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Research article

Manufacture of a flying robot propeller made from plant-based composite material derived from snake plant (Sansevieria trifasciata) fibers

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ABSTRACT

The development of flying robot technology, or Unmanned Aerial Vehicles (UAVs), requires innovations in lightweight, strong, environmentally friendly materials. This study aims to design and manufacture flying robot propellers using composite materials with an epoxy resin matrix reinforced with natural fibers from snake plants (Sansevieria trifasciata). Sansevieria trifasciata fibers were chosen for their potential as an alternative material with good specific strength, abundant availability, and light weight. The propeller was manufactured using the hand-lay-up method, followed by mechanical testing to characterize the composite material, including tensile and impact tests. In addition, functional testing was conducted to assess the propeller's thrust-generating performance. The results of the study show that Sansevieria trifasciata fiber composites exhibit sufficient mechanical properties to serve as propeller materials for small-scale UAVs. The thrust performance produced is comparable to that of similar commercial propellers, indicating that natural fibers can replace conventional synthetic fiber-based materials and support more sustainable technological advances.

1. INTRODUCTION

Rapid developments in Unmanned Aerial Vehicle (UAV) or flying robot technology have driven change across many fields, such as agricultural mapping, civil surveillance, and logistics [6]. A UAV's propulsion system is central to its aerodynamic performance, with propellers responsible for generating lift and thrust [1]. Propellers are usually made of synthetic polymers reinforced with carbon or glass fibers. These materials are chosen for their exceptional strength-to-weight ratio, exceptional rigidity, and fatigue resistance [2]. However, as environmental awareness grows worldwide, the dependence on these fossil-based materials is being questioned [3]. The production of synthetic fibers requires substantial energy and generates significant carbon emissions [12]. In addition, their non-biodegradable nature causes significant waste problems when they are discarded. Because of these issues, scientists around the world are seeking more sustainable, environmentally friendly alternative materials that do not significantly compromise performance [4]. The development of biocomposite materials, which are hybrids combining polymer matrices from renewable and synthetic sources with natural fibers as reinforcing phases, has

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excellent prospects. Natural fibers are excellent substitutes for synthetic fibers because they have low density, are readily available, have lower production costs, and are biodegradable [4], [5].
The snake plant (Sansevieria trifasciata), one of thousands of plant species, has emerged as a highly promising source of natural fiber for technological applications [7]. This plant is easy to cultivate in various climatic conditions, and the fiber extracted from its leaves has remarkable mechanical properties. Sansevieria trifasciata fiber has promising tensile strength, stiffness, and thermal stability, according to several studies. These results warrant consideration as a composite reinforcement material [8]. Compared to pure epoxy, snake plant fibers significantly improve all mechanical properties (tensile, flexural, and impact). This demonstrates the fibers' function as a good reinforcing agent [14], [15].

As a result, this study focuses on the design, manufacture, and testing of flying-robot propellers made from innovative biocomposite materials. Mother-in-law's tongue plant fibers (Sansevieria trifasciata) are used as a reinforcing phase in an epoxy resin matrix [9], [10]. The main objective of this study is to evaluate the performance and technical feasibility of these biocomposite propellers. In addition, they will compare its characteristics with those of conventional propellers [11]. It is hoped that this research will make significant progress in the development of sustainable aerospace materials and enable the use of local natural fibers in modern technology.

2. METHOD

This study uses a direct experimental methodology. A hybrid composite method was used for fabrication. An existing wooden propeller served as the structural basis to maintain aerodynamic properties. Extracted Sansevieria trifasciata fibers were then woven into a structural shell, wrapped around the core, and thoroughly impregnated with epoxy resin. Pressure wrapping was used as a low-cost alternative to vacuum bagging. This minimized air voids and achieved an ideal fiber-to-resin ratio. During the drying process, the entire resin-impregnated assembly is tightly wrapped with adhesive tape. This method improves the mechanical properties of the final propeller by ensuring a dense composite structure.
To evaluate the propeller's initial performance, a thrust test was conducted in the workshop, and a tensile test was performed using hanging scales. Tensile and compression tests were also conducted at the Metallurgy Laboratory in the Faculty of Engineering at Andalas University to determine the mechanical characteristics of the propeller material. The purpose of these tests was to collect data on the strength and performance of the propeller material. This performance includes maximum thrust, resistance to compressive and tensile loads, and deformation behavior under real loading conditions. (If available, a flow chart will provide an overview of the experimental process.

