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Strength Analysis of Fiberglass Reinforced Sandwich Composites with Extruded Polystyrene Core

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Abstract:

The use of drones has rapidly increased across various sectors due to technological advancements and reduced production costs. One of their applications is transporting materials in hard-to-reach construction areas. Carbon fiber is commonly used for drone frames; however, it has drawbacks such as high cost, low impact resistance, and difficulty in recycling. This study investigates the potential of a sandwich composite material made from WR200 fiberglass and extruded polystyrene (XPS) foam core as a lightweight and economical alternative for drone frame manufacturing. Tensile testing (ASTM D638 Type 1) and bending testing (ASTM C393) were conducted to evaluate the material's strength. The results showed the highest tensile strength of 131 MPa at a 40% fiber volume fraction, with a consistent increase in strength observed from 20% to 40% fiber volume. Bending tests also revealed strength improvement, reaching a maximum value of 47.80 MPa at 40% fiber volume, with an average maximum load of 585 N. The results from both tensile and bending tests indicate that the amount of E-glass fiber in the epoxy matrix significantly affects tensile and bending strength. As the fiber content increases, the strength improves as well; however, it also leads to increased stiffness

Keywords: sandwich composite, fiberglass, extruded polystyrene, ASTM D638, ASTM C393

1. Introduction

In recent years, the use of drones or unmanned aerial vehicles (UAVs) has increased across various sectors, including the military, agriculture, and industry. This growth has been driven by technological advancements and decreasing production costs, making drones more accessible to a wide range of users. Currently, drones are being utilized as material transport vehicles in hard-to-reach construction areas. This application is considered more effective and efficient for moving goods quickly and at lower costs compared to clearing land and building access roads, which can harm the environment.

As the demand for advanced materials continues to grow, the development of materials for drone chassis structures has become increasingly important. Material selection is a crucial factor in determining the drone's performance and durability. Currently, carbon fiber composites are among the commonly used materials for drone chassis due to their high strength and lightweight properties. However, carbon fiber also has limitations, such as high production costs and difficulty in recycling. Therefore, there is a need for alternative materials that not only offer excellent mechanical properties but also have advantages such as lower cost and ease of production [1]. Recognizing the limitations of metal and plastic materials, researchers are now exploring the use of alternative materials for drone manufacturing to improve performance without increasing weight and cost [2].

Sandwich composite materials reinforced with fiberglass and an extruded polystyrene (XPS) core present a promising solution for use in the construction of cargo drone frames due to their lightweight nature and lower production costs compared to carbon fiber. However, to be considered suitable for use, the mechanical strength of the sandwich composite must be tested through tensile and bending tests [3].

The reinforcing fibers in the laminate, which are bonded by the matrix, are typically chosen for their strength, flexibility, and toughness. These properties allow the fibers to withstand external forces. Fiberglass is an effective and economical choice due to its lower cost, good mechanical properties, and wide availability [4].

Fibers are classified into two types: synthetic fibers and natural fibers. Synthetic fibers are made from various inorganic materials with specific chemical compositions. Some advantages of synthetic fibers include their relatively uniform properties and dimensions, as well as the ability to maintain consistent strength along the entire length of the fiber. One example of a synthetic fiber is E-glass fiber [5].

By selecting the appropriate fiber, adjusting its volume fraction, applying alkali treatment, and utilizing hybrid composites, researchers have successfully developed composite materials that are strong, lightweight, and environmentally friendly.

The lightweight nature of Styrofoam makes it a suitable core material, helping to minimize the overall weight of the sandwich composite. Sandwich composites are designed to achieve the lightest possible weight while maintaining high stiffness and strength. While there are many definitions of sandwich composites, the key factors are a lightweight core, which reduces the material's density, and strong skin layers that provide strength and durability to the composite structure [6].

Foam cores are often used due to their very low density, which helps improve the efficiency and performance of unmanned aerial vehicles (UAVs). The Styrofoam used in this study is a type of extruded polystyrene (XPS). Styrofoam falls under the category of synthetic polymers with high molecular weight. It is made from ethylene-based monomers derived from petroleum cracking." Styrofoam" is merely a commercial name; the actual material is polystyrene, or poly (phenylethane) [7].

The characteristic of sandwich construction consists of layered skins, one or more of which have high external strength and low-density inner layers [8]. A sandwich composite consists of several structural components, including the skin, which functions to withstand tensile and compressive stresses; the core, which serves as the central part of the sandwich composite; and the adhesive, which bonds the skin and core together [9].

