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Mechanical Characterization of Polyester Matrix Composites Reinforced by *Neuropeltis acuminatas* Fibers and Properties Evaluation in Structures

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Abstract: This paper aims to determine the technical feasibility of introducing *Neuropeltis acuminatas* fibers into polymer matrix composites. The Young's modulus of polyester without reinforcement is higher than that of polyester containing *Neuropeltis acuminatas* fibers. The *Neuropeltis acuminatas* fibers are good candidates for reinforcing polyester resin composites. The results of three-point bending tests enabled us to compare Young's moduli as a function of fibers orientation between different reinforcement ratios. For unidirectional orientation, the mechanical properties of the composite changed significantly as a function of the *Neuropeltis acuminatas* fibers content ratio. A slight decrease in load is then observed, probably corresponding to the point of first macroscopic damage to the composite. This load recovery may reflect good adhesion at the fiber-matrix interface. During mechanical testing, increasing the level of randomly oriented fiber reinforcement (to levels of 35%, 45% and 55%) progressively increases the Young's modulus of the composites used. In unidirectional composites (at levels of 35%, 45% and 55%), the Young's modulus changes slightly before gradually decreasing. The linear elastic model implemented in the finite element calculation code was tested to verify the linear behaviour of the composite. The composite material exhibits a complex behaviour including damage under the three-point bending loadings.

Keywords: Polyester Matrix Composite, *Neuropeltis acuminatas* Fibers, Mechanical Behaviour, Short Trips

1. Introduction

In a sustainable development and eco design approach are integrating research into the fields of biocomposites [1–4]. These materials are appreciated for good mechanical, thermal, physical and phonic properties in many sectors (automobile, packaging, etc.) [5–7]. The major lock of the production of natural fibers reinforcing composites is to integrate hydrophilic fibers into polymeric matrices generally hydrophobic character [8–11]. In the face of environmental problems and the current energy crisis, building materials whose reinforcement is made of vegetable fibers, are the subject of a growing interest, because of good ability to replace the synthetic fibers [12–14]. Indeed, the vegetable fibers present many assets [15–17]: renewable, abundant, cheap resources, interesting specific mechanical properties. In developing countries, the strengthening of materials by vegetable fibers is a way to explore [1, 18–20].

The *Neuropeltis acuminatas* (NA) plant is a woody vine with twisted stems up to 40 m long and up to 25 cm in diameter. It has alternate, simple leaves with petioles $8-25$ mm long; The lamina is elliptical, $5-12cm$ $\times$5-6 cm, rounded to wedge-shaped at the base, having an entire margin.

The *Neuropeltis acuminatas* (NA) fibers have since been used by our ancestors in South Cameroon [21–23]. These formed a pile of fibers that they used as a dish sponge and toilet gang. In a sustainable development and eco design approach are integrating research into the fields of bio-composites [24]. These materials are appreciated for good mechanical, thermal, physical and phonic properties in many sectors (automobile, packaging, etc...). The major lock of the production of natural fiber composites is to integrate hydrophilic fibers into polymeric matrices generally hydrophobic character. Indeed, the vegetable fibers present many assets: renewable, abundant, cheap resources, interesting specific mechanical properties. In developing countries, the strengthening of materials by vegetable fibers is a way to explore [18, 19, 25].

For a first study, the process used is the traditional method. This method consists after retting for a few days, in crushing the vine. Then the epidermis and the bundle of fibers are removed for the rest of the operation; The epidermis and the fibers bundle are beaten, gradually removing the wax that emerges with the hand; When the wax is completely removed, the fiber bundle is washed with water [10]. Polyester is a thermosetting resin and it has a low elastic modulus of Thermosetting resins are polymers which, after a thermal or physico-chemical treatment (catalyst, hardener), turn into essentially infusible and insoluble products [26, 27]. These resins therefore have the particularity of being able to be shaped only once. Thermosetting resins have high mechanical properties. These resins can only be shaped once [18, 28]. They are in solution in the form of an uncrosslinked polymer suspended in solvents. Unsaturated polyester resins, condensation resins (phenolics, amioplasts, furans) and epoxy resins are thermosetting resins. Examples of thermosetting resins conventionally encountered are 914, 5208, 70, LY556 [29]. This project makes it possible to make a contribution to the development of local resources and to integrate it rationally in the industrial sector. These new eco-composites have interesting mechanical properties [30]. As the incorporation of NA fibers into polyester has not yet been studied, the main objective of our experimental work is to evaluate the mechanical behaviour in three-point bending of polyester-fiber composites of NA.

