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Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres

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HIGHLIGHTS

- Natural fibre inclusion in soil blocks positively affects mechanical properties.
- Fibre reinforced soil blocks have improved resistance against wearing and erosion.
- 0.5% fibre content by weight is recommended to practitioners for use.
- Correlations between properties do not follow those for binder stabilised blocks.
- The importance of soil type vs. fibre type depends on the property of interest.

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ABSTRACT

This study investigates the properties of soil blocks stabilised with fibres from agricultural waste. Laboratory experiments including density, water absorption, shrinkage, compressive strength, tensile strength, wearing and erosion were conducted on soil blocks made with two soil types and enhanced with three fibre types at 0.25–1 wt.%. It was found that the physical, mechanical and durability properties of the blocks were generally improved and a recommendation of 0.5 wt.% fibre content and high clayey soil are made. Many assumptions about relationships between properties established for binder stabilised blocks are found to be inappropriate for fibre reinforced blocks.

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1. Introduction

Conventional construction and building materials such as steel bar, cement, concrete, sandcrete blocks, burnt bricks and tiles require the extraction of large quantities of materials, causing depletion of natural resources and environmental damage. The manufacturing process of these materials is energy intensive, releasing carbon dioxide and other pollutants such as particulate matter, sulphur oxides, nitrogen oxides and carbon monoxide into the atmosphere. These emissions contaminate water, air, soil, flora, fauna and aquatic life as well as affecting human health [1]. In addition, the cost of conventional building materials keeps increasing because of the energy required for the production, increasing scarcity of natural resources and high transportation cost from the factories to the construction site. These environmental and economic concerns have generated interest in research into alternate building materials, such as soil building blocks, and construction techniques that are more sustainable.

Soil building blocks enhanced with agricultural waste are one of the alternate building materials that have shown to provide social, environmental and economically sustainable buildings [2]. These have been used to produce low-cost housing, improved thermal comfort and for maintaining cultural heritage buildings. The advantage of agricultural waste fibres is their availability in many economies, since most countries have significant agricultural

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activity [3]. Different agricultural wastes can be found in different countries depending on the type of crops available. For example, there are abundant wastes generated in Ghana from coconut husk, sugarcane residue (bagasse) and oil palm fruit residue. Different agricultural wastes have therefore been used to enhance the properties of soil blocks in different countries.

The use of wastes as alternate building material has had a great deal of interest in recent years. Industrial wastes such as blast furnace slag [4], phosphogypsum and natural gypsum [5], coal combustion by-products [6], salvaged steel fibres from used tyres [7], sawdust [8], crumb rubber [9] and plastics [10] have been used to enhance the properties of soil building blocks/bricks. Animal wastes such as sheep wool fibre [11] and cow-dung [8] have also been used to enhance the properties of soil building blocks/bricks. Furthermore, agricultural wastes such as chopped barley straw [12,13], processed waste tea [14], seaweed [15], oil palm empty fruit bunches [16], lechuguilla [17], pineapple leaves [18], cassava peel [6], hibiscus cannabinus [19], date palm [20] and coir [21,22] have been investigated. These studies have shown that the presence of waste fibre has often improved the properties of the soil blocks.

The aim of this study is to investigate the properties of soil building blocks reinforced with three fibres, namely sugarcane bagasse, oil palm fruit and coconut husk in two different soils. To achieve this, the physical, mechanical and durability properties of the fibre reinforced soil blocks were measured and optimum fibre content determined. The applicability of proxy measures, such as physical properties for strength and durability, were then evaluated as these have been shown to be applicable to blocks reinforced with binders, such as Portland cement [23,24], but not well defined for blocks reinforced with fibres. The relative importance of soil-type and fibre type in determining the properties of fibre reinforced earth blocks were then assessed. These were then compared to the published criteria for soil suitability which have been generally developed for binder stabilised blocks [25] and therefore may not be appropriate for fibres. This work extends the existing database of different fibres used for reinforcement of soils blocks across a range of performance measures and evaluates them against the existing guidance.

2. Materials and methods

The practical work was undertaken in Ghana where earth/soil block construction is a common technique for low-cost housing, particularly in rural areas. To ensure the study was applicable to other countries soils were selected to cover a range of properties and fibres were selected from widely available waste products.

