Synergistic Effect of Ramie and Pineapple Fibres Reinforcement on The Strength of Epoxy Matrix Composite

J. Lilly Mercy[1], D Alex Anand[2], Antony V Samrot[3*], D. Rajalakshmi[4], N. Shobana[5], S. Dhiva[6], Kasipandian Kasirajan[7]

[1]School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, 600119, India.

[2]Department of Bioinformatics and the Centre for Molecular Data Science and System Biology, Sathyabama Institute of Science and Technology, Chennai-6000119, Tamil Nadu, India

[3]School of Bioscience, Faculty of Medicine, Bioscience and Nursing, MAHSA University, Jenjarom 42610, Selangor, Malaysia; E-mail: antonysamrot@gmail.com

[4,5]Department of Biotechnology, Sathyabama Institute of Science and Technology, Chennai-600119, Tamil Nadu, India

[6]Department of Microbiology, Sree Narayana College, Alathur, Palakkad 678682, Kerala, India

[7]Faculty of Engineering, Built Environment and IT, MAHSA University, Jalan SP2, Bandar Saujana Putra, Jenjarom 42610, Selangor, Malaysia

Abstracts: Natural fibre reinforced composite of pineapple and ramie fibre unidirectional mats were fabricated through handlayup process and curing through compression molding process. Six samples of the composite material with different combinations of alternating fibres and orientations of the fibre mats were fabricated and tested for their mechanical properties. It was observed that the stacking sequence, type of fibre and orientation of the fibres make a pronounced difference in the mechanical properties. The outer layer of Ramie fibre mat and the 45° orientation of either of the fibres resulted in better mechanical properties. By making a perfect combination of the stacking sequence of the fibres, type of fibres and orientation, it is possible to enhance the properties of the composite.

Keywords: Ramie and Pineapple Fibres, Epoxy Matrix Composite, Fibre Orientation.

1. INTRODUCTION

Natural fibre reinforced composites has been under extensive research due to its ease of availability, potential strengthening capacity and most importantly its biodegradability. A synthetic polymer with synthetic fibre reinforcement is completely non-biodegradable and it is a hazard to the environment as it releases harmful gases during the common recycling process. Hence the replacement of synthetic fibres with natural fibres has paved way for a better and a greener environment. Agricultural waste post-harvest is available in plenty and hence it's a better usage of waste for productive usage in composite materials.

Pineapple fibres extracted from the pineapple leaf has high cellulose content and low micro fibrillar angle which results in good tensile strength [1]. Several researchers have used the fibers extracted at different geographical locations and found many of the properties at par or higher than many of the natural fibres. Ramie fibres are listed among the top natural fibres for its strength and length [2-5]. Pineapple fibre crystallinity is close to ramie fibre and hence can be chosen as a perfect combination to make a hybrid composite, as fiber crystallinity induces moisture absorption of the fibres. However, the moisture absorption lag value of the pineapple fiber is more than double that of Ramie fiber [6]. Mercy et al [7] have tested 384 samples of pineapple fiber reinforced polypropylene composite for moisture absorption and correlated with its mechanical properties. By making a hybrid composite of pineapple and ramie fibres, it is possible to harvest the best properties of both. Also, the synergy that exists at the right combination of the fibres, might make the strength of the composite better.

It has been observed and proved by several researchers that the ply orientation in a composite plays a significant role in influencing its final properties [8-10]. Ply orientation along the direction of load gives maximum strength and the orientation perpendicular to the direction of load gives the minimum strength. Tian et al [11] have reported that the tensile strength of C_{sf}/Mg composites was found to be decreasing with the fiber orientation between 0° to 60° and gradually increasing from 60° to 90°. The synergy between carbon nano tube orientation and its length was disclosed by Zhou et al [12]. They have concluded that the right orientation of Carbon nano tube enhances the inter tube contact surface area and shear force along the axial direction, which subsequently results in higher tensile strength.

In this paper, 6 samples of unidirectional ramie and pineapple fiber mats were embedded in epoxy resin with different orientation and different stacking sequence and its tensile and flexural properties were studied.

2. EXPERIMENTAL PROCEDURE

2.1. Material

Epoxy LY556 resin and HY951 hardener were procured from Shakthi fibres, Chennai. Unidirectional pineapple fibre mat and Ramie fibre mat were procured from Go Green Products, Chennai. The properties of the fibres and resin as specified by the supplier are given in Table 1. The physical properties of the fibres are given.