With the continuous advancement of composite technology, it is now possible to design composites according to the desired material characteristics, making them stronger, lighter, stiffer, and more heat-resistant. Laminated composite is a composite type consisting of two or more layers that are merged into one and each layer has its own characteristics [10].

There are three main factors that influence the strength properties of composites: the constituent materials, the structural arrangement of the components, and the interaction between the materials [11]. One common way to improve composite properties is to treat the fibers with chemicals, such as alkali (NaOH) [12].

The matrix is the primary and continuous phase, functioning to support the reinforcement phase and transfer loads. Meanwhile, the reinforcement is the secondary and discontinuous phase that is embedded within the matrix [13]. The use of sandwich composite materials in ships may increase thickness and cost, but it significantly reduces weight compared to single-skin structures [14].

In fiber reinforced polymer composites, the area that distinguishes the fiber from the polymer is very important for better mechanical properties [15]. However, predicting the mechanical behavior of these materials remains challenging, primarily due to their inhomogeneous structure and complex damage mechanisms [16].

From the description above, the aim of this research is analyze strength of fiberglass reinforced sandwich composites with extruded polystyrene core to be used as drone material.

2. Methods

The tools used in this research include a ruler, caliper, analytical balance, measuring cup, scissors, hot wire, glass plate, cutter, gas torch, stirring stick, and brush. The materials used consist of E-glass WR 200 as the reinforcement, epoxy resin and hardener as the matrix, miracle gloss wax to facilitate mold release, and extruded polystyrene as the core.

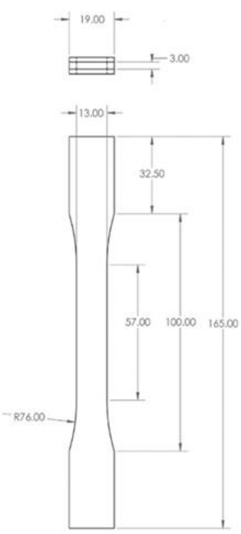

Figure 1. Engineering drawing of tensile test specimen (ANSI)

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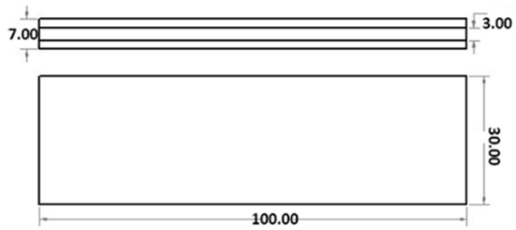

Figure 2. *Engineering drawing of bending test specimen (ANSI)*

2.1. Test Specimen Design

The specimen dimensions in this study follow the standard sizes of ASTM D638-14 Type1 for tensile testing and ASTM C393 for bending testing. The specimen dimensions are shown in Table 1.

Table 1. *Specimen dimensions*

Standard	Length (mm)	Width (mm)	Thickness (mm)
ASTM D638 t-1	165	19	7
ASTM C393	100	30	7

2.2. Volume Fraction

First, calculate the volume fraction to find out the composition of the matrix and fiber needed to fill the empty space in the mold. To calculate the volume fraction, the parameters that need to be known are the density of the matrix, the density of the fiber, and the volume of the mold, as seen in Table 2.

Table 2. *Material parameters*

Material	Value
Density fiber	0.67 g
Density epoxy	1.2 g
Density hardener	1.1 g

The variations in fiber volume fraction for the tensile and bending test specimens are as follows:

80% Matrix, 20% E-glass
70% Matrix, 30% E-glass
60% Matrix, 40% E-glass

The composite calculation is based on the total volume of the mold. The dimensions of the mold to be used are as follows:

Tensile test specimen mold = 16.5 cm x 1.9 cm x 0.4 cm = 12.54 cm^3

Bending test specimen mold = 10 cm x 3 cm x 0.4 cm = 12.00 cm^3

2.3 Specimen Manufacturing Process

Place the plastic container on the scale and press reset. Then, fill the container with epoxy resin according to the calculated amount and reset the scale again. Also, pour the hardener into the container according to the calculated ratio and stir for 1 minute to ensure the resin and hardener are thoroughly mixed.

Wax coating process on the mold and glass: Prepare the wax and apply it to all sides of the mold and glass to make it easier to release the specimen. Let it sit for a few minutes to allow the wax to dry.

Next, insert Styrofoam into the mold that has been coated with wax, then assemble the outer and inner molds. Place the mold on the surface of the glass.

