Materials Circular Economy (2021) 3:15
https://doi.org/10.1007/s42824-021-00028-0

ORIGINAL PAPER

Properties of Plantain Pseudo-Stem Fibres, Plantain Bunch Fibres, and Rice Husk for Construction Application

Humphrey Danso[1]

Received: 7 June 2021 / Revised: 29 July 2021 / Accepted: 14 August 2021
© The Author(s), under exclusive licence to Springer Nature Singapore Pte Ltd. 2021

Abstract

In the past decade, the substitution of conventional composite materials with natural fibres such as agricultural by-products has become common in the production of sustainable construction materials. The purpose of this study is to assess the properties of plantain (*Musa paradisiaca*) pseudo-stem fibres, plantain bunch fibres, and rice (*Oryza sativa*) husk as sources of reinforcing elements for composite materials especially for construction application. Experiments were conducted to test and analysis the fibres and the husk for surface texture, length and diameter, specific weight, water absorption, and tensile strength. It was revealed that the fibres and the husk have different lengths and diameters, and their surface texture was found to be rough which is likely to improve the bond between the fibres/husk and the matrix. It was also found that the specific weight (between 0.35 ± 0.043 and 0.67 ± 0.089 g/cm^3), water absorption (between 58 ± 6.12 and $245 \pm 37.03\%$), tensile strength (between 59.9 ± 10.62 and 101.6 ± 20.02 N/mm^2), and stress–strain properties of the fibres and the husk are within acceptable parameters for natural fibre application. The study, therefore, concludes that the plantain pseudo-stem fibres, plantain bunch fibres, and rice husk possess properties that are suitable for use as reinforcement in composite material for construction application.

Keywords Natural fibres · Plantain pseudo-stem fibres · Plantain bunch fibres · Rice husk

Introduction

The use of conventional building materials such as cement and steel rods has globally contributed to environmental issues, resulting in increased greenhouse gas emissions due to the release of carbon dioxide (CO_2) into the atmosphere. Some of the materials can be substituted with natural fibres from waste especially in a composite for use in construction to promote the circular economy concept. According to Bonnet-Masimbert et al. (2020), several studies used natural fibres such as bagasse, hemp, coir, flax, and pineapple as reinforcement and have shown a great potential as a building material. The use of natural fibres as a building material also helps in reducing the energy footprint of buildings thereby contributing to sustainable construction application. Recent advances in the application of natural fibres as reinforcement in composite materials are applicable in aerospace parts, automotive components, sporting equipment, and building construction (Ighalo et al. 2020).

Natural fibres can be sourced from plants leaf, bast, seed/fruit hair, trunk/stem, or fruit bunch. Some examples of fibres that can be sourced are leaf fibres (abaca, palm, sisal, pineapple), bast fibres (hemp, jute, flax, kinaf), seed/fruit hair fibres (palm nut, cotton, coir, poplar), trunk/stem fibres (palm, banana, plantain, *Citrus sinensis*), and fruit bunch (oil palm, plantain, banana, date palm). Natural fibres are versatile materials that possess properties that vary with chemical composition and physical structure (Adeniyi et al. 2019). They are abundantly available and affordable and possess good mechanical properties for sustainable construction application (Danso 2020a). The fibres are cellulosic consisting of hemicellulose and microfibrils in an amorphous matrix of lignin (Kulkarni et al. 2020).

Several studies have been conducted to determine the characteristics and properties of natural fibres for composite materials, specifically for construction applications. Danso (2017) investigated the properties of oil palm,

---

This article is part of the Topical Collection on *Natural Fibers: Materials of the Future*

✉ Humphrey Danso
hdanso@uew.edu.gh; dansohumphrey@yahoo.co.uk

[1] Department of Construction & Wood Technology Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, P. O. Box 1277, Kumasi, Ghana

coconut and bagasse fibres as potential building materials. The study found that the fibres possess properties such as specific weight, moisture content, tensile strength, modulus of elasticity, and water absorption that are acceptable as for construction application. Stanislasa et al. (2020) studied the properties of raffia fibre, cassava bagasse, and ambarella to determine their suitability as reinforcing elements for composite materials and found that the nanosize nature, high specific surface area and aspect ratio, biodegradability, and renewability of nanofibrillated cellulose have demonstrated the potential of raffia fibres and cassava bagasse as suitable sources for composite. A study by Prakash and Kavitha (2020) investigated and confirmed the various mechanical properties of the *Cocos nucifera* fibres for textile application. Momoh et al. (2020) studied the physical and mechanical properties of oil palm broom fibres as an eco-friendly building material, and found that the fibres have a specific gravity between 0.45 and 0.84 g/cm^3 and diameter varying between 0.20 mm (at the tail) and 4.00 mm (at the cap), and maximum tensile strength of 900 MPa was recorded.