Table 1 Properties of Pineapple and Ramie fiber

	Pineapple fibre	**Ramie fibre**
Density *(g/cm³)*	1.5	1.3
Tensile Strength *(MPa)*	400-700	300-440
Elongation *(%)*	2.2-3	1.3-2
Young's Modulus *(GPa)*	30-52	44-63

2.2. Composite Preparation

Composite laminates of 3mm thickness were fabricated by alternating layers of fibres and resin. Both the fibre mats were alkali treated with 15% of NaoH solution for 2 hrs and washed and dried. The fibres were laid on the resin through hand layup process and the laminate thickness was controlled through compression molding. Compression molding process starts immediately after the handlay up process gets completed. Laminates of 15 cm x 15 cm were prepared. Through trial-and-error method, it was found that stacking 5 layers resulted in 3±0.2mm after compression at 80°C for 4 hrs at 20 bar pressure. Hence, all the composite laminates were prepared with 5 layers of fibres stacked in epoxy resin. The orientation and the fibre at each layer for each sample are given in Table 2. Sixorthotropic laminate samples were fabricated with different stacking sequence of both Ramie and Pineapple fibres. Figure 1 shows the direction of the fibre placement in the mat for various degrees of orientation. The samples required for testing were cut from these samples (Figure 2).

2.3. Measurement of Mechanical Properties

Two fundamental tests- Tensile (ASTM-D3039) and flexural tests (ASTM D790) were considered for this study. Each of the 6 samples were cut by laser machining to the ASTM standard shape needed for this study. To avoid any sort of water seepage in the fibres, conventional water jet machining is avoided. Tensile test was conducted using the Universal UTE-2001 series with a measuring range of 0-200KN. The hydraulic ram loads the sample and the pressure experienced by the sample is sensed by the digital straining unit. The transducer sends pressure signals and the mechanical signals are sent by the digital straining unit. Both these signals are digitally displayed, and the graph can be plotted. Flexural strength was measured using the same set up with a 3-point bend test fixture attachment. Figure 3 and 4 shows the tensile and flexural test set up in Universal Testing Machine.

Table 2 Composite samples, their orientation and stacking sequence

Sample Name	Number of fibre mat reinforcement in the sample	Orientation and Stacking sequence
S1	5 layers of Pineapple fibre mats	 0 45 90 45 0
S2	5 layers of Ramie fibre mats	 0 45 90 45 0
S3	3 layers of pineapple fibre mats and 2 layers of Ramie fibre mats	 0 45 90 45 0
S4	3 layers of Ramie fibre mats and 2 layers of Pineapple fibre mats	 0 45 90 45 0
S5	4 layers of Pineapple fibre mats and 1 layer of Ramie fibre mat at the centre	 0 90 45 90 0
S6	4 layers of Ramie fibre mats and 1 layer of Pineapple fibre mat at the centre	 0 90 45 90 0

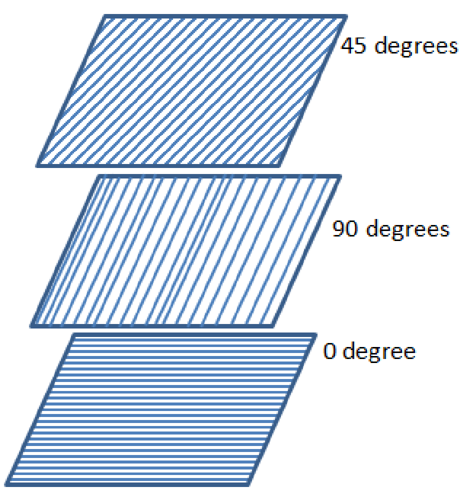

Figure 1 Orientation of fibres during stacking

Figure 2 Hand-layup process of fiber mats

Figure 3 Tensile Testing of composite in Universal Testing Machine

Figure 4 Flexural testing with 3 point bend test fixture

2.4. Theoretical Estimation of Fiber Volume Fraction

One of the simplest and proven way to estimate the synthetic fibre value fraction is through the burn off test(13). In this procedure, the composite laminate will be weighed and then raised to the burning point of the matrix, where the matrix burns leaving behind the fibres. The fibres are then weighed and the fibre volume fraction is determined. In case of natural fibres, the fibres will also burn or get damaged at elevated temperature. However, estimating fibre volume fraction is one of the crucial parameters in the study of fibre reinforced polymers. According to ASTM D-2584, the fiber volume fraction can be calculated by

$$V_f=[\rho_m.w_f/(\rho_m.w_f+\rho_f.w_m)] \quad \text{---- Equation (1)}$$

This theoretical procedure is used to find the fibre volume fraction of the fibers. The weight of the fibres mats after cutting were weighed. For each sample, depending on the number of layers and the type of fibre mat, the weight was calculated. It was found that the weights of similar sizes of Ramie and pineapple showed negligible difference. In every sample, the fibre volume fraction ranged between 50 to 58%.

3 RESULTS AND DISCUSSIONS

3.1 Experimental Measurements of Mechanical Properties

Figure 5 shows the experimental tensile and flexural modulus results found experimentally. It can be observed that the highest tensile modulus and flexural modulus is obtained for the Sample 4 with alternate layers of Ramie and pineapple fibres. This is followed by Sample 2 and 6 having all layers of Ramie fibres and 4 layers of Ramie fibres respectively. As the binding of the ramie fibres goes better with the epoxy resin and it has inherently high strength than the pineapple fibre, the final strength of the composite is also high. However, the sample 4 with alternate layers of pineapple and Ramie fibre seems to exceed the strength of the sample with pure ramie fibre reinforcement.