Insert the fiber according to the calculations on top of the XPS with a fiber orientation of 90°. Then pour the matrix over the fiber and core as calculated and use a torch jet tool to remove any air bubbles trapped in the epoxy resin.

Press the matrix using a glass sheet over the surface that has been torched, then flip the mold and repeat the process as in step 4.

Carefully cover the top part with a glass sheet, then press and leave it to cure for approximately ±16 hours.

Once cured, remove the specimen from the mold. Trim off the excess mold material from the specimen and cut it using a cutter so that testing can be carried out according to the initial design.

The experimental tensile strength can be calculated using the following equation, assuming that the load is distributed equally over the cross section:

$$\sigma = \frac{F}{A_0} \quad \text{or} \quad \left(\frac{N}{\text{mm}^2}\right) \tag{1}$$

Where(F) the load applied in the perpendicular direction, and (A) the initial cross-sectional area before the load is applied. The composite strain can be calculated using the equation:

$$\varepsilon = \frac{\Delta L}{l_0} \times 100\% \tag{2}$$

Where the increase in length is divided by the initial length and multiplied by 100%. Bending strength can use the following equation:

$$\sigma_b = \frac{3PL}{2bd^2} \tag{3}$$

Where (P) is the concentrated load, (L) the span length, (b) the specimen width, and (d) the specimen height.

3. Result and Discussions

In this study, a series of tests were conducted to evaluate the tensile and bending strength of sandwich composite materials consisting of an epoxy resin matrix reinforced with E-glass WR 200 fibers and an extruded polystyrene core. Three samples were prepared for each variation, following the respective testing standards. Tensile testing was carried out according to ASTM D638 Type I, while bending testing followed the ASTM C393 three-point bending standard. These tests were performed to analyze the mechanical properties and to determine the effect of fiber content on the tensile and bending strength.

3.1 Tensile test results

Based on Figure 3, the tensile strength results for specimens with a 20% fiber volume fraction showed an average tensile stress of 100.6 MPa. The maximum tensile stress was 98.5 MPa for both specimen 1 and specimen 2, and 105 MPa for specimen 3. For specimens with a 30% fiber volume fraction, the average tensile stress was 115.3 MPa, with maximum tensile stresses of 129 MPa for specimen 1, 110 MPa for specimen 2, and 107 MPa for specimen 3. This indicates an increase in tensile stress from 20% to the 30% fiber volume fraction. The tensile strength results for specimens with a 40% fiber volume fraction showed an average tensile stress of 130.6 MPa. The maximum tensile stresses were 131 MPa for specimen 1, 130 MPa for specimen 2, and 131 MPa for specimen 3. The 40% fiber volume fraction exhibited higher tensile strength compared to both the 20% and 30% fiber volume fractions.

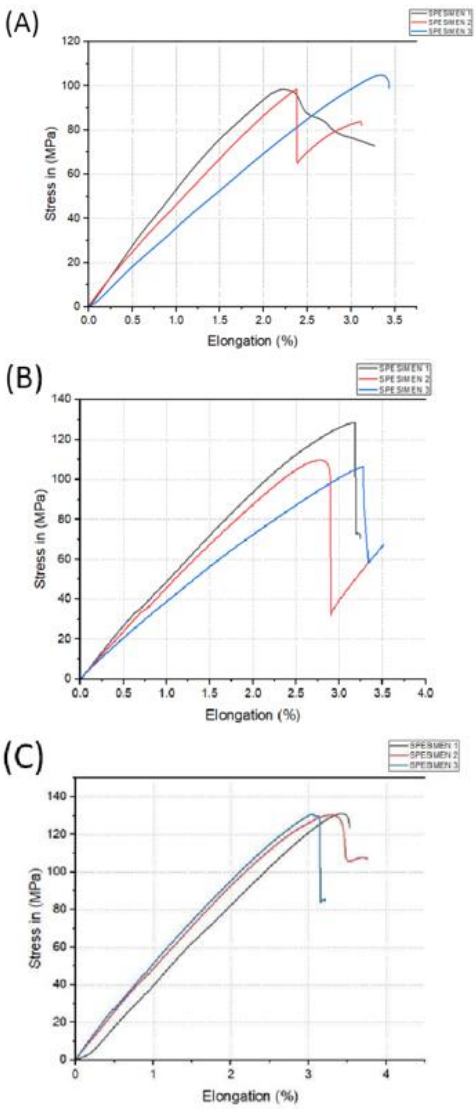

Figure 3. *Tensile test graph (a) Fiber volume fraction 20%; (b) Fiber volume fraction 30%; (c) Fiber volume fraction 40%.*