Recent studies have shown that the use of natural fibres as reinforcement in composite materials is possible for construction application (Das et al. 2021a, b). Ouedraogoa et al. (2019) studied the physical, thermal, and mechanical properties of adobes stabilized with fonio (*Digitaria exilis*) straw and found improvement in the mechanical properties of the adobe. Danso and Manu (2020) investigated the effect of coconut fibres and lime on the properties of soil–cement mortar and found improvement in the mechanical and durability properties of the mortar. de Azevedo et al. (2021) investigated the technological performance of açaí natural fibre-reinforced cement-based mortars and found that açaí fibres in addition of up to 3.0% relative to cement mass and properly treated with NaOH solution can be used as reinforcement mechanism for mortar applications. Danso (2020a) investigated the properties of cement mortar reinforced with plantain pseudo-stem fibres and lime, and concluded that the addition of plantain pseudo-stem fibre and lime positively influenced the properties of the cement mortar with the 0.25% fibre content being recommended for construction application. Other studies (Akinwumi et al. 2016; Chen et al. 2018; Bisht et al. 2020; Danso 2020b) investigated different composite materials with rice husk; however, the properties of the rice husk identified in the studies were limited. There is the need to undertake an extensive investigation on the properties of rice husk as reinforcement in composite materials. According Danso (2017), the technology of reinforcement in composite materials has not been fully adopted by the formal building sector due to the lack of information on the properties of the natural fibre use in the composite materials. There is therefore the need to investigate the properties of natural fibres to be used as reinforcement in composite materials for better understanding of their behaviour in the composite materials.

From the foregoing, it is evident that several natural fibre properties have been investigated, including oil palm, coconut, bagasse, raffia fibre, cassava, ambarella, *Cocos nucifera*, and oil palm broom fibres. However, other natural fibres have potential for use as composite materials such as plantain pseudo-stem, plantain bunch, and rice husk which their properties have not fully been investigated. This study, therefore, seeks to assess the properties of plantain (*Musa paradisiaca*) pseudo-stem fibres, plantain bunch fibres, and rice (*Oryza sativa*) husk as sources of reinforcing elements for composite materials, especially for construction application. The plantain pseudo-stem fibres, plantain bunch fibres, and rice husk were selected for this study because of abundance of plantain plant and rice farms globally and relatively cheap cost due to the fact that the fibres and the husk are obtained as waste. The novelty of this work is the complete assessment of the potential use of plantain pseudo-stem fibres, plantain bunch fibres and rice husk for construction application. The experimental study, therefore, conducted various analyses and tests on the fibres and the husk including scanning electron microscope (SEM), length and diameter, specific weight, water absorption, and tensile strength. This research contributes to the advancement of studies on the properties of natural fibres as potential composite material for construction application.

Experimental Procedure

Fibres and Husk

The fibres and husk used in this study are plantain pseudo-stem fibres, plantain bunch fibres, and rice husk. These fibres were sourced from different locations in Ghana. All the fibres were obtained from agricultural by-products which are usually allowed to dry and are burnt. The burning of the agricultural by-product pollutes the environment, thereby contributing to CO$_2$ in the environment leading to increased greenhouse gases.

Preparation of Fibres and Husk

The plantain pseudo-stem was obtained from the plantain tree after the fruit was harvested, leaving the trunk (Fig. 1a). The trunk was obtained after cutting off the branches and the root. A number of trunks were collected from plantain farms in Kumasi, Ghana, to the laboratory. The trunks were cut into 300 mm length and soaked in water for 24 h, and the fibres were manually extracted on a wooden surface with a wooden mallet of 450 mm length and 80 mm diameter. The

(a) Plantain pseudo-stem (b) Plantain bunch (c) Rice panicle with seed

(d) Plantain pseudo-stem fibres (e) Plantain bunch fibres (f) Rice husk

Fig. 1 Types of fibres and husk. **a** Plantain pseudo-stem. **b** Plantain bunch. **c** Rice panicle with seed. **d** Plantain pseudo-stem fibres. **e** Plantain bunch fibres. **f** Rice husk

fibres were then washed with water and dried in the sun for 48 h as shown in Fig. 1d.

The plantain bunch was obtained from the plantain fruit bunch (Fig. 1b) after the fruit was cut off from the bunch. A number of bunches were collected from the market in Kumasi, Ghana, where the plantain fruit was cut off from the bunch and sold. The bunches that were considered waste and to be disposed of were then collected and sent to the laboratory. The bunches were soaked in water for 24 h, and the fibres were manually extracted on a wooden surface with a wooden mallet of 450 mm length and 80 mm diameter. The fibres were then washed with water and dried in the sun for 48 h as shown in Fig. 1e.

