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Research Article

Characterisation of *Luffa cylindrica* Fibre from Cameroon for Use in Composites: Effect of Alkaline Treatment

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The study of *Luffa cylindrica* is seen as an alternative solution for the development of green materials. However, a lack of knowledge about some of their characteristics can slow down these applications. The present study focuses on the characterisation of the fibre derived from the *Luffa cylindrica* sponge. In this study, the fibre was extracted using a manual technique, followed by a treatment cycle with 5%, 7.5%, and 10% NaOH at a temperature of 28°C for 60 min. The results obtained show the lightness of the fibre through its low density (0.233-0.419 g·cm^{-3}), and a hydrophilic nature of the fibre is observed through its water absorption capacity (106.86-180.53%), its relative humidity (9.86-15.33%), and its capacity to diffuse water (2.03×10^{-14} m^2·s^{-1} to 4.61×10^{-14} m^2·s^{-1}), which is close to that of other plant fibres, which means that it can be classified as porous, with possible applications in insulating and lightweight materials. Its diameter (418.61-554.42 μm) and linear mass (34-58 g·km^{-1}) are high, in contrast to other fibres used in the textile industry to produce yarns. The mechanical results, namely, stress at break (9.744-27.45 MPa), Young's modulus (307.56-582.41 MPa), and elongation at break (3.45%-8.11%), are close to those of other plant fibres used as reinforcement in polymer matrix composites for applications in the automotive, insulation, furniture, and construction industries. *Luffa cylindrica* fibre could have applications in the same direction. Fibres treated with 5% NaOH effectively improve the properties of raw fibres.

1. Introduction

The development of green materials based on natural fibres to replace synthetic fibres in the fight against protection is attracting the attention of many researchers [1, 2]. The automotive, textile, construction, and thermal insulation industries are major consumers of energy [3, 4]. The development of low-density biodegradable materials should help to protect the environment [5]. These materials can be obtained from fibres derived from stems, fruits, and stipes. These raw materials are available in the environment.

Research in Africa, and more specifically in Cameroon, a country committed to sustainable development, abounds in natural resources, including *Sida rhombifolia* [6], *Grewia* bicolor [7], the fruit of the *Luffa cylindrica* [8, 9], *Triumfetta cordifolia* [10], *Raffia vinifera* [11–13], hemp [11], and banana [14–16] may or may not be used to reinforce composites. However, one of the limitations of using plant fibres

to reinforce composites is the nonuniformity of their properties [12]. This great variability in their characteristics can be linked to the maturity of the plants [17], the experimental conditions [18], the nature of the soil and natural constraints [19, 20], the extraction method [21], and the area from which the plant was harvested [15, 22–25]. *Luffa cylindrica* is one of these natural resources that can be used as an alternative solution for developing materials for a more sustainable energy future. This plant, which is available in northern Cameroon, is of interest to many researchers. The literature does not provide any information on the characteristics of the *Luffa* sponge in this locality. However, the literature available on the *Luffa* plant worldwide shows great interest in the development of ecomaterials from *Luffa* sponge. Several studies have been carried out on *Luffa* sponge fibre in different countries. It has been shown that to improve the interface of *Luffa* sponge fibres, treatment with NaOH at different concentrations gives better results than treatment with hot water. Although hot water treatment is less expensive than alkaline treatment, it gives satisfactory results over a long period. Effective treatment of fibres improves their properties, which will be an advantage in terms of durability in the reinforcement of composite materials [26]. Martinez-Pavetti et al. [27] found this to be the case with *Luffa* fibres from Paraguay, and similar results were obtained by Chen et al. [8, 9] on the alkaline treatment of *Luffa* fibres from China. The authors [8, 9, 27, 28] have shown that the place of harvest has an effect on the characteristics of *Luffa* fibres. The microstructure presented in the literature on *Luffa* fibres allows them to be classified as porous materials [8, 9]. This justifies the known applications of *Luffa* to date, particularly in the field of acoustic absorption, and its incorporation as a reinforcement in composite materials with thermosetting and thermoplastic matrices [28–31]. During this period, the transformation phenomenon of *Luffa* fibres was studied. In their work, Chen et al. [8] had to perform coupling treatments to improve the fibre interface and it was shown that treatment with 10% NaOH for 30 minutes promotes fibre elongation but not moisture, by reducing the cellulose content and the cross-sectional area of the fibre.

The literature provides information on the microstructure, possible applications, chemical and mechanical characteristics of *Luffa* fibres from China, Paraguay, Brazil, etc., but not those from Cameroon, which could be the subject of several studies, particularly for the manufacture of absorbent, acoustic, and thermal materials. Lack of knowledge of these characteristics is a problem when it comes to understanding this material. Are the physical and mechanical characteristics of this fibre similar to those already proposed in the literature by other authors, whatever its origin? In this work, we examine the physical and mechanical tensile characteristics of *Luffa cylindrica* fibre from Cameroon, in particular, its linear mass (fineness), diameter, density, relative humidity, absorption rate, and water absorption diffusion theory, taking into account the effect of alkaline treatment, which is the most widely used in the literature. The results obtained will be compared with those of other authors and with those of other plant fibres available in the literature.

