

Influence of Empty Fruit Bunch Stalk and Spikelet Fibres on the Mechanical Properties of Cement-stabilised Soil

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ABSTRACT--- *The performance of natural-fibre reinforced cement stabilized soil prepared differently with stalk and spikelet from empty fruit bunch (EFB) was investigated. Standard test specimens were prepared with fibre loading varied from 0 to 3.0wt% and tested in compression and flexure for cured strength after 7 and 28 days. The densities of the composites were also determined. The test results are compared for cement stabilized soil without fibre additions as well as between reinforcement with stalk or spikelet fibre. The introduction of fibres prominently improves the compressive and bending strength of the composites, suggesting possibilities of reducing cement additions by introducing natural fibre reinforcements. The improvement for spikelet fibre reinforced soil is consistently higher for spikelet fibres than for stalk fibre. The separation and differentiated use of stalk and spikelet presents the possibility of enhancing the sustainability of recycling EFB for competing uses in nutrient recycling and natural fibre production.*

Keywords--- sustainability; natural fibres; cement-stabilised soil composites,; EFB, stalk; spikelet; compressive strength,; flexural strength

1. INTRODUCTION

The construction and automobile sectors represent the highest consumers of raw and processed materials and any improvements in resource utilisation in these sectors is expected to have a big impact on sustainability of manufacturing and infrastructure development. Increasing socio-economic and environmental sustainability are providing construction industry being a global emerging sector in a highly developed and developing countries [1,2]. These two sectors are increasingly using composites in place of conventional materials and natural fibres are more actively investigated as reinforcements for both organic and inorganic matrix composites. The competitive advantage of natural fibres compared to synthetic polymeric, glass and carbon fibres is due to several factors including; environmental impact of production, renewable sources, industrial safety in producing and handling, higher specific strengths and lower production costs. Earth is the oldest material used for buildings and the Egyptians first used straw to stabilise earth more than 3000 years ago. About 50% of the world population use natural materials for their structures, with majority in Africa, Asia and Latin America. Sustained interest in earth buildings is attributed to availability of raw materials, low processing requirements, low cost, and low embodied energy [3]. The use of binders to improve the properties of earth is widespread and these include synthetic and natural fibres, lime and hydraulic cement. In the home construction sub-sector, earth-based composites are used in a variety of products such as walls, decking, fencing, window frames, panels and roofing/ceiling tiles.

Additives like cement and lime, bitumen and fibres have been used to ameliorate mechanical performance and longevity of soil blocks. Gaining the strengthening mechanisms differ according to additive. In the case of cement, this is typically achieved through additions of up to 15 wt% hydraulic cements [4, 5, 6]. Strength is also dependent on density and this can be controlled by the compaction pressure, for any given formulation. The introduction of cements however leads to issues of shrinkage that must be controlled and increases the embodied energy, thus reducing the sustainability of earth as a construction material. Fibres in stabilized earth brick decreases shrinkage and increases tensile and shearing strengths [7, 8, 9]. Consoli et al. (2002) [10] have reviewed that fibre-reinforced in cement treated soil increases the peak and residual shear strength with changes in their brittle to ductile behaviour. Both natural and synthetic fibres have been used and these studies have demonstrated that sisal [8], coconut fiber [11, 12], straw [13] and polyethylene [14] can all be feasible options. Agricultural residues as source of natural fibres are of particular interest because they can be available in

large quantities from the cultivation and transformation of food and energy crops, as well as in significant quantities in rural settings

Palm oil is the most important seed oil globally and its production generates important amounts of fibrous waste, notably in the empty fruit bunch (EFB). Studies have shown that fibres from the empty fruit bunch can be used as reinforcement in polymers and cements, with improvements in performance EFB has also been investigated for many competing uses such as; nutrient recycling, renewable energy production, mulching and soil enhancer, substrate for mushroom and pulping for paper. All recycling options that do not return EFB to the farms will negatively affect farm-gate nutrient balance which compares the nutrients exported in marketable products with fertilizer inputs, resulting to reduced sustainability in farm practice (RSPO) Previous studies have demonstrated that fibres from the spikelet and stalk have different composition and properties [15]. A judicious exploitation of this residue for co-product development is expected to promote nutrient recycling as stipulated by the RSPO and improve the availability of eco-friendly materials for home constructions..

2. MATERIALS AND METHODS

Empty fruit bunches for stalk and spikelet were obtained from an oil mill of a national agro - industrial operator, Cameroon Development Corporation (C.D.C) located at Mondoni in the South West Region of Cameroon. The stalks and spikelet were shredded, the fibres obtained washed and then ground to pass through a 2mm mesh sieve. Soil samples were obtained from Bamenda, North West Region of Cameroon from a sampling site 632820.96m E and 662930.41m N Soil sample was taken from the homogenous layers and below 150cm from the top of soil to exclude all organic matter. Portland cement was a commercial grade used for home constructions produced by the national cement company CIMENCAM. The dry soil and cement were thoroughly mixed up manually with water consistently then fiber was introduced into the process. This process continued until the required results were obtained as tabulated below.

Table 1: Formulation of composites

		%Fibre						
		0	0.25	0.50	0.75	2	2.5	3
%Ceme	0	▪	▪	▪	▪	▪	▪	▪
	5	▪	▪	▪	▪	▪	▪	▪
	10	▪	▪	▪	▪	▪	▪	▪
	15	▪	▪	▪	▪	▪	▪	▪

Specimens of standard dimensions (40mm x 40mm x 40mm) were cast for compressive strength determinations and prismatic specimens of (40mm x 40mm x 160mm) were cast for bending strength. The moulds were filled and a pressure of 0,028MPa was applied on each of the sample in the mould. All the specimens were cured for a period of 7 and 28 days before test. Each mixture had ten samples and the total bricks manufactured were 560 samples each for fibre from stalk and spikelet.

