Mechanical Characteristics of Shear Strength of Ramie Fiber/Epoxy and Ramie-E-Glass/Epoxy Hybrid Composites

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Abstract. As an alternative to materials, composite are currently the subject of extensive research due to their strength, stiffness, lightweight, resistance to corrosion, and ease of manufacturing. This study aims to compare the shear strengths of thermosetting composite materials made of ramie and rami-E-glass fiber hybrid as reinforcement and epoxy as matrix with fiber orientation variations of ±45° and (0°,90°)s which refers to the ASTM D5379 standard. Hand lay-up and vacuum bagging are used to create composite specimens. Meanwhile, the method for analyzing composite specimen test results is the Weibull distribution to determine its reliability at 50% and 90%. Based on the research results, it show that the shear strength of the ramie-E-glass/epoxy fiber hybrid thermosetting composite with a fiber orientation of ±45° has the highest shear strength when compared with the orientation of (0°,90°)s. The material has the potential to be used as an alternative material for application in the outer skin structure that can withstand shear loads for components in the automotive and unmanned aerial vehicles (UAVs) industries automotive and unmanned aerial vehicle (UAV) industries.

Keywords: ramie-glass, hybrid composite, shear strength

1 Introduction

Environmental awareness has motivated researchers worldwide to study the natural fiber-reinforced polymer composite in recent years. Natural fiber composite can replace synthetic fiber reinforced composite owing to its advantages, such as being lightweight, bio-degradable (depending on polymer ma- trix), and environment friendly [1]. A composite material can be defined as a combination of two or more materials that result in better properties when compared to the material itself [2]. Becauses of its many benefits including low weight, corrosion resistance, and high fatigue strength, that will be increas- ingly important in the future [3]. Because the fiber reinforcement is incredibly flexible, it can be utilized to build complicated multifunction structural components. Synthetic fibers as reinforcements for poly- mer, metal, and ceramic as composite materials can be traced to the use of glass fibers for reinforcement of thermoset polyester and epoxy matrix materials which first occurred in the mid-20th century [4]. The natural bast fiber called ramie fiber is taken from the stems of the Boehmeria nivea plant. It contains cellulose (68.5–85%), hemicellulose (13.16.7%), and lignin (0.5–0.7%) [5]. It is renowned for having remarkable luster, strength, durability, low weight, and inherent flame resistance [6. 7. 8, 9]. Therefore, to overcome such problems, a combination of natural and synthetic fibers can be used, which can create a balance of natural and synthetic fiber properties in the hybrid composites [10]. Good tensile strength were found by Thiyagu and Narendrakumar (Thiyagu and Narendrakumar 2022). The hybrid compo- site material was made of glass and ramie fiber which contained two layers ramie fiber as reinforcement [11]. Investigation of glass and natural fiber hybrid composites has demonstrated superior physical properties compared to similar composites [12.13.14]. Using natural and glass fiber reinforced to create hybrid composites is composite to create economical option.

During the trial and error, it was found that the optimum fiber volume fraction is 50%, based on research that has been done previously [15], flax/PLA fiber-reinforced epoxy hybrid nanocomposites.

In previous of glass/ramie fiber reinforced hybrid polymer composite research, the following was conducted: the mechanical properties of the glass/ramie fiber composite were evaluated through tensile and flexural Strength [16]; Ramie-Glass fiber/polyester were evaluated through tensile, flexural, and impact strength with 90°/60° fiber orientation [17]. Based on the literature, there are still not many people who have

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conducted which is a novelty in this research in developing the mechanical properties of the shear strength of of glass/ramie fiber reinforced hybrid polymer composites with fiber orientation variations of ±45° and (0°/90°).

