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Research Article

Mechanical Strength Analysis of Bamboo Fiber and Glass Powder Reinforced Composites Using Epoxy Matrix as an Alternative Visor

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Abstract

This study aims to analyze the mechanical strength of composites with bamboo fiber and glass powder reinforcement using an epoxy matrix. The study used a hand lay-up method with three variations of volume fraction composition, namely (1) 15% bamboo fiber, 15% glass powder, 70% resin, (2) 20% bamboo fiber, 10% glass powder, 70% resin, and (3) 25% bamboo fiber, 5% glass powder, 70% resin. The bamboo fiber used was the result of alkali treatment using 15% NaOH solution to remove lignin and cellulose, while the glass powder was obtained from household glass waste with a particle size of 60 mesh. Mechanical property testing included tensile testing (ASTM D638 Type 1), compression testing (ASTM D695-96), and impact testing (ASTM D256), while morphological structure analysis was carried out using Scanning Electron Microscope (SEM) testing. The results showed that the volume fraction composition of 25:5:70 produced the highest tensile strength with an average value of 95.69 N/mm^2 and the highest impact strength of 29.91 J/mm. Meanwhile, the composition of 15:15:70 obtained the highest compressive strength of 57.13 MPa. SEM analysis of the composite fracture showed the occurrence of full out fiber, debonding, and void phenomena in the matrix, which affected the decrease in the material strength value. This indicates that variations in the composition of bamboo fiber and glass powder can optimize the mechanical properties of composites, while supporting the utilization of natural materials and waste as environmentally friendly innovation materials for automotive applications, especially Yamaha Vixion motorcycle visor products.

Keywords: *composite, bamboo fiber, glass powder, mechanical properties, SEM*

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INTRODUCTION

Composite materials are two or more types of materials that are combined and produce a material that has different characteristics from the properties of the parent material [1], [2]. Composite materials consist of two elements: first, fiber as a reinforcing material (filler) that determines the properties of the composite material and second, a matrix that functions as a binding material for the fibers in the form of a polymer that is easy to shape [3]. Composite material properties include strength, stiffness, and other mechanical properties. The choice of matrix material used also plays an important role in determining the mechanical properties of the composite [4]. The use of natural fibers as composite materials continues to be developed to improve performance and to determine other natural fibers whose mechanical properties have not yet been identified with certain variations [5].

One of the natural fibers currently being developed is bamboo fiber. Bamboo fiber has advantages over other natural fibers such as: high tensile strength, good density and strong adhesion to epoxy matrices, especially after alkali treatment [6]. Alkali treatment of bamboo fiber can remove lignin and improve interfacial bonding in the matrix fiber [7]. In addition, another advantage of bamboo is that the material is very abundant and easy to obtain, which can support the sustainability of renewable materials. Meanwhile, the addition of glass waste fibers that function as inorganic fillers can increase the hardness, elastic modulus and abrasion resistance of the composite [8]. Therefore, the combination of bamboo fiber filler and glass powder provides a synergistic effect, bamboo fiber can increase strength and stiffness, while glass can provide strength to the matrix structure and close micro-cavities that can become sources of cracks [9].

