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Influence of Moisture on the Mechanical Properties of *Rhecktophyllum camerunense* Vegetable Fiber

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Abstract: Plant fibers are become an environmentally friendly substitute to glass fibers for the reinforcement of composites, particularly in automotive and civil engineering. The fundamental difference between these two types of fibers is their behavior to the humidity. Plant fibers absorb moisture when they are used as reinforcement in composite materials and drawback their mechanical properties. It is important to analyze hygromechanical behavior of plant fibers in order to treat them before using in composite material as reinforcement. The treatment can be electrically, physically, chemically and other. Indeed, the RC fibers used in this study come from the roots of RC collected in central Cameroon. Fresh ones have been selected for this purpose**.** Some samples were submitted to hygroscopic ageing in an environmental enclosure of 23%, 54% and 75% relative humidities at 23±1°C and others immersed in distilled water (100%). Hygroscopic ageing is noted by the saturation of the fibers after several weighing on a balance until the constant mass is obtained. This experiment followed steps described by NF EN ISO 483: 2006-01 standard. After that tensile test was done on those saturated individual fibers according to ASTM D 3397-75 standard. Twenty specimens were used to evaluate elastic properties of RC at each hygroscopic condition. The qualitative analysis of behavior curve shows that no matter the relative humidity, the RC fiber presents a toughness behavior and elastic material, characterized by a relatively prevalent viscoelastic area and a great elongation at break. However, we note a decrease of the stress at break and decrease of the elastic modulus for all humidities.

Keywords: RC Fiber, Humidity, Water Absorption, Tensile Test

1. Introduction

Plant fibers are become an environmentally friendly substitute to glass fibers for the reinforcement of composites, particularly in automotive engineering [1]. A vegetal fiber extracted from the *Rhectophyllum camerunense* (RC) plant is studied in this paper. The first works on the RC fiber was done by Béakou et al. [2]. Tensile tests were performed to measure the mechanical properties of the fiber. The Young's modulus of 5.8 GPa and elongation at break is very high up to 50%. Many authors have also worked on that fibers [3-6]. Figure 1 shows the RC plant and fibers.

Due to their wide availability, low cost, low density, high-specific mechanical properties and eco-friendly image, they are increasingly being employed as reinforcements in polymer matrix composites [7]. Research subjects about such fibers are abundant because there are always some issues to prevent their use at large scale (poor adhesion, variability, low thermal resistance, hydrophilic behavior). The use of plant fibers compared to that of glass causes variations in the ultimate characteristics of the composite. The fundamental difference between these two types of fibers is their behavior to the humidity. Indeed, glass fibers are hydrophobic whereas plant fibers have naturally hydrophilic behavior. During their lifetime composites are exposed to climatic variations, including unsteady hygroscopic conditions. However, in humid conditions, strong hydrophilic behavior of such reinforcing fibers leads to high level of moisture absorption in wet environments [8].

This results in the structural modification of the fibers and an evolution of their mechanical properties together with the composites in which they are fitted in [9-11]. Thus a better knowledge of the mechanisms of absorption and desorption as well as their impact on the mechanical properties of plant fibers and of composites is of very great interest. Thiis the objective of our work.

(a) (b) (c)

Figure 1. *RC: a- Plant; b-Roots; c-Extracted fibers [6].*

Many authors showed a relationship between moisture and mechanical properties of plant fibers. Although this influence has been clearly demonstrated, the different results of the literature are not consistent altogether. Indeed, Davies and Bruce, observed experimentally a tendency to a decrease of the young's modulus with increasing relative humidity for flax and nettle fibers (from 30 to 80 %) [12]. This trend is also highlighted by Symington et al., 2009 for flax [11], Ho and Ngo, 2005 for hemp and coir fibers [13] and Roudier, 2012 for flax on 33, 60 and 75% relative humidity [14]. Figure 2 below shows the influence of telative humidities of 33 and 60 % on tensile properties of flax. However, other studies show an increase of the young's modulus of fibers with relative humidity up to a specific threshold of water absorbed [10, 11]. Particularly Placet et al., 2012 show the young modulus of hemp fibers increases about 20% in the 25- 80 % relative humidity range [10].

