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Original Article

Comparative tensile strength analysis between epoxy composites reinforced with curaua fiber and glass fiber[☆]



Natalia de Oliveira Roque Maciel^a, Jordana Barreto Ferreira^a, Janaína da Silva Vieira^a, Carolina Gomes Dias Ribeiro^c, Felipe Perissé Duarte Lopes^a, Frederico Muylaert Margem^b, Sergio Neves Monteiro^c, Carlos Maurício Fontes Vieira^a, Luís Carlos da Silva^{c,*}

^a State University of the Northern Rio de Janeiro, UENF, Advanced Materials Laboratory, LAMAV, Av. Alberto Lamego, 2000, 28013-602 Campos dos Goytacazes, RJ, Brazil

^b Faculdade Redentor Rodovia BR 356, n° 25, Itaperuna, RJ 28.300-000, Brazil

^c Instituto Militar de Engenharia (IME), Materials Science Program, Praça Gen. Tibúrcio, n° 80, Urca, Rio de Janeiro, RJ 22290-270, Brazil

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ABSTRACT

Currently, one of the major concerns in our society is related to environmental issues, which has motivated researches and materials development from renewable and environmentally friendly resources. This study aims to compare, the composite strength developed with natural fibers, with those with glass fiber, which has environmental impacts from manufacturing to disposal. Specimens were fabricated with 0% fiber, 30% curaua fiber and 30% glass fiber in epoxy matrix and tested in a tension. The results show higher tensile strength values for the samples containing glass fiber. However, by relating the composite strength with its fiber density, it was found that the epoxy composites with natural fibers showed better specific strength results than those with glass fiber. Therefore, from the point of view of mechanical strength, glass fiber can be replaced by curaua fiber, in epoxy composites.

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* Corresponding author.

E-mail: lcarloseng@gmail.com (L.C. Silva).

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1. Introduction

Modern composite materials, particularly those reinforced with synthetic fibers, such as glass fiber and carbon, have been used since last century to fulfill the demands required for many technological fields, from home appliances to aerospace parts [1]. However, the energy required to manufacture these fibers generates a huge emission of CO₂, which is a major factor responsible for global warming. In addition, glass fiber is not recyclable and cannot be incinerated. As a waste, discarded in landfills, it contributes to environmental pollution [2]. Currently, environmental concern has highlighted the claims demanded by the society in view of pollution relevance to the quality of life. It has also imposed to the companies a new position in their interaction with the environment [3]. Alternatively, studies have been conducted to replace, whenever possible, synthetic fibers by natural fibers, since the latter have not only lower costs, but are renewable and biodegradable. Moreover, their production system does not demand the use of processing equipment and are energy efficient [4]. Table 1 briefly summarizes the main advantages of using natural fibers in comparison to glass fiber as presented by Wambua et al. [2]. In their work 5 natural fibers were tensile tested and the results compared to glass fiber (E-glass). In addition, polypropylene matrix composites reinforced with 40 wt% of investigated natural fibers, were both tensile and 3 points bend tested. For comparison polypropylene composite reinforced with glass fiber mat was similarly tested. Table 2 adapted from Wambua et al. [2], presents tensile strength and corresponding specific strength (divided by the density) for their investigated composites.

Ledo [5,6] states that among the natural fibers with potential applications in composites, curaua stands out as a fiber with excellent quality that can be used in the automobile industry since it has good strength, smoothness and low weight. Takahashi et al. [7] found that curaua is the fiber that has greater mechanical strength among many others that are cataloged in the global market. The tensile strength of curaua fiber was reported to be 1250–3000 MPa [8]. The main objective of this study is to investigate the mechanical behavior, specifically the tensile strength of reinforced epoxy composites with natural curaua fibers and epoxy composites reinforced with glass fiber (roving) to quantitatively measure the difference between their specific strength.