I Several previous studies have analyzed the characteristics of bamboo and glass fibers as filler materials for epoxy composites. Hasan et al., [10] comprehensively studied polymer composites reinforced with bamboo fibers in sustainable applications. Bamboo fibers were treated with alkali NaOH, silane, and stearic acid. The volume fraction of bamboo fibers used was between 10% and 40%. The results showed that composites with an optimum fiber fraction of 25–30% tended to provide significant increases in tensile, flexural, and impact strength, while at fractions above 35–40% there was a decrease in mechanical properties due to agglomeration and uneven fiber distribution. Furthermore, Prashanth et al., [11]studied the mechanical and tribological properties of epoxy composites reinforced with bamboo fibers treated with NaOH and the addition of TiO2 filler. The bamboo fiber fraction used was 0.5 to 2 wt.%, while the TiO_2 content was constant at 1 wt.%. The optimum composition was obtained at 1.5 wt.% bamboo fiber + 1 wt.% TiO_2, which resulted in an increase in tensile strength of up to 71% and flexural strength of up to 69% compared to pure epoxy, as well as reducing mass loss due to wear by up to 70%. Furthermore, another study related to glass powder by Ostrowski et al., [12] analyzed the use of used glass fiber and basalt powder as additives in an epoxy matrix for concrete structure repair applications. The composite formulation used varied the percentage of basalt powder from 0% to 20% by weight. The results showed that the addition of basalt powder tended to reduce the tensile strength from 47.1 MPa to 34.8 MPa for a basalt fraction of 20%. However, when combined with glass fiber, this negative effect could be offset slightly higher than pure resin. Finally, Sheikh [13] studied the potential of glass waste as a filler for thermoplastic polypropylene, affecting its mechanical and morphological characteristics. The glass fraction percentages were 10 wt%, 15 wt%, and 20 wt%. Good strength and flexural modulus were achieved at 10 wt% and 15 wt%, while high tensile strength was achieved at 20 wt%. Adding fractions above 20 wt% resulted in uneven dispersion and clumping in the composite.

Previous research has largely focused on the characteristics of single bamboo fibers and glass powder as fillers in epoxy composites to improve mechanical properties.


(a) (b) (c)
Figure 1. a) Visor Design, b) Visor Products, c) Visor Installation on Motorcycle

Furthermore, previous research has been very limited in discussing the effect of the fractional ratio of bamboo and glass fiber additions on the mechanical properties of composites, particularly tensile, compressive, and impact strengths. Optimal fiber fraction analysis is crucial for producing epoxy composites with high strength and toughness. This study aims to fill this research gap by comparing variations in fiber-powder fractions on the mechanical properties and morphology of epoxy composites.

Therefore, the research gap lies in the lack of quantitative studies comparing variations in fiber-powder fractions on the mechanical properties and microstructure of bamboo-glass hybrid epoxy composites. The optimal fraction in this study will be applied to environmentally friendly motorcycle visor materials (Figure 1).

METHODS AND ANALYSIS

The method used in this study is an experimental method and quantitative research by clearly presenting the results of laboratory experiments on a number of test objects, then analyzing the data using numbers. This method is used to determine the mechanical properties of bamboo fiber and glass powder composites with an epoxy resin matrix reviewed from tensile, compression, and impact tests. In addition, to determine the morphological structure from the results of SEM (Scanning Electron Microscope) photos.

Materials

This research used bamboo fiber and glass waste as materials. The bamboo fiber was cut to 25 mm lengths, while the glass fiber was obtained from used glass bottles, ground and sieved to a 60-mesh mesh. The epoxy used was Sikadur-52 ID (Indonesia) and used as an amine hardener. Chemicals included NaOH solution for the alkali process, and distilled water and ethanol for mold cleaning.

Alkali Treatment

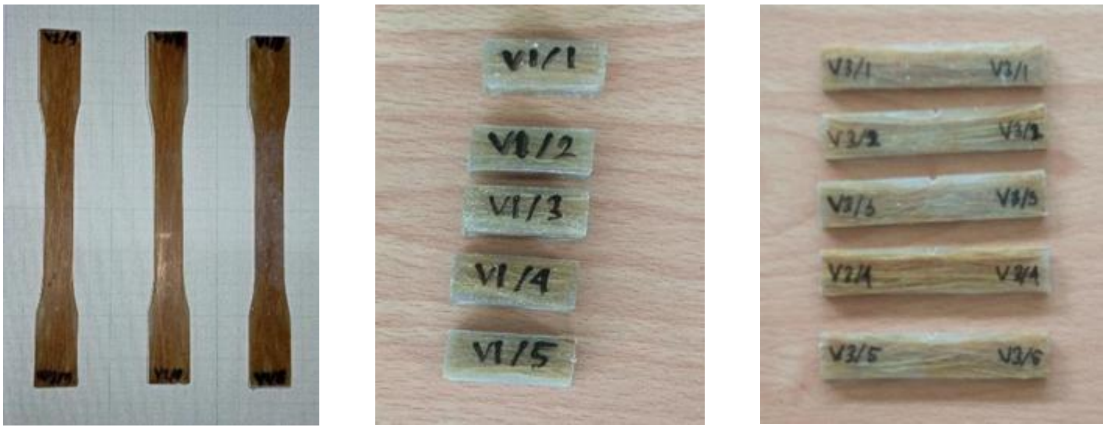
The cut bamboo fibers were soaked for 3 hours in a 15% NaOH solution. After soaking, they were cleaned with distilled water and dried for 24 hours. The final process was combing with a steel brush to separate the bundles and uniform the fiber length.