2.1. Materials

The principal materials used for the experiment are soil and agricultural waste fibres. Red (R) soil and Brown (B) soil from Ghana were selected as these are the two main soil types that are used for earthen construction in Ghana, and represent the main types of soil used for constructing soil block houses. They also represent a range of properties with one of the soils (B) within the limits generally specified for earth construction, while the other (R) is partially outside the limits. The properties of the soils are reported in Table 1. The particle size distribution curve is shown in Fig. 1, with the lower and upper limits usually recommended for soil blocks. The results indicate that soil B is low plasticity clay (CL) soil which lies within the limits, while soil R is high plasticity clay (CH) soil which lies partially outside the limits according to unified soil classification system (USCS) [26]. Chemical element/composition of the soil was determined through inductively coupled plasma–mass spectrometry (ICP–MS) analysis method in accordance with BS EN ISO 17294-1 [27] and the result is also reported in Table 1.

Stabilisation was achieved by using coconut husk, bagasse and oil palm fruit fibres in the production of soil blocks. These fibres have been selected as they cover a wide range of properties, and are also abundant agricultural waste materials in West Africa. More information on these fibres can be found in a previous study [2]. Each fibre type is illustrated in Fig. 2. SEM images of single fibre were determined with JSM-6100 scanning microscope at 35 and 500× magnification for each fibre type to show the texture of the fibres. It can be seen that the bagasse fibres are very rough in texture as compared to coconut and oil palm fibres. The oil palm fibres also appear slightly smoother than the coconut. The properties of the fibres were measured according to methods developed by Ghavami et al. [28] for determining the properties of natural fibres such as bamboo, sisal and coconut. The properties of the selected fibres are reported in Table 2, the lengths of the fibres used were a result of the optimum lengths that produced maximum strength in the previous study [2].

Table 1
Properties of the experimental soil.

Properties	Soil type	
	Brown	Red
Proctor test		
Optimum moisture content (%)	18	19
Maximum dry density (Mg/m^3)	1.78	1.79
Atterberg limits		
Liquid limit wL (%)	13.3	51.2
Plastic limit wP (%)	17.2	27.3
Plasticity index PI	13.9	23.9
Soil classification		
USCS	CL	CH
Particle size distribution		
Gravel (>2 mm) (%)	12	15
Sand (2–0.063 mm) (%)	46	39
Silt (0.063–0.002 mm) (%)	28	16
Clay (<0.002 mm) (%)	14	30
pH		
Value	7.33	7.44
Chemical composition (mg/kg)		
Al^{3+}	0.06	0.09
Ca^{2+}	44.0	65.0
SiO_2	0.06	0.08
K	3.88	4.19
Zn	0.86	0.91
Pb	0.10	0.15
Fe^{2+}	1.038	1.047
Mg^{2+}	14.8	15.80
Cl^-	18.99	31.49
PO_4^{3-}	6.17	3.09
SO_4^{2-}	20.0	28.0

2.2. Methods

The blocks were tested for density, water absorption, linear shrinkage, compressive strength, splitting tensile strength, wearing and erosion. These tests were selected to cover a wide range of properties important for soil blocks, such as physical, mechanical and durability after a review of previous studies [29]. Five blocks from each mix ratio, fibre type and soil type were randomly selected and used for each test.

2.2.1. Preparation of blocks

Soil blocks of 290 × 140 × 100 mm were made with soil and 0.25, 0.5, 0.75 and 1 wt.% fibre content. The soil was first spread on a platform, then the fibre was spread on top and turned over and over until a uniform mixture was obtained. Water was added to achieve the optimum moisture content (OMC) (Table 1) by sprinkling on to the soil–fibre mixture and repeatedly turned to obtain a homogenous mixture. It must be noted that the OMC was for the soil without fibres. The fibres were soaked in water for 48 h to saturation before being added to the mix. The blocks were made with BREPAC block making machine with a constant pressure of 10 MPa (Fig. 3). They were sun dried (Fig. 4) at an average temperature of 27 °C and relative humidity of 72% for 21 days. The blocks were packed and the surfaces cleaned with soft duster before testing.

2.2.2. Physical properties tests

Density of the specimen was determined in accordance with BS EN 771-1 [30]. The blocks were selected and their dimensions measured. They were weighed and then the density was calculated.

Water absorption by capillary testing was performed in accordance with BS EN 772-11 [31]. The blocks of each mix ratio and soil type were oven dried at a temperature of 40 °C until a consistent mass was recorded, indicating a normal dried block. The mass of the specimens were taken and recorded. The 290 × 140 mm side of the specimen was immersed to a depth of 5 mm in a constant head-water bath for 10 min. The mass of the absorbed specimen was recorded and the absorption of water by capillarity rise was then calculated.

Linear shrinkage of the specimen was determined by measuring the length of the specimen with a dial gauge before and after drying.

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