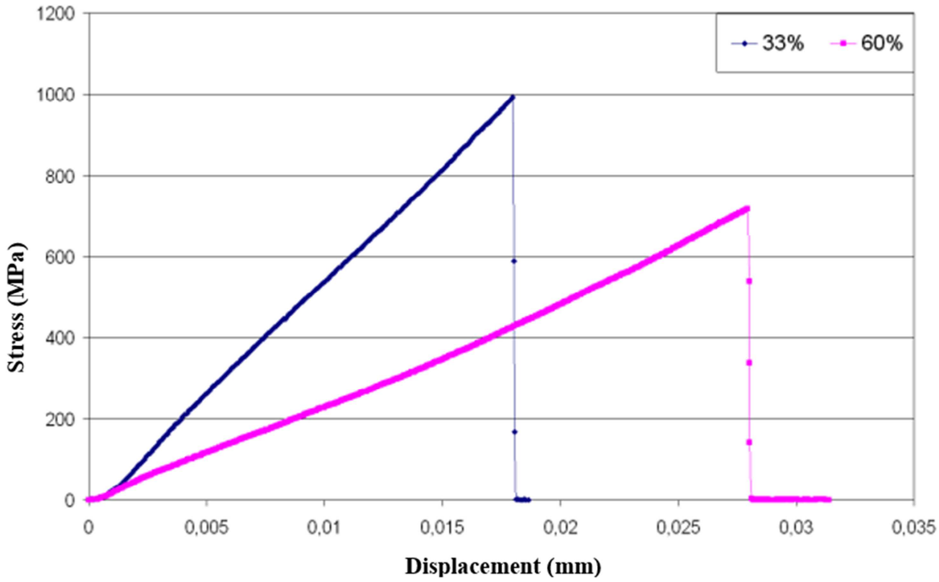

Figure 2. *Tensile testing of flax fibers at relative humidities of 33 and 60 % [14].*

This increase in stiffness could be explained by a rearrangement of the microfibrils and the surrounding molecules acting as a matrix [10]. This rearrangement could be activated by the swelling of the fibers. Beyond a certain moisture content threshold, the decrease of the young's modulus could be explained by the plasticization of the fiber. In fact, the formation of hydrogen bonds replacing bonds in hemicellulose macromolecular network could make the material more flexible and compliant. The aim of this study is to evaluate the influence of water on the mechanical properties of RC fibers. The fibers samples were submitted to hygro-thermal ageing in an environmental enclosure of 23%, 54% and 75% relative humidities at 23±1°C and in immersed distilled water (100%). Then following by the tensile test on the saturated fibers.

2. Material and Methods

2.1. Material

Indeed, the fibers treated in this study are extracted from the roots of RC collected in central Cameroon. Fresh ones have been selected for this purpose. We also use the thermostatic oven of Memmert mark to dry fibers. A balance PMI 400 mark with a precision of 0.001g was used to carry out the weighing. A desiccator containing silica crystals to maintain fibers at dry state. Figure 3 presents materials used.