Composite Fabrication by Hand Lay-Up

The composition variations are divided into three parts: fiber, glass powder, and matrix. The percentage values can be seen in Table 1. There were 3 specimens in each

Table 1. Variation of Bamboo Fiber, Glass Powder and Matrix Percentage

No	Bamboo Fiber (wt%)	Glass Powder (wt%)	Matrix (wt%)
1	15%	15%	70%
2	20%	10%	70%
3	25%	5%	70%



(a) (b) (c)

Figure 2. a) Tensile Test Specimen, b) Compression Test Specimen, c) Impact Test Specimen

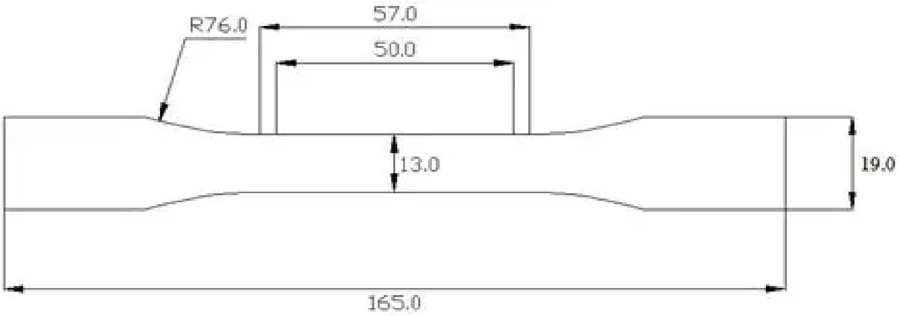


Figure 3. Dimensions of ASTM D638 Type 1 Tensile Test Specimen

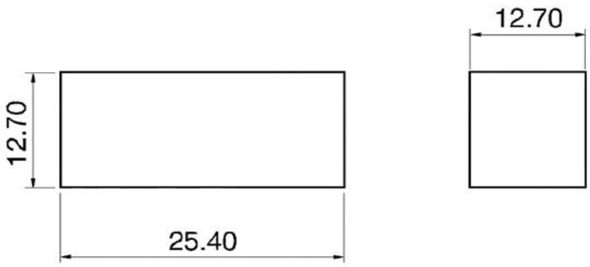


Figure 4. ASTM D695 Compression Test Specimen

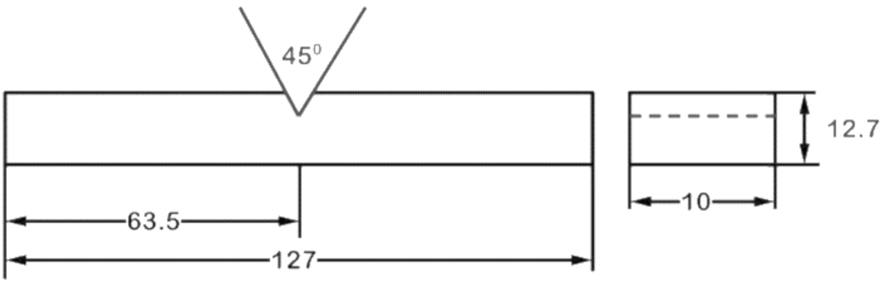


Figure 5. ASTM E23 Impact Test Specimen Size

variation, each specimen was then calculated as an average for each test.

Bamboo fiber and glass powder are weighed according to the target %vol. The fiber is evenly distributed, the powder is homogenized in the resin (pre-mix), then the resin and glass powder mixture is poured while pressing/rolling to wet the fiber. Lay-up: This is done in stages until the thickness meets the standards from tensile, compression, and impact tests (Figure 2).

