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Properties of Coconut, Oil Palm and Bagasse Fibres: As Potential Building Materials

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Abstract

The use of natural fibres in composite materials is attracting research interest worldwide due to the fibres ability to increase the strength, reduce environmental impact and reduce cost of the material. In this study the properties of coconut husk fibre, oil palm fruit fibre and sugarcane bagasse fibre have been investigated. Experiments on length and diameter, specific weight, tensile strength, modulus of elasticity, moisture content and water absorption tests on the fibres have been conducted to determine their properties for possible use as reinforcement in composite. It was found that different fibres have different properties and behave similarly in wet and damp conditions. The study concludes that all the fibres possess properties that are acceptable as natural fibres to be used as reinforcement in soil blocks.

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Keywords: Coconut fibre, oil palm fibre, sugarcane bagasse fibre, tensile strength, specific weight, water absorption, SEM analysis.

1. Introduction

In the last decade, considerable effort has been directed towards using various natural fibres, which are available in abundance in tropical and sub-tropical countries, as reinforcement in composites for producing cost-effective building materials with a view to have a sustainable development. Natural fibres which are usually used in weaving, sacking and ropes have good potentials to be used as reinforcement in composite materials such as soil blocks [1]. These materials have good physical and mechanical properties, provide good environmental benefits and low cost advantage for use as building material [2]. In addition, natural fibres can be used in composite materials to reduce weight, increase strength and are also very safe during handling, processing and use [1, 3]. Requirement for economical and environmentally friendly materials has extended an interest in natural fibres [4, 5].

The use of natural fibres in composite materials will not only increase the strength of the composite but also address sustainability issues [6]. In addition, these materials will not pollute the environment, utilise local skills, be available and abundant, and be low-cost. Ali [7] 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.

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In tropical and sub-tropical regions, natural fibres such as sisal, bamboo, coconut husk, sugar cane residue (bagasse), oil palm and pineapple leaves are in abundance and cheap. In this study, fibres from agro-based wastes such as coconut husk, oil palm nut fruit and bagasse which are abundant in Ghana are used. The properties of these fibres are investigated for the purpose of using as reinforcement in soil blocks for producing environment friendly and low-cost housing.

1.1. Coconut fibre

Coconut fibre also known as coir is extracted from the outer shell of a coconut fruit. Coconut plants are mainly cultivated in tropical and sub-tropical regions. In Ghana, the annual production of coconut is about 305,000 tones [8], and this generates a lot of waste in the country. Coconut fibres are generally available for use in three main ways, (1) bristle (in long fibre), (2) mattress (in short fibre) and (3) decorticated (mixed fibre lengths) [7]. The engineering use of coconut fibre is not much known, however it possesses good properties for engineering purposes. Coconut fibre dimensions vary, and are said to be dependent on the type of species, location and maturity of the coconut plant. The flexibility and rupture of the fibre is affected by the length-to-diameter (aspect ratio) of the fibre which largely determines its usage [7]. Coconut fibre consists mainly of cellulose, hemi-cellulose and lignin as its main composition which affect the physical and mechanical properties of the fibre.

1.2. Oil palm fibre

Oil palm fibres are extracted from three parts of oil palm plant, namely (1) empty fruit bunch, (2) trunk/stem and (3) the fruit nut. Oil palm originally came from the Western part of Africa in the tropical rain forest where it is processed for its fruits for consumption as edible food and oil, medicine, wine, hand craft [9] and for industrial used. The annual production of oil palm in Ghana is about 1,900,000 tones [8]. Oil palm fibres are porous, short in length and have varying diameter which affect the mechanical properties. Oil palm fibres have low cellulose content as compare to coconut and bagasse fibres, which makes it easy to extract.

1.3. Sugarcane bagasse fibre

Sugarcane bagasse is the residue obtained after extracting the sugarcane juice for sugar or wine [10]. During the processing, the sugarcane stalk is crushed to extract sucrose, and the process produces a large volume (32%) of bagasse [11]. The fibres are then extracted from the sugarcane residue; hence, bagasse fibre is easily obtained as a waste product [12]. The annual production of sugarcane in Ghana is about 145,000 tones [8]. The stalk of the sugarcane plant includes an outer rind and inner pith, the rind is made up of a hard fibrous substance surrounding a central core of pith, which is softer due to a spongy structured component [12]. Sugarcane fibre is used due to its properties as a natural filler reinforcement that has played an important role in enhancing the composites performance [13].

2. Experimental methods

2.1. Fibres

Fibres obtained from three different agricultural wastes (sugarcane residue 'bagasse', coconut husk and oil palm fruit residue) were used for the study. These were selected because they are among the common agricultural wastes generated in Ghana. These wastes are usually burnt which pollutes the air and affect the health of the general public.