Production of stabilized earth samples

The soil was first mixed with the cement to attain the homogenous structure before adding the fibres in the mixture. The low pressures applied compared to the typical pressures for producing CESB puts the samples closer to adobe, where no pressure is applied.

Curing

After demoulding, the specimens were cured inside a thick plastic pouch for required duration (7 and 28 days) before testing. The cement based composite was kept under thick plastic pouch paper to conserve moisture for hydration,



Figure 1: Sample in curing pouch

Compression test

The compressive test was carried out using RMU machine, serial 121288 in the civil engineering laboratory at the Government Technical High School BAMENDA

The hydraulic machine press was consistently applied on the specimen till failure occur to obtain the maximum load.

The compressive strength was calculated from the maximum load recorded before failure, by.

$$\text{Compressive strength} = F_c / A$$

Where:

F_c: force measured from the compression test machine in N

A: area of the composite brick in mm²

Flexural test

The three point bending test were carried out using RMU machine serial 1461288. The loading arrangement as shown in Figure 3

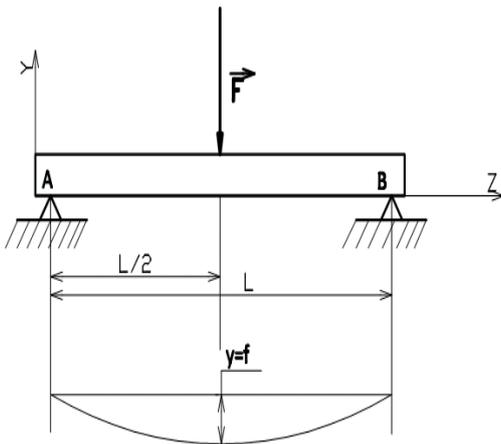


Figure. 2a: 3 point bending test

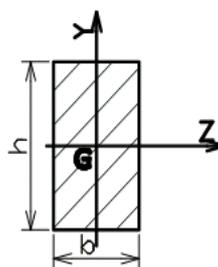


Figure. 2b: Flexural Machine

The moisture contents of the EFB fibre.

Moisture content was carried out using gravimetric method in a muffle furnace. 10g of fibre sample was weighed and dried at 104°C in an oven for 24hrs. The sample were weighed immediately on removal from the oven and stored. The calculations were done as follows:

$$\% \text{ of moisture content} = \frac{(\text{weight of wet sample} - \text{weight of dry sample}) \times 100}{\text{weight of dry sample}}$$

The water absorption contents of the EFB fibre.

The determinations of water absorption (WA) were performed. These were carried out by immersing EFB Fibres in distilled water, at room temperature. After every 2 hours, the samples were removed and the surfaces were dried up using a dry towel for reweighing with a balance of 0.001mg precision within a minute. The water absorption of each specimen calculations were done as follows:

$$\text{Water absorption \%} = \frac{(\text{weight of wet sample} - \text{weight of dry sample}) \times 100}{\text{weight of dry sample}}$$

3. RESULT AND DISCUSSION

DENSITY

Figure 3 reveals that the density of stalk and spikelet reduces with an increase in fibre content