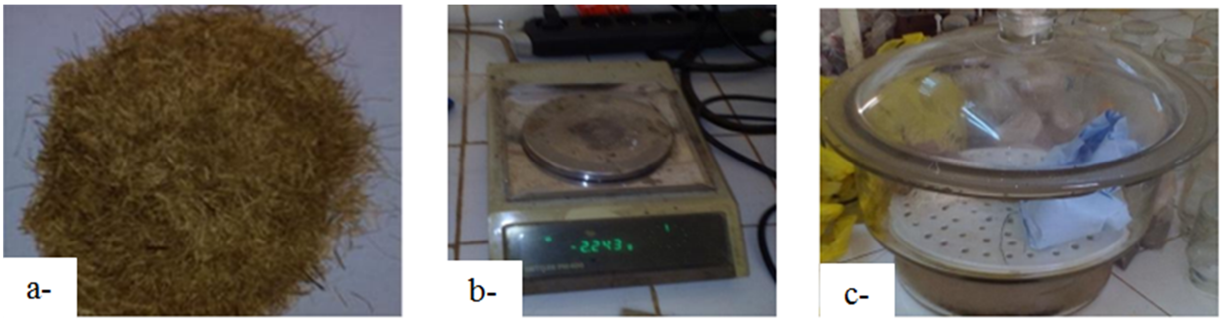

Figure 3. *Material used: a- RC fibers; b- Balance; c- Desiccator.*

Three chemical salts were used to prepare saturated aqueous solutions to create relative humidity in a small enclosure as mentioned in table 1. The conditioning small enclosure was made up with the plastic bottles as indicated on Figure 4. For tensile test we used the machine of the mechanic laboratory of the University of Douala presented on Figure 5.

Table 1. *Salt solutions used and their relative humidity (RH) at saturation.*

Saturated Salt solution	Solubility (g/l)	Quantity for 20 ml of water (g)	RH (%) at 23°C
Potassium acetate	2000	42	23
Magnesium nitrate hexahydrated	1250	27.5	54
Sodium chloride	357	8	75

2.2. Methods

The extraction of fibers was made according to a method prescribed in literature [2]. The Hygroscopic ageing test procedure is described by NF EN ISO 483: 2006-01 standard. It was done in mechanical laboratory of the University of Douala. The saturated salt solutions were prepared with distilled water 24 hours before the beginning of the test at 23±1°C. The fibers length was 40mm and dried in oven at 60°C for 48 hours then, introduced into a desiccator to avoid reabsorption of ambient moisture. For each environmental condition, specimens were introduced in small enclosure as presented on Figure 3. Another specimen was immersed on distilled water. After 24 H we used our balance to control the saturation of fibers. After saturation, the elastic properties of RC fibers (stress at break, Young's modulus, and elongation at break) were obtained according to ASTM D 3397-75. Twenty fibers coupons of RC fibers were designed by providing the two ends with anchoring, in fact a short skidproof sheath maintained by pinching and joined using the cyanocrylate adhesive. All measurements were conducted with a gauge length of 20 mm and at a constant speed of 20 mm/min. The cross-section of the fiber was calculated from the diameter measured by using optical microscopy assuming a cylindrical fiber and an average of three different point readings. To simplify, we considered that the fibers are perfectly circular cross-sections.

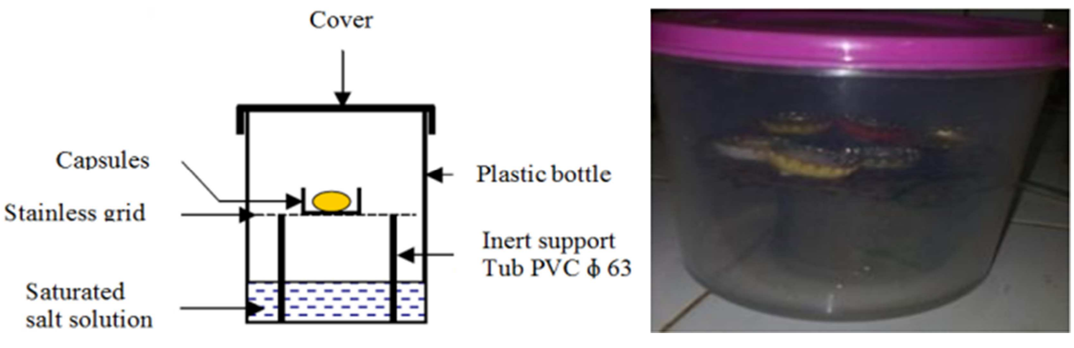

Figure 4. *Experimental setup and small enclosure chamber with specimens.*

A statistical analysis of the measurements was performed. The objective of this treatment was to adjust the values measured with a probabilistic distribution in order to estimate the mean value and the dispersion of the fiber mechanical properties.