2. Materials and Methods

2.1. Polyester Matrix Composites Reinforced by NA Fibers

The *Neuropeltis acuminatas* fibers cut to a certain length that is fairly short, constant and arranged without special realization of the composite material. For the implementation of the test pieces, we will proceed by the following steps. Figures 1(a) and (b) show the mat of short fibers of NA. These steps are not without difficulties. Indeed, the problem of polishing the plates had to be faced. Because after demoulding, the surface finish of the plates was very irregular. Polishing had to be done using a universal milling machine. When sawing the specimens to a standard size, there was a problem with the breaking of the specimens because the dimensions used for the specimens are: $10mm \times 10mm \times 150mm = 15000mm^3$ This mold is made up of 9 compartments having for dimension common: $90 \times 10 \times 150$. The test pieces obtained must be machined in order to have those of the dimensions defined above with regular surfaces. Below are the representations in view of the mold. After molding the specimen plates, it requires machining in order to have standardized specimens; for this the material below has been used and proceed as follows. Figures 2(a) and (b) show the resulting composites. For the experiment, five samples will be tested.

2.2. Three-Point Bending Tests Device

The three-point bending takes place according to the NF EN 310 standard [30, 31]. The modulus of elasticity is thus determined. The measuring device used is brand SHIMADZU and model LDW-5kN. Specimens are cut from the composite panels.

Figure 1. *Short fibers ready for the production of the composite material. (a) Sisal short fiber mat. (b) NA Short fiber.*

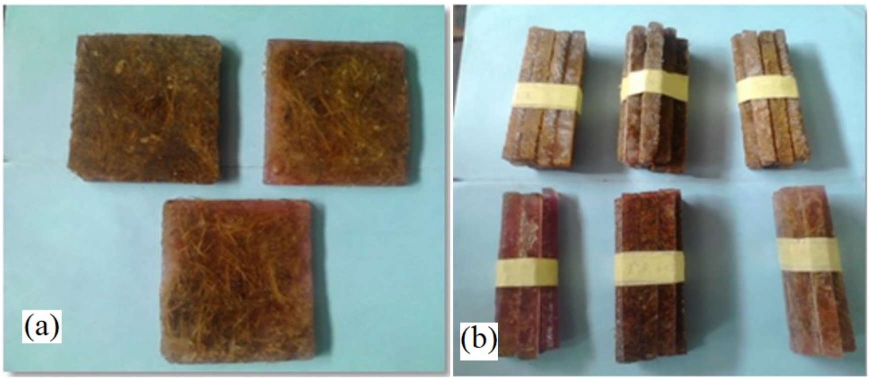

***Figure 2.** Short fibers ready for the production of the composite material. (a) Shape of the plates after demolding; (b) Shape of the specimens after machining.*

The dimensions chosen vary according to the size of the original panels but comply with all the test constraints imposed in the standard. The specimen is placed on a support consisting of two fixed cylinders, and the third cylinder mounted on a movable cross member is brought into contact with the specimen. The speed of descent imposed on the cross head is set at 2 mm/min in order to obtain a break at $60s \pm 30s$. The force exerted by the device is continuously measured until the specimen breaks. Two characteristics of the material can then be calculated, the flexural modulus of elasticity. The modulus at rupture is:

$$\sigma = \frac{3PL}{2bt^2} \quad (1)$$

where: P is the maximum load (N), L is the distance between the axes of the cylindrical supports (mm), b and t are the width and thickness of the specimens respectively (mm).

$$E = \frac{L^3 P_1}{4bt^3 d} \quad (2)$$

With d the deflection in the middle of the span corresponding to the load P_1 (mm). The data obtained in this way are entered into Excel to be processed in order to draw the Stress/Strain curve of each of the specimens by formulating our composite.

