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EFFECT OF SUGARCANE BAGASSE FIBRE ON THE STRENGTH PROPERTIES OF SOIL BLOCKS

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Abstract

The use of natural fibres as enhancement in soil blocks has attracted much research interest in the past decade. In this paper the effects of sugarcane bagasse fibres on the strength properties of soil blocks have been investigated. Laboratory experiments including density, water absorption, compressive strength, splitting tensile strength and erosion tests were conducted on soil blocks reinforced with 0.25-1% mass of fibres. It was determined that by utilisation of an optimum (0.5%) of sugarcane bagasse fibres in the soil matrix improved the strength properties of the soil blocks. Furthermore, the study shows that although the reinforced soil blocks were of lower density and higher water absorption, they had a better resistance against erosion. In addition, it was found that high clayey soil achieved better strength and durability properties. This research therefore recommends the use of 0.5% fibre content and high clayey soil for production soil blocks reinforced with sugarcane bagasse.

Keywords: soil blocks; sugarcane bagasse fibres; compressive strength; splitting tensile strength; erosion

1 INTRODUCTION

In the last decade, considerable effort has been directed towards using various natural fibres which are available and in abundance in tropical and sub-tropical countries as reinforcement in soil composites for producing cost-effective building materials. Natural fibres are usually used in weaving, sacking and ropes and have good potentials to be used as reinforcement in composite (Sen and Reddy, 2011) materials such as soil blocks. These materials have good physical and mechanical properties, provide good environmental benefits and low-cost advantage for use as building material. Natural fibres can be used in composite materials to reduce weight, increase strength and are also very safe during handling, processing and use (Sen and Reddy, 2011, Rodriguesa et al., 2011). Ali (2010) explained that natural fibres in composite can be applied in civil engineering for plastering, use as roofing material, slabs, boards, wall panelling systems, house construction and slope stabilization. The requirement for economical and environmentally friendly materials has extended an interest in the use of natural fibres (Ghazali et al., 2008). The use of natural fibres in composite materials helps to address sustainability issues.

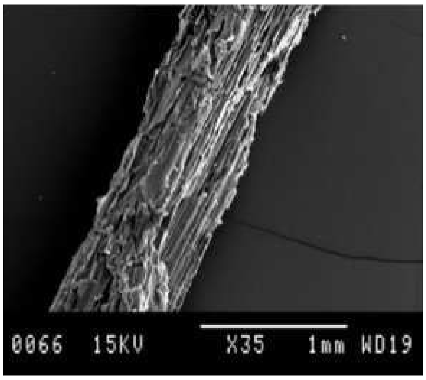
In tropical and subtropical regions, natural fibres such as sisal, bamboo, coconut husk, sugar cane residue (bagasse), oil palm and pineapple leaves are in abundance and cheap. The utilisation of these bio-based waste in building material has attracted research interest by researchers to promote sustainable construction. Chopped barley straw (Bouhicha et al., 2005), processed waste tea (Demir (2006), vegetal (Achenza and Fenu, 2006), oil palm empty fruit bunches (Kolop et al., 2010), lechuguilla natural fibres (Juárez et al., 2010), pineapple leaves (Chan, 2011), cassava peel (Villamizar et al., 2012) and hibiscus cannabinus (Millogo et al., 2014) have been used to reinforced the properties of soil blocks/bricks. Studies on the possible use of other natural fibres such as sugarcane bagasse to enhance the properties of soil blocks will add to knowledge and extend the debate on the utilisation of natural fibres in soil matrix. Ghazali et al. (2008) studied the characteristics of sugarcane bagasse in cement composite. There is therefore the need to also study the characteristics of sugarcane bagasse in soil matrix. The aim of the present work is to study the effect of sugarcane bagasse fibre on the strength properties of soil blocks.