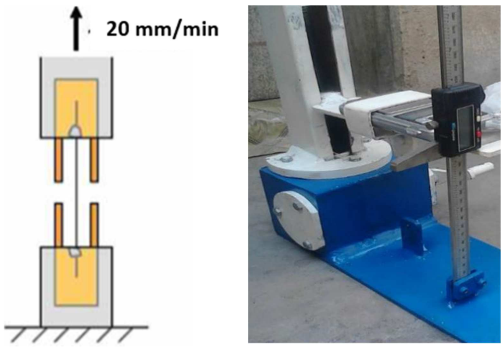

Figure 5. *Experimental setup and tensile test machine.*

3. Results and Discussion

Our experimental values are different than those of some authors [2, 4] tested in ambient moisture and temperature. This difference would be due to the fact that the fibers tested were not from the same origin, the conditions of tests were different and the presence of defects (cracks) from cellulose fibers. Those factors could be also the reason for the great dispersion of the values of the properties in tensile test of the studied fibers. Table 2 presents properties in tensile test of fibers at different humidities.

Table 2. *Properties in tensile test of fibers at different humidities.*

Fibres	Humidity (%)	Stress at break σ (MPa)	Elastic Modulus E (GPa)	Strain at break ε
	0	455.06 (82.7) *	9.81 (2.6) *	0.24 (0.07) *
	23	432.80 (41.4)	8.66 (1.8)	0.29 (0.09)
RC	54	416.98 (56.9)	7.29 (2.2)	0.35 (0.04)
	75	407.11 (43.7)	5.85 (1.6)	0.43 (0.10)
	100	358.11 (66.2)	2.43 (0.5)	0.62 (0.12)