The rice husk used for the study was obtained from a rice mill in the Ashanti Region, Ghana, where the husk was trashed to remove the edible rice from it leaving the husk as waste. Usually, the waste rice husk is dumped at a location to allow for drying and burning. The rice husk waste was collected and sent to the laboratory for experimental work. The rice husk was thoroughly washed to remove any foreign material and dried in the sun for 24 h as shown in Fig. 1f.

Testing of Fibres and Husk

The properties of the fibres and the husk were determined through laboratory experimental testing. The various analysis and tests conducted on the fibres and the husk are SEM analysis, energy dispersive spectrometer (EDS) analysis, length and diameter test, specific weight test, water absorption test, and tensile strength test.

The SEM analysis was conducted to determine the textural evolution of the fibres and the husk. Phenom ProX Scanning Electron Microscopy Machine with magnification up to 150,000×. The fibres and husk samples were cut to 20 mm lengths, placed on a sample holder, and slotted into the microscope to capture the microscopic images.

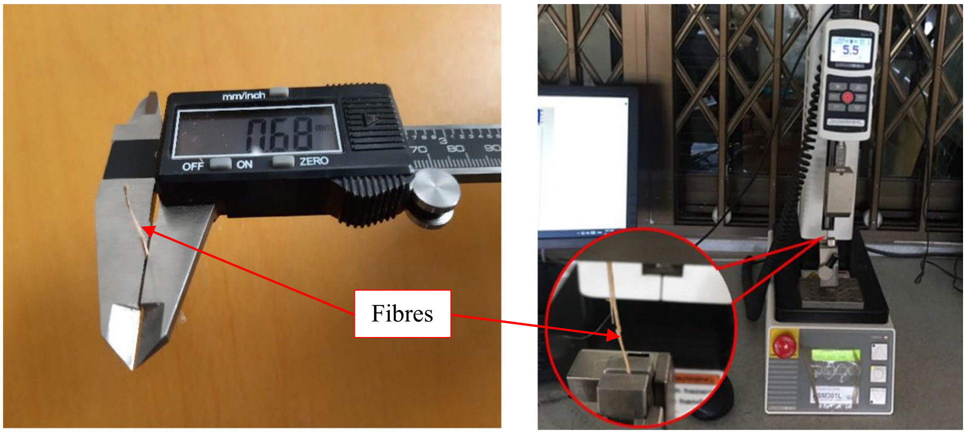
The length and the diameter of the fibres and the husk were measured with the help of a steel rule and digital caliper. In measuring the length, only the plantain bunch fibres and the rice husk were used because of their medium and short lengths, respectively. However, the plantain pseudo-stem fibres were not measured for length because they have very long lengths depending on the height of the plantain tree which can grow even beyond 4 m. For easy handling, the plantain trunk was cut to the length of 300 mm before transporting to the laboratory for the extraction of the fibres. The plantain bunch fibres and the rice husk were straightened for their lengths to be measured with the steel rule. The diameter of the fibres and the husk was also measured using a digital caliper (see Fig. 2a). In all, 100 samples from each fibre and husk type were measured for both length and diameter. After that, the mean and standard deviation of each fibre and husk type were determined.

The specific weight of the fibres was determined following the procedure used in previous studies (Danso 2017; Ghavami et al. 1999). The fibres and husk bundle samples were air-dried, and the mass was measured with an electronic balance. Three bundles of each fibre and husk type were tightly wrapped with polythene sheets and were immersed in a container full of water. The displaced water was collected after the immersion and their volume was calculated. The specific weight was then calculated using Eq. 1.

$$\gamma = \frac{P_\mathrm{d}}{V} \tag{1}$$

where γ is the specific weight of fibres and husk, P_d is the dried mass of fibres and husk, and V is the volume of

Fig. 2 Testing of the fibres and the husk. **a** Diameter measuring. **b** Tensile strength testing



a Diameter measuring

b Tensile strength testing

fibres and husk. The mean and the standard deviation of each fibre and husk type results were determined.

The water absorption of the fibres and the husk was determined following the procedure used in previous studies (Danso 2017; Ghavami et al. 1999). Three bundles of each fibre and husk type were air-dried, and their mass was measured. The fibres and the husk were soaked in water for 24 h to saturation, and their mass was measured. The percentage water absorption of the fibres and the husk was calculated using Eq. 2.

$$W = \frac{P_{\mathrm{h}} - P_{\mathrm{d}}}{P_{\mathrm{d}}} \times 100 \tag{2}$$

where W is the water absorption, P_{h} is the saturated mass of fibres and husk, and P_{d} is the dried mass of fibres and husk. The mean and the standard deviation of each fibre and husk type results were determined.

