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An Evaluation of the Porosity and Pore Volume Fractions of Coir Fibres in Relation to Their Diameters and Tensile Properties at a Crosshead Displacement Rate of 0.5 mm/Minute for Composite Applications

Chioma I. MADUEKE[1*], Reginald UMUNAKWE[2], Oluwole D. ADIGUN[3]

[1*,2,3]Department of Materials and Metallurgical Engineering, Federal University, Oye-Ekiti, Nigeria

[1*]chioma.madueke@fuoye.edu.ng, [2]reginald.umunakwe@fuoye.edu.ng, [2]oluwole.adigun@fuoye.edu.ng

Abstract

The diameters, tensile properties at a cross-head displacement rate of 0.5 mm/minute and porosity (via microstructure) of as-received coconut fibres have been investigated. The average diameter and average tensile strength obtained from 30 individual brown coconut fibres of the same batch were 0.227 ± 0.04 mm and 138.57 ± 55.05 MPa respectively. 40% of the samples with an average diameter of 0.200 ± 0.04 mm showed high tensile strengths (above average) of 190.93 ± 42.57 MPa, another 40% with average diameter of 0.249 ± 0.03 mm showed low tensile strength (below average) of 88.89 ± 20.80 MPa while 20% of the samples showed mid tensile strength (within the average). The volume fraction of the coconut fibre pores (porosity) was 31.7 ± 7.59%. The average pore count, pore size and pore perimeter were: 609 ± 129, 84.55 ± 28.75 μm^2 and 31.91 ± 6.23 µm respectively within the studied diameter range. More than 74% of the fibres showed increase in the pore volume fraction as the diameter of the fibre increased. Both the porosity and pore count increased with increase in diameter. The microstructures of the fibres indicate the level of the fibre porosity which may have contributed to its tensile properties. Coir fibre porosity can be applied in the design and development of new materials for engineering applications such as light weight composites and insulating panels.

***Keyword**: Coconut fibre, diameter, tensile strength, porosity, microstructure.*

1.0 Introduction

Natural fibres from plants (jute, hemp, sisal, flax, Kenaf, coir) and animals have been exploited for use as reinforcements in composites [1–5]. Unlike synthetic fibres, bio fibres are not dependent on petroleum-based precursors [6]. Several studies have indicated that coir, a natural lignocellulosic fibre extracted from coconut husk is an upcoming natural fibre reinforcement for bio and synthetic polymer composites [6,7]. Coir possesses advantages which include; high elongation at break of up to 17-47% [6] they are light weight and hence low density as shown in Table 1 and therefore offer savings in fuel and energy [8]. Moisture ingress of coir is also much less than moisture ingress of most natural fibres [6]. There are brown and white coconut fibres resulting from mature (brown) and immature coconut respectively [9]. Some traditional uses of coir are in items such as mattresses, rugs and pillow stuffing [10] while the modern uses are in panels for automotive, panels for sound insulation [9], and reinforcement in concrete [11] among others. The mechanical properties of reinforcing fibres play a vital role in the efficiency of the fibre in composites. The properties of coir are displayed in Table 1 showing their tensile strength to be in the range of 102 – 140.5 MPa while their densities lie between 1100-1550kg/m³ depending on the source, their diameter also varies between 0.160- 0.560 mm.

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Table 1: Diameter, density and tensile properties of coir fibre from different sources

Fibre	Diameter (mm)	Tensile strength (MPa)	YM (GPa)	Eb (%)	Density (Kg/m³)	References
Coir (India)	0.250	102	-	23	1100-1500	[9]
Coir	0.175	140.5	6	27.5	1250	[12]
Coir	0.200	-	-	-	1550	[13]
Coir (Nigeria)	0.37	105.81	1.51	30.79	1345	[14]
Coir (Trinidad)	0.16–0.56	1.39	1.74	50.35	-	[15]

Eb= Elongation at break; YM =Young's modulus

2.0 Materials and methods

2.1 Coir fibre treatment

The coir fibres used are brown as-received coir fibres. The fibres were placed in a sieve and sieved to remove loose debris and particles. They were washed several times in hot water at a temperature of 60 °C and

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dried in a laboratory oven at 80 ^{o}C for two hours in order to get rid of oily substances and unwanted particles [6].