The waste fibres have been selected as they cover a wide range of properties, and are also abundant agricultural waste materials in West Africa. They are not the only wastes in the study location from which their fibres can be used. There are other waste from agriculture products such as bamboo, sisal and rice husk which are also available. However, lack of clear methodological process of extracting the fibres, the low scale production in the study location resulted in their exclusion from the study.

2.2. Preparation of fibres

The agricultural wastes were processed to obtain their fibres. The fibres were prepared through different, but similar processes for each type. The processes have been described below.

Bagasse fibres used in the study were obtained from sugarcane residue at a local sugarcane alcohol distillery mill in Somanya, Ghana (Fig. 1a). The juice (liquid) from the sugarcane had been extracted for producing alcoholic drink leaving the residue (bagasse). The sugarcane residue was already crushed (Fig. 1b) at different sizes through the alcohol extraction process. It was soaked in water for 48 hr, and then cut at their joint at smaller sizes and beaten manually on wooden surface with a wooden bar of 80 mm diameter and 450 mm length until the fibres were exposed. The fibres were then separated from the pith particles and washed in water. The fibres were spread out in the sun for a period of two weeks to dry (Fig. 1c). To assure a uniform drying process the layer of bagasse fibre was turned over once a day.

Fig. 1: Preparation of bagasse fibre

(a) Extraction of juice from sugarcane, (b) sugarcane residue, (c) bagasse fibres extracted

Coconut fibres were obtained from the husk of coconut fruit. They are the fibrous material found between the internal shell and the outer coat of a coconut fruit. The coconut husks were obtained from coconut vending points in Cape Coast, Ghana. After the juice (liquid) and the food were consumed from the coconut fruit, the vendors collect the husks with the internal shells as waste to dispose them by throwing away or burning. The wastes were collected, and the shells removed, leaving the fibrous husks (Fig. 2a). The fibrous husks were soaked in water for 48 hrs and beaten with wooden bar on wooden surface to expose the fibres. The fibres were then separated from the pith particles and washed. The fibres were dried (Fig. 2b) under the sun for two weeks, turning it over each day to ensure uniform drying.

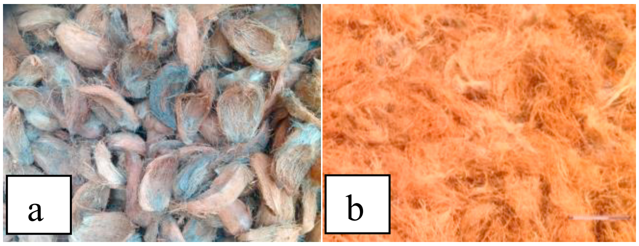

Fig. 2: Preparation of coconut fibres

(a) Coconut husks, (b) coconut husk fibres

Fig. 3: Drying of oil palm fruit fibres

Oil palm fruit fibres were obtained from palm oil extraction plant in Kumasi, Ghana. The fruits were crushed and the oil extracted, leaving the fibres and the shells as waste to be thrown away or burned. These wastes were collected, and the fibres were separated from the shells. The fibres were washed in warm water to remove any oil content left in them. They were then dried in the sun (Fig. 3) for two weeks.

2.3. Methods for determining fibres properties

The fibres were examined to determine their physical and mechanical properties. The physical properties of the fibres use determined using fibre length and diameter, moisture content, density and water absorption. The mechanical property of the fibres was also determined using tensile strength test of the fibres. These tests were conducted using the methodological approach of Ghavami, et al. [14], because it provided detailed information on determining the properties of natural fibres such as bamboo, sisal and coconut. The microstructure of the fibres was determined using scanning electron microscopy (SEM) analysis.

The lengths of the fibres were measured with a steel rule. The fibres were straightened on steel rule for which their lengths were measured. One hundred specimens (the same used for diameter measurement) from each fibre type were used. After that the mean, standard deviation and relative standard deviation (RSD) of each type of fibre were determined after normality tests were conducted with Minitab 16 statistical software. The fibres were measured at five different points along the length due to irregular shape of the fibres for their mean and distribution diameters to be determined.

A compound light Microscope (Leitz HM-LUX3) of 10x magnification with graticule eye piece was used for measurement. The eyepiece graticule which is located at the primary image of the microscope was focused on the fibres. Each fibre was superimposed on the slide for 0.1mm ÷ objective magnification. Typically, this gives 0.01mm per division at 10x. The diameters of the fibres were checked by calibrating the eyepiece using a stage micrometre.