2 MATERIALS AND METHODS

2.1 Materials

The main materials used for the study are sugarcane bagasse fibre and soil. Sugarcane is plant which grows up to 6 m high and has a diameter up to 6 cm, and the bagasse is the fibrous residue which is obtained from sugarcane processing after extraction of the juice from the cane stalk (Hejaz et al., 2012). Sugarcane residue was obtained from a local alcohol distillery in Ghana. The residue was mechanically crushed and washed to obtain the fibres (Fig. 1). The fibres used were cut to 80 mm of lengths with 0.31 to 1.19 mm range of diameter. SEM images of the fibre are shown in Figure 2. The SEM images of single fibre were determined with JSM-6100 scanning microscope at 35x and 500x magnifications to show the texture. Properties of fibres are reported in Tab. 1. More information on the bagasse fibre can be found in the study by Danso et al. (2015a) Two kinds of soil were obtained from Ghana which are: (1) brown denoted by B, and (2) red denoted by R. The properties of the soils are reported in Tab. 2. The results indicate that B is low plasticity clay (CL) soil while R is high plasticity clay (CH) soil according to unified soil classification system (USCS).

Fig. 1: Sugarcane bagasse fibre.



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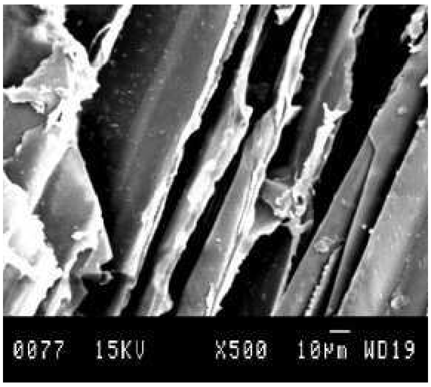

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Fig. 2: SEM images of sugarcane bagasse fibre.

Tab. 1: Properties of sugarcane bagasse fibres.

Property	Value
Fibre form	Single
Average length (mm)	110
Average diameter (mm)	0.8
Tensile strength (MPa)	62 - 25
Modulus of elasticity (GPa)	1.3 – 0.5
Specific weight (g/cm^3)	0.56
Natural moisture content (%)	9.7
Water absorption (%)	153 - 219

Tab. 2: Summary of the result of soil properties.

Properties	Soil Type	
	B	R
Proctor test		
Optimum moisture content (%)	18	19
Maximum dry density (Mg/m^3)	1.78	1.79
Atterberg limits		
Liquid limit LL (%)	13.3	51.2
Plastic limit PL (%)	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

2.2 Methods

Soil blocks of 290 × 140 × 100 mm were made with soil and 0%, 0.25%, 0.5%, 0.75% and 1% fibre content by mass. The blocks were made with pressure gauge hydraulic block making machine with a constant pressure of 100 bars. The blocks were sun dried (Fig. 3) at an average temperature of 27 °C and relative humidity of 72 % for 21 days before testing. Density, water absorption, compressive strength, splitting tensile strength and erosion tests were conducted to determine the properties of the soil blocks.

Density of the specimen was determined in accordance with BS EN 771-1 (2003). Five blocks from each mix ratio were selected for the test. Their volumes were calculated and were oven-dried at a temperature of 105°C until constant masses of the blocks were obtained. The blocks were weighed and then the density was calculated.

Fig. 3: Drying of enhanced soil blocks.

(a) Soil R blocks, (b) Soil B blocks

Water absorption by capillary test was performed in accordance with BS EN 771-1 (2003) procedure for clay masonry units. Five blocks of each mix ratio 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 lower side of the specimen of an area at a 5 mm was placed in a constant head-water bath for 10 min. The mass of the absorbed specimen was recorded. The absorption of water by capillarity rise was then calculated.

Compressive strength test was conducted in accordance with BS EN 772-1 (2011). A CONTROLS 50-C46G2 testing machine with maximum capacity 2000 KN was used for conducting the test. The testing machine applied load 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.

Splitting tensile strength test was conducted in accordance with BS EN 12390-6 (2009) with the testing machine and splitting jig which were placed centrally above and below the block. Load was applied continuously at a rate of 0.05N/mm^2/s up to failure of the block and splitting tensile strength of the blocks was calculated according to the standard.