The tensile strength test was carried out on dried single fibres and husk. A computerized tensile strength testing machine (ESM301L with a maximum load of 1.5 kN) was used for conducting the tensile strength of the fibres and husk. The fibres were cut into 25 mm lengths due to long length, while the full length of the rice husk was used for the tensile test. The diameters of single fibres and the husk were measured, then inserted in the upper and the lower jaws of the test machine and tightened to ensure a firm grip of the fibres and the husk. The test machine was then started which pulled the fibres and the husk until they fractured. The maximum force at which the fibres and the husk failed was recorded, and the tensile stress was calculated using Eq. 3.

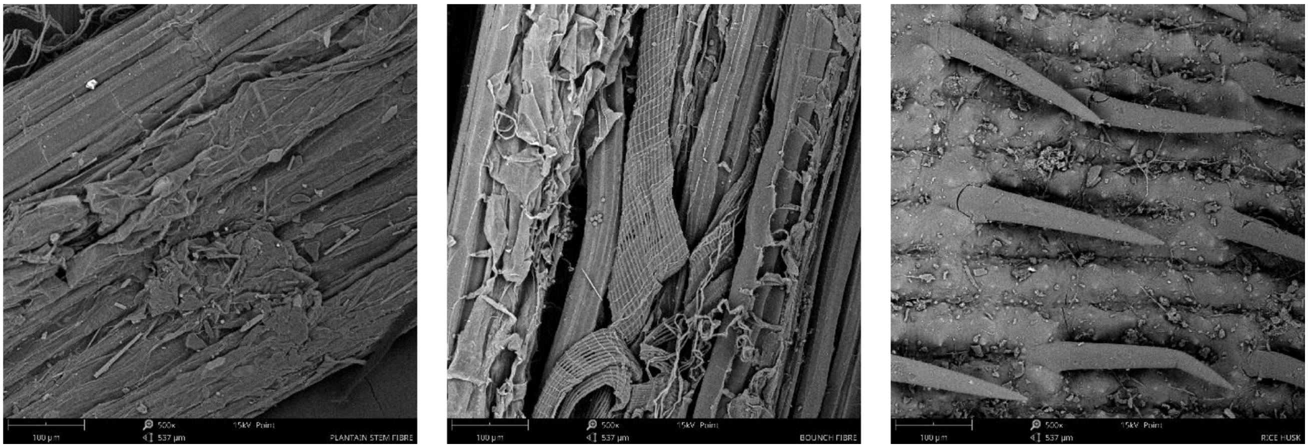
$$\sigma = \frac{F}{A} \tag{3}$$

where σ is the tensile strength, F is the maximum force at which the fibres and husk failed, and A is the cross-sectional area of fibres and husk. The mean and the standard deviation of each fibre and husk type results were determined.

Results and Discussion

Surface Characterization of the Fibres and the Husk

The SEM analysis was conducted to determine the surface texture of the fibres and the husk in the form of microstructure. The result obtained from the SEM analysis is shown in Fig. 3. All the images were set to an accelerating voltage of 15 kV and at 500× magnification. The single plantain pseudo-stem fibre image as shown in Fig. 3a indicates continuous micro strip layers with slight indents and a few clustered portions on the surface of the fibre. Equally, the single plantain bunch fibre image in Fig. 3b shows continuous micro strip layers; however, it contains deep indents and more clustered portions on the surface of the fibre. The image of a single rice husk is presented in Fig. 3c. It can be seen from the image that the surface of the rice husk contains some micro-rough texture and slightly linear indents with some extruded parts. All the features of the fibres and the husk are not seen with the naked eyes. Similar results were found in the studies by Ige and Danso (2020). The result implies that the texture of the fibres and the husk is not smooth as naked eyes perceive, and therefore will provide a good bond, good interlocking relationship with a matrix such as mortar and soil or laterite for construction material application (Danso 2020a, b). The roughness of the natural fibres and the husk is an advantage to the bonding with matrix to ensure proper adhesion of the constituents of the composite materials. A study by Bonnet-Masimbert et al. (2020) observed that the surface of the natural fibres further helps to improve bond characteristics when it is treated with chemicals. It is therefore found that the rough surface



(a) Plantain pseudo-stem fibres (b) Plantain bunch fibres (c) Rice husk

Fig. 3 SEM images of the fibres and the husk. **a** Plantain pseudo-stem fibres. **b** Plantain bunch fibres. **c** Rice husk

texture of the fibres and the husk is likely to improve the bond between the fibres/husk and the matrix.