(*) indicates the values of standard deviations

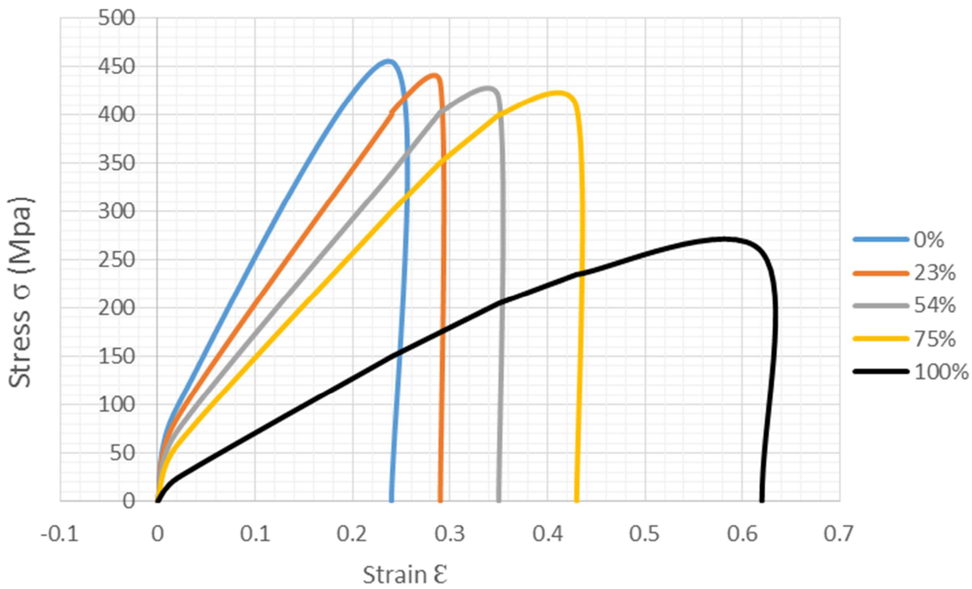

Figure 6. *Stress-strain curves of RC at different humidities.*

Figure 6 presents the curve of stress-strain at different humidities A qualitative analysis of the RC curve shows that no matter the relative humidity, the RC fiber presents the behavior of a tough and elastic material, characterized by a relatively prevalent viscoelastic area and a great elongation until the rupture. The same type of behavior was observed in the literature [2, 4]. As regards the relative humidity going from 0 to 75%, the variation of the stress at break is not significant. It varies from 407,11 to 455,06 Mpa. This low variation of the stress at break have been also observed by many authors on the vegetable fibers like flax and nettle for the relative humidities of 30, 40, 50, 60, 70% [12]. That was also observed on hemp, sisal, flax, jute, plant for the relative humidities of 10, 25, 50, 80% [11]. This allows to explain the resistance and the longevity of the RC roots in the extremely wet zones. However, we note a decrease of the stress at break which is 12.03% when we pass from the relative humidity to the absolute humidity (100% immersed fibers). On the other hand, we observed a decrease of the elastic module to all relative humidities as presented on Figure 6. From 0 to 75% we note a variation of 9.8 to 5.85Gpa. For 100% of moisture we have the decrease to 2.43 Gpa. With regard to the elongation at break we observe an increasing. From 0 to 100% we note a variation from 0.24 to 0.62. This high elongation at break shows the ductile behavior of the RC fiber. The decrease of the elastic modulus and the increasing of the elongation at break at different humidities were also observed by many authors on several fibers like hemp, sisal, flax, jute, nettle and others [10-15]. Figures 7, 8 and 9 present respectively the variation of stress at break, elastic modulus and elongation at break versus the humidity.