The erosion test was conducted in accordance with Section D of New Zealand Standard NZS 4298 (1998). The apparatus for the test are pressure spray test nozzle with meter gauge and valve, plastic bath and shield board with gasket. Five blocks from each mix ratio were selected for the test. The test rig was set up with shield board positioned in the plastic bath and the pressure spray nozzle set on the bath at a distance 470 mm from the shield. Each block was mounted behind the shield and was exposed to spray through a 100 mm diameter hole. The shield ensured that only limited area of the block face was subject to water spray. Tap water was connected to the pressure spray nozzle and then opened at pressure 50 kPa through the nozzle onto the block. Water was sprayed onto the block and run out through the outlet for 60 min. The spray was stopped at every 15 min to allow for assessment. The depth of pitting was measured using a 10 mm diameter flat ended rod. The rate of erosion was expressed as the pitting depth (mm) per minute of exposure to the spray water.

3 RESULTS AND DISCUSSION

3.1 Dry Density

Summary of the results obtained from dry density test are presented in Fig. 4. The results show that the average dry density of the reinforced soil blocks decreased with increase sugarcane bagasse fibre content. Similar trend was obtained in a study by Ismail and Yaacob (2011) as the density of laterite bricks also decreased with the increase in the oil palm empty fruit bunch fibre content. This was expected as fibres have a low density, and therefore increase of its content with the reduction of the soil content which is heavier will invariably decrease the density of the blocks. It can be seen that the unreinforced (0 % fibre) blocks dry density were higher than all the reinforced blocks. Contrarily, studies with cement and lime enhanced soil blocks obtained higher density with increase cement or lime content (Arumala and Gondal, 2007, Ngowi, 1997). Fibre enhanced soil block's density is a function of the water absorption, fibre content, and porosity. Increase content of these factors affects the density of the blocks. Soil R blocks obtained higher density than the soil B. This might be due to higher clay content in the soil R, which is likely to increase the compact effect on the soil matrix.

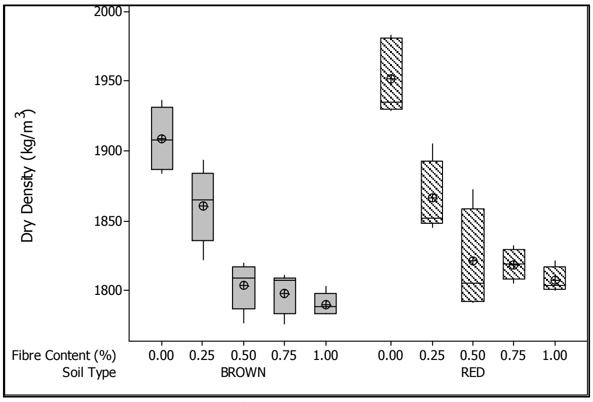

Fig. 4: Density of the enhanced soil blocks

3.2 Water Absorption

Fig. 5 presents the summary of the water absorption test results of the reinforced soil blocks. It can be seen that the water absorption of the soil blocks increased with the increase fibre content. The high water absorption of reinforced soil blocks may be attributed to the amount of water absorbed by the cellulose of the fibres, which is due to the void volume and the amount of cellulose material present in the blocks (Jeefferie, 2011) coupled with capillary action. This may have contributed to the reduction of the density of the reinforced soil blocks.