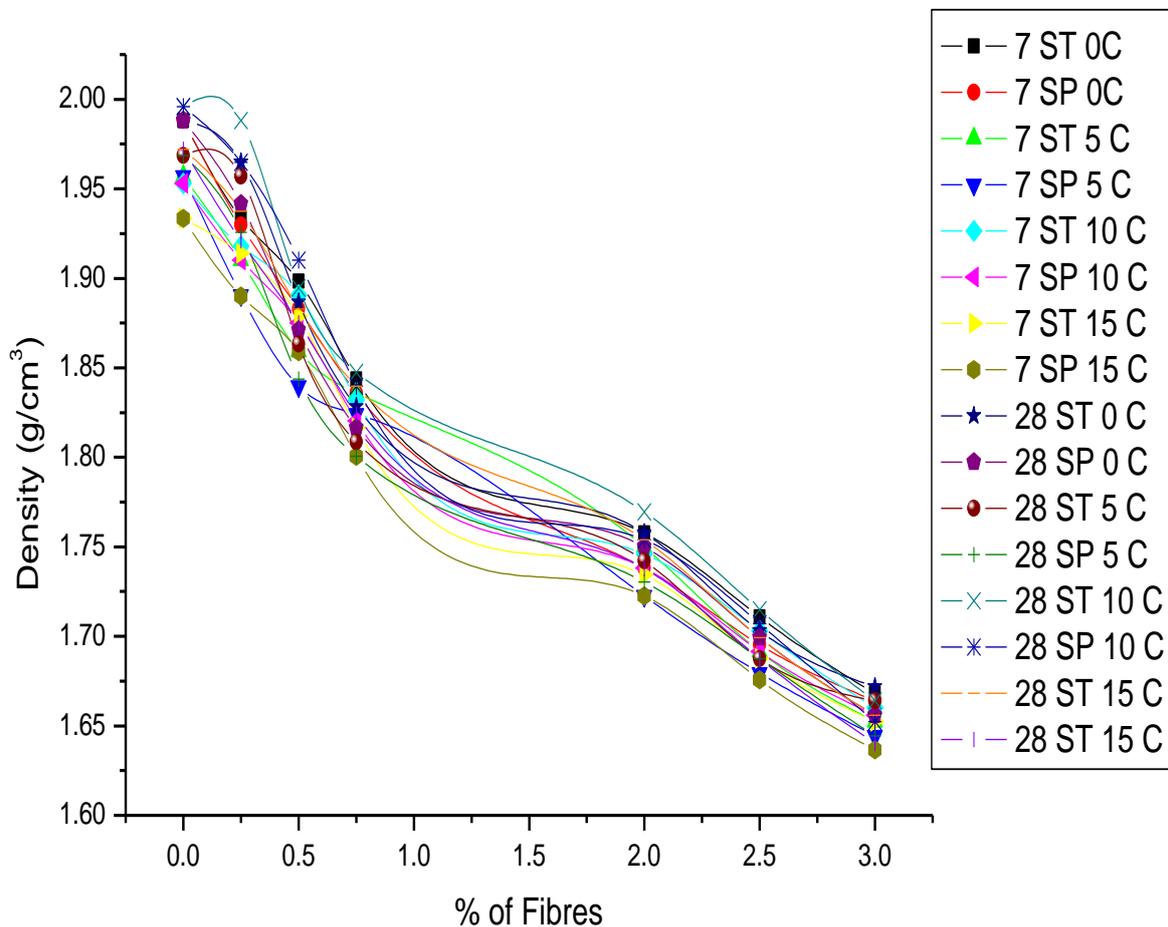


Figure 3: Densities of stabilized reinforced composites

This trend is evident in the plot of the percentage of fibres against the densities of the sample as shown in figure 3. The densities of composites with relatively high fibre loadings (2 to 3%) lie just above the upper limit of the density of lightweight concrete blocks.

Other researchers [16, 17] have reported the decrease in density of cement-stabilized blocks with increase in fibre content and highlighted the potential usefulness for thermal isolation of buildings, especially in regions with extreme climate changes.

$$\text{Compression strength (MPa)} = F_c/A$$

Calculation of compressive strength and statistical analysis

The previous data was analyzed with 99% confidence bounds in the software Matlab version 7.7

The average compressive strength of the samples on fibre from stalk and spikelet composites after 7 days is presented in figure 4 below. It was observed that the results show a little improvement in the compressive strength with an increase of fibre for 7 days of curing.