3. Finite Elements Method

The small perturbation assumptions can be considered for the three-point bending tests that were previously performed on the samples [32]. Samples of unreinforced polyester materials, then with NA reinforcement of 35%, 45% and 55% were modelled by finite element to determine the evolution of the displacements of each specimen using their respective Young's moduli while maintaining the Poisson's ratio of the polyester (ν=0.38). The linear elastic behaviour of the specimens makes it possible to use the equation of compatibility between deformation $\overline{\overline{\varepsilon}}$ and displacement u by:

$$\overline{\overline{\varepsilon}} = \frac{1}{2}(\overline{\overline{grad}}\,\overrightarrow{u} + (\overline{\overline{grad}}\,\overrightarrow{u})^T). \quad (3)$$

The stress-strain law is defined by [33, 34]:

$$\sigma_{ij} = \frac{\nu E}{(1+\nu)(1-2\nu)}\varepsilon_{kk}\delta_{ij} + \frac{E}{(1+\nu)}\varepsilon_{ij}, \quad (4)$$

where δ_{ij} is the Kronecker's coefficient, ε_{ij} component of strain tensor. At the level of the external surfaces on which the forces are imposed, the following equilibrium relations are respected [33, 34]:

$$div\overline{\overline{\sigma}} + \overrightarrow{F}_d = \overrightarrow{0}, \quad (5)$$

where $\overrightarrow{F}_d$ is the external surface force.

4. Results and Discussion

4.1. Mechanical Characteristics of the Samples of the Different Test Pieces

The Mechanical characteristics of the samples for different levels of reinforcement are obtained during three-points bending tests. the following Figures 3(a) to (g) show the evolution of the force applied as a function of the displacement at the center of the sample. Figure 3(a) presents the experimental tests results for the pure polyester.

Figures 3(a) to (d) present the experimental tests results for test tubes with 35%, 45% and 55% of random fibers (RTT). Figure 3(e) to (g) present the experimental tests results for test tubes with 35%, 45% and 55% of Unidirectional Fibers (UTT). Three types of behaviour are observed for different reinforcement levels [31]. The first behaviour of the polymer matrix composite material reinforced by NA fibers corresponds to a pure polyester and is characterized by a linear and brittle behaviour before rupture, which reflects a load supported mainly by the matrix which is gradually transferred to fibers; The second behaviour of the composite material, relating to the reinforced polyester, results in a linear behaviour up to load recovery from which a slight load drop is observed, probably corresponding to the point of first macroscopic damage to the composite; This recovery of load probably reflects good adhesion to the fibers-matrix interface. The third behaviour of the composite material is resulting from the appearance of significant non-linearity up to the peak, which most likely corresponds to damage that progresses to the maximum applied force.