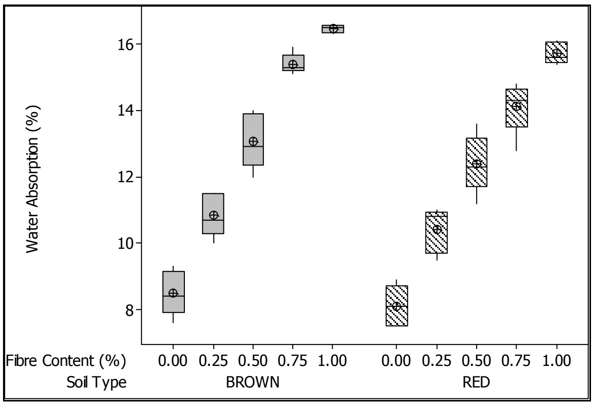

Fig. 5: Water absorption of the enhanced soil blocks

The relationship between water absorption and density is reported in Fig. 6. The result indicates a strong negative correlation (with Pearson's correlation of -0.940 and -0.951 respectively for soil R and soil B) between water absorption and density of the enhanced soil blocks, as the density decrease the water absorption increase. Similar trend was obtained in the study by Ismail and Yaacob (2011) which the density decreased with increase water absorption of the laterite bricks reinforced with oil palm empty fruit bunch fibre. This was explained by Coutts and Ni (1995) that the amount of water absorbed by the fibre reinforced soil composites depends on their void volume and the amount of cellulose material present; both these parameters have an effect on density. Thus, one would expect the density to decrease and the water absorption to increase as the fibre content is increased, due to the low specific weight of the sugarcane bagasse fibres. Furthermore the reinforced soil blocks become less efficient as the fibre content is increased, and so void volume increases accompanied by decreased density and increased water absorption.

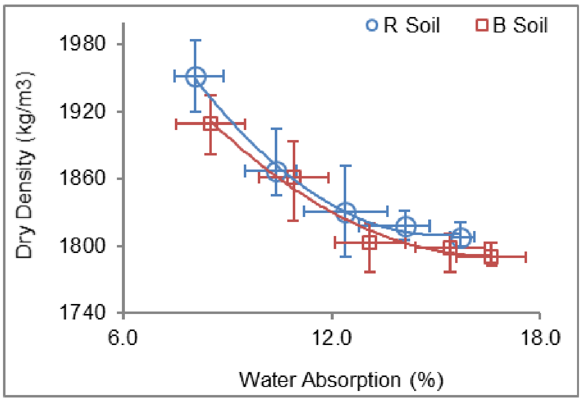

Fig. 6: Relationship between density and water absorption of reinforced soil blocks.

3.3 Compressive Strength

Summary of the compressive strength test results are presented in Fig. 7. It can be seen that the compressive strength of the blocks increased with increase fibre content until it reached 0.5%, and then decreased with further increase in fibre. This indicates that the reinforced soil blocks obtained an optimum compressive strength with about 26% and 19% increase over the unreinforced blocks respectively for soil R and soil B. This means peak strength was obtained along the fibre mix ratios. This is consistent with the trend in previous studies (Bouhicha et al., 2005, Ismail and Yaacob, 2011, Millogo et al., 2014). It is likely that the increase in strength could be linked to the homogeneous microstructure of the reinforced soil blocks because of the presence of fewer pores due to few fibre incorporation in the soil matrix, as demonstrated by Millogo et al. (2014) with microscopic studies (SEM and video microscopy). Furthermore, the association of fibres and the soil matrix prevents the spread of cracks in the blocks and therefore contributes to the improve strength. Further increased fibre content causes strength reduction when fibres begin to knot together (Ismail and Yaacob, 2011) resulting in lost cohesion with the soil (Medjo Eko et al., 2012) or break-up of the soil matrix (Millogo et al., 2014) causing the soil-fibre composite to weaken.

The effectiveness of the reinforcement was more pronounced with soil R (high plasticity clay soils) as compared to the soil B (low plasticity clay soil), as was also in the study by Bouhicha et al. (2005). This implies that for fibre reinforced soil blocks, high clayey soils produce better result. Paired sample t-test was conducted at 95% confidence interval with the two soil values provided <0.001 P-value (Tab. 3). This implies that there is a statistically significant difference between the strengths of soil R and soil B, which could be linked to the clay content in the soils. Soil R was found to be high plasticity clay soil which may have contributed to its better performance. In the reinforced soil blocks, the clay content act as a binding agent which links the bigger particles of the soil with the fibres together to ensures high binding effect by providing better performance.