2.2 Property Characterizations

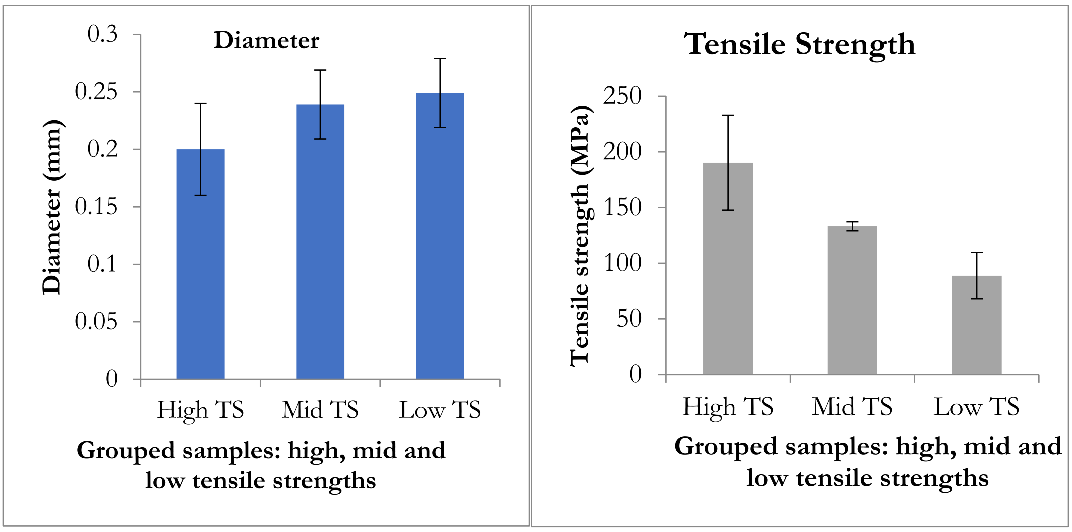
The properties of the coir fibres were characterized for tensile in accordance with ASTM D3822-07[6] using Instron 5566 with a load cell of 100N, a cross head displacement rate of 0.5mm/minute, a sample gauge length of 20 mm and a minimum sample size of 30. The microstructure was characterized with Table top and Joel 6060 Electron Microscopy (SEM) and Zeiss Axioskop-2 microscopy.

3 Results and discussions

3.1 Diameters, Tensile properties and porosities

The average diameter from thirty (30) individual coir fibres was 0.227 ± 0.04 mm. This can be compared with the diameters obtained by [9,13]. The average tensile strength obtained was 138.57 ± 55.05 MPa. This follows the trend of tensile strengths obtained by[12,15]. The insignificant variations could be attributed to the different gauge lengths and load displacement rates employed [21]. A significant standard deviation in the tensile strength was observed even with the low standard deviation of 0.04 in the diameter. The tensile strengths were grouped into high (above the average), mid (within the average) and low (lower than the average). 40% of the samples fell into the category with high tensile strength of an average diameter and tensile strength of 0.200 ± 0.04 mm and 190.93 ± 42.57 MPa respectively. Another 40% fell into the category of low tensile strength with an average diameter of 0.249 ± 0.03 mm and 88.89 ± 20.80 MPa respectively. 20% was in the category of mid tensile strengths with an average diameter and tensile strength of 0.239 ± 0.03 mm and 133.21 ± 4.06 MPa respectively. This is represented in Figure 1(a and b). The sample with the highest tensile strength of 261.984 has a diameter of 0.195. The average Young's modulus and elongation at break of the 30 fibre samples studied were 1.361 ± 0.7 GPa and 31.37 ± 12.33% respectively. The Young's modulus is comparable to the Young's modulus obtained by [15]. As with the tensile strength grouping, About 37% of the samples with average diameter of 0.211 ± 0.03 displayed a high Young's modulus (above average) of 2.15 ± 0.67. About 4% and 15% displayed mid and low respectively as depicted in Figure 2 (a and b) with their corresponding diameters The sample with the highest Young's modulus of 3.38 has a diameter of 0.195mm.

However, the average elongation at break of the 30 coir fibre samples was about 40% higher than those obtained by [21]. This can be attributed to the variations in the head displacement rate and the type of processing carried out before tensile tests [15]. About 37% of the fibres with an average diameter of 0.224 ± 0.05 mm displayed a high elongation at break (above average) of 44.09 ± 9%. Besides, the sample with the highest elongation of 58.22% has a diameter of 0.225 mm. And about 13 and 50% displayed a mid and low elongations as shown in Figure 3 (a and b).