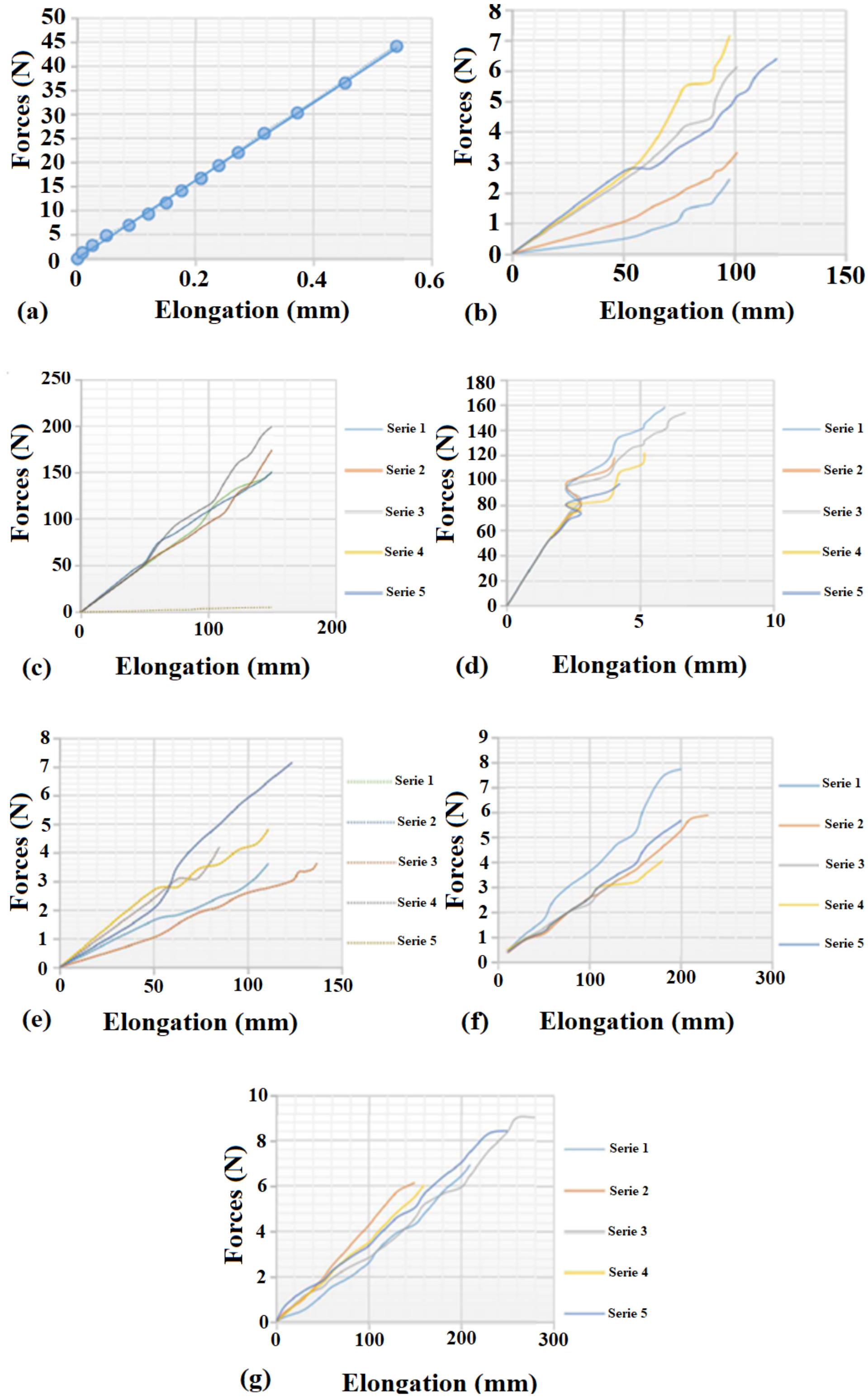

Figure 3. *Force-displacement curves: a) 0% of ETT; b) 35% of RTT fibers content; c) 45% of RTT fibers content; d) 55% of RTT fibers content; e) 35% of UTT fibers content; f) 45% of UTT fibers content; g) 55% of UTT fibers content.*