Even though studies on hybrid composites which include glass and ramie fibers have been studied. However, reports on the effect of different fiber direction variations of the glass and ramie fibers on the physical and mechanical properties of hybrid composites are scarce in the literature. Besides that, it will also compare the shear strength between ramie fiber composites and a combination of hybridized ramie and E- glass fiber composites. The failure modes that occur in composite specimens will be analyzed visually. In the present study, two parameters Weibull distribution was used to analyze the test results. Weibull distribution is widely used statistical theory to analyze the strengths of materials [18], and recently is received well in the composite community to analyze the fracture tensile strength of composite [19] as well as for composite filament wound structures [20]. Two parameters Weibull distributionis used in this study, which is in the form of Eq.1:

$$F(x;b,c) = 1 - \exp\left(-\left(\frac{x}{b}\right)^c\right), b > 0, c > 0 \quad (1)$$

F(x;b,c) represents the probability that the fracture strength is equal to or less than *x*. Using the equality *F(x;b,c)* + *R(x;b,c)* = 1, the reability *R(x;b,c)* is given by Eq.2:

$$R(x;b,c) = \exp\left(-\left(\frac{x}{b}\right)^c\right), b > 0, c > 0 \quad (2)$$

Several methods have been used to estimate the two parameters *b* and *c*. In this study, we will use a linear regression method for practical purposes. Hence, a linear regression model in the form of $Y = m X + r$ is obtained as in Eq.3:

$$\ln\left[\ln\left(\frac{1}{1-F(x;b.c)}\right)\right] = c\ln(x) - c\ln \quad (3)$$

Since *F(x;b,c)* is unknown in Eq.3, therefore, it is estimated from observed values: order *n* observations from smallest to largest, and let $x_{(i)}$ denote the smallest observation (i=1 correspond to the smallest and i= n corresponds to the largest). Then a good estimator of *F(x;b,c)* is the median rank of $x_{(i)}$ as in Eq.4:

$$F(x_{(i)};b,c) = \frac{i-0{,}3}{(n+0.4)} \quad (4)$$

By using Eq.3 and Eq.4 and based on least square minimization of linear regression, both parameters b and c can be estimated. Then, by using Eq.2, the reliability curve can be drawn.

2 Research Methods

Fig.1 and 2 shows the materials and manufacturing steps to produce ramie fiber/epoxy and ramie-e-glass/epoxy hybrid composites. Fig. 1 shows the fibers were carefully arranged eventually producing a bidirectional ±45° and (0°/90°)s fiber specimens Fig. 2 shows the fibers were then laminated using hand lay-up and vacuum bagging methods which was the epoxy resin and fiber placed into the mold. The temperature was set to room temperature (30°C) for 7 hours. During the trial and error, it was found that the optimum fiber volume fraction is 50%. Therefore, during the manufacturing processes, the epoxy resin and the fibers were measured in order to achieve 50% fiber volume fraction. Shear tests were carried out according to ASTM (American Society for Testing Materials) D 5379. The tests were done using a universal testing machine Tensilon with a maximum capacity of 10,000 N. Fig.3 shows the final specimens for shear tests.

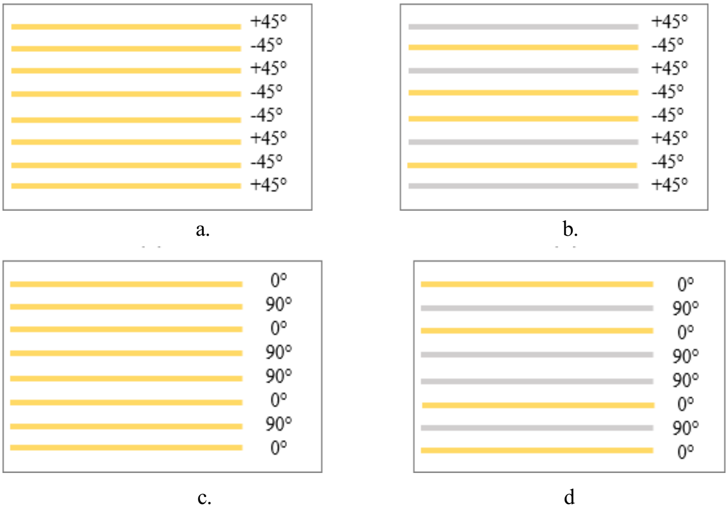
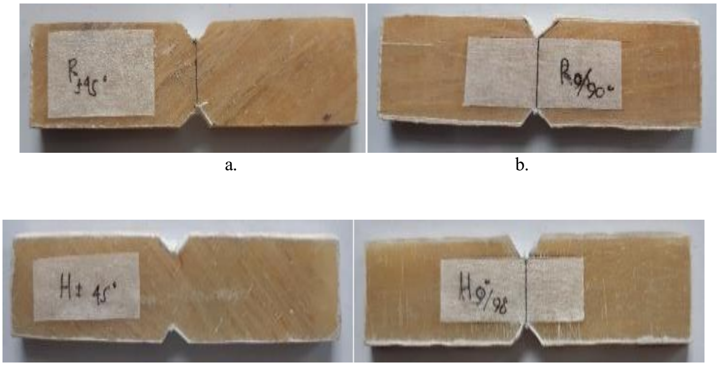