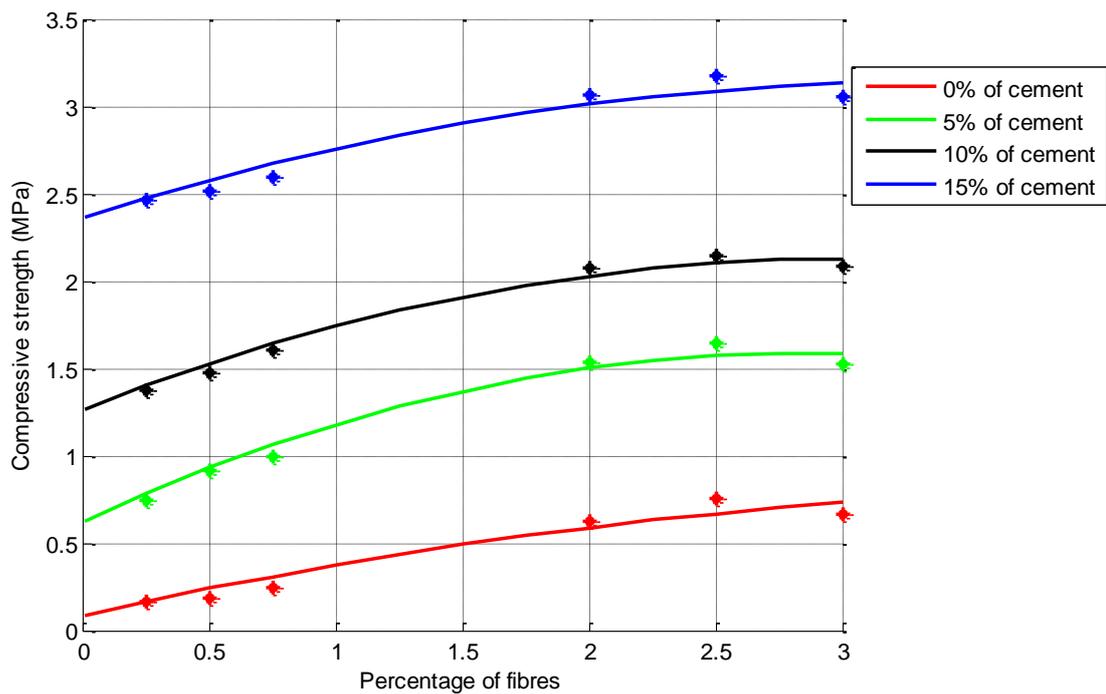


Figure 4: Average Compressive strength vs % Stalk fibres for 7 days of curing