The dry moisture content was determined by using three bundles of each fibre type, which were first air-dried and the weight measured with electronic balance as *Pd*, then the same fibres were oven-dried at temperature 45 ^{O}C for 24 hrs and the weights measure as *Po*. The moisture content *(MC)* was then calculated by the Equation 1.

$$MC = \frac{P_d - P_o}{P_o} \times 100 \tag{1}$$

In determining the specific weight *(γ)*, three bundles of each fibre type were air-dried and the weight measured with electronic balance as *Pd*. The volumes of the displaced water after immersion of fibres for 24 hrs were measured as *V*. The specific weight was calculated using the Equation 2.

$$\gamma = \frac{P_d}{V} \tag{2}$$

The mean, standard deviation and RSD of each fibre type results were determined after normality tests were conducted.

The water absorption of the fibres was determined by air-drying three bundles of each fibre type and their weights measured *(Pd)*, then the fibres were soaked in water and their weights measured *(Ph)* at 24 hrs intervals for 14 days. The water absorption *(W)* of the fibres was calculated by the Equation 3.

$$W = \frac{P_h - P_d}{P_d} \times 100 \tag{3}$$

The tensile strength test was conducted on dried and wet fibres. For the wet sample, randomly selected fibres were kept in: (1) water, and (2) damp tissue for which tests were done at 30 days intervals for 120 days. The tests were carried out in a testing machine "Tinius Olsen H50KS" (Fig. 4a) with a maximum capacity of 50 KN. Each fibre was held in the test machine and load applied (Fig. 4b) starting from 50 N and at speed of 1 mm/min which continued until the fibres failed. The maximum load at which the fibres failed was recorded and the tensile strength calculated.

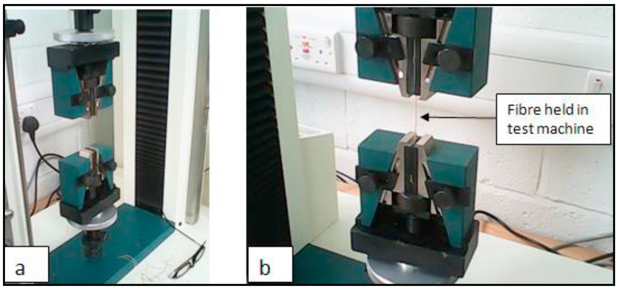

Fig. 4: Determining tensile strength of fibres using Tinius Olsen H50KS
(a) Test set-up, (b) Fibre held in test machine under tensile stress

After the tensile strengths tests were carried out, the maximum load *(N)* and distance (mm) at which the fibre failed were recorded for which the tensile stress *(σ)* and tensile strain *(ε)* were calculated. After, the modulus of elasticity *(E)* of the fibres was calculated using the Equation 4. The mean, standard deviation and RSD of each fibre type results were determined after normality tests were conducted.

$$E = \frac{\sigma}{\varepsilon} \tag{4}$$

SEM images of single fibre were taken with JSM-6100 scanning microscope at 35x and 500x magnification for each fibre type to show the texture of the fibres.

3. Results and analysis

3.1. Lengths and diameters of fibres

Table 1 presents the summary of the results obtained from laboratory tests performed on the lengths and diameters of coconut, oil palm and bagasse fibres.

Table 1: Lengths and diameters of fibres

Fibre	Length (mm)				Diameter (mm)			
	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)
Bagasse	110	28	26	0.056	0.78	0.19	23	0.270
Oil palm	38	6	17	0.136	0.38	0.08	23	0.075
Coconut	103	17	17	0.112	0.40	0.17	42	0.065

Bagasse fibre recorded the highest average length and diameter while oil palm fibre had the least based on the 100 fibres tested. The fibres lengths and diameters recorded are within the values obtained in previous studies [15-17].

3.2. Dry moisture content and specific weight

The dry moisture content and specific weight results of the fibres are presented in Table 2.

Table 2: Dry natural moisture content and specific weight

Fibre	Dry moisture content (%)				Specific weight (g/cm^3)			
	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)
Bagasse	9.7	0.4	4	0.633	0.56	0.04	7	0.398
Oil palm	7.4	0.3	4	0.264	0.77	0.03	4	0.631
Coconut	6.4	0.3	5	0.631	0.81	0.04	5	0.399

Bagasse fibre had the highest dry moisture content (9.7 %) while coconut fibre recorded the least (6.4 %). Contrarily, coconut fibre obtained the highest specific weight (0.81 g/cm3) while bagasse fibre had the least (0.56 g/cm3). Moisture is attracted through the hydrogen bonding of natural fibres due to the hydroxy and oxygen-containing groups [18]. Any change in the moisture content of natural fibres may cause changes in the dimension of a composite and also cause swelling and shrinkage when dried [19]. This means that the low dry moisture contents of the fibres are good for use as reinforcement material for soil blocks.