2. Materials and Methods

Luffa cylindrica was collected (Figure 1(a)) in the Far North Region of Cameroon, more precisely in Maroua. Once collected, the bark was separated from the sponge (Figure 1(b)) and the sponge from the seed (Figure 1(c)). The temperature of the water (Figure 1(d)) was measured using a thermocouple. Bath concentration ratios were used to obtain solution concentrations of 5% (50 g NaOH granules to 1 L water), 7.5% (75 g NaOH granules to 1 L water), and 10% (100 g NaOH granules to 1 L water) in a bath with a solid/liquid ratio of 1 : 20. Once the solutions were prepared, the sponge was immersed in the various 5%, 7.5%, and 10% NaOH solutions for 60 minutes at 28°C (Figure 1(e)) [13, 32]. Once the immersion time had been reached, the treated sponge was washed with distilled water to attenuate the effects of NaOH and exposed to the sun for 24 hours, as shown in Figure 1(f). The fibres were extracted manually (Figure 1(g)). Figure 1(h) shows some of the extracted fibres.

For fibre characterisation, codes are assigned as follows: untreated fibres (FNT), fibres treated with 5% NaOH (FT 5), fibres treated with 7.5% NaOH (FT 7.5), and fibres treated with 10% NaOH (FT 10).

2.1. Characterisation of Luffa cylindrica Fibres

2.1.1. Determination of Linear Mass. Fibre mass was assumed to be constant. The fibres were dried in a Memmert oven at 90°C for 3 hours [33]. Once dried, bundles of 40 fibres, each 20 mm long, were formed and weighed on a digital balance accurate to 0.001 mm. Five bundles were used for each treatment, for a total of 20 bundles. The method used was gravimetric, as described in standard NF G 07-007 [34]. The linear mass was calculated using the following equation:

$$\text{Linear mass} = \frac{m_f}{N * L_f}, \tag{1}$$

where m_f is the mass of anhydrous fibres (g), N is the number of fibres, and L_f is the fibre length (km).

2.1.2. Determination of Fibre Diameter. Fibre diameter was determined using a micrometer. The measurement was carried out at three points on each 15 mm long fibre, in accordance with ASTM 2130-90 [22]. 10 fibres from each treatment were tested, for a total of 40 samples.

2.1.3. Density Determination. The fibres were made anhydrous in an oven at 90°C for 3 hours. Density was obtained by immersing the fibre bundles in a solvent (benzene) for 5 minutes. The method used was the gravimetric method described in ASTM D3800-99. Measurements were carried out on 5 bundles of each treatment, for a total of 20 bundles. Equation (2) was used to calculate the density [33].

$$\rho_f = \frac{\rho_b * mf_a}{mf_a - mf_b}, \tag{2}$$

Figure 1: (a) Supply. (b) Peeling. (c) Separating the seeds from the sponge. (d) Measuring the water temperature with the thermocouple. (e) Treatment in NaOH solution. (e) Treated *Luffa* sponge extraction. (f) Treated *Luffa* and dehydration. (g) Manual extraction. (h) Extracted *Luffa cylindrica* fibre.

where ρf is the fibre density, ρb is the benzene density (0.8765 g/m^3), mf_a is the mass of fibre bundle in free air in g, and mf_b is the mass of fibre bundle in benzene in g.

2.1.4. Water Absorption Phenomenon. The fibre bundles from each treatment were made anhydrous at 90°C for 3 hours using a Memmert oven. During the process, the samples were weighed discontinuously until mass stability was achieved. The method used was gravimetric with discontinuous weighing [3, 35]. The degree of hygroscopicity, also known as relative humidity, was calculated using the following equation:

$$\mathrm{HR}\,(\%) = \left(\frac{M_H}{M_S} - 1\right) * 100, \tag{3}$$

where HR is the relative humidity (%), M_H is the wet mass (g), and M_S is the dry mass (g).

Once the samples were anhydrous, they were immersed in distilled water at 28 ± 2°C using the gravimetric method with discontinuous mass measurement over 24 hours according to the principle of ASTM D 2402 [35]. The water absorption rate (W (%)) is calculated from equation (4), and the ratio (MR), which is a dimensionless number, is calculated from equation (5) [3, 36].

$$W\,(\%) = \left(\frac{M_f}{M_i} - 1\right) * 100, \tag{4}$$

$$\mathrm{MR} = \frac{M_t - M_i}{M_f - M_i}, \tag{5}$$

where W (%) is the water absorption rate, M_f is the mass of water-saturated fibres (g), M_i is the mass of fibres in the anhydrous state (g), MR is the absorption ratio, and M_t is the mass at time t.