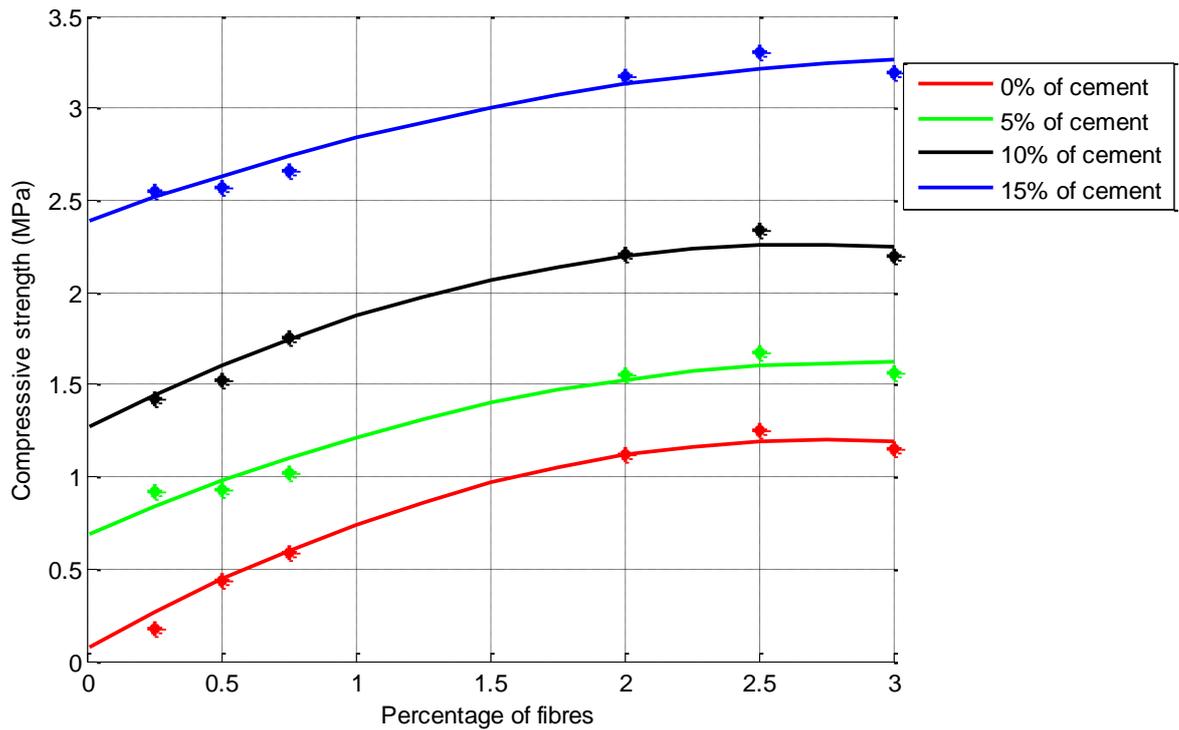
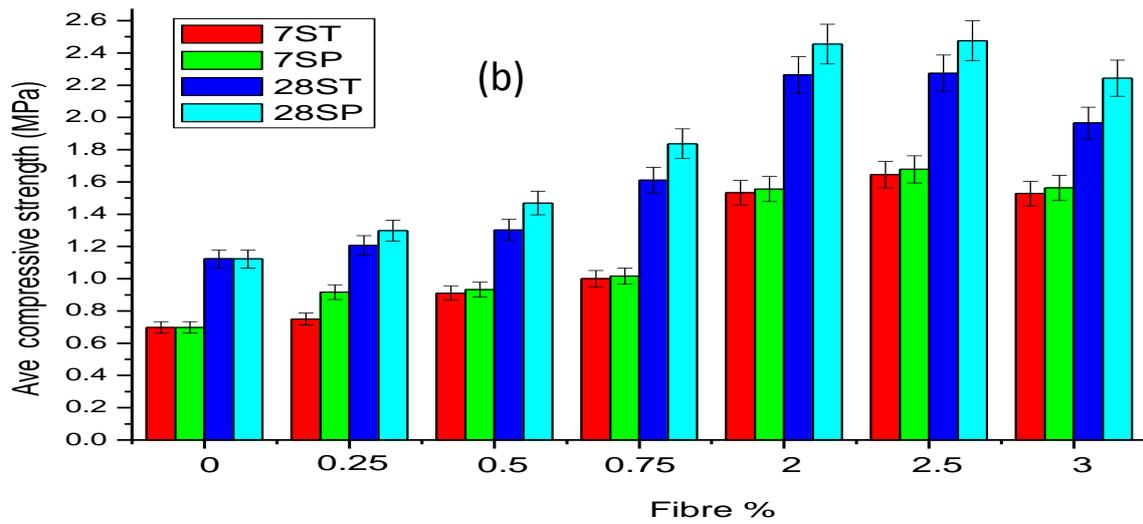
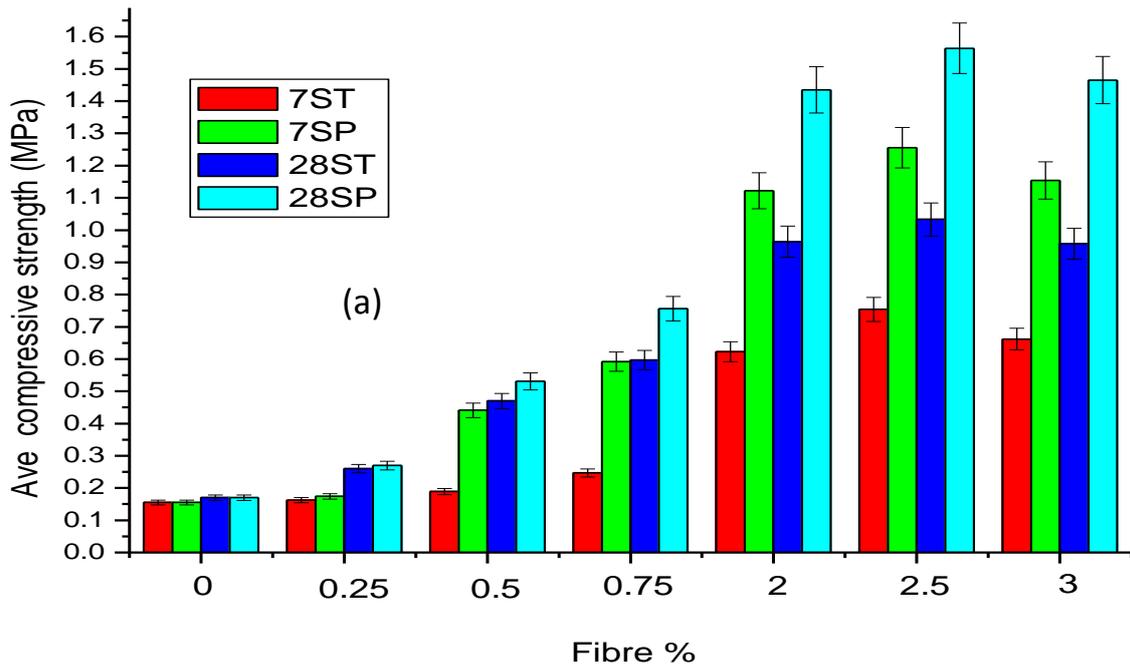