Tensile Testing

Tensile testing was conducted using a Universal Testing Machine (UTM) in accordance with ASTM D638 TYPE 1 (Figure 3). The specimen was clamped between two grippers subjected to static loads until fracture occurred. Tensile testing was conducted to determine the mechanical properties of the material, namely the strength and elasticity of the resulting composite material.

Compression Testing

Compression testing is performed to determine the material's strength and deformation behavior under compressive load. Testing is performed using a 10 kN Universal Testing Machine. The testing standard used is ASTM D695 (Figure 4).

Impact Testing

Impact testing is carried out using the Charpy method with the aim of testing the toughness of a specimen against sudden loading through impact. The specimens are tested using the ASTM E23 testing standard.

Scanning Electron Microscope (SEM) Photo

The SEM images will produce various images containing information about the surface topography and material composition. The SEM images were taken on a 2015 Vixion visor by breaking it and then photographing the fracture using a Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSIONS

Mechanical Properties

The tensile test results can be seen in Figure 6.Based on the tensile test graph, it shows that the tensile stress increases along with the increasing fiber composition in the volume fraction variation. The highest average tensile stress is in the volume fraction variation of 25% fiber, 5% powder and 70% epoxy matrix at 95.69 N/mm^2. It can be concluded that the higher the fiber volume fraction, the greater the tensile strength of the material.

Increasing the fiber fraction will result in a more effective load transfer from the epoxy matrix to the bamboo fibers through interfacial shear stress. Alkali treatment increases the surface roughness of the bamboo fibers, thereby strengthening the mechanical interlocking and adhesion between the fibers and the matrix [6], [14]. This improved adhesion reduces the likelihood of slippage and debonding during tensile loading, thereby increasing tensile strength.