For water absorption kinetics, a number of absorption models have been identified in the literature (Table 1), with a number of constants (parameters) varying from one model to another to correlate the experimental points of the absorption test.

The empirical model will be the one with a high correlation coefficient (R^2) and a low squared error (RMSE). For the calculation of the diffusion coefficient, the fibre cross-section is assumed to be circular and uniform. The diffusion coefficient is calculated by equation (6) as has been done for other plant fibres [35].

$$D_{\mathrm{eff}} = \pi\left(\frac{K * D_{\mathrm{moy}}}{4 * M_{\mathrm{sat}}}\right)^2, \tag{6}$$

where D_{eff} is the diffusion coefficient (m^2·s^{-1}), K is the slope of the linear part of the equation $K = \ln(M_R) = g(t)$, D_{moy} is the fibre diameter, and M_{sat} is the water content.

2.1.5. Mechanical Characterisation by Tensile Testing. The test was carried out according to the protocol described in standard NF T25-501-2 [22]. The sample parameters are shown in Figure 2(a). The sample was clamped between

Table 1: Presentations of the different water absorption models.

Authors	Model mathematical	Parameters	References
Czel and Czigany	$g(t) = a * t\text{^}m$	02	[3, 5, 45]
Page	$g(t) = 1 - a * \exp(-k * t\text{^}n)$	03	
Mohsenin	$g(t) = a * [1 - \exp(-k * t)] + c * d * t$	04	
Sikame	$g(t) = c - a * \exp(-k * t) - b * \exp(-m * t)$	05	

a, b, c, d, k, m, and n are model constants.

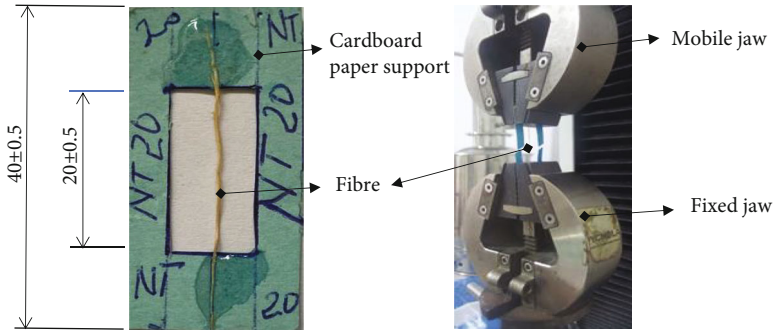

Figure 2: Sample of *Luffa cylindrica* fibre being tested.

the jaws of the test bench (Figure 2(b)). The specimen was subjected to a load of 5 kN at a rate of 2 mm·min^{-1} at room temperature until the specimen failed. 25 specimens were tested for each treatment, giving a total of 100 specimens. Stress at break (σ_r) is calculated by equation (7) and strain at break (ε_r) by equation (8). Young's modulus is determined by the method of least squares by exploiting the stress-strain curve of Hooke's law, which is of the type $y = Ax + B$, where A which is the coefficient of the linear slope of the equation represents Young's modulus (MPa).

$$\sigma_r = \frac{F}{S}, \tag{7}$$

$$\varepsilon_r = \frac{\Delta l}{L_0}, \tag{8}$$

where F is the force (N), S is the cross-sectional area (mm^2), σ_r is the stress at break (MPa), ε_r is the strain at break, Δl is the displacement, and L_0 is the working length.

3. Results and Discussion

3.1. Linear Mass. The linear mass varies from 58 ± 4.4 g·km^{-1} for untreated fibres to 34 ± 5.4 g·km^{-1} for fibres treated with 5% NaOH. Figure 3 shows that the linear density of *Luffa cylindrica* fibres increases with the percentage of NaOH treatment from 5% to 10%. This could be explained by the fact that above 5% NaOH, the treatment would no longer be very effective, which would modify the fibre structure and justify the increase in density with fibre treatment. It can be said that 5% NaOH is the optimum treatment in this study. The values obtained for the untreated fibres are higher than those for the treated fibres. This can be explained by the

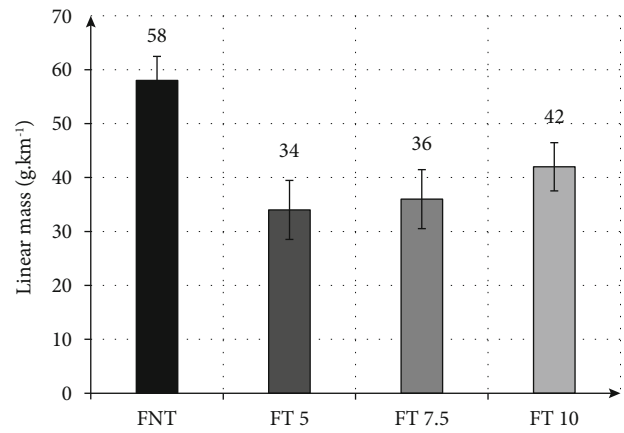

Figure 3: Linear density of untreated and NaOH-treated *Luffa cylindrica* fibres.