Figure 5: Average Compressive strength vs % spikelet fibres for 7 days of curing

Table 2: Equations for prediction of Average Compressive strength of stalk and Spikelet composites for 7 days of curing

% cement	Average Compressive strength Stalk (MPa)	Average Compressive strength Spikelet (MPa)
0	$\sigma_{st} = -0.03666w_f^2 + 0.3244w_f + 0.08732$	$\sigma_{sp} = -0.1481w_f^2 + 0.8195w_f + 0.07114$
5	$\sigma_{st} = -0.1169w_f^2 + 0.6717w_f + 0.6247$	$\sigma_{sp} = -0.1085w_f^2 + 0.6375w_f + 0.6864$
10	$\sigma_{st} = -0.09366w_f^2 + 0.5677w_f + 1.268$	$\sigma_{sp} = -0.1372w_f^2 + 0.7367w_f + 1.272$
15	$\sigma_{st} = -0.06815w_f^2 + 0.4608w_f + 2.363$	$\sigma_{sp} = -0.07814w_f^2 + 0.5264w_f + 2.389$



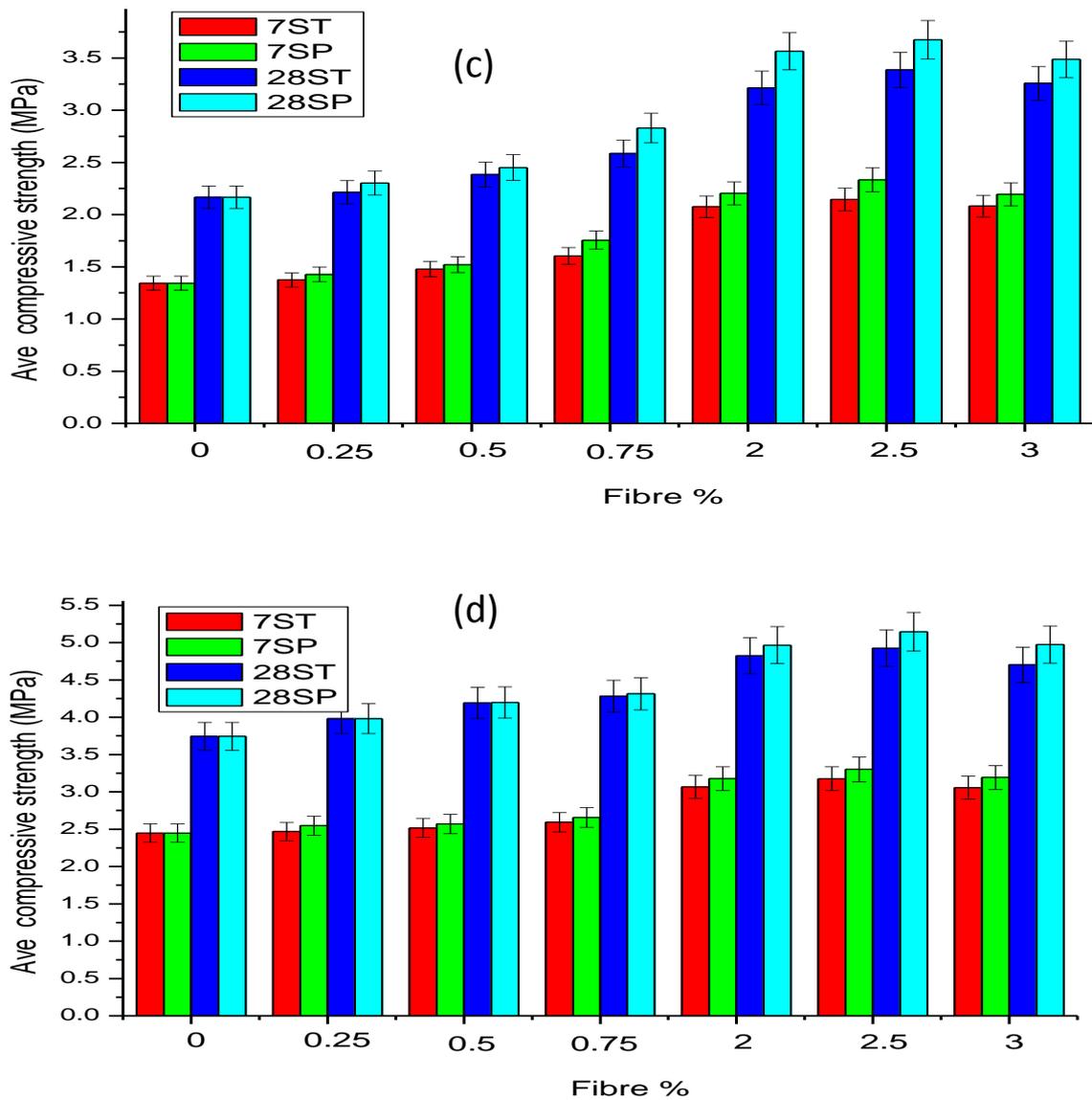


Figure6: Compressive error bar for 7 and 28 days with a) 0% cement b) 5% cement c) 10% cement d) 15% cement

The introduction of fibres improves compressive strength for all formulations, with the highest improvements (up to 400%), recorded for mixtures without or low cement additions (up to 200%). The compressive strengths lie well within the range of 1-4MN/m² recommended for single storey buildings for most of the formulations. The exceptions are formulations with 0% cement and fibre loadings lower than 2%, and 5% cement at fibre loadings lower than 0.5%. At high fibre loadings the performance of the composites containing 5% cement and above approaches or exceeds the 2.8MN/m² recommended for precast masonry units and load bearing fired clay bricks.

Flexural Test Results on stalk and spikelet Composites

$$\text{Flexural strength } \sigma = \frac{3FL}{2bh^2} \text{ for a rectangular cross section}$$

For 560 samples tested, failure mostly occurred at the mid point Typical Young Modulus vs % of fibres are presented in modeling of flexural results. In this study the Young Modulus and tensile strength were higher in the spikelet than the stalk. Generally, the fibre-reinforced soil performed better in post-initial crack behaviour compared to the plain matrix. The non-reinforced samples exhibited sudden failure in all instances whilst more gradual was observed for all fibre-reinforced samples

. Figure 7 represent the variation strength of stalk and spikelet The flexural test increases significantly with increase in fibres content but drops at fibre content beyond 3wt%. probably due to various factors such as fibre to fibre interaction, voids and dispersion problems. In all cases stalk composites show inferior performance to spikelet composites either with or without cement. The differences are most pronounced at low cement content.

The variation of specific strength of both the stalk and spikelet composites with different cement content is presented The improvement in strength for the composites with the addition of fibres content is more significant at lower cement additions.