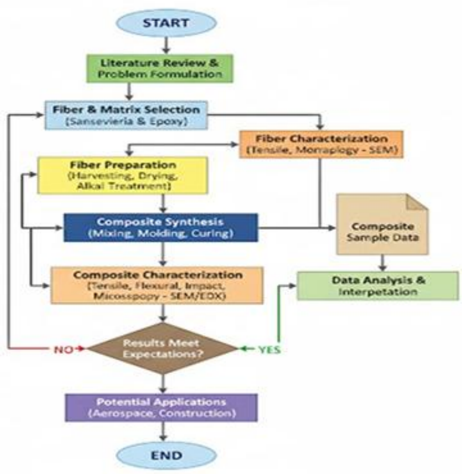


Figure 1. Flowchart of the Natural Fiber Composite Research & Development Process

2.1. Fiber Tensile Test Using Hanging Scales

To test the strength of the mother-in-law's tongue fiber, several tests were conducted, including hanging weights using a hanging scale that measures load-bearing capacity in kilograms. Mother-in-law's tongue fiber was tested without the use of other mixed materials, such as epoxy or other substances. We can see the results in the table below.

Table 1 below summarizes the test results from various studies.

Fiber Fraction (% by Volume)	Fiber Treatment	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact strength (kJ/m²)	Source (Researcher)
0% (Pure Epoxy)	-	35.8	60.1	4.8	Athijayamani et al. (2009)
10%	Not Treated	40.2	72.3	6.5	Athijayamani et al. (2009)
20%	Not Treated	46.5	85.6	8.9	Athijayamani et al. (2009)
20%	Alkali Treatment	55.1	98.4	11.2	Athijayamani et al. (2009)
30%	Alkali Treatment	48.7	90.2	9.8	Athijayamani et al. (2009)
20% (Length 20 mm)	Alkali Treatment	56.4	-	13.5	Sreekala et al. (2012)
20% (Length 30 mm)	Alkali Treatment	50.1	-	12.1	Sreekala et al. (2012)

Table 2. Tensile Test Results for Hanging Scales

Number of Fiber Strands (strands)	Load Bearing Ability(kg)
5	0,72
10	1,04
15	1,44
20	2,76
25	3,48

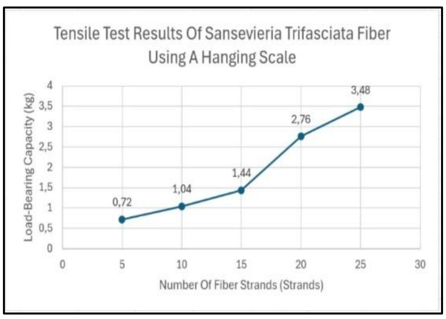


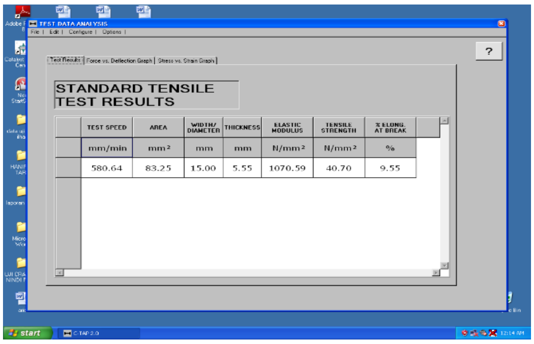
Figure 2. Tensile Test Graph of Hanging Scales