fact that during alkaline treatment with NaOH, lignin is effectively removed, making the fibres very susceptible to separation into finer fibres, and their fineness is higher than that of the raw fibres [10]. The results obtained are superior to those obtained for plantain stem fibres [34], *Triumfetta cordifolia* fibres [37], and pineapple *comosus* leaf fibres [22]. The results are of the same order of magnitude as those obtained for plantain pseudo trunks [15]. In agreement with other authors, the linear mass of *Luffa* fibres shows that they cannot be spun for textile use.

3.2. Diameter. Figure 4 shows the diameter of untreated and treated *Luffa cylindrica* fibres. The diameter ranges from 418.61 ± 31 μm for untreated fibres to 554.42 ± 30 μm for fibres treated with 7.5% NaOH. The values obtained are higher than those found on plantain trunk fibres, *Triumfetta*

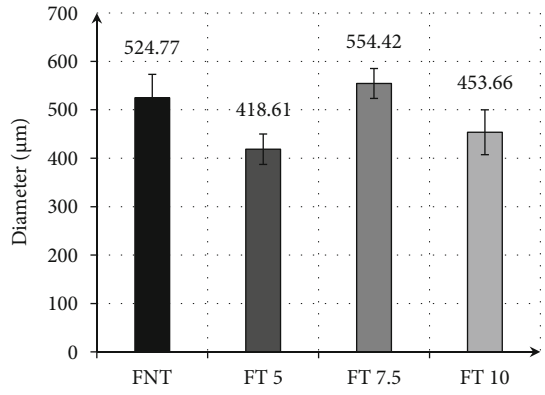

Figure 4: Diameter of untreated and NaOH-treated *Luffa cylindrica* fibre.

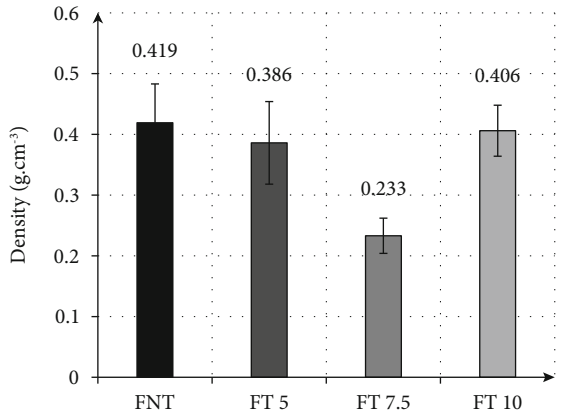

Figure 5: Density of untreated and NaOH-treated *Luffa cylindrica* fibre.

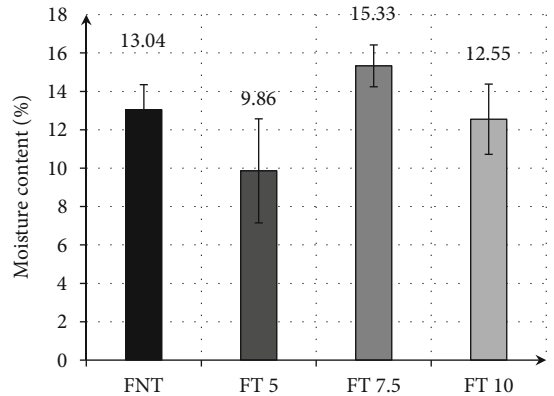

Figure 6: Relative humidity of untreated and NaOH-treated *Luffa cylindrica* fibres.

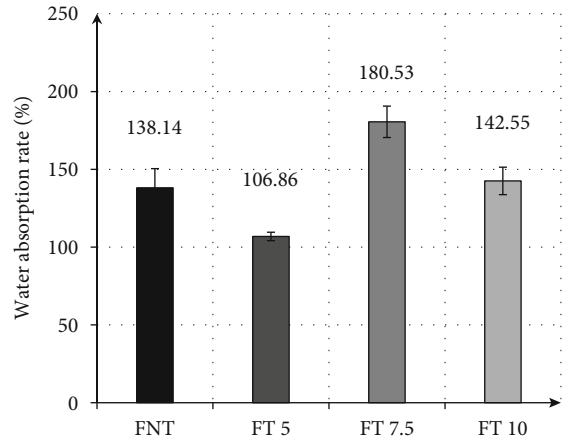

Figure 7: Water absorption percentage of untreated and NaOH-treated *Luffa cylindrica* fibre.