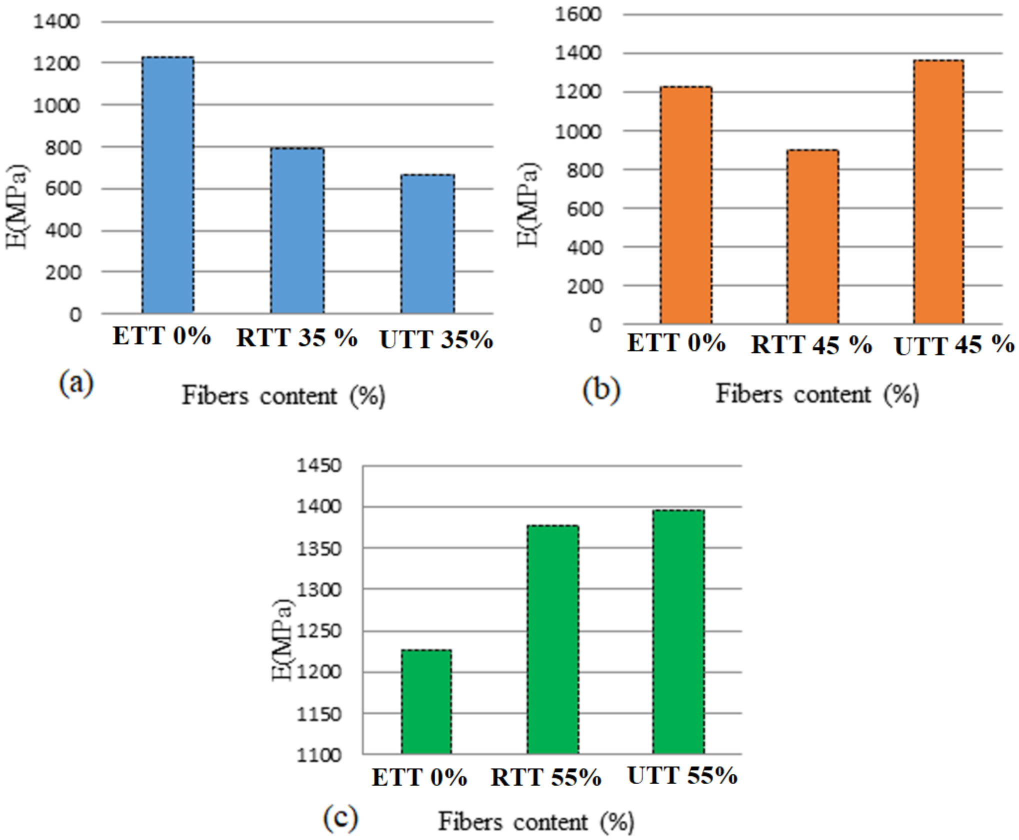

Figure 4. *Young's modulus in three-point bending of the different samples as a function of the fibers content (a) 0% of ETT fibers reinforcement; 0% of ETT fibers reinforcement RTT 35% UTT 35%. (b) ETT 0%, RTT 45%, UTT 45%. (c) ETT 0%, RTT 55%, UTT 55%.*

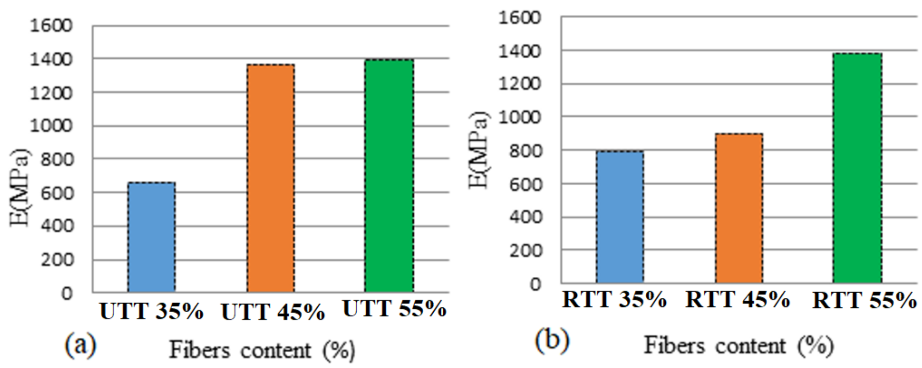

Figure 5. *Young's modulus in three-point bending of the different samples UTT and RTT (a) UTT 35%, 45%, 55% (b) RTT 35%, 45%, 55%.*

4.2. Evolution of Young Modulus in Three-point Bending Tests

The Young's modulus is 1225.386 MPa for the fibers free test tube (ETT), which decreases to 794.091 MPa for a composite material with 35% of RTT fibers content; and then decreases to 662.497 MPa for the composite material with 35% of UTT fibers content (see Figure 4(a)). This modulus leaves from 1225.386 MPa for a pure polyester, decreases to 896.237 MPa for 45% of RTT fibers content, and then increases again to 1363.715 MPa for 45% of UTT fibers content (see Figure 4(b)). This modulus increases respectively from 1225.386 MPa for a pure polyester, to 1376.813 for 45% of RTT fibers content, then increases further to 1395.186 for 55% of UTT fibers content (see Figure 4(c)). Apart from to the 35% of fibers content, the NA fibers increase the Young's modulus at the break of polyester and reach the highest breaking peak at 55% of UTT fibers content. The analysis of the histograms of evolution of the Young's modulus in three-point bending as a function of the architecture (see Figure 5) and the proportion of fibers shows that the content effect begins to become important from 45% and increases further up to 55%. In addition, the random continuous fibers have a slightly higher bending Young's modulus compared to short ones, which are 55% of fibers content.

4.3. Polyester / NA Fibers Mechanical Behaviour Modeling

The polyester resin samples were produced with 35%, 45% and 55% of fibers content, randomly and unidirectionally. These specimen were subjected to a three-point bending test to determine the Young's modulus and the ideal content ratio. In this section, only the specimens with unidirectional fibers were simulated using a Finite elements code software in order to evaluate the maximum numerical deflection of the polyester composites. Three point-bending tests on polyester composite reinforced by 35%, 45% and 55% of NA fibers content in the longitudinal direction show non-linear curves, whereas modeling of mechanical behaviour for all specimens. The distribution of the displacement in the composite material sample was obtained using the Equations (3), (4) and (5) implemented in the Finite elements code (see Figures 6(a) to (c)). Figure 6(a) presents the cartography of the composite structure after the three-point bending loading. Figures 6(b) and (c) show the displacement evolution with the length of the composite structure. These results show the flexibility of the composite material structure during the three-point bending tests.