Fig 1. Orientation of the fiber arrangement in the composites: a. ramie/epoxy ±45°, b. hybrid ramie-E-glass/epoxy ±45°, c. ramie/epoxy $(0°,90°)_s$, and d. hybrid ramie-E-glass/epoxy $(0°,90°)_s$

a. b.

Fig 2. Lamination method of composite specimens: a. hand lay-up, b. vacuum bagging



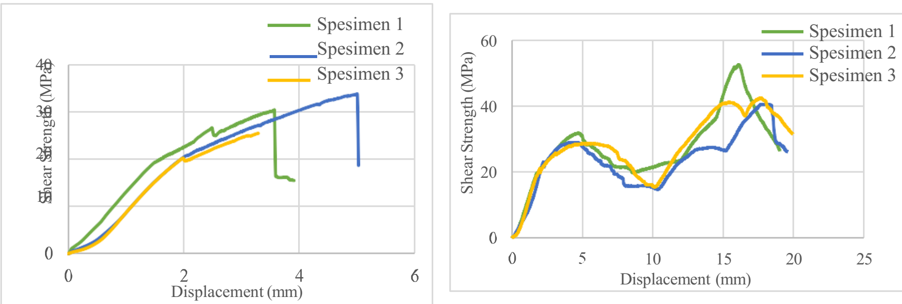
a. b.

c. d.

Fig. 3 Composite specimens: a. a. ramie/epoxy ±45°, b. hybrid ramie-E-glass/epoxy ±45°, c. ramie/epoxy $(0°,90°)_s$, and d. hybrid ramie-E-glass/epoxy $(0°,90°)_s$

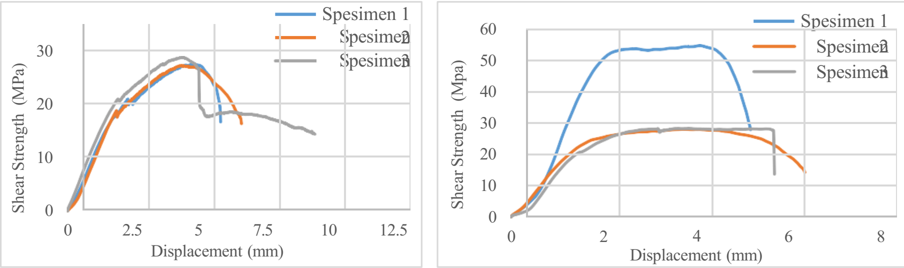
3 Results and Discussion

Typical load-displacement curves for shear tests are given in Fig. 4 for bidirectional ±45° and $(0°/90°)s$ orientation specimens. The maximum shear strengths were then evaluated and statistically analyzed using two parameters Weibull distribution. Fig. 5 shows the example of final reliability distribution for bidirectional ±45° ramie/epoxy composite specimens. The analysis was done for all fiber configuratis.