Length and Diameter of the Fibres and the Husk

The length and diameter of the fibres and the husk are presented in Table 1. The plantain pseudo-stem fibres were characterized as long lengths because the fibres can take the entire height of the plantain tree which can grow even beyond 4 m. The plantain trunks were cut to 300 mm in length before extracting into fibres for easy handling. The mean lengths of the plantain bunch fibres and the rice husk were 391.33 and 8.94 mm, respectively. This indicates that the rice husk has a very short length as compared to the plantain bunch fibres, and the plantain pseudo-stem fibres also have longer lengths than the plantain bunch fibres. In terms of the diameter, the plantain pseudo-stem fibres, plantain bunch, and rice husk recorded 0.65, 0.52, and 1.90 mm, respectively. This implies that the rice husk had the largest diameter while the plantain bunch had the least. The diameter of the fibres and the husk obtained in this study falls within the diameter of the natural fibres studied by Danso (2017). One-sample *t*-test analysis conducted on the data as seen in Table 1 generated result of $t = 2.326$ and $p = 0.0128$, indicating that the difference between the diameter values is positive and significant. According to Danso et al. (2015), there are two important parameters that influence the strength of any fibre-matrix composite, which are the fibre content in the matrix and the fibre aspect ratio (thus the ratio of the length to the diameter of the fibre). This suggests that determination of the length and diameter of fibres and conversion to aspect ratio is important in the production of fibre-based composite materials.

The Specific Weight of the Fibres and the Husk

The specific weight result of the fibres and the husk is shown in Table 1, and the trend is illustrated in Fig. 4. The fibres and the husk recorded mean specific weight of 0.35, 0.48, and 0.67 g/cm^3, respectively for plantain pseudo-stem fibres, plantain bunch, and rice husk. The result indicates that the rice husk obtained a better specific weight of about 91 and 40%, respectively, over plantain pseudo-stem fibres and plantain bunch fibres. Plantain bunch fibres recorded better specific weight of about 27% over the plantain pseudo-stem fibres. A similar specific weight result (between 0.56 and 0.81 g/cm^3) was obtained in the study by Danso (2017) for coconut, oil pal, and bagasse fibres, and between 0.45 and

Table 1 Properties of fibres and husk

Fibre/husk	Length (mm)	Diameter (mm)	Specific weight (g/cm^3)	Water absorption (%)	Tensile strength (N/mm^2)
Plantain pseudo-stem	Long	0.65 ± 0.36	0.35 ± 0.043	245 ± 37.03	59.9 ± 10.62
Plantain bunch	391.33 ± 80.8	0.52 ± 0.21	0.48 ± 0.051	174 ± 29.38	77.1 ± 12.76
Rice husk	8.94 ± 0.9	1.90 ± 0.44	0.67 ± 0.089	58 ± 6.12	101.6 ± 20.02
t-value	-	2.326	5.381	2.917	6.574
p-value	-	0.0128	0.016	0.048	0.022

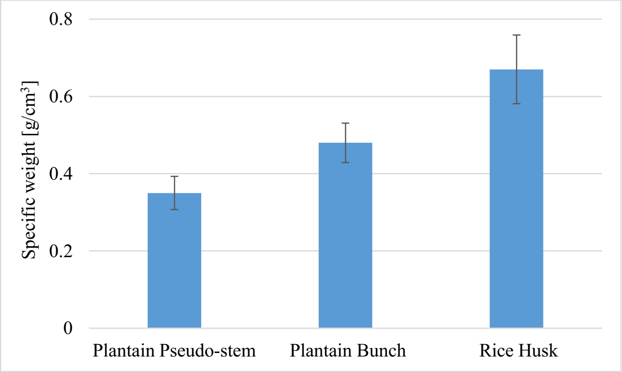


Fig. 4 Specific weight of the fibres and the husk

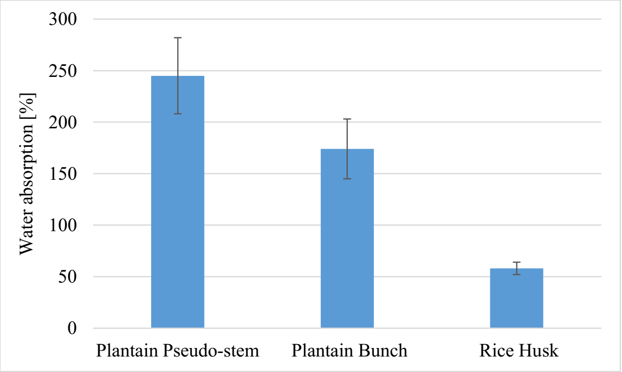


Fig. 5 Water absorption of the fibres and the husk

0.84 g/cm^3 for oil palm broom fibres studied by Momoh et al. (2020). Contrarily, the specific weight (between 1.3 and 1.5 g/cm^3) of jute, hemp, flax, and abaca fibres studied by Kandan and Rajakumar (2020) were higher. One-sample *t*-test analysis results in Table 1 indicate that the difference between the specific weight of the fibres and the husk is positive and significant ($t = 5.381$ and $p = 0.016$). As can be observed in Table 2, the specific weight of the natural fibres and the husk in the present study falls within the specific weight of the fibres used in previous studies. The specific weight of the natural fibres indicates the amount of cellulose in the fibres; therefore, a higher specific weight implies higher cellulose content in the fibre.