(a) (b)

Figure 1: (a) Coir fibre diameters at high, mid and low tensile strengths
(b)Coir fibre samples at high, mid and low tensile strengths

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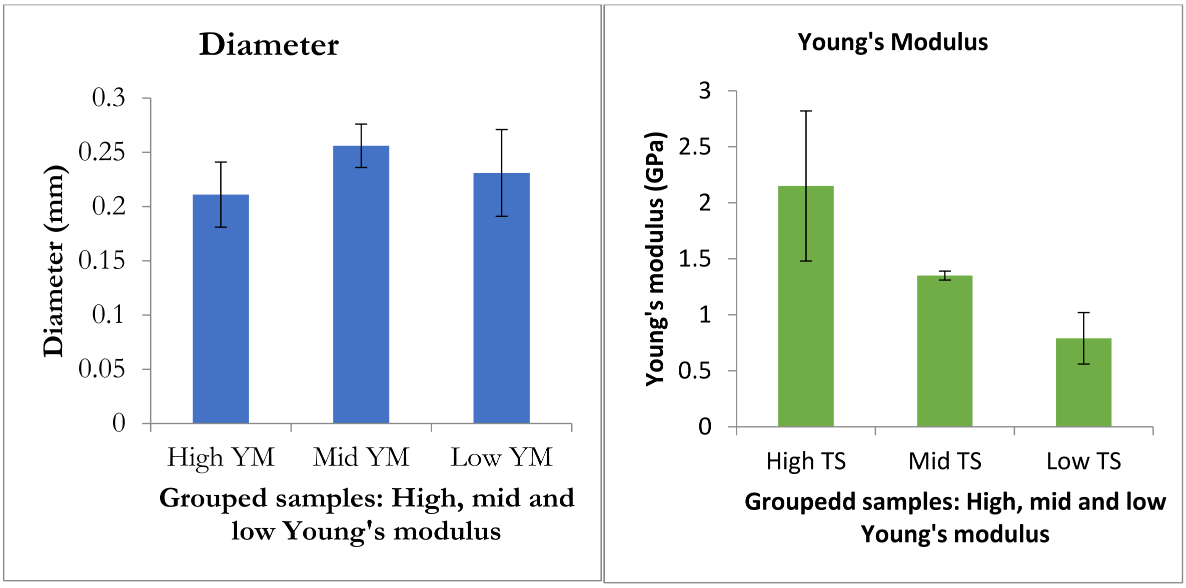
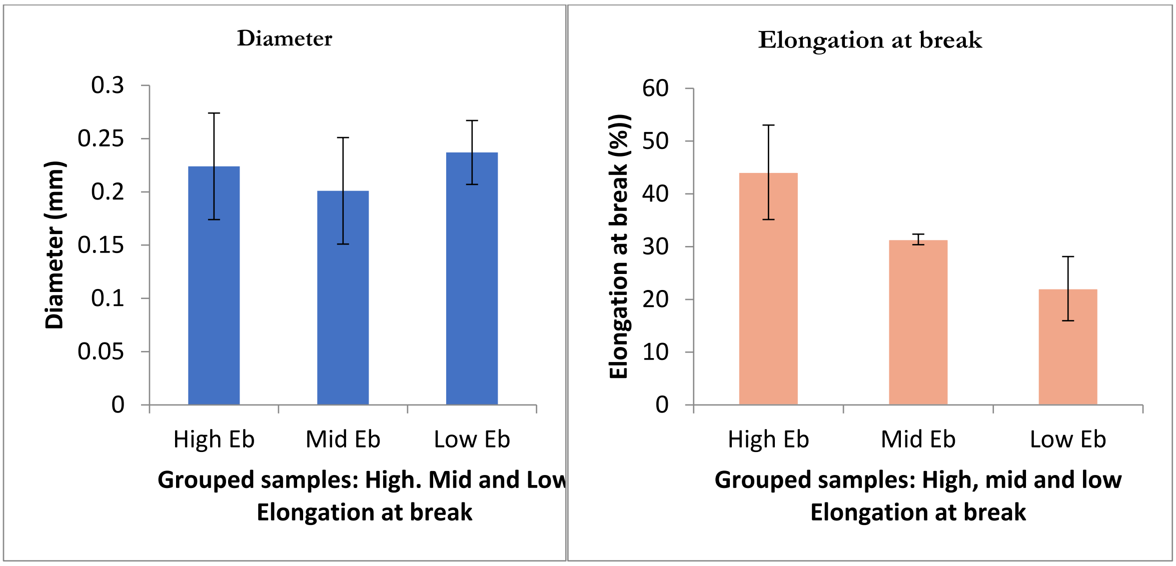


(a) (b)

Figure 2: (a) Coir fibre diameters at high, mid and low Young's modulus
(b) Coir fibre samples at high, mid and low Young's modulus



(a) (b)

Figure 3 (a) Coir fibre diameters at high, mid and low Elongation at break
(b)Coir fibre samples at high, mid and low Elongation at break

3.2 Microstructural characterization and Image analysis

3.2.1 Microstructural Characterization

The cross-sectional morphology of coir is shown in Figure 4. Coir possesses several pores called lumen with a larger lumen that seems to be located at the center, though the location of the larger lumen depends on the part of the coir length sectioned; head, middle or tail [6]. Some of these lumens appear to be of varying shapes and sizes.

