Tensile Behavior of Epoxy Matrix Composites Reinforced with Pure Ramie Fabric

Caroline G. de Oliveira, Janine F. de Deus, Ygor M. de Moraes, Marcos V.F. Fonseca, Djalma Souza, Frederico M. Margem, Luiz G.X. Borges and Sergio Monteiro

Abstract Recently, the natural fibers have been studied as alternative reinforcement material to the use of synthetic fibers. Aiming to improve the properties of natural fibers composites, it is investigated the use of natural fibers fabrics, since they provide multidirectional reinforcement and enables the introduction of a larger fiber volume fraction. In this work, it was investigated the tensile behavior of the epoxy matrix composites reinforced with different volume fractions of fabric made of Ramie, a highly resistant lignocellulosic fiber. The specimens were made by pressing the fabric with liquid resin to guarantee total impregnation, and then cutting the fabric in the mold format. Finally, the fabric layers were placed into the mold with the liquid resin and catalyst. They were cured for 24 h and tested. The results revealed an increase in the tensile strength and almost no effect in the elastic modulus with the increase of fabric volume fraction.

Keywords Natural fibers · Ramie fabric composite · Epoxy composites

Introduction

With the rapid development of technology over the past decades, many studies have been made in order to develop materials that meet the new demands. In this context, it is extremely important to consider not only the technical benefits of projects and researches, but also their environmental advantages aiming their long-term sustainability. One of the most important concerns is finding alternatives to non-renewable materials, which contribute to the air pollution, to resources shortage

C.G. de Oliveira (✉) · J.F. de Deus · Y.M. de Moraes · M.V.F. Fonseca · D. Souza
State University of Northern Rio de Janeiro, Campos dos Goytacazes, RJ, Brazil
e-mail: caroline.oliveyra@gmail.com

F.M. Margem · L.G.X. Borges
Faculdade Redentor, Itaperuna, RJ, Brazil

S. Monteiro
Military Institute of Engineering, Rio de Janeiro-RJ, Brazil

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and to increasing the quantity of non-biodegradable residues. In this scenario, natural fibers emerge as an advantageous alternative [1–3].

Among the natural fibers, the lignocellulosic ones must be highlighted for having high mechanical resistance. The presence of lignine and cellulitis makes the fibers simultaneously flexible and resistant [4–6]. Moreover, they are abundantly cultivated all around the world and it offers the possibility of social development, once the cultivation can be a source of income for poor communities in many countries [1].

Ramie fiber must be particularly noted for being one of the most resistant, which can reach a tensile strength higher than 1000 MPa. Furthermore, epoxy matrix composites reinforced with Ramie fibers reached 102.26 MPa for 30% of fibers in tensile tests [7, 8]. Aiming to further improve the performance of the natural fiber composites, it is investigated the performance of composites reinforced with Ramie fabric (Fig. 1), instead of its aligned fibers. The fabric reinforces the matrix in more than one direction simultaneously and also enables the introduction of a higher fraction of reinforcement material. This new structure, regarding the use of Ramie fabric, has already been tested for bulletproof panels and jackets [9].

The objective of this work is to evaluate the tensile behavior of epoxy matrix composite reinforced with Ramie fabric.

Experimental Procedures

The fabric used for this work was obtained by the Chinese company Rose Natural Healthy Items Wholesale. The specimens with different fabric volume fractions were individually confectioned by incorporating 1, 2 and 3 fabric layers into the composite. For this, the fabric was initially cut in the mold format and then pressed

Fig. 1 Ramie fabric (*Source* Trade Korea)

with the liquid resin (Epoxy + DEGEBA/TETA) to guarantee a total impregnation. After this, enough amount of epoxy resin was poured into the mold and then the fabric layers were placed onto it alternately with new resin layers. The specimens were cured for 24 h and tested in an universal Instron machine, model 5582, at 25 °C.

The tensile specimens are shown in Fig. 2.

Results and Discussion

The typical load versus elongation curves for the pure epoxy (0% fabric) and different composites are exemplified in Fig. 3. These curves were recorded directly from the Instron software. After a straight elastic line, a sudden fracture occurs, indicating a brittle behavior for both the pure epoxy and the ramie fabric composites tensile specimens.

Figure 4 shows the macro aspect of tensile ruptured specimens corresponding to the different volume fraction of ramie fabric. In this figure, the fracture of all specimens tends to be transversal to the tensile axis. No macroscopic evidence of ramie fabric participation has been observed.

From the data observed in the curves shown in Fig. 3, it was possible to obtain the average tensile strength (maximum stress) and elastic modulus for different volume fractions of ramie fabric. This data is presented in Table 1. These results show that the presence of ramie fabric increases the composite tensile strength and has almost no influence in the stiffness.