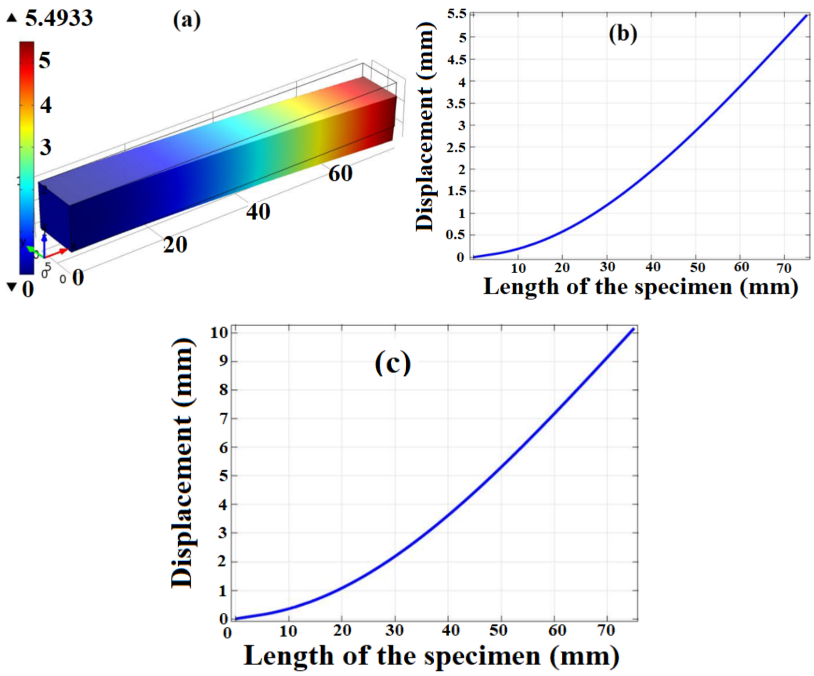

Figure 6. *Distribution of the displacement in the specimen length (mm)(a) repartition in the sample; (b) for 35% of UTT fibers content. (c) for 45% of UTT fibers content.*

5. Conclusions and Recommendations

The aim of this study was to study the processing of a composite material reinforced with plant fibers, in particular the *Neuropeltis-acuminatas* fibers, at different mixing ratio (35%, 45%, and 55% content). The *Neuropeltis acuminatas* fibers have particular properties for the manufacturing of polyester matrix composite. The polyester has been reinforced with continuous and short fibers of *Neuropeltis acuminatas* in random and unidirectional. Composites were developed which made it possible to carry out three-point bending tests. The mechanical characterization made it possible to obtain the force-elongation curves, then to have the Young's moduli of the different samples. All these characterizations allowed the following results to be obtained: between the polyester matrix and the *Neuropeltis acuminatas* fibers, there is poor adhesion at the interface; the analysis of Young's moduli shows that the reinforcement effect begins to become important from 45% in fibre mass and increases further up to 55% in fibre mass, moreover composites with random continuous fibers have a slightly higher Young's modulus in three-point bending compared to those with random short fibers at 55% by mass of fibers. In other hand, the bending test were modelled by applying a force on a block of composite and the distribution of the displacement has been obtaining in the lenght of the sample by modelling. These numerical investigations have shown a non-linear behaviour of the polyester matrix composite reinforced by *Neuropeltis acuminatas* fibers with a damade appearence.

Abbreviations

NA	*Neuropeltis acuminatas*
ETT	Empty Test Tubes
RTT	Random Test Tubes
UTT	Unidirectional Test Tubes

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Author Contribution

Ismaël Figapka Pagoré: Conceptualisation, Data curation, Formal Analysis, Investigation, Methodology and Software

Yannick Serge Evoung Nnengué: Conceptualisation, Data curation, Formal Analysis, Investigation, Methodology and Project administration

Layndé Tawé: Formal Analysis, Investigation, Methodology and project administration

Prosper Fils Edouma: Conceptualisation, Data curation, Formal Analysis, Investigation and Software

Fabien Ebanda Betené: Conceptualisation, Formal Analysis, Investigation, Methodology, Project administration, Resource and Software

Armand Zogo: Conceptualisation, Investigation and Project administration

Ateba Atangana: Conceptualisation, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resource and Software

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None reported.

Conflicts of Interest

The authors declare no potential conflict of interests.

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