determine the mechanical properties of the blocks. The compressive test was conducted in accordance BS EN 771-1 [22]. A CONTROLS 50-C46G2 testing machine with maximum capacity 2000 kN was used for conducting the test. The load was applied at a rate of 0.05 N/mm^2/s until the block failed, the load at which the blocks failed was recorded and maximum compressive stress was calculated.

The tensile splitting test was conducted in accordance with BS EN 12390-6 [23] with the testing machine and splitting jig which were placed centrally above and below the block. The load was applied continuously at a study rate of 0.05 N/mm^2/s up to failure of the block and tensile splitting strength calculated according to the standard.

3. Results and discussion

3.1. Effect of fibre aspect ratio on compressive strength

The details of compressive strength test results of the enhanced soil blocks are reported in Table 4. Fig. 5 summarises the compressive strength tests results for the fibre aspect ratios tested. It can be seen that for coconut fibre, the increase of fibre aspect ratio up to 125 increased the compressive strength by about 26% compared to the aspect ratio of 50. Oil palm fibres show a continual increase up