Table 3. *Tensile test result data*

Volume fraction (%)	Test	σ_m (MPa)	Avg ε_m (%)
	1	98.5	
20%	2	98.5	2.6
	3	105	
	Avg	100.6	
	1	129	
30%	2	110	3.1
	3	107	
	Avg	115.3	
	1	131	
40%	2	130	3.2
	3	131	

Based on the tensile test results shown in Table 3, the highest average tensile strength was 130.6 MPa at a 40% fiber volume fraction, while the lowest was 100.6 MPa at a 20% fiber volume fraction. At a 30% fiber volume fraction, the average tensile strength was 115.3 MPa. There was a continuous increase in tensile stress from the 20%, 30%, to 40% fiber volume fractions. The tensile strength is directly proportional to the increase in fiber volume fraction in the sandwich composite specimens—the higher the fiber content, the greater the tensile strength of the composite. Figure 4 shows the comparison of tensile stress at three variations of fiber volume fraction (20%, 30%, and 40%). Overall, the specimen with 40% volume fraction has the highest tensile stress, followed by the specimen with 30% and 20% volume fraction. Figure 5 shows the condition of the specimen after tensile testing was conducted according to ASTM D638 standard.

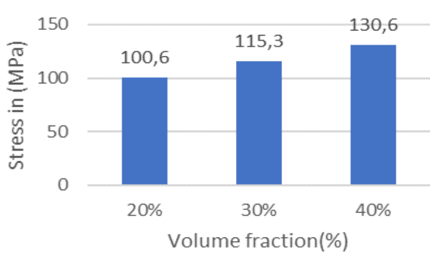

Figure 4. *Tensile stress comparison diagram*

Figure 5. *Specimen after tensile test*

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3.2 Bending test results

Based on Figure 6, the results of the bending strength test for specimens with a 20% fiber volume fraction showed an average maximum bending stress of 31.9 MPa. The maximum bending stress values for each specimen for specimen 1, 29.79 MPa for specimen 2, and 36.08 MPa for specimen 3. There was a notable variation in specimen 3. For specimens with a 30% fiber volume fraction, the average maximum bending stress was 36.4 MPa, with individual values of 34.69 MPa for specimen 1, 39.59 MPa for specimen 2, and 34.93 MPa for specimen 3.

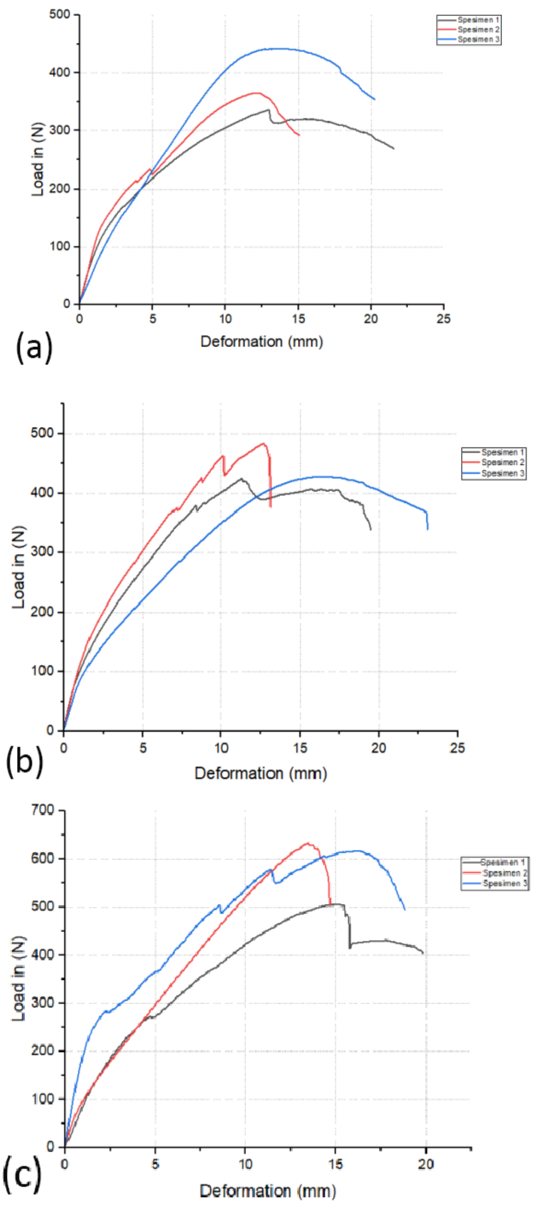

Figure 6. *Bending test graph (a) Fiber volume fraction 20% (b) Fiber volume fraction 30% (c) Fiber volume fraction 40%.*