The fibres specific weights recorded are within the values obtained in previous studies [14, 16, 17]. The relationship between specific weight and dry moisture content of each fibre can be seen in Fig. 5. It shows that bagasse fibre with less specific weight rather obtained a high dry moisture content, while coconut fibre with high specific weight had less dry moisture content.

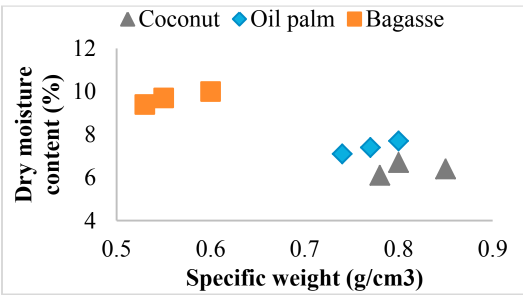

Fig. 5: Relationship between dry moisture content and specific weight of fibres

3.3. Water absorption

The percentage water absorption of the fibres was studied for a period of 14 days. The trend of the absorption is presented in Fig. 6. The results show that there was rapid absorption of water by all the fibre types in the first 24 hrs. The absorption continued gradually until the fourth day and then very low increase was observed until the fourteenth day, a similar trend was found in the study by Ghavami, et al. [14].

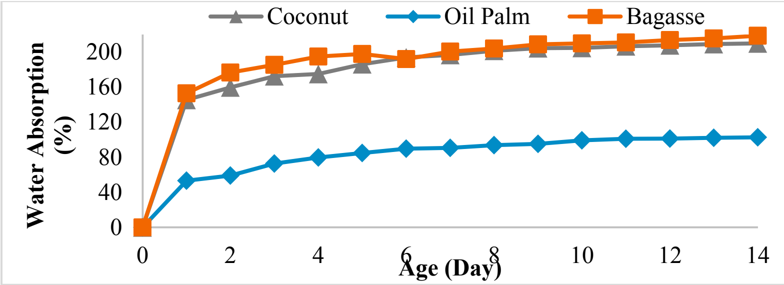

Fig. 6: Water absorption behaviour of fibres for 14 days

Bagasse and coconut fibres recorded closely high water absorption rates, with bagasse obtained the highest, thus an increase of between 153% on the first 24 hr and 219% on the fourteenth day. Oil palm fibre recorded the least absorption between 54% on the first 24 hr and 103% on the fourteenth day. Study on sisal, coir and bamboo fibres by Sen and Reddy [1] recorded similar absorption rates. However, kenaf fibres which was studied by Millogo, et al. [20] obtained a very high water absorption of 307%.

3.4. Tensile strength and modulus of elasticity

The results of the tensile strength and the modulus of elasticity of dry fibres are presented in Table 3.

Table 3: Tensile strength and modulus of elasticity

Fibre	Tensile strength (MPa)				Modulus of elasticity (GPa)			
	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)	Mean	Std Dev	RSD (%)	Anderson-Darling Normality (p-value)
Bagasse	42	11	26	0.875	0.89	0.22	24	0.939
Oil palm	110	21	19	0.725	0.95	0.12	12	0.638
Coconut	162	45	28	0.673	2.49	0.16	6	0.347

It shows that coconut fibre obtained the highest tensile strength and modulus of elasticity while bagasse had the least. The tensile strength and modulus of elasticity results recorded are within the values obtained in previous studies [6, 14, 16, 17].

The changes in the tensile strength of the fibres kept in water (wet) and damp tissue (damp) are reported in Fig. 7. The day zero (0) on the graph represent tensile strength of the dry fibres. It can be seen that all the fibres recorded decreasing tensile strength in both wet and damp conditions over age. There was a reduction in tensile strength of about 50% for all the fibres in both damp and wet conditions at day 120 as compare to the tensile strength of dry fibres. There was slightly increased tensile strength of fibres in damp condition over the wet condition for all the fibre types, however the difference seem very little.