The table above shows the correlation between the number of Sansevieria trifasciata fiber strands and the maximum load-bearing capacity of the sample. The test results show that a greater number of fiber strands used is proportional to the fiber's capacity to withstand higher loads. With 5 strands of fiber, the maximum load that can be supported is 0.72 kg, while with 25 strands of fiber, the maximum load increases to 3.48 kg. This increase indicates that the overall tensile strength improves with increasing effective cross-sectional area, due to the addition of more fiber strands. However, this increase in load capacity is not entirely linear. This may be due to variations in fiber diameter, uneven tensile force distribution, and the inconsistent structure of natural Mother-in-Law's tongue (Sansevieria trifasciata) fibers. Overall, this study shows that Sansevieria trifasciata fibers have a strong capacity as natural reinforcements in biocomposite materials, as the load-bearing capacity of the fibers increases with the number of fibers.

2.2. Tensile Testing at the Andalas University Materials Laboratory using ASTM D3039 Standard

In addition to tensile testing using weights on hanging scales, tensile testing was also conducted using a metallurgical laboratory scale in the mechanical engineering department at Andalas University using a tensile testing device on a universal testing machine. The results can be read via a computer. For more details, please refer to Table 3 below.

Table 3 shows the tensile test results obtained using a universal testing machine.



TEST DATA ANALYSIS

File | Edit | Configure | Options |

Test Results | Force vs. Deflection Graph | Stress vs. Strain Graph

STANDARD TENSILE TEST RESULTS

TEST SPEED	AREA	WIDTH/ DIAMETER	THICKNESS	ELASTIC MODULUS	TENSILE STRENGTH	% ELONG. AT BREAK
mm/min	mm²	mm	mm	N/mm²	N/mm²	%
580.64	83.25	15.00	5.55	1070.59	40.70	9.55

Based on this table, the tested biocomposite material exhibits the following characteristics:

● Moderate stiffness (E = 1070 MPa)

● Good tensile strength (σ_max = 40.70 N/mm²)

● Slightly elastic (ε = 9.55%)

a) Elastic Region

The linear relationship on the graph at the beginning of the curve (epsilon < 0.02) indicates that the material follows Hooke's Law. In this region, damage can still be repaired. The slope of the region indicates moderate stiffness, as indicated by the elastic modulus (E approximately 1070 MPa).

b) Plastic Region

After the elastic limit is exceeded, the curve begins to bend upward. This indicates that permanent deformation has begun — the polymer matrix softens, and the natural fibers bear the main load.

c) Maximum Point

With a sigma point of 40.70 N/mm2 and an epsilon of 0.095, the material has its highest tensile strength. At this point, the stress begins to decrease as the fibers or the bonds between the fibers and the matrix begin to fail.

d) General Characteristics

According to the non-linear curve, these biocomposites are not brittle but rather tough, as they can deform before breaking. This material is suitable for light structural applications due to its combination of moderate strength and moderate strain. However, due to its relatively low stiffness (E < 2 GPa), it is not suitable for high-speed components such as aircraft propellers.

2.3. Compression Test Using ASTM D6641 Specimens

In addition to tensile testing, epoxy-coated mother-in-law's tongue fiber material was also tested using the ASTM D6641 compression test. ASTM D6641 is a standard test method for measuring the compressive strength and elastic modulus of polymer matrix composite materials under combined loading (CLC). This test uses specially prepared specimens to ensure that failure does not result from buckling or grip failure.

Figure 3. The needle indicates the Universal Testing Machine's compression testing capability.

For maximum strength against compressive force before

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failure, with load = 3 tons and Pmax (maximum load) = 1500 x 5 = 7500 kgf. According to the data collected, a maximum load of 7,500 kgf caused the material to break.

- Maximum Load: 7,500 kgf.
- Conversion to Newton: F = 7,500 × 9.81 = 73,575 N.
- With a cross-sectional area of 4,000 mm²

Ultimate compressive strength (sigma ult): The maximum compressive stress that can be withstood before failure is 18.39 MPa (F = 73,575 A = 4000mm2).