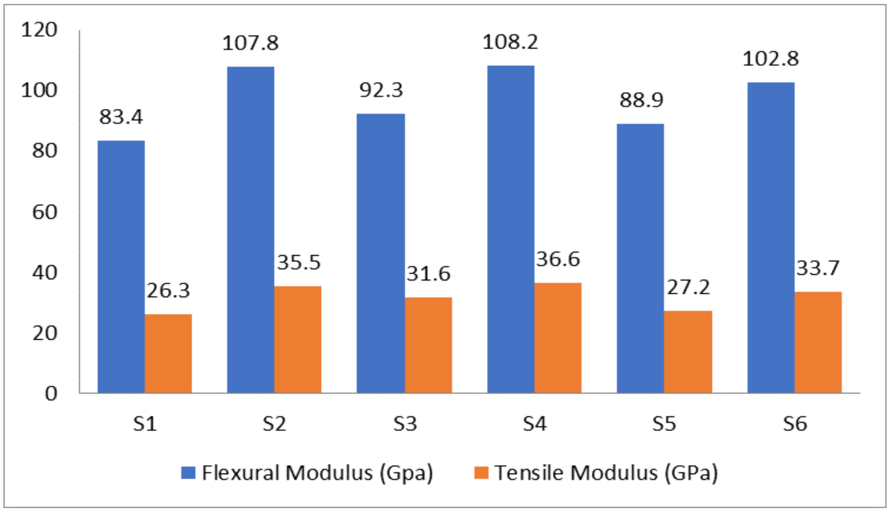

Figure 5 Tensile and Flexural Modulus of the samples

3.2 Effect of The Type of Fibre on The Mechanical Properties

The synergy caused by the right layup of the fibres seems to be the reason behind the strength enhancement than its potential counterpart- Sample 3 with similar alternate layer arrangement. However, Sample 3 has only one layer of Ramie fibre less than Sample 4. The major difference in the layup arrangement between Sample 3 and Sample 4 is the outer most surface layer of fibre. The outer surface layer of Ramie fibre, gives a sturdy strength enhancement at the grips during testing, resulting in better properties. The outer surface layer of enhanced strength than the pineapple fibre, capsulates the stress inside and acts as a barrier towards fracture. The stress gets transferred and uniformly shared inside the material, where the pineapple fibre takes and responds to the load. This perfect balance between the fibres develops the synergy to result in better mechanical property of the final composite.Sample 2 reinforced with only Ramie fibres shows lesser strength comparing to Sample 4 because the cushioning effect pronounced due to the change in stress absorption is lacking. Samples 5 and 6 are similar to Sample 1 and Sample 2 respectively with one layer replaced by the alternate fibre and that makes the small difference.

3.3 Effect of Fibre Orientation on The Mechanical Properties

The orientation of the fibres also affects the mechanical properties. It could be observed that the 45° orientation of any fibre gives additional strength to the composite as the action of load was longitudinal along the axis of the composite. Though the longitudinal fibre mat gives the maximum strength as the load is longitudinal, the transverse fibres are less assistive in the strength building. However, the 45° fibre mat gives adequate support in holding these two fibre mats together and gives the balanced load bearing capacity. Table 3 shows the average tensile and flexural strengths of the samples with respect to the orientation of fibres.

Table 3 Orientation of fibres and its effect on mechanical strength

Fiber orientation	Samples	Average Flexural Strength (Gpa)	Average Tensile Strength (GPa)
0°, 90° Pineapple fibre	S1, S3, S5	88.2	28.36
45° Pineapple fibre	S1, S4, S6	98.13	32.2
0°, 90° Ramie fibre	S2, S4, S6	106.26	35.26
45° Ramie fibre	S2, S3, S5	96.3	31.43

It can be observed that the highest values of mechanical strength are when the ramie fibres are along the axis of tensile or flexure. However, lowest mechanical strength was recorded when the pineapple fibres are along the axis of tensile or flexure. This is due to the inherent strength or load bearing capacity of the individual fibres. The 45° orientation of either of the fibres gave good results as the strength is more dependent on the orientation than the property of the individual fibres. It is clearly evident that the final strength of the composite first depends on the nature of the fibre followed by its orientation. Hence the right choice and optimization of the fibre combination and orientation will give better results.

CONCLUSION

Based on the experimental observations, it can be concluded that there exists a positive synergy between different fibre reinforcements in the matrix, which seems to exceed its parent composite strength. Strong ramie fibres wrapped around the combination of weak pineapple and strong ramie fibres result in better mechanical properties when the adhesive nature of the fibres are more or less uniform. However, the choice of fibre combination plays a crucial role. The fiber orientation angle of 45° of either of the fibres results in considerable enhancement of tensile and flexural strength.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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