Water Absorption of the Fibres and the Husk

The result of the water absorption test of the fibres and the husk is presented in Table 1, and the trend is illustrated in Fig. 5. The result shows a mean absorption rate of 245, 174, and 58%, respectively, for plantain pseudo-stem fibres, plantain bunch fibres and rice husk. The absorption rate of the rice husk was about quarter of the plantain pseudo-stem fibres and about one-third of the plantain bunch fibres. This means the absorption resistance of the rice husk is three- and fourfold better than the plantain bunch fibres and plantain pseudo-stem fibres, respectively. The rate of the absorption for the fibres and the husk in this study is consistent with the study conducted by Danso (2017) for coconut, oil palm, and bagasse fibres with water absorption between 54 and 219%. However, a study by Prakash and Kavitha (2020) on *Cocos nucifera* fibres obtained less water absorption (49%) as compared to the fibres and husk in this study. As shown in Table 1, the one-sample *t*-test result of $t = 2.917$ and $p = 0.048$ suggests that the difference between the water absorption values is positive and significant. As can be seen in Table 3, the water absorption of the natural fibres and the husk in the current study concords with the water absorption of other fibres used in previous studies. The water absorption characteristics is a crucial drawback of natural fibres for their application in composite materials, as its reduction is thus often desirable to improve the durability of composites (Bui et al, 2020). To reduce the uptake of water by the natural fibres, Pacheco-Torgal and Jalali (2011) suggested coating the fibres with some chemicals to reduce the water absorption, thereby improving the durability of the composite materials.

Table 2 Specific weight of natural fibres used in present and past studies

Reference	Type of fibre	Specific weight (g/cm^3)
Present study	Plantain pseudo-stem	0.35 ± 0.043
	Plantain bunch	0.48 ± 0.051
	Rice husk	0.67 ± 0.089
Bui et al. (2020)	Coconut	1.41
Adeniyi et al. (2019)	Banana	0.80
Saka et al. (2008)	Oil palm	0.34
Danso (2017)	Bagasse	0.56

Tensile Strength of the Fibres and the Husk

The tensile strength of the fibres and the husk is presented in Table 1, and the trend of the result is illustrated in Fig. 6. The mean tensile strengths recorded are 59.9, 77.1, and

Table 3 Water absorption of natural fibres used in present and past studies

Reference	Type of fibre	Water absorption (%)
Present study	Plantain pseudo-stem	245 ± 37.03
	Plantain bunch	174 ± 29.38
	Rice husk	58 ± 6.12
Bui et al. (2020)	Coconut	133
Danso (2017)	Bagasse	219

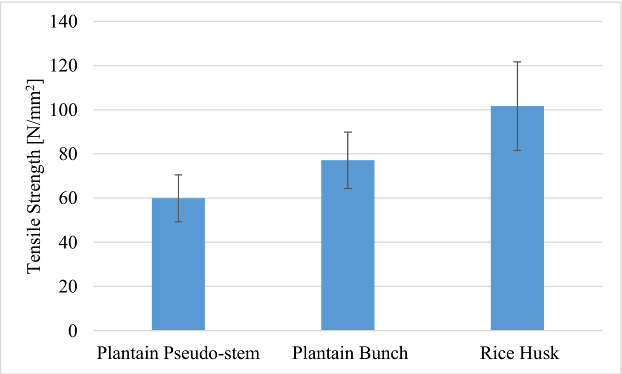


Fig. 6 Tensile strength of the fibres and the husk

101.6 N/mm^2, respectively, for plantain pseudo-stem fibres, plantain bunch fibres, and rice husk. The rice husk recorded the highest tensile strength with about 69.6 and 31.8% increased strength over the plantain pseudo-stem fibres and plantain bunch fibres, respectively. The tensile strength of the fibres and the husk obtained in this study was higher than the tensile strength (26 N/mm^2) of *Cocos nucifera* fibres which was investigated by Prakash and Kavitha (2020). On the contrary, the tensile strength (140–450 N/mm^2) of jute, hemp, coir, flax, and abaca fibres studied by Kandan and Rajakumar (2020) were higher. One-sample *t*-test analysis results in Table 1 indicate that the difference between the tensile strength of the fibres and the husk is positive and significant ($t=6.574$ and $p=0.022$). The comparison between the tensile strength of the natural fibres and the husk in the present study and previous studies as shown in Table 4 indicates that the tensile strength of the fibres used in the current study can be related to those in the previous studies. According to Baley (2002), the cellulose in natural fibre is largely responsible for the mechanical properties of the fibres. This implies that the fibres with higher tensile strength contain more cellulose. The removal of binding hemicellulose and lignin in the interfibrillar regions of the natural fibres allows for the cellulose microfibrils to re-arrange themselves along the direction of the load applied (Bonnet-Masimbert et al. 2020).