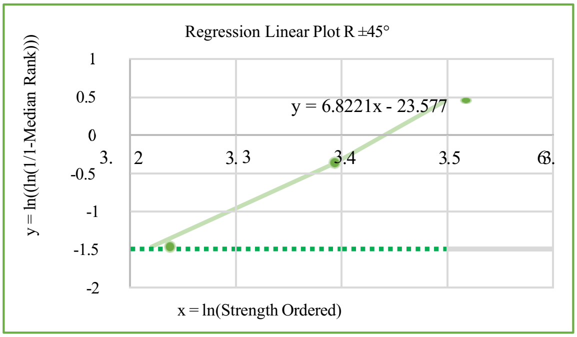
a. b.

Fig. 4 Typical strength-displacement curves for shear tests of rami/epoxy composite specimens: a. ramie/epoxy±45°, b. hybrid rami-E-glass/epoxy ±45°

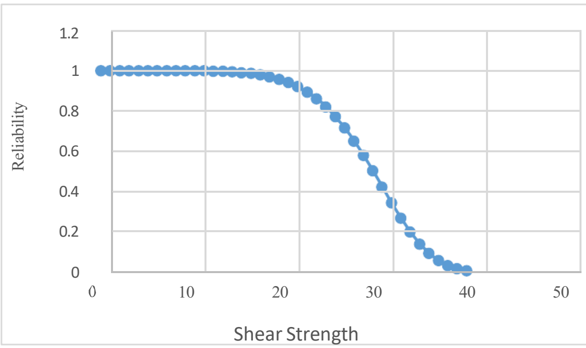


a. b.

Fig. 5 Typical strength-displacement curves for shear tests of rami/epoxy composite specimens: a. ramie/epoxy $(0°,90°)_s$ b. hybrid ramie-E-glass/epoxy $(0°,90°)_s$



a.



b.

Fig. 6 Typical two parameters Weibull statistical analysis for flexural strengths of bidirectional $(0°/90°)_s$ specimens: **Fig. 6.a** linear regression of Eq. 3, where $Y = ln\left[ln\left(\frac{1}{1-F(x;b,c)}\right)\right]$ and $X = \ln(x)$. The parameter c is the slope and b can be calculated using Eq. 3, **Fig.6.b** : the reliability curve for bidirectional specimens of Eq.2.

By using Fig. 6.b, we are able to determine the reliability of fracture of the specimens. In this study, we use 50% reliability. It means that in the particular stress level, the probability of the specimens failing is 50%.

The result for all fiber configurations and test types is given in Table 2 for 50% reliability level. Table 1 shows that the value of shear strength for rami/epoxy and hybrid rami-E-glass/epoxy with ±45° fiber orientation specimen is higher than $(0°/90°)_s$ fiber orientation respectively. This is typical for composite materials since bidirectional ±45° composite materials usually have higher compressive strengths. Further investigations are needed to get a valid conclusion in this matter.

Table 1. Present Results on the Shear Strengths of Composites

Composite	Shear strength, τ (MPa)	Elongation (%)	Densitas, ρ (g/cm^3)
Ramie/epoxy ±45°	30	4,1	1,27
Ramie/epoxy $(0°/90°)_s$	28	7,3	1,27
Hybrid ramie-E-glass/epoxy ±45°	45	19	1,38
Hybrid ramie-E- glass/epoxy $(0°/90°)_s$	36	5,9	1,44