cordifolia fibres [37], and pineapple *comosus* leaf fibres [22]. Similar observations have been made with other fibres. This variation is associated with the reduction of certain fibre constituents such as cellulose, hemicellulose, lignin, and pectin. The wide range observed from $524.77 \pm 40\,\mu$m for untreated fibres to $554.42 \pm 30\,\mu$m for fibres treated with 7.5% NaOH could be explained by the significant nonreduction of volatile matter, hemicellulose, and pectin. Fibres treated with 7.5% NaOH had higher diameters, which could be explained by the lack of significant reduction in volatile matter, hemicellulose, lignin, and pectin [13, 32]. In addition, the diameter values observed could influence the mechanical properties since, according to, increasing the diameter reduces the stiffness and strength of the fibres but increases their deformation. As a result, *Luffa* fibre has a larger diameter than other plant fibres used to produce yarn, which limits the applications of *Luffa* in the textile industry, particularly for producing yarns.

3.3. Density. Figure 5 shows the density of untreated and treated *Luffa cylindrica* fibres. The lowest fibre density value was $0.233 \pm 0.029\,\text{g·cm}^{-3}$ for fibres treated with 7.5% NaOH, and the highest value was $0.419 \pm 0.064\,\text{g·cm}^{-3}$ for untreated fibres. The values obtained are of the same order of magnitude as those for jute fibres [34], pseudo plantain trunk fibres [15], and *Luffa* fibres found by Saw et al. [9]. The results show that *Luffa* fibres can be used to lighten composite materials with thermoplastic and thermosetting matrices. The density of the fibres decreased with NaOH treatment. This result is contrary to observations made on *Neuropeltis acuminatas* fibres [32]. This may be explained by the different nature of the two fibres. The NaOH treatment therefore acted differently.

3.4. Relative Humidity. Figure 6 shows that relative humidity, also known as hygroscopic degree, is the lowest for fibres treated at 5% ($9.86 \pm 2\%$) and highest for fibres treated at 7.5% ($15.33 \pm 1\%$). These results are of the same order of magnitude as those obtained for cotton [38], sisal [37], jute [29], and *Luffa cylindrica* Chinese fibres [8]. This variation profile is in line with the work of Chen et al. [8]. Treatment of the fibre with 5% NaOH considerably reduces the hydrophilic character of the fibre linked to the cellulose and hemicellulose [8]. Similar observations have been made on other fibres [8, 39]. The aim of the chemical treatment is to reduce the water content of the fibres, but at 7.5% NaOH, the

Table 2: Comparison of physical results for some plant fibres.

Fibres	Density (g·cm^{-3})	Water absorption (%)	Moisture content (%)	Fineness (g·km^{-1})	References
Banana trunk	0.88–1.61	347.1–517.4	—	8.3-34	[15]
Cotton	1.5–1.6	—	8–25	—	[38]
Sisal	1.33–1.5	190–250	5–10	—	[37, 38]
Flax	1.52	136	12	—	
Ananas comosus	1.25	188.6	12.2	—	[42]
FNT	0.419	138.14	13.04	58	In this study
FT 5	0.386	106.86	9.86	34	
FT 7.5	0.233	180.53	15.33	36	
FT 10	0.406	142.55	12.55	42	

FNT: untreated fibre; FT 5: 5% treated fibre; FT 7.5: 7.5% treated fibre; FT 10: 10% treated fibre.

Table 3: Model parameters for water uptake kinetics.

Authors	Treatments	R^2	RMSE	k	n	a	b	c	d	m
Czel and Czigany	FNT	0.942	0.082	—	—	0.267	—	—	—	0.185
	FT 5	0.931	0.081	—	—	0.421	—	—	—	0.123
	FT 7.5	0.944	0.076	—	—	0.324	—	—	—	0.157
	FT 10	0.958	0.062	—	—	0.403	—	—	—	0.128
Page	FNT	0.995	0.025	0.149	0.467	1.013	—	—	—	—
	FT 5	0.993	0.026	0.289	0.404	1.012	—	—	—	—
	FT 7.5	0.992	0.030	0.222	0.401	1.018	—	—	—	—
	FT 10	0.996	0.021	0.312	0.359	1.006	—	—	—	—
Mohsenin	FNT	0.973	0.061	0.045	—	0.765	—	0.002	0.161	—
	FT 5	0.969	0.059	0.096	—	—	0.818	0.001	0.085	—
	FT 7.5	0.976	0.054	0.068	—	0.759	—	0.001	0.103	—
	FT 10	0.955	0.070	0.105	—	0.779	—	0.003	0.124	—
Sikame et al.	FNT	0.992	0.035	0.059	—	0.553	0.371	0.978	—	0.004
	FT 5	0.991	0.034	0.239	—	0.507	0.435	0.965	—	0.001
	FT 7.5	0.994	0.030	0.077	—	0.619	0.313	0.987	—	0.002
	FT 10	0.985	0.043	0.285	—	0.503	0.441	0.968	—	0.010

chemical treatment actually increases the relative moisture content, proving that the chemical treatment is no longer effective above 5% NaOH.