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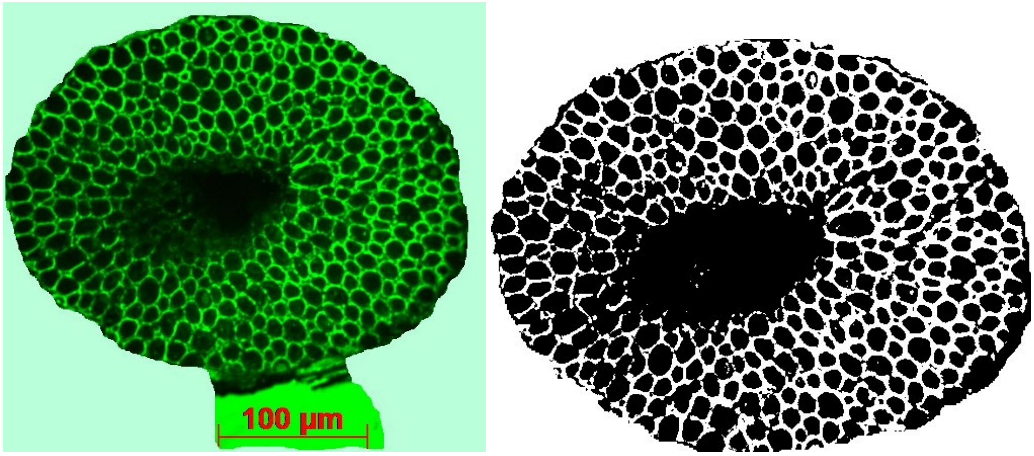

(a) (b)

Figure 4: (a) Microstructure of coir (b) ImageJ detection of the pores present in coir fibre

3.2.2 Image analysis of coir

ImageJ software was used to analyze the polished coir fibre samples. Figure 4b shows the ImageJ detection of the pores present in coir fibre. Table 2 displays the properties obtained from ImageJ. Figures 5 shows the comparisons between fibre diameters pore count and pore size. Figure 6 displays the comparisons between fibre diameter and pore volume fraction. The findings are as follows: The volume fraction of the coir fibre pores (porosity) was 31.77 ± 7.59% with an average pore count, pore size and pore perimeter of 609 ± 129, 84.55 ± 28.75 µm^2 and 31.91 ± 6.23 µm within the studied diameter range. 75% of the fibres showed increase in diameter as the pore volume fraction (porosity) increases. The pore volume fraction obtained is in line with the values obtained from literature.

Table 2: Coir fibre porosity Parameters determined using ImageJ

Sample	**Pore count**	**Pore size (µm^2)**	**Volume fraction of pores (Porosity) (%)**	**Pore perimeter (µm)**	**Feret diameter (µm)**
1	382 ± 78	72 ± 0.69	37.08 ± 0.58	30.73 ± 1.22	10.24 ± 0.58
2	636 ± 53	105 ± 9.39	31.32 ± 0.32	36.81 ± 2.05	12.53 ± 0.64
3	778 ± 71	84 ± 13.94	37.13 ± 3.25	33.22 ± 3.80	10.80 ± 1.00
4	491 ± 31	36 ± 3.26	19.38 ± 0.58	21.60 ± 1.17	7.2 ± 0.39
5	692 ± 74	83 ± 18.07	36.74 ± 78	29.17 ± 3.34	9.06 ± 1.03
6	633 ± 42	136 ± 13.95	41.21 ± 3.08	41.58 ± 3.29	13.07 ± 0.87
7	550 ± 20	90 ± 5.68	24.27 ± 0.78	35.33 ± 1.40	12.75 ± 0.49
8	685 ± 23	48 ± 5.51	18.78 ± 1.17	24.97 ± 1.02	8.62 ± 0.31

Feret diameter or maximum caliper: the longest distance between any two points along the selection boundary.