Figure 5 shows the graphical results for the variation of tensile strength and elastic modulus with the volume fraction of ramie fabric. It can be seen that tensile

Fig. 2 Tensile specimens

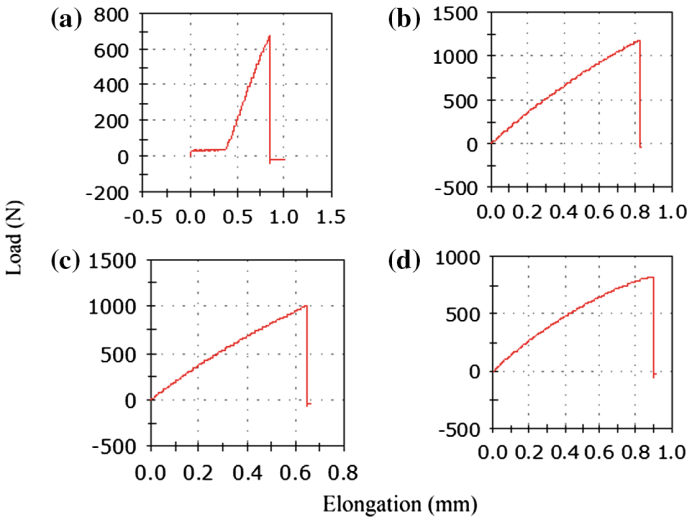

Fig. 3 Load versus elongation curves: **a** pure epoxy, **b** 1 fabric layer, **c** 2 fabric layers and **d** 3 fabric layers

Fig. 4 Ruptured tensile specimens

strength (Fig. 5a) reasonably increases, within the error bars, in almost linear way with the number of fabric layers. It represents a considerable reinforcement effect of the fabric to the matrix. Indeed, the increase in the tensile strength is approximately

Table 1 Tensile properties of epoxy composites reinforced with different volume fraction of ramie fabric

Number of fabric layers	Tensile strength (MPa)	Elastic modulus (GPa)
0	24.15 ± 3.88	1.851 ± 0.011
1	31.41 ± 3.57	1.844 ± 0.011
2	34.24 ± 3.09	1.830 ± 0.012
3	37.63 ± 2.06	1.827 ± 0.011

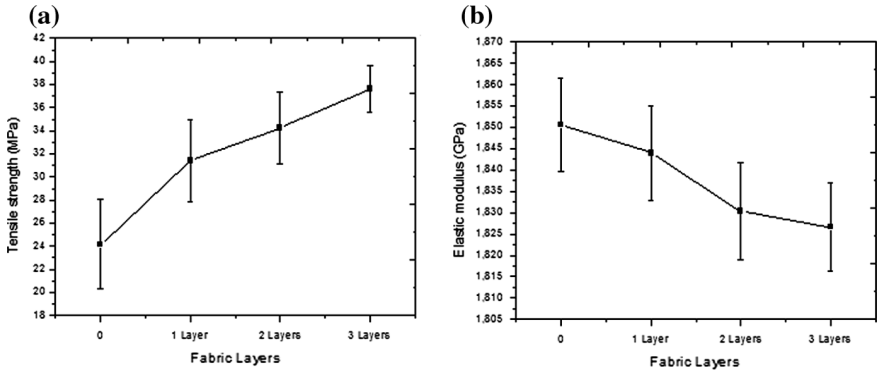

Fig. 5 Graphical results of (**a**) tensile strength (**b**) elastic modulus for composites with different ramie fabric volume fraction

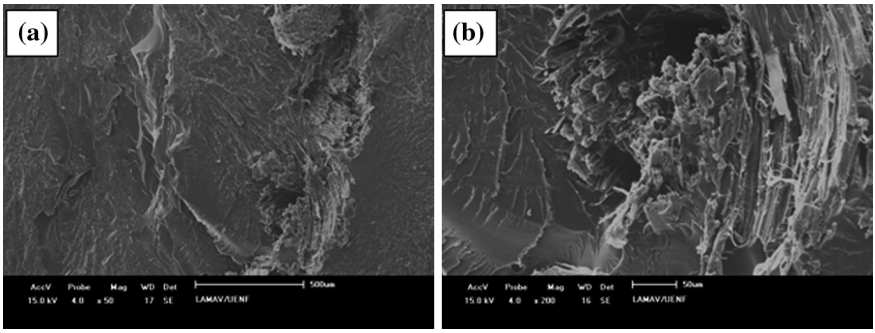

Fig. 6 SEM fractograph of a tensile ruptured epoxy composite specimen with 3 ramie fabric layers: **a** 50× and **b** 200×

55%. It is also possible to observe that the elastic modulus (Fig. 5b) is almost not affected by the presence of fabric, remaing the same, withing the error bars.

In Fig. 6 it is possible to see the SEM fractographs of the fracture surface. It is observed that the fabric slightly pulls out from the matrix. This is due to delamination effect, common in composites reinforced with laminate materials, such as

natural fiber fabrics. However, the delamination effect is not highly intense in composites subjected to tensile stresses, thus, even with this effect, the fabric still retains a reasonable adhesion to the matrix. It can also be observed, based on the fracture marks on the epoxy matrix surface, that the fabric worked as a barrier to the crack propagation, increasing the composite tensile strength compared to the correspondent value of pure epoxy.

Conclusions

- Tensile tested epoxy composites reinforced with ramie fabric exhibit a reasonable increase in the tensile strength and almost no variation in the elastic modulus.
- With three fabric layers, the tensile strength increases approximately 55% while the elastic modulus remains the same, considering the error bars.
- Although the fabric provides multidirectional reinforcement and enables the introduction of higher volume fractions of reinforcement material, it is also subjected to delamination and debonding effects, which can mitigate the reinforcement effect.
- The SEM fractographs analysis reveals that, even with a slight delamination effect, the fabric has a reasonable adhesion to the matrix, working as barrier to crack propagation and reinforcing the matrix.

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