3.5. Water Absorption Uptake. Water absorption varied from 106.86 ± 2.71% for the 5% treatment to 180.53 ± 10.09% for the 7.5% NaOH treatment, showing the hydrophilic nature of this fibre. The values obtained are lower than those for pseudo banana trunk fibre [15] and *Raffia vinifera* fibre [11]. They are of the same order of magnitude as those for oil palm mesocarp fibre (OPMF) [35]. Figure 7 shows the curve for the percentage of water absorbed; it shows that fibres treated with 7.5% have a higher absorption percentage than untreated fibres. This can be explained by the fact that untreated *Luffa* fibres contain impurities. According to the authors, the 5% treatment eliminates impurities from the fibre without damaging its structure, allowing better adhesion with polymers [32, 37]. On the other hand, at 10%, the fibre constituents (cellulose, hemicellulose, lignin, and pectin) are reduced [10, 32]. Table 2 shows a comparison of physical characteristics with those of other fibres. It can be seen that chemical treatment above 5% NaOH rather increases the rate of water absorption, which proves that treatment is no longer effective above 5% NaOH.

The experimental points of the absorption kinetics were modelled using the MATLAB 2010b environment. Table 3 shows the various parameters obtained during the process.

Table 3 shows that the Page model has the best correlation with the different experimental points. In addition to this model, the Sikame et al. model has a high correlation, but the Page model has fewer static parameters than the Sikame model. The curve representing the Page model is shown in Figure 8.

The curve in Figure 8 shows a strong correlation, and the diffusion coefficient was calculated using equation (5). In the first phase, the diffusion coefficient varies from 2.03×10^{-14} m^2·s^{-1} for fibres treated with 7.5% NaOH to 4.61×10^{-14} m^2·s^{-1} for fibres treated with 5% NaOH. Above 5%, the treatment

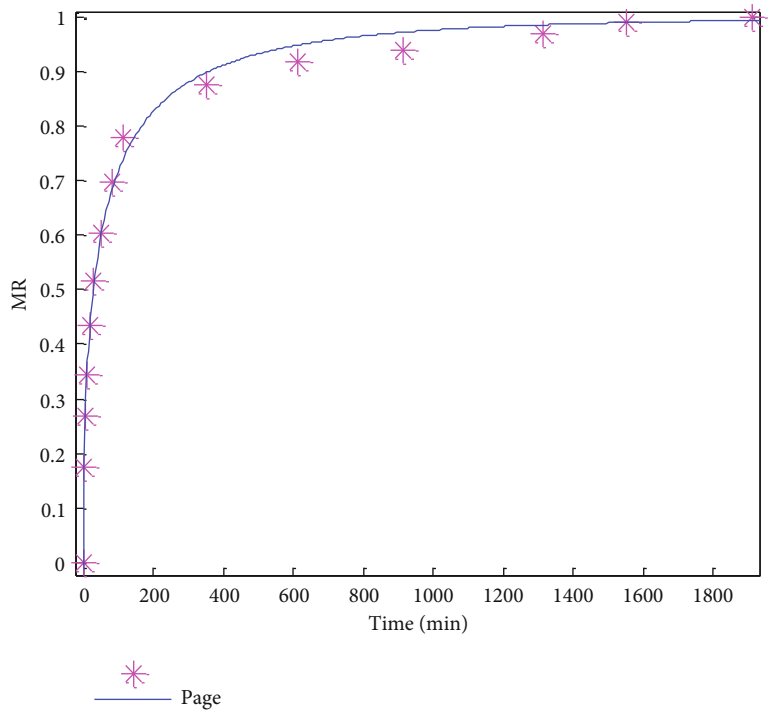

Figure 8: Representative curve for the Page model.

Table 4: Comparison of diffusion coefficients.

Plant fibres	Diffusion coefficient for water absorption		References
	Deff1 ($m^2 \cdot s^{-1}$)	Deff2 ($m^2 \cdot s^{-1}$)	
Hemp fibre	5.29×10^{-12}	5.80×10^{-13}	[46, 47]
Flax fibre	2.11×10^{-12}	2.11×10^{-13}	
Sisal fibre	4.00×10^{-12}	4.38×10^{-13}	
Jute fibre	4.02×10^{-4}	—	[48]
OPMF-Du fibre	4.27×10^{-12}	—	
OPMF-Ti fibre	5.26×10^{-12}	—	
OPMF-Te fibre	2.31×10^{-12}	—	
Raffia vinifera fibre	7.12×10^{-11}–2.36×10^{-10}	2.87×10^{-14}–6.73×10^{-14}	[11]
Raffia vinifera cork	1.063×10^{-9} – 8.746×10^{-9}	7.668×10^{-11}–1.615×10^{-10}	[45]
FNT	3.58×10^{-14}	2.60×10^{-16}	In this study
FT 5	4.61×10^{-14}	1.51×10^{-16}	
FT 7.5	2.03×10^{-14}	1.03×10^{-16}	
FT 10	1.24×10^{-14}	1.21×10^{-16}	