Table 4 Tensile strength of natural fibres used in present and past studies

Reference	Type of fibre	Tensile strength (N/mm^2)
Present study	Plantain pseudo-stem	59.9 ± 10.62
	Plantain bunch	77.1 ± 12.76
	Rice husk	101.6 ± 20.02
Bui et al. (2020)	Coconut	123.6 ± 37.6
Adeniyi et al. (2019)	Banana	210
Danso (2017)	Bagasse	42

Stress–Strain Relationship of the Fibres and the Husk

Figure 7 illustrates the stress–strain relationship of the plantain pseudo-stem fibres, plantain bunch fibres, and rice husk. The result shows that the rice husk obtained the highest stress, followed by the plantain bunch fibres and the plantain pseudo-stem fibres as the least, consistent with the tensile strength results. It can also be seen that the plantain bunch fibres had the highest strain, followed by the plantain pseudo-stem fibres, while the rice husk had the least strain. Studies have shown that the higher strain of the natural fibres in composite materials, the better the toughness of the composites (Danso 2020a; Danso and Manu 2020). This suggests that the use of natural fibres and husk in a matrix will help to improve the toughness of the composite materials.

Conclusion

The properties of plantain pseudo-stem fibres, plantain bunch fibres, and rice husk have been studied for use as reinforcing elements for composite materials, especially for construction application. The study revealed that the fibres and the husk have different lengths and diameters, and their surface texture was found to be rough which is likely to improve bond between the fibres/husk and the matrix. It was also found that the specific weight, water absorption, tensile strength, and stress–strain properties of the fibres and the rice husk are within acceptable parameters for natural fibre application. The study, therefore, concludes that the plantain pseudo-stem fibres, plantain bunch fibres, and rice husk possess properties that are suitable for use as reinforcement for use as composite material for construction application. These fibres and husk are obtained from agricultural waste,

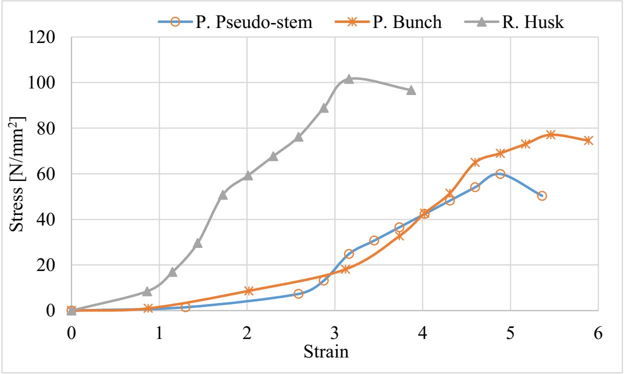


Fig. 7 Stress–strain relationship of the fibres and the husk

which, instead of burning to contribute to the increased CO_2 in the environment, can rather be used in composite materials for construction application to promote the circular economy concept.

Acknowledgements The author wish to thank Edmund Borbi, George Opare Anim, and Alfred Osei who are laboratory technicians at the Construction Laboratory of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Ghana, for their assistance during the experimental activities.

Author Contribution The author contributed to the whole work, from planning of the study, experimental works, gathering of data, writing of the paper, reviewing, to submission of the papers.

Data Availability The data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Competing Interests The authors declare no competing interests.

References

Adeniyi AG, Ighalo JO, Onifade DV (2019) Banana and plantain fiber reinforced polymer composites. J Polym Eng 39(7):597–611

Akinwumi II, Awoyera PO, Olofinnade OM, Busari AA, Okotie M (2016) Rice husk as a concrete constituent: workability, water absorption and strength of the concrete. Asian J Civ Eng 17(7):887–898

Baley C (2002) Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase. Compos Part A Appl Sci Manuf 939–948

Bisht N, Gope PC, Rani N (2020) Rice husk as a fibre in composites: a review. J Mech Behav Mater 29:147–162

Bonnet-Masimbert P-A, Gauvin F, Brouwers HJH, Amziane S (2020) Study of modifications on the chemical and mechanical compatibility between cement matrix and oil palm fibres. Results in Eng 7:1–9. https://doi.org/10.1016/j.rineng.2020.100150