Table 1 – Comparison between natural fiber and glass fiber. (Reproduced with permission from ref [2])

	Natural fibers	Glass fiber
Density	Low	Twice the natural fiber
Cost	Low	Low, however higher than natural fiber
Renewable	Yes	No
Recyclable	Yes	No
Energy consumption	Low	High
CO ₂ (neutral)	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Degradation	Biodegradable	Nonbiodegradable

2. Materials and methods

2.1. Curaua fibers

The curaua fiber is obtained from a plant with same name, a bromeliad (*Ananas erectifolius*), from pineapple family and was purchased from “Amazon Paper”, a company that sells natural lignocellulosic fibers grown in the Northern Region of Brazil [4–9]. The typical aspect of curaua plant and fiber are shown in Fig. 1. The fibers were used without any surface treatment, just cleaning and air dried.

Hundred fibers were chosen to measure the length and diameter through a caliper and a profile projector, respectively. The average length (*L*) and the average diameter (*d*) were then calculated. Fig. 2 shows histograms in which it was possible to obtain *L* = 442 mm and *d* = approximately 0.17 mm [4]. The fibers were individually weighed and, by considering each fiber a geometric cylinder, the density of the curaua fiber was found as 0.92 g/cm³ [7].

2.2. Glass fiber

The glass fibers were purchased from Glass Company, Brazil. This company provides repairs on vehicles and surfboards using glass fiber as reinforcement of composite material. According to the manufacturer, the glass fiber is E-type with a density of approximately 2.6 g/cm³ and a mean diameter in the range from 8 to 14 mm.

Table 2 – Tensile properties and corresponding specific values for polypropylene composites reinforced with glass fiber and natural fibers. (Adapted with permission from ref [2])

Polypropylene composites reinforced with	Fiber density (g/cm ³)	Tensile strength (MPa)	Specific strength (MPa.cm ³ /g)
Glass fiber	2.25	88.6 ± 78	39.4 ± 34.7
Kenaf fiber	1.40	28.3 ± 3.7	20.2 ± 2.6
Coir fiber	1.25	11.1 ± 1.0	8.9 ± 0.8
Sisal fiber	1.33	33.2 ± 6.8	25.0 ± 5.1
Hemp fiber	1.48	53.0 ± 2.0	35.8 ± 1.4
Jute fiber	1.46	28 ± 1.0	19.2 ± 0.7



Fig. 1 – (a) Curaua plant and (b) curaua fiber processed and ready for use.

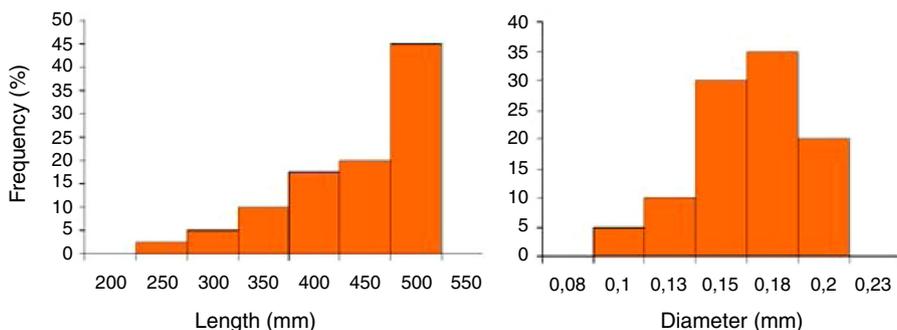


Fig. 2 – Histograms for length and diameter distributions of curaua fiber.