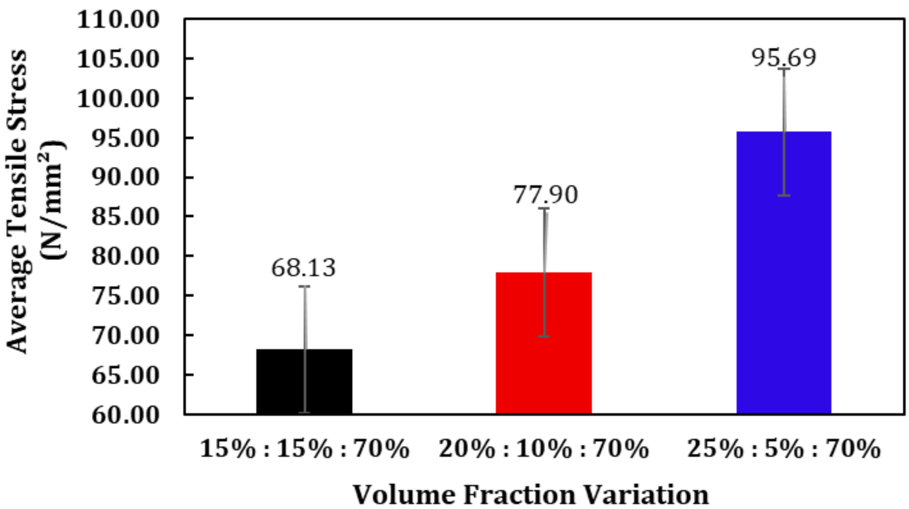


Figure 6. Tensile Stress Results Graph

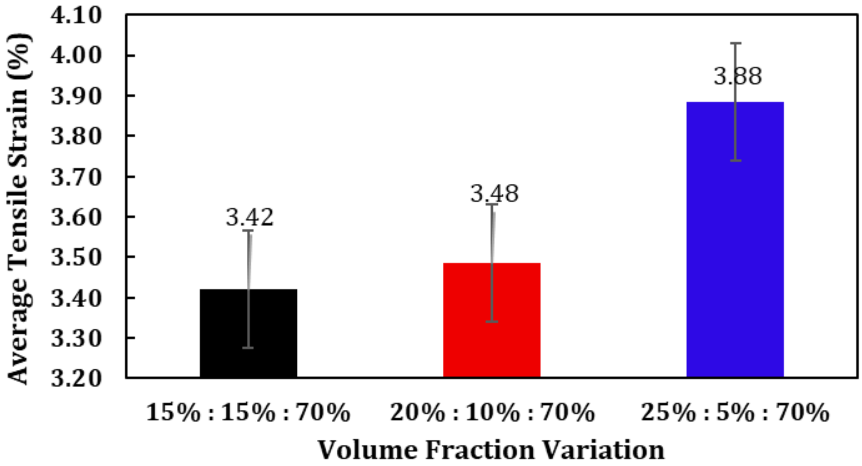


Figure 7. Graph of Tensile Strain Calculation Results

The strain results are shown in Figure 7. Based on the graph of the tensile strain calculation results, it shows that the tensile strain increases with increasing fiber composition in variations in volume fraction. The highest average tensile strain is in the volume fraction variation of 25% fiber, 5% powder and 70% epoxy matrix at 3.88%. This shows that increasing the fiber volume fraction not only increases tensile strength, but also the material's ability to deform before breaking. Materials with higher fiber content show better elasticity so they can increase resistance to deformation.

The relatively short fiber length and random orientation support multidirectional load distribution, which in this condition delays the occurrence of initial cracks in the matrix and increases the ability of plastic deformation [15]. At higher fiber fractions, energy dissipation occurs through controlled fiber pull-out mechanisms and interfacial friction, so that the composite can experience greater strain before fracture. Conversely, at low fiber fractions, the brittle nature of the epoxy matrix dominates and causes sudden fracture due to its limited energy absorption capacity. Thus, the increase in strain at a fiber fraction of 25% indicates that optimal interfacial adhesion and fiber dispersion increase the toughness and strain resistance of this hybrid composite.

Figure 8 shows the results of the elastic modulus values. Based on the graph of the results of the calculation of the modulus of elasticity, it shows that the modulus of elasticity increases along with the increase in fiber composition in the volume fraction variation. The highest average modulus of elasticity is in the volume fraction variation of 25% fiber, 5% powder and 70% epoxy matrix at 2471.52 N/mm2. This shows that the greater the fiber content, the material becomes stiffer and more resistant to elastic deformation. Glass powder plays a role in increasing stiffness by filling microvoids and reducing matrix plasticity, thereby improving dimensional stability [16]. However, excessive fiber addition can cause fiber clumping, local stress concentration, and incomplete wetting, which actually reduce stiffness. Therefore, the highest modulus value in the composition of 25% bamboo fiber and 5% glass powder indicates an optimal balance between effective stress transfer, limiting matrix deformation, and uniform reinforcement distribution.

The compression test results are shown in Figure 9. Based on the graph of the compression test results, it shows that the compressive strength decreases with increasing fiber composition in the volume fraction variation. The lowest average compressive strength is in the volume fraction variation of 25% fiber, 5% powder and 70% epoxy matrix at 48.69 MPa. This shows that the addition of fiber and reduction of glass powder in the volume fraction can reduce the material's ability to withstand compressive loads. So, to be able to withstand the compressive load best is with a balan-