Meanwhile, specimens with a 40% fiber volume fraction exhibited an average maximum bending stress of 47.80 MPa. The maximum stress values were 41.30 MPa for specimen 1 to 51.67 MPa for specimen 2, and 50.44 MPa for specimen 3. It can be observed that the 40% fiber volume fraction yielded a higher maximum bending stress compared to the 20% and 30% fiber volume fractions. The overall bending test results data can be seen in Table 4.

Table 4. *Material density information*

Volume fraction (%)	Test	Maks Load (N)	Bending stress (MPa)
	1	336	27.42
20%	2	365	29.79
	3	442	36.08
	Avg	381	31.09
	1	425	34.69
30%	2	485	39.59
	3	428	34.93
	Avg	446	36.4
	1	506	41.30
40%	2	633	51.67
	3	618	50.44
	Avg	585	47.80

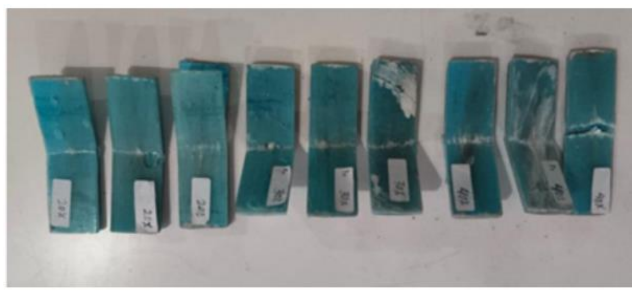

Figure 7. *Bending specimen after testing*

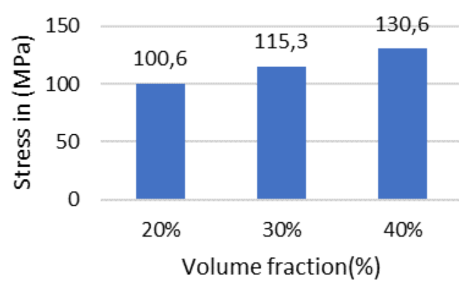

Figure 8. *Bending stress comparison diagram*

Figure 7 and 8 shows that the results of the bending stress for three variations of fiber volume fractions whereas 20%, 30%, and 40%. As the results to 20% fiber volume fraction produced the average bending stress is to 31.09 MPa, which is lower than that of the 30% fiber volume fraction with an average of 36.4 MPa. The highest bending stress was recorded for the 40% fiber volume fraction, with an average of 47.80

MPa, exceeding the values of both the 20% and 30% fractions for bending stress increases proportionally with the rise in fiber volume fraction, as demonstrated by the diagram, which shows a continuous increase from 20% to 30% and up to 40%. The greater the fiber volume fraction, the higher the resulting bending strength.

4. Conclusion

Based on the analysis and calculations of the data obtained from the tensile tests, it can be concluded that the tensile strength of the epoxy matrix sandwich composite reinforced with 200 woven roving E-glass and an extruded polystyrene Styrofoam core reached its highest strength at a 40% fiber volume fraction, with an average value of 131 MPa. A continuous increase in tensile strength was observed with increasing fiber volume fractions of 20%, 30%, and 40%. Meanwhile, the highest bending strength was also achieved at the 40% fiber volume fraction, with a value of 47.80 MPa and an average maximum load of 585 N. The bending strength of the sandwich composite increased progressively at fiber volume fractions of 20%, 30%, and 40%, with respective values of 31.09 MPa, 36.4 MPa, and 47.80 MPa.

The results of the tensile and bending tests indicate that the amount of E-glass fiber in the epoxy matrix significantly affects both tensile and bending strength. This is due to the uniform stress distribution along the reinforcing fibers, which allows a greater number of fibers to withstand higher loads. The highest tensile and bending strengths were observed at the 40% fiber volume fraction. However, with the increase in fiber content, the resulting stiffness also increases. This was evidenced in the bending test, where the 40% fiber volume specimen exhibited a more brittle and separated fracture compared to the 20% and 30% fiber volume specimens.

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