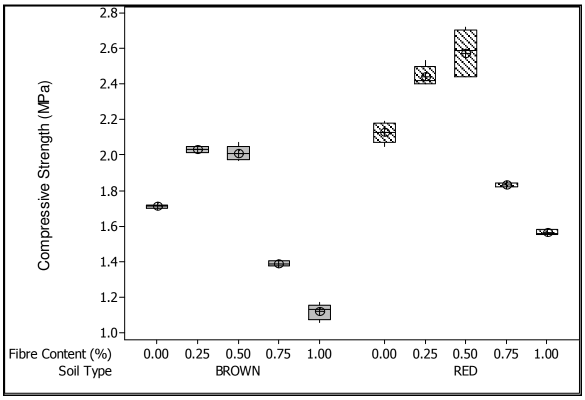

Fig. 7: Compressive strength of the enhanced soil blocks.

Tab. 3: Test of significance difference between compressive strength of soil R and soil B.

Soil	N	Mean	Std Dev	t	P-value
R	25	2.148	0.438	11.815	<0.001
B	25	1.652	0.363		

3.4 Splitting Tensile Strength

Fig. 8 summaries the average splitting tensile strength results of the enhanced soil blocks. It can be seen that the tensile strength increased with increase fibre content up till 0.5% and then decreased. It obtained an optimum as was in the case of the compressive strength test results. There was about 16% and 20% mean tensile strength increase of the reinforced blocks over the unreinforced at optimum respectively for soil R and soil B. The ratio of tensile to compressive strength improvement ($\sigma_{f,max}/\sigma_{c,max}$) is 59% and 105% respectively for soil R and soil B, which is slightly lower than 133% reported by Danso et al. (2015b). It was observed that failure of unreinforced blocks was sudden and produced only one large crack, while the failure of the sugarcane bagasse fibre reinforced soil blocks was with multiple finer cracks. This means the failure was more gradual, acting more like a ductile than a brittle material which agrees well with Bouhicha et al. (2005) and Cai et al. (2006). Upon removal of the blocks from the testing machine, though they were split into two, the two parts were still held together by the fibre. This indicates that fibre enhanced soil blocks will fail slowly rather than suddenly and will still hold a load for some time after failure.

The effectiveness of the enhancement was more pronounced with soil R than soil B. Paired sample t-test was conducted at 95% confidence interval with the two soil values provided 0.001 P-value (Table 4). This means that there is a statistically significant difference between the tensile strength of soil R and soil B.

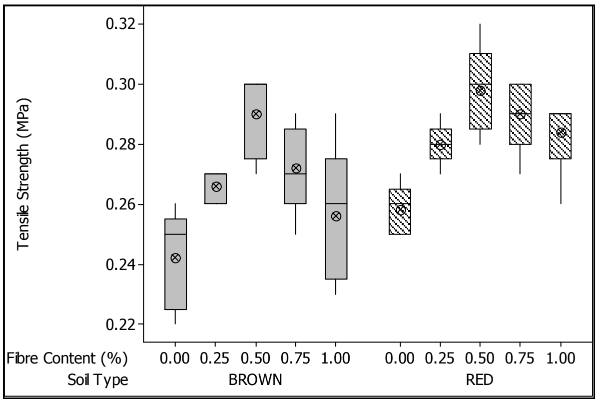

Fig. 8: Splitting tensile strength test results.

Tab. 4: Test of significant difference between tensile strength of soil R and soil B.

Soil	N	Mean	Std Dev	t	P-value
R	25	0.282	0.0173	3.734	0.001
B	25	0.265	0.0218		

3.5 Erosion

Summary of the erosion test results is presented in Fig. 9. The results show rapid reduction in erosion with increase fibre content up to 0.5%, and then recorded a steadily trend for both soil types. With the exception of the unreinforced blocks, all the reinforced soil blocks passed the erosion test for soil R, which is less than 1 mm/min as general requirement for external walls (Walker, 2004). Contrarily, all the blocks from soil B failed the test and therefore not suitable for external walls but can be used for internal walling; however, there was reduction in the erosion for fibre reinforced soil blocks as compared to the unreinforced.