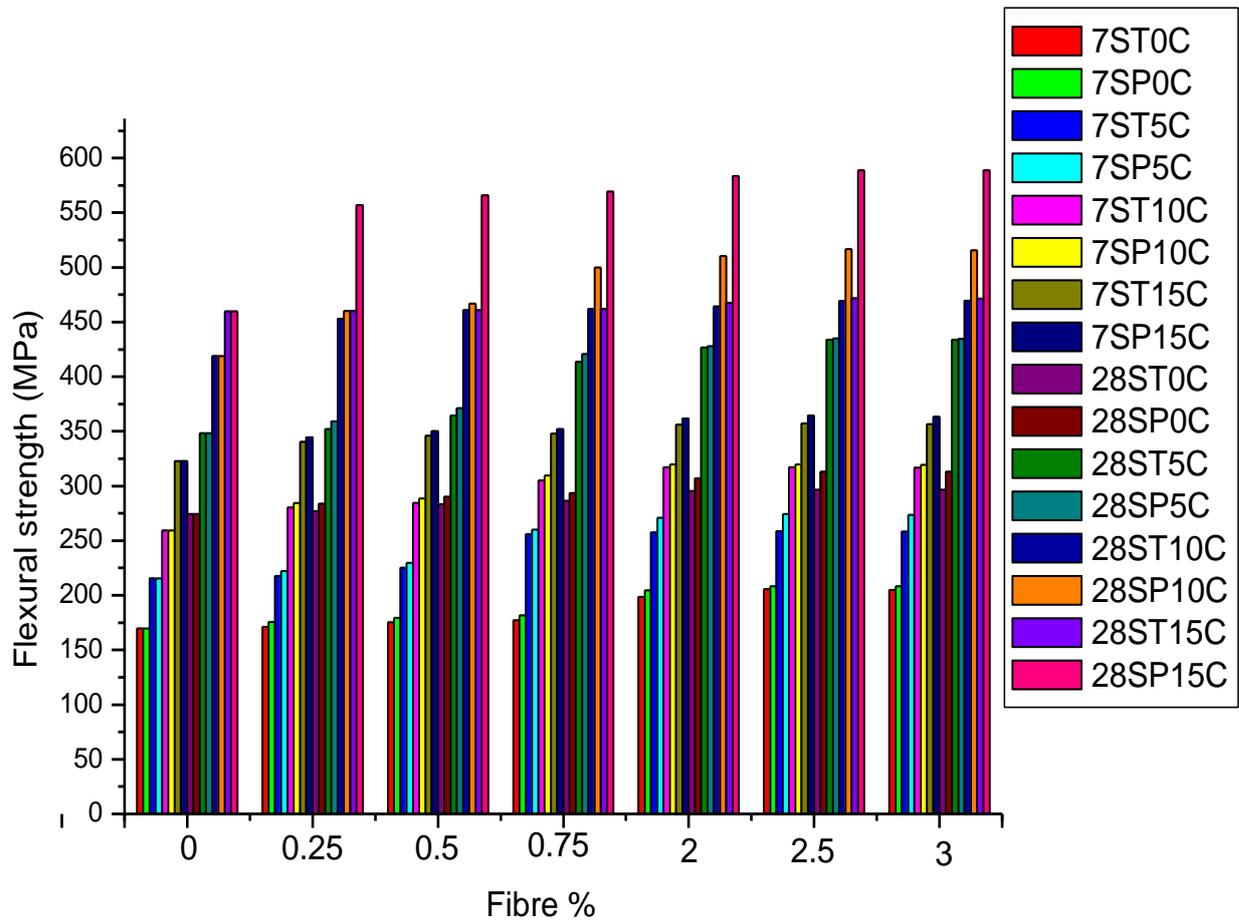


Figure 7: The Flexural Strength of composite

Shear Strength

. The different Shear Strength of stalk and spikelet is presented in Figure 8. The shear strength shows some slight increase with addition of fibres content up to 2.5% where further addition of fibres content decreases. This trend is exhibited by both stalk and spikelet cement-stabilised soil composites. This reduction may be due to the formation of voids in the matrix which is generally located at the inter-laminar region of composites. In the present investigation, the maximum value of shear strength has been recorded for the spikelet composite with 2.5% of fibres.

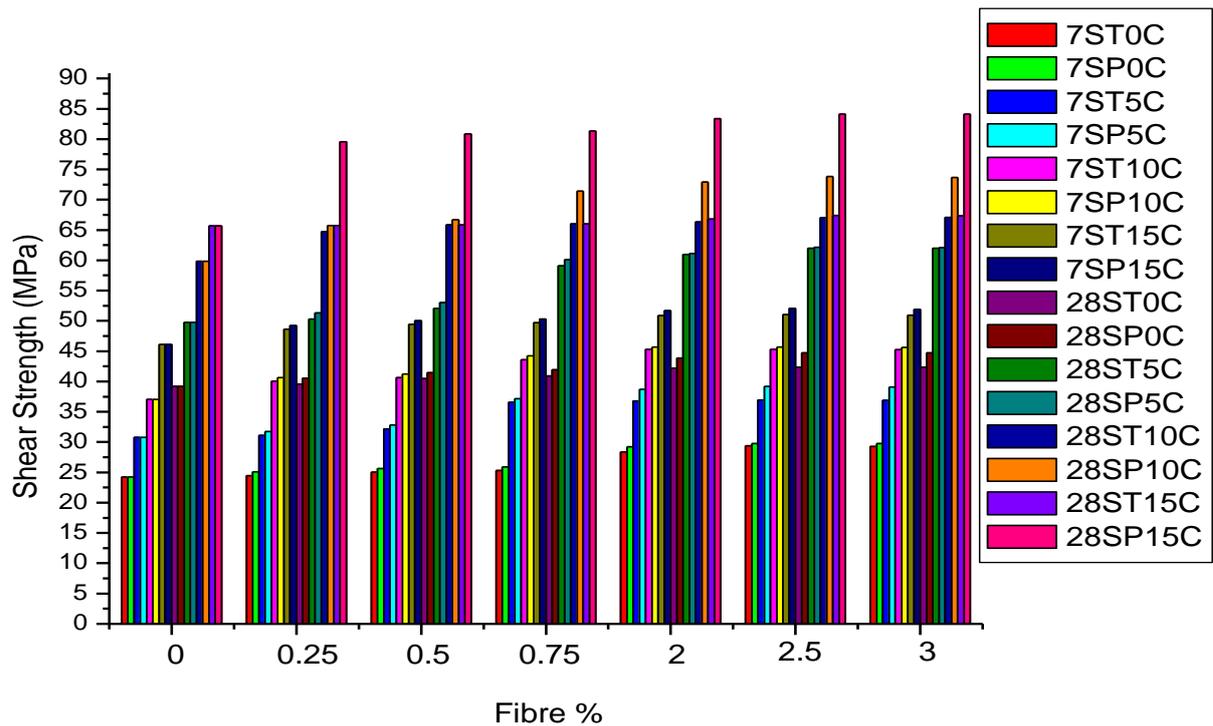


Figure 8: The Shear Strength of composites

Fibres are known to oppose crack formation in step with increasing stress and also bridge micro cracks from expanding [18].

It was also observed that some of the fibres bridged cracks. In this study, the fibres from the spikelet had a higher Young Modulus and produced a higher strength in matrices compared to the stalk fibres.

Moisture content

The moisture content of EFB fibres was higher in stalk than spikelet and review from the other researcher that the results was within the range as summarized in table 3 below

Table 3: Moisture content

Fibres	Moisture Content	Author
EFB	2.2-9.5%	Mohd et al (2009)
EFB	10.4%	Ismail et al (1997)
STALK FROM EFB	7.31- 10.28%	Present study
SPIKELET FROM EFB	2.18 – 6.42%	Present study

The higher the moisture content of the natural fibre the higher is the change in the mechanical and physical properties of composite can be affected and it leads to poor wettability with matrix which results in a weak interfacial bonding between the fibre and matrix [19].

Water absorption

The water absorption rate is higher in stalk than in spikelet. This may be due to the bigger viol found at the middle of the stalk of EFB fibres. The maximum water absorption of stalk and spikelet were 158.48% and 177.97% respectively. The water absorption of different part of EFB oil palm is presented in figure 9 below.