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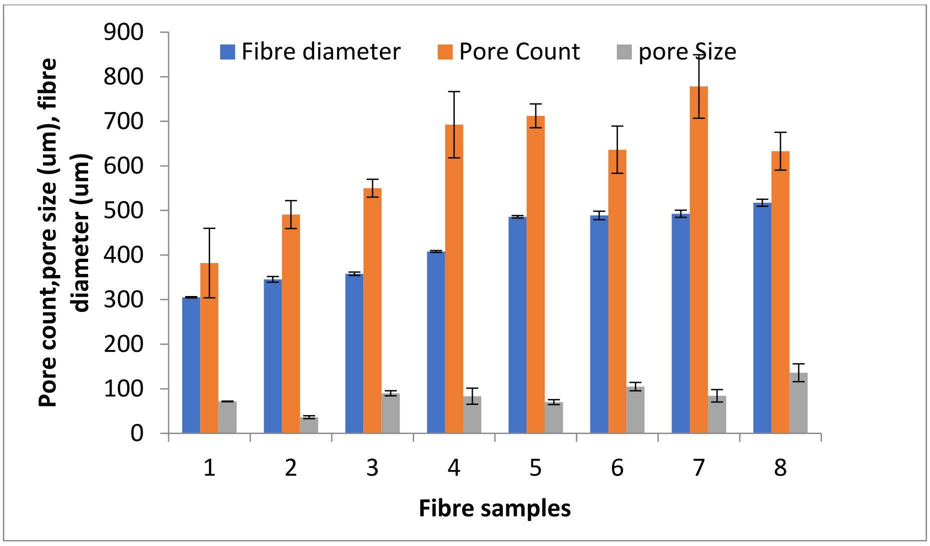

Figure 5: Comparison of fibre diameter with pore count and pore size

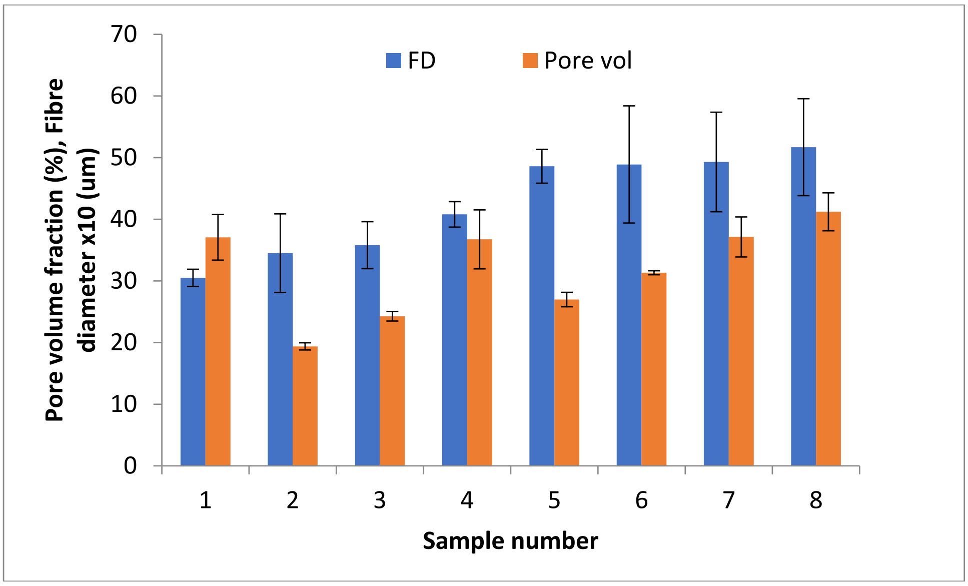

Figure 6: Comparison of fibre diameter with pore volume fraction

4.0 Conclusion

From the results; the average diameter obtained from 30 individual brown coconut fibres of the same batch was 0.227 ± 0.04 mm and the average tensile strength obtained at a cross-head displacement rate of 0.5 mm/minute was 138.57 ± 55.05 MPa. The average Young's modulus and elongation at break were: 1.361 ± 0.7 GPa and 31.37 ± 12.33% respectively. 40% of the samples with an average diameter of 0.200 ± 0.04 mm showed high tensile strengths (above average) of 190.93 ± 42.57 MPa, another 40% with average diameter of 0.249 ± 0.03 mm showed low tensile strength (below average) of 88.89 ± 20.80 MPa while 20% of the samples showed mid tensile strength within the average. The results indicate that tensile strength and Young's modulus of coir are influenced by the fibre parameters. Both the porosity and pore count increased with increase in diameter. The microstructures of the fibres indicate the level of the fibre porosity which may have contributed to its tensile properties. Hence it is imperative to properly and carefully carry out manual or automated fibre selection for specific applications.

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