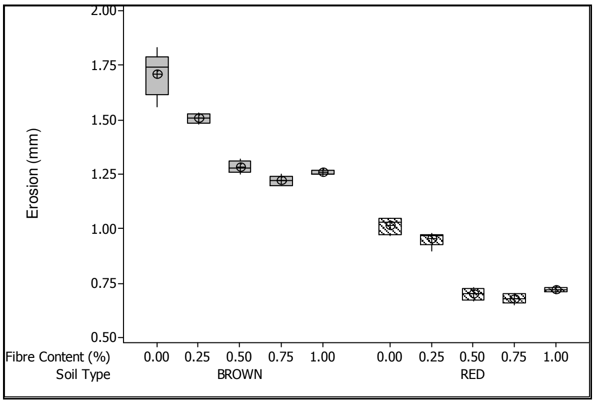

Fig. 9: Erosion test results.

This means that the inclusion of the sugarcane bagasse fibres in the soil matrix increased the soil resistance against erosion. It must be noted that the test requirement (pass or fail) by Walker (2004) is for cement stabilised soil blocks. The increase resistance of the reinforced soil blocks could be explained by the fibres' ability to block the water from penetrating through the soil particles, thereby reducing the eroding effect on the blocks. This test is important, particularly for high rainfall areas where erosion of earth buildings is common (Danso et al., 2015b). Paired sample t-test was conducted at 95% confidence interval with the two soil values recorded <0.001 P-value (Tab. 5), which means there is a significant difference in erosion between soil R and soil B.

Tab. 5: Test of significance difference between erosion of soil R and soil B.

Soil	N	Median	25%	75%	Z	P-value
R	25	0.73	0.70	0.97	4.374	<0.001
B	25	1.28	1.25	1.53		

4 CONCLUSION

The effects of sugarcane bagasse fibres on the strength properties of soil blocks were investigated in this study. The addition of fibres to the soil blocks contributed to a reduction in density of the blocks, which could be attributed to the low density of the fibre. This means that when the blocks are used for building houses, the total weight of the structure will be reduced. The fibre reinforced soil blocks were found to have a high water absorption rate, which was due to the fibres pores' effect on the blocks. This implies high fibre content in the soil blocks may absorb more water in rainy season which could affect some engineering properties of the blocks. This is important due to the strong negative relationship that was found between water absorption and density of the enhanced soil blocks; thus when the water absorption increased the density decreased.

Compressive strength and tensile strength of the reinforced soil blocks increased over the unreinforced soil blocks, and the optimum effectiveness of the enhancement was obtained at 0.5% mass content of the fibres to the soil. This means that the sugarcane bagasse fibres inclusion in soil blocks positively affect both the compressive and tensile strengths of the blocks. This is essential because compressive and tensile strengths are the primary indicators for determining the mechanical properties of soil blocks. 0.5% sugarcane bagasse fibre content by mass is therefore recommended to practitioners for use in enhancing the strength properties of soil blocks. Furthermore, the use of sugarcane bagasse fibres as reinforcement in the soil blocks reduced the rate of erosion of the soil blocks when subjected to water spray test. This indicates that the reinforced soil blocks have better resistance against erosion than the unreinforced soil blocks, which will contribute to solving the durability problem in earthen construction. Earthen construction practitioners and users should note that the inclusion of fibres in soil blocks could solve some of the problems earth construction suffers such as low strength and lack of durability.

In addition, the study established that the type of soil used for producing the blocks is important since soil is the larger material in the composite, constituting not less than 99% of the total weight of the reinforced soil blocks. It was found that soil R performed significantly better than soil B in the entire test performed, which was primarily linked to higher clay content in soil R. Practitioners and users of earthen construction may consider the use of high clayey soil as it provided better performance properties of soil blocks reinforced with natural fibres, contrarily to binders which perform better in sandy soil. The reinforced soil blocks are found to be suitable for use as a building material especially in developing countries, where housing deficits are high due to high cost of conventional building materials, meanwhile soil and bio-based materials are abundant and at low-cost.

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