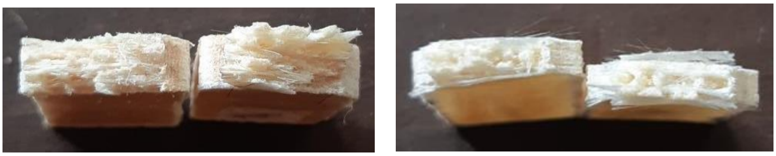
Table 1 shows that based on the results of the Weibull distribution analysis, it is possible to determine the reliability value of material strength to analyze structural strength. In other words, if the strength of the structure is analyzed using shear strength reliability of 50% it is safe, especially if using shear strength reliability of 90% the structure will be safer. The shear strength of the ramie/epoxy composite and the ramie-E-glass/epoxy hybrid fiber direction ±45° have the highest shear strength with values of 30 MPa and 45 MPa respectively, which has the highest shear strength value for hybrid composites because it is combined with e-glass fiber reinforcement which has a higher tensile strength than hemp fiber. Be- sides that, composites with a fiber direction of ±45° have better shear strength values because the load during the shear test received by the resin is then distributed entirely in the fiber direction ±45° and is better able to withstand shear loads because the load received by the resin is distributed entirely in the direction of the fiber ± 45°, while the fiber direction (0°,90°)s is lower because the load received is partially distributed in the 90° fiber direction which is in the same direction as the shear test load which causes a decrease in shear strength. Fig. 7, 8, and 9 shows the failure mode that occurred in the composite specimens with fiber directions of 45° and (0°,90°)s respectively.

a. b.

Fig. 7. Composite specimens with fiber directions of 45°: a. rami/epoxy 45, b. hybrid ramie-E-glass/epoxy 45°

a. b.

Fig. 8. Composite specimens with fiber directions of $(0°,90°)_s$: a. rami/epoxy $(0°,90°)_s$, b. hybrid ramie-E- glass/epoxy $(0°,90°)_s$



a. b.

Fig. 9 Transverse position of failure mode that occurred in the composite specimens: a. ramie/epoxy, b. hybrid ramie-E-glass

When a composite experiences fiber breakage, the resulting damage can propagate through various paths. When there is a tough bond between fiber and matrix with a brittle matrix, the stress concentration at the crack tip can lead to the crack spreading throughout the entire section. Shear failure can happen at the interface, enabling the unbound fiber to begin to retract back into the material. The spread of fiber failure that takes place is an intricate crack path because of variations in fiber strength and debonding. The characteristics of fracture surfaces for both strongly and weakly bonded interfaces are illustrated in Figures 8 and 9. The combination of a strong interface results in a relatively smooth surface; however, certain areas exhibit significant debonding, leading to a brush-like appearance. This highlights the significance of interfacial strength in influencing fracture behavior and toughness. A substantial amount of energy is consumed during the process of extracting fibers from the matrix.

Longitudinal splitting in the 0° plies which are parallel to the fiber develops because of the Poisson's ratio mismatch between the 0° plies which has a higher Poisson's ratio value when compared with the 90° plies perpendicular to the fiber which has a lower Poisson's ratio. As the 0° plies extend, they try to contract inwards but are restrained by the 90° plies which carry less load and have high stiffness along the fiber direction. This results in tensile stresses in the 0° plies, perpendicular to the loading axis, causing longitudinal splits through fiber/matrix debonding and matrix fracture. Transverse ply cracking is another type of matrix cracking that occurs in the 90° plies.

This process typically begins under low-stress conditions, leading to fiber/matrix debonding and the formation of matrix cracks. As the applied load escalates, the cracks spread quickly throughout the ply, multiplying in number until they achieve a state of saturation characterized by evenly distributed cracks. The spacing observed at this stage is indicative of the specific laminate configuration and is referred to as the characteristic damage state. In a cross-ply laminate, delamination and matrix cracking represent two of the primary damage mechanisms. In cross-ply laminates that include layers with fibersaligned with the loading direction (0° plies) and those oriented perpendicular to it (90° plies), additionaldamage accumulation mechanisms emerge under tensile loading. Alongside fiber fracture and interface de- bonding, delamination and matrix cracking manifest as longitudinal splitting and transverse ply cracking.

4 Conclusion

Based on the research results, it was concluded that the ramie-E-glass/epoxy hybrid composite with a fiber direction of ±45° has higher shear strength and elongation and thus produces a strong structure, even though it uses economical hand lay-up and vacuum bagging manufacturing methods. This shows that composites by combining hybrid ramie and e-glass fibers have the potential to be further developed as alternative materials for application in the outer skin structure that can withstand shear loads for components in the automotive and unmanned aerial vehicles (UAVs) industries which uses high local raw material content.

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