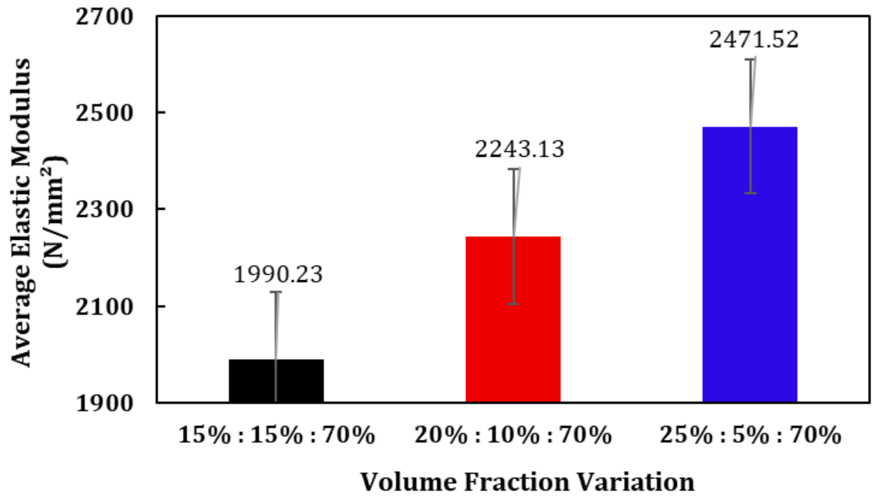


Figure 8. Graph of Elasticity Modulus Calculation Results

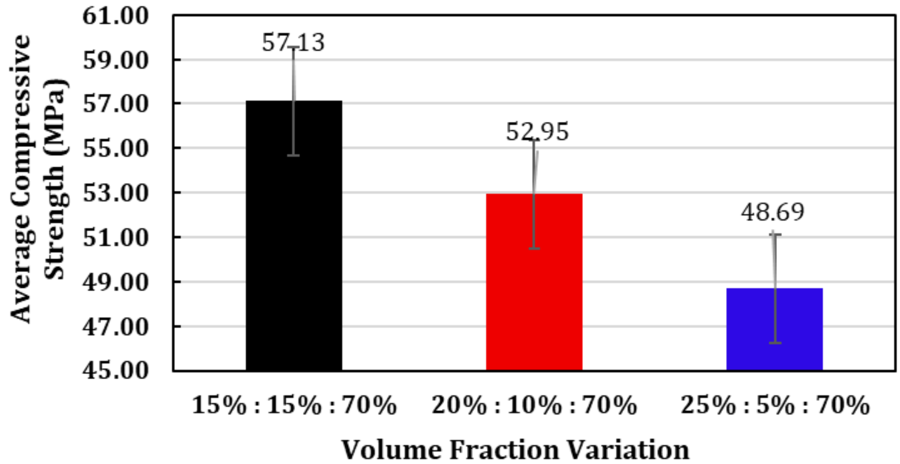


Figure 9. Compression Test Results Graph

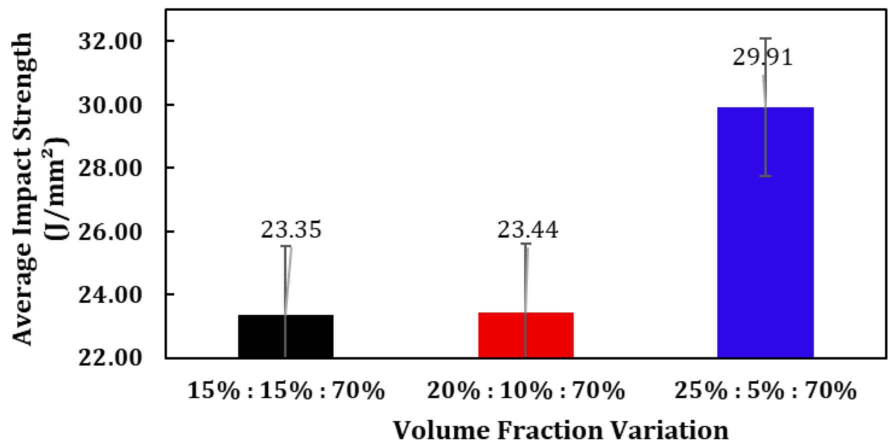


Figure 10. Impact Test Results Graph

ced fiber and powder composition. Compression test results show a decrease in compressive strength with increasing bamboo fiber fraction, indicating that the composite's ability to withstand compressive loads is highly dependent on the balance between the fiber and matrix phases. Under compressive conditions, the epoxy matrix plays a dominant role in resisting loads due to its continuous and isotropic structure, while the fibers are more effective in resisting tensile loads [17]. When the fiber fraction is too high, matrix continuity is disrupted, resulting in local buckling, debonding, and microvoid formation, which reduce compressive strength.