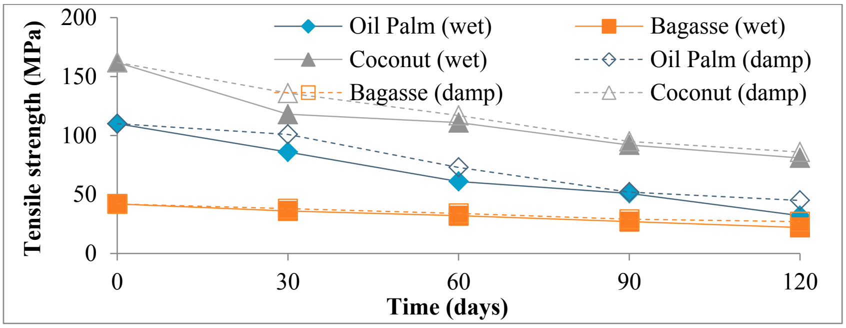

Fig. 7: Tensile strength of fibres in wet and damp conditions over 120 days

This implies that the tensile strength of natural fibres depreciates slightly more in water than in damp condition. A similar result was observed by Ghavami, et al. [14].

3.1. SEM of fibres

The images of the fibres and SEM results of each fibre type are shown in Figs. 8, 9 and 10 respectively for bagasse, coconut and oil palm fibres. SEM images of single fibre were taken in 35x and 500x magnifications for each fibre type to show the texture of the fibres. As can be seen, the bagasse fibres are rougher in texture as compared to coconut and oil palm fibres. The oil palm fibres look slightly smoother than the coconut. Similar result was observed by Danso et al [21].

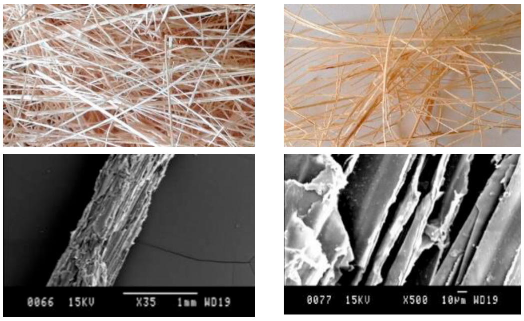

Fig. 8: Photograph and SEM micrographs of bagasse fibres

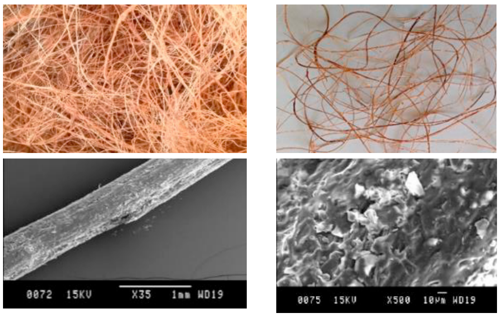

Fig. 9: Photograph and SEM micrographs of coconut fibres

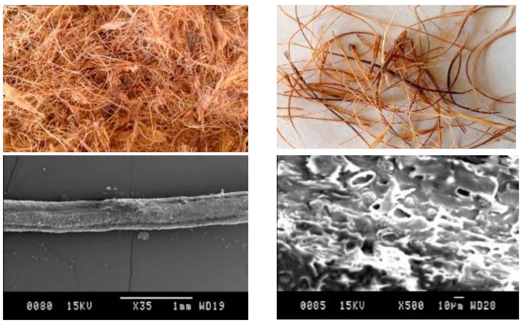

Fig. 10: Photograph and SEM micrographs of oil palm

4. Conclusion

The properties of three natural fibres are investigated in this study for the purpose of using them as reinforcement in soil blocks for producing environmentally friendly and low-cost housing. Based on the results, the following findings can be summarised:

- Different types of fibres have different dimensional properties, thus length and diameter. Bagasse fibres possessed greater dimensional properties, followed by coconut fibres and the least been oil palm fibres.
- Different types of fibres have different specific weight, in relation with mass and volume of the fibres. Coconut fibres achieved higher specific weight, followed by oil palm with the least been bagasse. The specific weight of the fibres have effect on the dry moisture content of the fibres, as high specific weight could lead to low dry moisture content.
- The tensile strength of dry and wet/damp fibres differs over a period of time. There was a consistent reduction in tensile strength of fibres in wet/damp condition for 120 days. However, all the fibres recorded suitable tensile strengths, as they still obtained some strength after period of time in water.
- The water absorption of fibres over a period of time differs. There was a considerable absorption in the 24 hr period, gradual increase followed until the fourth day and very little increase up to the fourteenth day. The most affected are bagasse and coconut fibres with bagasse been the highest, while the absorption effect on oil palm fibres was minimal.
- SEM results showed that bagasse fibres have rough texture, while coconut and oil palm fibres are smooth in texture. The oil palm fibres looked slightly smoother than the coconut.

From the findings, the investigation concludes that different fibres have different properties and behave similarly in wet and damp conditions. However, all the fibres types (coconut, bagasse and oil palm) possess a good estimate for design and construction purpose as described by Ghavami, et al. [14], and are therefore suitable to be used as reinforcement in composite materials such as soil blocks for low-cost housing.

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