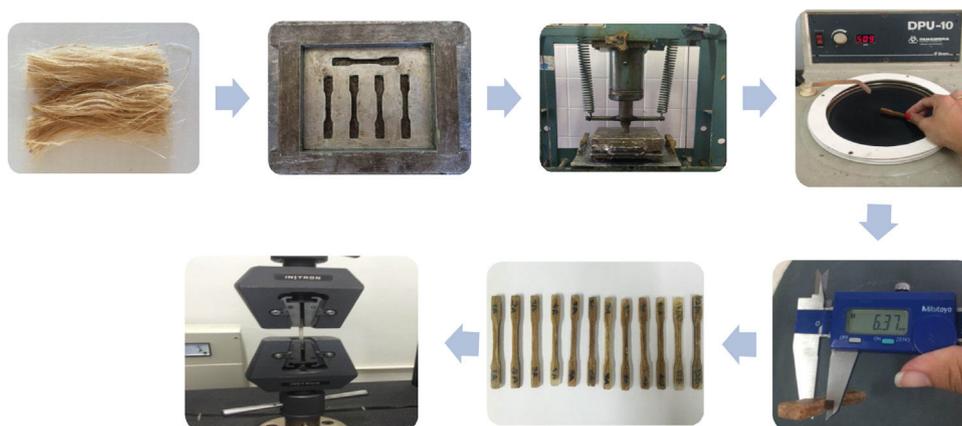


Fig. 3 – Description of the procedure from manufacturing of 30% curaua fiber composite specimens up to the tensile test.

2.3. Specimens

To carry out the work, 10 tensile specimens were fabricated for each fiber concentration: 0% fiber, 30% curaua fiber and 30% glass fiber in epoxy matrix. The specimens with 0% fiber were made in a silicone matrix. In the case of those with 30% fiber the fibers were first cut in specimen size, and then long and continuously inserted in a steel mold. The aligned fibers were then embedded in epoxy resin. All specimens were manufactured at room temperature. Those manufactured in the steel mold were subjected to a pressure of to 2.5 tons for 24 h during the curing process.

After curing, the specimens were measured, numbered and then subjected to tensile test in a model 5582 INSTRON machine with a speed of 2 mm/min at room temperature. Fig. 3 illustrates the aforementioned steps of processing and testing the tensile specimens.

3. Results and discussion

Fig. 4 illustrates the macro aspect of tensile ruptured specimens corresponding to the different fibers. In this figure, the fracture of neat epoxy specimens tends to be transversal to the

Table 3 – Results of tensile tests for samples: 0%, 30% curaua and 30% glass fiber.

	0% (MPa)	30% curaua fiber (MPa)	30% glass fiber (MPa)	30% curaua fiber specific strength (MPa)	30% glass fiber specific strength (MPa)
Average	34.31	54.79	71.91	141.65	64.53



Fig. 4 – Typical tensile ruptured specimens with 0% of fiber, 30% curaua fiber and 30% glass fiber reinforced epoxy composites.

tensile axis. This fact indicates that the fracture mechanism for the pure epoxy matrix was mainly associated with the propagation of transversal cracks. However, for the amount curaua fiber composite, the fracture tends to change the direction of rupture because delamination between the fiber and the epoxy matrix. This behavior is associated with a low interface resistance between the curaua and the epoxy matrix.

Table 3 presents the average tensile strength and corresponding specific strength for the neat epoxy (0% fiber) as well as epoxy reinforced composites with 30 vol% of curaua fiber and 30 vol% of glass fiber. In this table, one should notice that, in absolute values, the glass fiber reinforced composites with 131 MPa is stronger than the curaua fiber composite with 55 MPa. Both have higher strength than the neat epoxy matrix with 34 MPa. As compared to the polypropylene composites in Table 2, the curaua fiber composite has greater tensile strength than any of the investigated natural fibers by Wambua et al. [2].

Fig. 5 shows a graph of the tensile results obtained for samples with 0% fiber, 30% curaua fiber and 30% glass fiber. A significant increase of the tensile strength when fibers are added to resin, both for composites with 30% curaua fiber and 30% glass fiber, is observed when compared to samples with 0% fiber [9]. The tensile strength obtained for specimens with 30% glass fiber is greater than that obtained with the specimens of curaua fiber, which is expected, since natural fibers being hydrophilic have low compatibility with the epoxy matrix that is hydrophobic, resulting in low interfacial adhesion fiber-matrix. This directly impacts