Based on the graph (Figure 10), the impact test results show that the impact strength increases with increasing fiber composition in the volume fraction variation. The highest average impact strength is at a volume fraction variation of 25% fiber, 5% powder and 70% epoxy matrix of 29.91 J/mm2. This improvement is due to effective energy absorption mechanisms such as fiber pull-out, debonding, and crack deflection, which delay the occurrence of sudden fracture [18]. Alkali treatment of the fibers creates a rougher surface and strengthens the interfacial bond with the epoxy matrix, allowing for more efficient stress and friction transfer during the pull-out process [19].

The increase in tensile and impact strength of composites with increasing bamboo fiber fraction can be explained by micromechanical mechanisms related to efficient load transfer between the fibers and the epoxy matrix. The strong interfacial adhesion condition due to alkali treatment will result in stress being transferred effectively from the matrix to the fibers, thereby increasing the stiffness and tensile strength of the composite. Similar results were also reported by Hasan et al. (2023) [10] and Liu et al. (2025) [6] that alkali-treated bamboo fibers can improve interfacial bonding and reduce the possibility of fiber slippage. Meanwhile, the addition of glass powder plays a role in closing microvoids in the matrix, improving load distribution, and inhibiting crack propagation, as reported by Ostrowski et al. (2025) [12]. At a higher fiber fraction (25%), overlapping bamboo fibers and uniform resin wetting result in increased energy absorption capacity in impact tests, indicating an effective energy dissipation mechanism as noted by Prashanth et al., [11]. Thus, the combination of the use of processed bamboo fiber and glass powder in the epoxy matrix provides a synergistic mechanical strengthening effect through the integration of load transfer mechanisms, crack deflection, and interfacial strengthening.

Morphology

The results of morphological observations using SEM can be seen in Figure 11. Based on the results of SEM photos with magnification from 50 to 500x, At 50x and 100x magnification can be seen the relationship between the matrix and filler that has gone through the alkalization process, while at 200x and 500x magnification can be seen the shape of the fracture. At 50x and 100x magnification there are small voids and many fibers experience pull out and debonding this is caused by the matrix stirring is not long enough so that the resin and hardener are not mixed evenly resulting in the fiber experiencing pull out. Debonding is also related to the less than optimal alkalization results where the alkalization process still leaves residual lignin on the surface of the fiber resulting in a less than optimal relationship between the fiber and the matrix, While at 200x and 500x magnification provides information on fractures of bamboo fibers and shows glass powder and clarifies the occurrence of pull out and debonding in bamboo fibers.

SEM images show clear differences in interfacial bond strength and fracture patterns between the composite variations. The specimens with a composition of 25% bamboo fiber and 5% glass powder exhibited fewer voids and better fiber–matrix adhesion, confirming the effectiveness of the alkali treatment in improving surface roughness and mechanical interlocking between fiber and resin [14]. The presence of elongated fiber pull-out areas indicates partial load transfer before fracture, which contributes to the increased tensile and impact strengths in this composition. In contrast, the specimens with 15% bamboo fiber and 15% glass powder exhibited larger voids and wider debonding zones, indicating incomplete fiber wetting and weak interfacial bonding, consistent with the observed decrease in compressive strength. These findings strengthen the micromechanical interpretation that the balance between strong interfacial bonding and controlled fiber pull-out mechanisms determines the overall