FNT: untreated fibre; FT 5: 5% treated fibre; FT 7.5: 7.5% treated fibre; FT 10: 10% treated fibre.

considerably slows the rate at which water is absorbed into the fibre. In the second phase, the diffusion coefficient varies from 1.03×10^{-16} $m^2 \cdot s^{-1}$ for fibres treated with 7.5% NaOH to 2.6×10^{-16} $m^2 \cdot s^{-1}$ for untreated fibres. The values obtained are lower than those for palm nut mesocarp fibres [35] and *Raffia vinifera* fibres [11]. The diffusion coefficients of some plant fibres are shown in Table 4, for comparison with *Luffa cylindrica* fibre.

3.6. Tensile Test. The tensile test was carried out on treated and untreated fibres. Twenty-five samples were subjected to each treatment, giving a total of one hundred samples. The curve representing one sample from each treatment is shown in Figure 9.

Figure 9 shows the stress-strain curves for untreated and treated *Luffa cylindrica* fibres. Whatever the amount of NaOH, the fibre exhibits brittle behaviour. Young's modulus

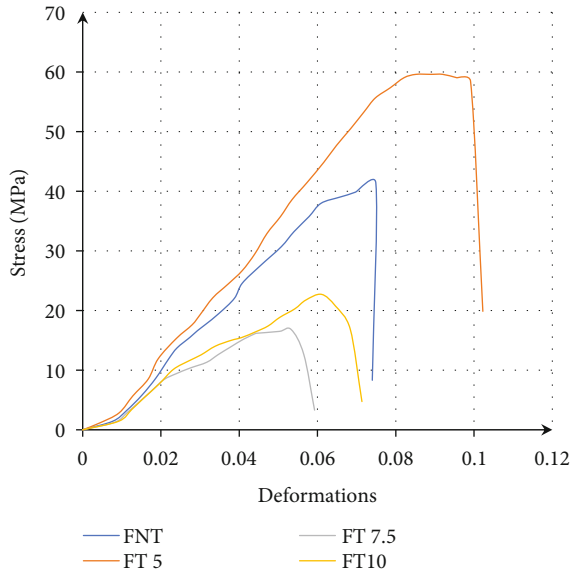

Figure 9: Representative curve of treated and untreated *Luffa* fibres.

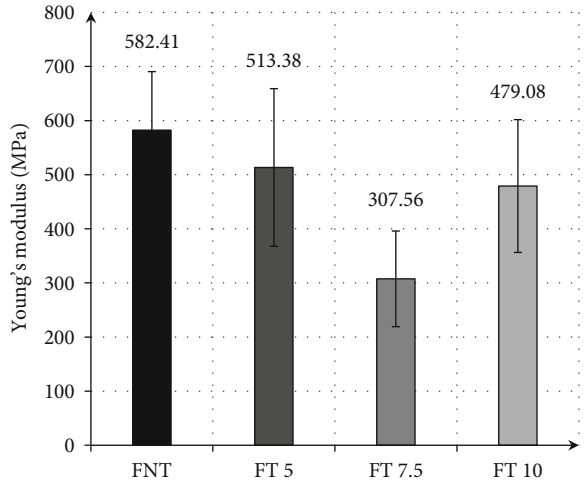

Figure 10: Young's modulus of untreated and NaOH-treated *Luffa cylindrica* fibre.

is obtained by the method of least squares, demonstrating Hooke's law. This Young's modulus is identified in the linear part of the sample. Young's modulus distribution curve is shown in Figure 10. Young's modulus varies from 582.41 ± 108.41 MPa for the untreated fibre to 307.56 for the fibre treated at 7.5%. The mechanical stress (Figure 11) varies from 9.744 ± 2.6 MPa for fibres treated at 10% to 27.4 ± 7.05 MPa for fibres treated at 5%. Elongation (Figure 12) varied from $8.11 \pm 2.57\%$ for fibres treated with 7.5% NaOH to $3.45 \pm 0.9\%$ for fibres treated with 10% NaOH. The results obtained are of the same order of magnitude as those found by Chen et al. [8]. The results are lower than those found for pseudo plantain trunk fibre [15] and *Raffia vinifera* fibre [13]. A comparison of the results obtained with other