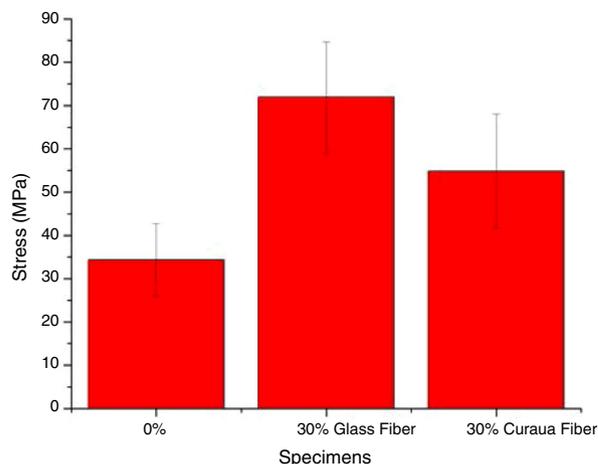


Fig. 5 – Comparative tensile strength between specimens with 0% fiber, 30% curaua fiber and 30% glass fiber.

the results of the mechanical properties [10]. Moreover, the mechanical and physical properties of natural fibers vary considerably depending on the chemical and structural composition as well as growth conditions. Therefore natural fibers show much more irregularities than the glass fiber. These defects led to lower strength of a natural fiber when compared to homogeneous materials such as glass fiber [11]. Although biodegradable materials (green materials) present lower mechanical properties than synthetic materials, their use on an industrial scale is not affected [12]. Indeed, the cost of natural fibers is significantly lower than that of synthetic fibers.

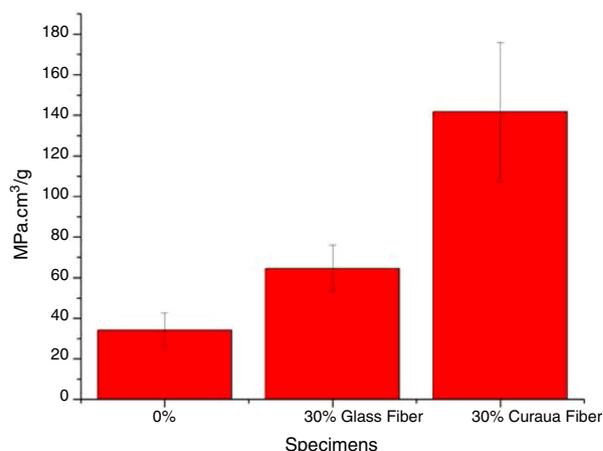


Fig. 6 – Comparative specific strength obtained between samples with 0% fiber, 30% curaua fiber and 30% glass fiber.

Because the materials studied are of different nature, it was necessary to evaluate the strength according to the density of each material. Thus specific strength values are shown in the graph of Fig. 6.

By dividing the tensile strength by its density, curaua composites become stronger than the glass fiber composite. Mechanical properties of plant fibers are much lower when compared to those of the most widely used synthetic fibers. However, because of their low density, the specific properties (property/density ratio), strength and stiffness of natural plant fibers are comparable to the values of glass fiber [2].

The results of Table 3 and Fig. 6 indicate, for the first time, that in terms of specific strength a natural fiber composite is significantly stronger than the glass fiber composite, both reinforcing the same kind of epoxy matrix. Moreover, the specific strength of the curaua fiber composite 142 MPa is higher than those of glass fiber and other natural fibers reinforcing polypropylene matrix composites shown in Table 2 from the work of Wambua et al. [2]. This corroborates their conclusions that specific properties of natural fiber composites might be in some cases better than those of glass fiber. Indeed, this is the case of curaua fiber in the present work. Furthermore, the results in Table 3 and Fig. 6, for the first time, experimentally confirm that a natural fiber polymer composite has a potential to replace glass fiber in engineering applications requiring a balance between higher load bearing capability.

4. Conclusions

- The increase amount of both curaua fiber and glass fibers has a directly influence on increasing the mechanical behavior of composites epoxy matrix. The neat epoxy sample has lower strength than composite with 30% of curaua or 30% of glass fiber reinforcing an epoxy matrix.
- The results show that the epoxy composite with glass fiber is stronger; however when comparing the results with the strength/density ratio it is possible to conclude that the curaua fiber epoxy composite is stronger than the glass fiber composite.

Conflicts of interest

The authors declare no conflicts of interest.

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