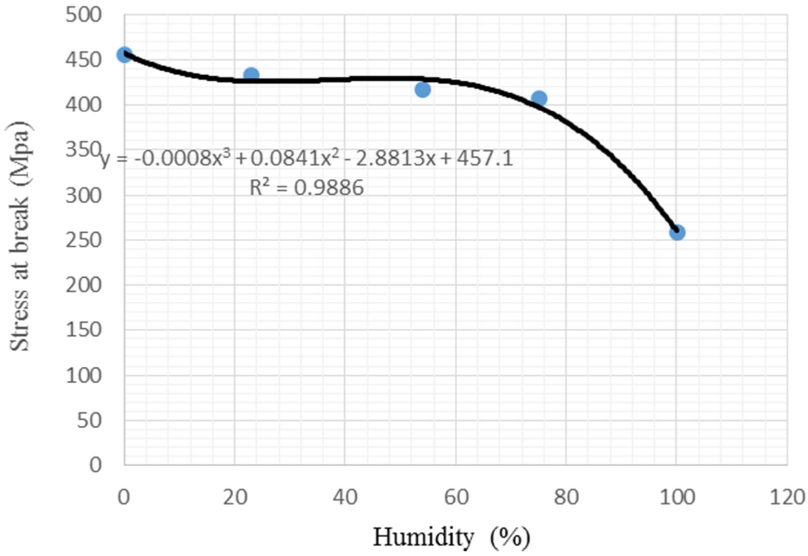

Figure 7. *Stress at break at different humidities.*

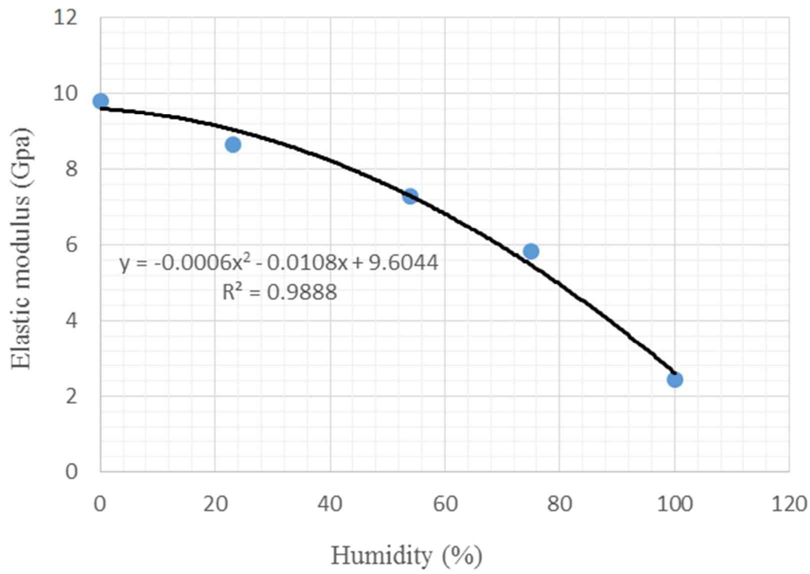

Figure 8. *Elastic modulus at different humidities.*

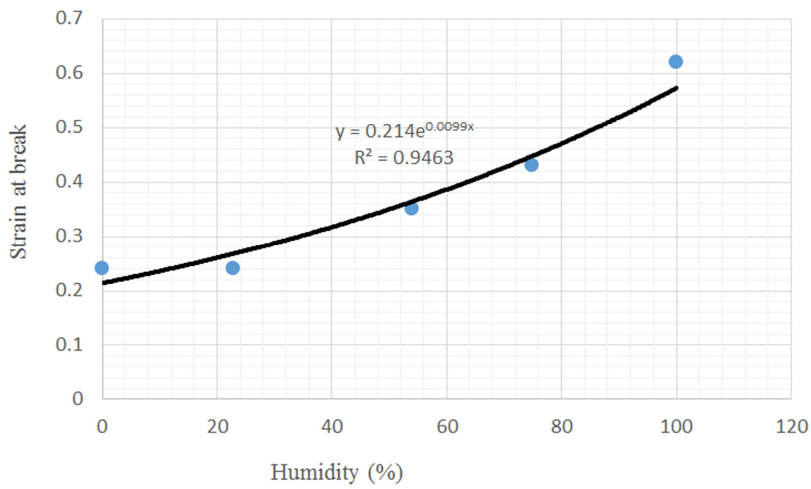

Figure 9. *Strain at break at different humidities.*

The experimental results obtained by the tensile tests in the various conditions of humidity show that moisture draws the elasticity modulus of fibers and does not have a significant effect on the stress at break. The elongation at break increases with humidity. Several factors influence the mechanical properties in tensile test of vegetable fibers such as the geometrical form, the morphological structure, the length of test, speed in tensile, the temperature, the ambient moisture and the mechanism of fiber break. Contrary to the synthetic fibers which are geometrically uniform, the vegetable fibers have a great variability of the intrinsic properties of one fiber to other and also throughout the same fiber. Moreover, the vegetable fibers have inevitable defects had with the processes of extraction, which is probably the principal cause of the dispersion of the experimental values of tensile test even under carefully controlled laboratory conditions.

4. Conclusion

Mechanical behavior in tensile test of RC fibers under the moisture was approached. Initially the material was subjected to an environmental ageing with various moistures. The test began once noted saturation. The experimental data were treated by the statistical analysis in order to obtain the average values of the mechanical properties as the elastic modulus, the strain and the stress at break. The behavior curve was plotted. A qualitative analysis of this curve enabled us to determine the behavior of fiber. It is noted generally that moisture shutdown the mechanical properties of RC fiber. For the variation of the Stress at break, an analysis by ANOVA shows that this variation is not significant. This allows to conclude that moisture does not have a great influence on the Stress at break. That justifies the longevity and the resistance of RC roots in water. On the other hand, one notices a drop of the Young modulus and an increase in the elongation with rupture. With regard to the tensile test behavior one notices that whatever the moisture, the RC presents an elastic and ductile character.

Conflicts of Interest

The authors declare no conflict of interest.

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