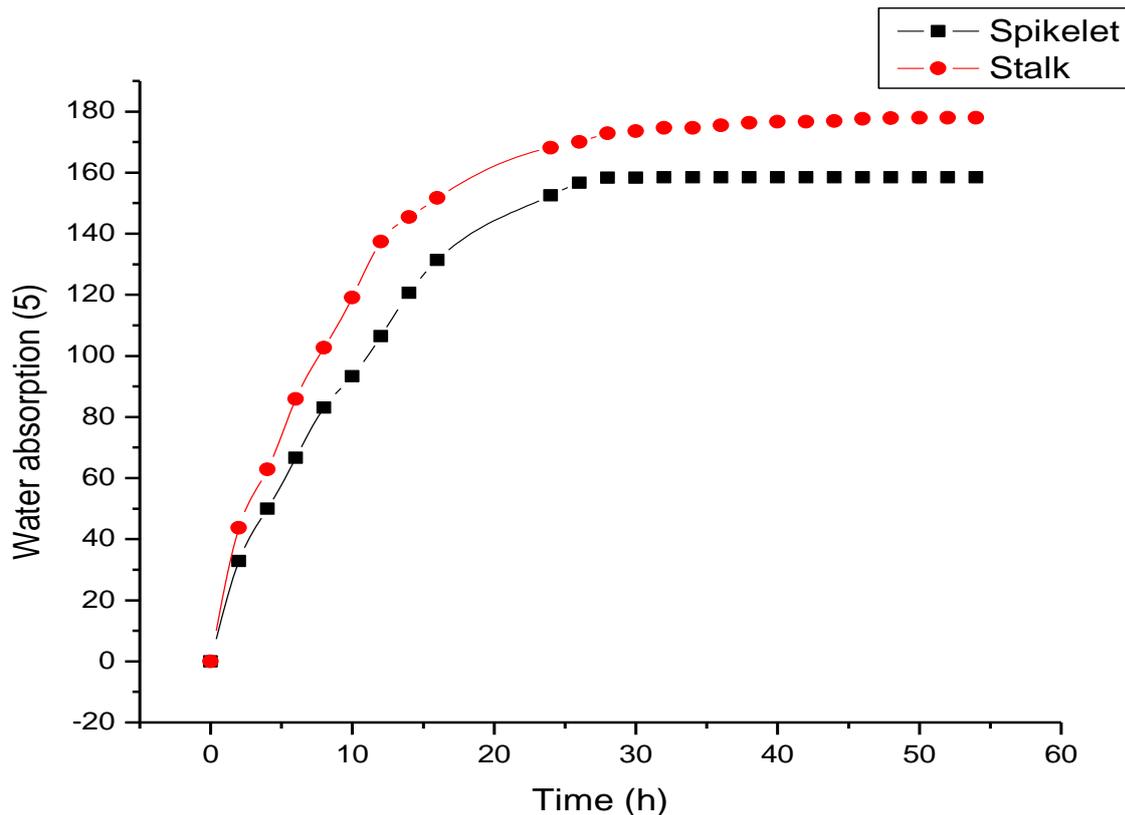


Figure 9: Water absorption of Stalk

The water absorption by the fibre is due to the fact that areca fibre contains very high percentage of hemicellulose in its structure. Also, in all natural cellulose fibres, a hollow cavity called lumen exists in the unit cell of the fibres which generates more pathways for water to diffusing into the fibre [20]. It also shows that the percentage of water uptake decreased with an immersion time. This is attributed to the fact that the initial and second absorption phases are governed respectively by the wetting of fibres and the capillary absorption process where the water diffuses into the fibres until reaching a maximum absorption. When the immersion time becomes significant, a decrease in the water absorption is due to the hydrophilic property of cellulosic fibres as more water molecules penetrate into the micro cracks present in these fibres, making the fibres swell and eventually leading to failure [21, 22]. It shows that alkali treatment had improved the ability of EFB fibres to absorb water. This improvement is likely due to the removal of the oil and waxy substances from the raw fibres. It is stated that an alkali treatment results in the partial dissolution of hemicellulose [23]. Hemicellulose, however, is responsible for the water absorption of the fibre [24]. The alkali treatment leads to a partial removal of waxes and therefore an increased accessibility of the protanable surface functions. An increased number of ‘polar’ surface functionalities will increased the amount of water absorbed on the fibres [25, 26]. The swelling process was much faster leading to higher water uptake and also removed the protecting cell-fibres, thus increasing the water absorption. This improvement could also be explained by both the change in the quality of the surface of the areca fibres after alkali treatment and the presence of several hydroxyl groups on these surfaces [27].

4. CONCLUSION

Our study aims at the influence of stalk and spikelet fibre on the mechanical properties of stabilized soil as a strategy for improving the sustainability of recycling EFB and use of cement-stabilised soil in buildings. The results show that there are significant improvements in mechanical performance with the introduction of fibres and differences in the influence of the fibres from the different parts of EFB on mechanical and physical properties. Fibres from the spikelet have superior performance to fibres from the stalk as reinforcement for cement-stabilised soil.

The increase in flexural and compressive strength values peaked at fibre loading of 2.5% fibre content by weight. with the maximum value of strength for our samples were recorded at 2.5% of fibres. The incorporation of fibres into the matrices prevented sudden failure of the tested samples during the test.

5. ACKNOWLEDGMENTS

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