Bui H, Sebaibi N, Boutouil M, Levacher D (2020) Determination and review of physical and mechanical properties of raw and treated coconut 8(6):37. https://doi.org/10.3390/fib8060037

Chen Z, Xu Y, Shivkumar S (2018) Microstructure and tensile properties of various varieties of rice husk. J Sci Food Agric 98(3):1061–1070. https://doi.org/10.1002/jsfa.8556

Danso H (2017) Properties of coconut, oil palm and bagasse fibres: as potential building materials. Procedia Eng 200:1–9

Danso H (2020a) Influence of plantain pseudostem fibres and lime on the properties of cement mortar. Adv Mater Sci Eng 2020. https://doi.org/10.1155/2020/4698603

Danso H (2020b) Effect of rice husk on the mechanical properties of cement-based mortar. J Inst Eng (india): Series D 101(2):205–213. https://doi.org/10.1007/s40033-020-00228-z

Danso H, Manu D (2020) Influence of coconut fibres and lime on the properties of soil-cement mortar. Case Stud Constr Mater 12:1–12

Danso H, Martinson B, Ali M, Williams J (2015) Effect of fibre aspect ratio on mechanical properties of soil building blocks. Constr Build Mater 83:314–319. https://doi.org/10.1016/j.conbuildmat.2015.03.039

Das SC, Paul D, Khan MA, Grammatikos SA, Papatzani S (2021a) A comparative study between jute and glass fiber reinforced composites. Key Eng Mater 891:125–130

Das SC, La Rosa AD, Goutianos S, Grammatikos SA (2021b) Natural fiber reinforced polymer composites for small/medium wind turbine blades: a LCA study, 5th International Conference on Natural Fibers (ICNF2021), paper ID 82, 191–192

de Azevedo ARG, Marvila MT, Tayeh BA, Cecchin D, Pereira AC, Monteiro SN (2021) Technological performance of açaí natural fibre reinforced cement-based mortars. J Build Eng 33:1–11. https://doi.org/10.1016/j.jobe.2020.101675

Ghavami K, Filho RDT, Barbosac NP (1999) Behaviour of composite soil reinforced with natural fibres. Cem Concr Compos 21:39–48

Ige O, Danso H (2020) Physico-mechanical and thermal gravimetric analysis of adobe masonry units reinforced with plantain pseudostem fibres for sustainable construction. Const Build Mater. 273. https://doi.org/10.1016/j.conbuildmat.2020.121686

Ighalo JO, Adeyanju CA, Ogunniyi S, Adeniyi AG, Abdulkareem SA (2020) An empirical review of the recent advances in treatment of natural fibers for reinforced plastic composites. Compos Interfaces. https://doi.org/10.1080/09276440.2020.1826274

Kandan AM, Rajakumar S (2020) A review on natural fiber and its characteristics. Indust Eng J 13(3):1–12

Kulkarni HB, Tambe PB, Joshi GM (2020) Influence of surfactant assisted exfoliation of hexagonal boron nitride nanosheets on mechanical, thermal and dielectric properties of epoxy nanocomposites. Compos Int 27(6):529–550

Momoh EO, Osofero AI, Martinez-felipe A, Hamzah F (2020) Physico-mechanical behaviour of oil palm broom fibres (OPBF) as eco-friendly building material. J Build Eng. https://doi.org/10.1016/j.jobe.2020.101208

Neeraj B, Chandra GP, Nisha R (2020) Rice husk as a fibre in composites: a review. J Mech Behav Mater 29(1):147–162

Ouedraogoa M, Dao K, Millogoa Y, Aubert J-E, Messan A, Seynou M, Zerbo L, Gominae M (2019) Physical, thermal and mechanical properties of adobes stabilized with fonio (Digitaria exilis) straw. J Build Eng 23:250–258. https://doi.org/10.1016/j.jobe.2019.02.005

Pacheco-Torgal F, Jalali S (2011) Cementitious building materials reinforced with vegetable fibres: a review. Constr Build Mater 575–581

Prakash TS, Kavitha S (2020) Development of non-woven landscape fiber mat with Cocos nucifera fiber and its testing property. Tathapi 19(29):164–169

Saka S, Munusamy MV, Shibata M, Tono Y, Miyafuji H (2008) Chemical constituents of the different anatomical parts of the oil palm (Elaeis guineensis) for their sustainable utilization. In: JSPS-VCC Group Seminar 2008, Kyoto: Natural Resources and Energy Environment

Stanislasa TT, Tendob JF, Ojoa EB, Ngasoha OF, Onwualuc PA, Njeugnad E, Savastano Junior H (2020) Production and characterization of pulp and nanofibrillated cellulose from selected tropical plants. J Natu Fibers. https://doi.org/10.1080/15440478.2020.1787915

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.