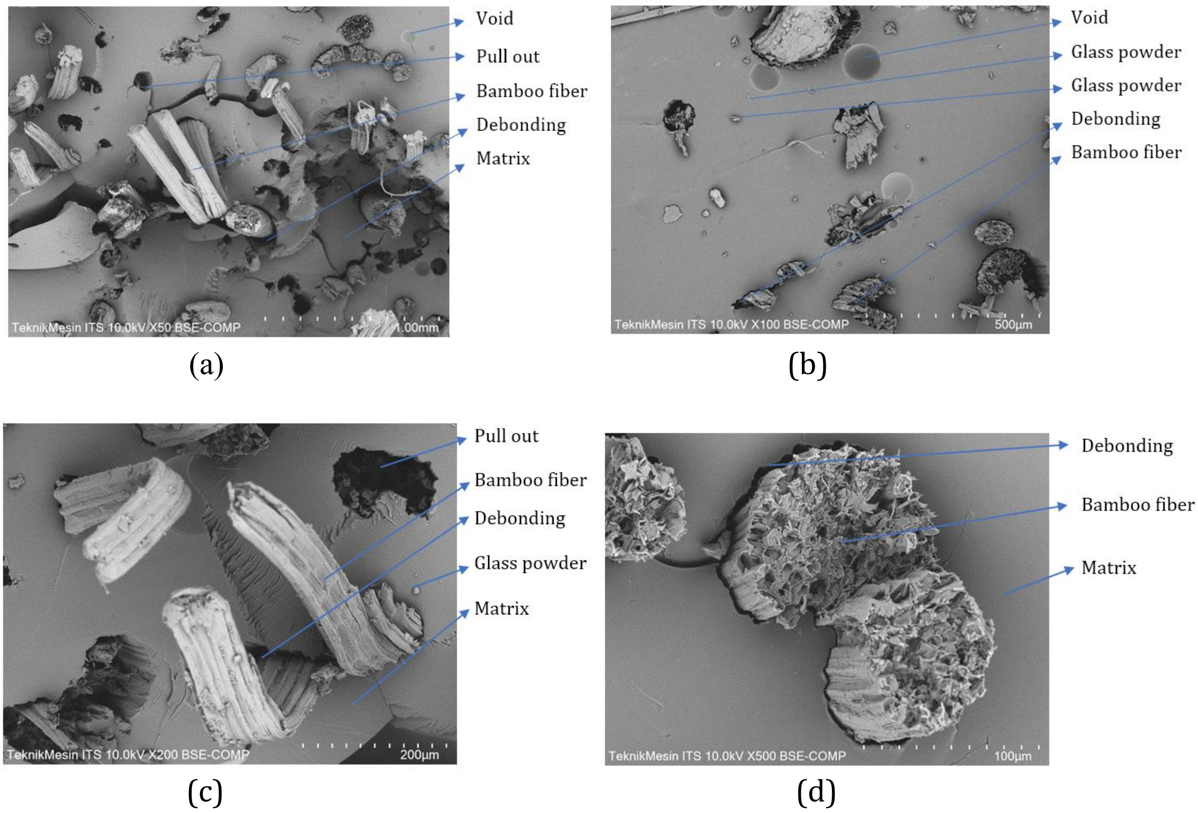


Figure 11. (a) SEM photo results with 50x magnification, (b) SEM photo results with 100x magnification, (c) SEM photo results with 200x magnification, (d) SEM photo results with 500x magnification

mechanical performance of bamboo–glass–epoxy hybrid composites. Similar results were also reported by Wang et al., [7] and Prashanth [11] on natural fiber–epoxy composite systems, which emphasizes the importance of fiber surface modification and filler dispersion in increasing composite strength.

CONCLUSIONS

This study analyzed the mechanical performance of epoxy-based hybrid composites reinforced with bamboo fiber and glass powder using the hand lay-up method. The results showed that a composition of 25% bamboo fiber and 5% glass powder produced the highest tensile strength (95.69 N/mm^2) and impact strength (29.91 J/mm^2), while a composition of 15% bamboo fiber and 15% glass powder produced the highest compressive strength (57.13 MPa). The results of this study confirm that the balance between fiber fraction and glass powder dispersion significantly influences the mechanical performance of the composite. Increasing the bamboo fiber fraction increases tensile and impact strength through load transfer and energy absorption mechanisms, while glass powder enhances compressive strength by filling microvoids and strengthening the matrix phase. This improvement is also supported by SEM analysis results, which show strong interfacial bonding and a decrease in the number of pores at the optimum composition. Practically, this study demonstrates that alkali-treated bamboo fiber and recycled glass powder can be an environmentally friendly and economical reinforcement for polymer composites in lightweight, impact-resistant automotive components, such as motorcycle visors. This hybrid reinforcement approach has the potential to reduce reliance on synthetic fibers while utilizing renewable and waste materials, thus supporting sustainable manufacturing practices in the transportation industry. Further research is recommended to evaluate the long-term durability, environmental impact, and thermal stability of hybrid composites to expand their use in other structural applications.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that they have no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

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