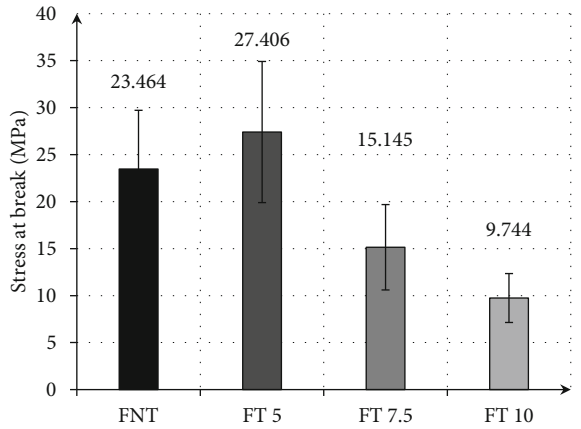

Figure 11: Stress at break of untreated and NaOH-treated *Luffa cylindrica* fibre.

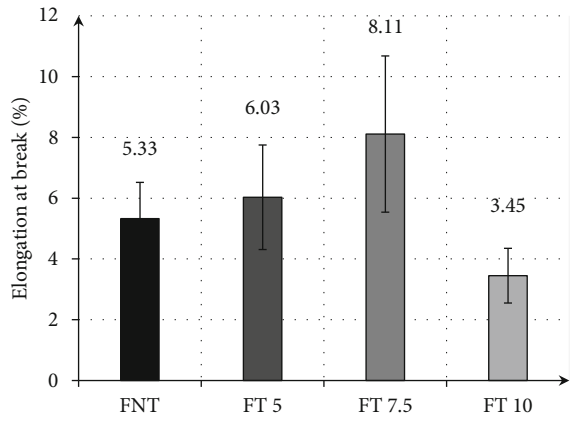

Figure 12: Elongation at break of untreated and NaOH-treated *Luffa cylindrica* fibre.

plant fibres is presented in Table 5. It can be seen that up to 7.5%, Young's modulus decreases and the elongation of the material increases. This is due to the cellulosic and woody elements contained in the fibre, which give it greater strength [13, 40]. However, the mechanical stress of the fibre increases by 5%. The mechanical properties of the fibre are mediocre at 10%. For composite applications, treatment of the fibre at 10% does not corroborate the work of Chen et al. [41]. This may be justified by the fact that the harvesting area and maturity of the plant have a significant effect on its characteristics. Similar observations have been made for agave fibres [32, 42, 43]. The decrease in Young's modulus at 7.5% NaOH shows that the treatment is not effective above 5% NaOH, which alters the fibre structure, and the lignin responsible for fibre stiffness is greatly reduced. It was found that the mechanical properties are weaker above 5% NaOH, which could be explained by the fact that the chemical treatment is no longer effective above 5% NaOH. The results confirm the reference [44] according to which it is necessary to treat the fibre between 2 and 5%.

Table 5: Tensile properties of some plant fibres as compared to *Luffa cylindrica* fibre.

Fibres	Diameter (μm)	Young's modulus (GPa)	Stress at break (MPa)	Elongation (%)	References
Pseudo banana trunk	117–247	6.6–34.6	91–343	0.88–2.61	[15]
Cotton	11–22	5.5–12.6	287–597	3–10	[38]
Kenaf	—	20	223–930	9.1–12.3	[49]
Jute	—	15–30	610–780	1.0–1.9	[49]
Luffa cylindrica fibre from China	—	0.207–0.821	8.38-35.12	4.19–12.14	[41]
Raffia vinifera fibre	—	1.49–7.25	32.7–203.7	1.57–4.20	[13]
FNT	419	0.582	23.464	5.33	In this study
FT 5	386	0.513	27.406	6.03	
FT 7.5	233	0.307	15.145	8.11	
FT 10	406	0.479	9.744	3.45	

FNT: untreated fibre; FT 5: 5% treated fibre; FT 7.5: 7.5% treated fibre; FT 10: 10% treated fibre.

4. Conclusion

The aim of this work was to extract, process, and characterise *Luffa cylindrica* fibre from Cameroon. The fibre was extracted manually. The fibres were treated with three concentrations of NaOH (5%, 7.5%, and 10%) for 60 minutes at a temperature of 28°C. Physical tests were carried out using a gravimetric method. Tensile tests were carried out in accordance with the NF T25-501-2 protocol. The results show that the treatment affects the properties of the raw *Luffa* fibre. However, fibres treated with 5% NaOH have the best physical and mechanical properties and can be used effectively to reinforce composites with thermoplastic and thermosetting matrices. The authors suggest using other chemical, thermal, or enzymatic treatments, supplementing the tests carried out with chemical tests (thermogravimetric analysis, Fourier transform infrared spectrometry) and microstructure analyses in order to fully understand the treatments developed, and applying these fibres to the reinforcement of composites intended for various industrial sectors (construction, automotive, and thermal insulation).

Data Availability

The data used to support the conclusions of this study are available on request from the corresponding authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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