Ultimate compressive strength (σ_ult): maximum compressive stress that can be withstood before fracture, calculated as:
σ_ult=F/A=73,575÷4000=18.39 Pa

3. RESULTS AND DISCUSSION

From testing the mother-in-law tongue and epoxy mixture, tensile and compression tests were conducted, including hanging tests with scales. Based on the mechanical engineering metallurgy laboratory test results, a propeller prototype will be manufactured for thrust testing.

3.1. Propeller Design for testing fiber and epoxy materials

To test the mother-in-law fiber and epoxy materials, a sample from an existing drone propeller was used, and the design was duplicated in wood to make a mold for the mother-in-law tongue-and-epoxy composite propeller.

a b c

Figure 4. (a) Wooden propeller to be modeled; (b) talcum propeller mold; (c) Molded propeller

The molded propeller is then refined, and its specific data is determined. It is balanced so that it does not vibrate when the engine is running.

Figure 5. Finished propeller made from mother-in-law's tongue fiber.

The finished propeller was measured to obtain its specifications in accordance with the commonly used drone propeller standards.

The propeller specifications obtained are:
Length = 9.13386 in
Width = 1.1811 in
Pitch = 4 in
Weight = 28 g

3.2. Thrust Test of Father-in-law Tongue Fiber and Epoxy Propeller

To test the thrust of propellers made from mother-in-law's tongue fiber and epoxy, a testing machine was used: a 2-stroke methanol-oil mixture-fueled, spark-ignition engine. This testing machine for mother-in-law's tongue fiber and epoxy propellers used an LA 40 OS methanol engine with a capacity of 0.40 cubic inches.

Figure 6. LA 40 methanol machine.

So, if we convert the LA40 OS engine to cubic centimeters (cc), the capacity of the methanol engine “40” is measured in cubic inches. To convert it to cc (cubic centimeters), you have to multiply that number by a conversion factor of 16.387.

So it can be calculated as 0.40 x {cubic inches} 16.387 = 6.5548 cc.

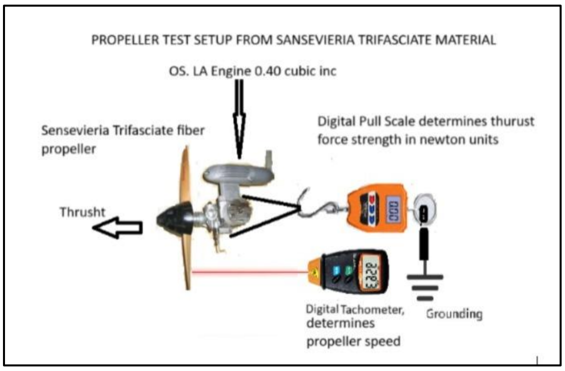

Figure 7. Propeller test rig with LA 40 OS engine.

a) Propeller Test Description

- LA 40 OS engine on rails that can move forward and backward.
- Hanging scales attached to the rear of the engine.
- Tachometer measures propeller speed.

b) Thrust Test

Thrust is required to propel the aircraft forward and overcome air resistance (drag). Thrust is the force that acts forward due to the airflow accelerated by the propeller blades. From this propeller test, two sets of data can be obtained: thrust force and propeller speed (revolutions per minute, RPM). This is shown in Figure 8.

Figure 8. Test results are read directly with a measuring device.

Based on the thrust test, the following results were obtained simultaneously:
Simultaneously, read the rotation speed: 2,957.1 rpm.
Simultaneously read thrust = 13.3 N
With the following conditions:
1 N = 0.102 kgf
Maximum rotation speed not read simultaneously = 7,768.7 rpm

$$\text{Thrust} = \frac{F_1}{RPM^{2}{}_1} = \frac{F_2}{RPM^{2}{}_2} \quad (1)$$

Figure 9. Maximum engine RPM with a propeller blade.

Where F_1 and RPM1 are the initial thrust forces, and F_2 and RPM2 are the final thrust forces to determine the thrust force in Newtons, if the propeller speed is 7768.7 RPM. If F_1 = 13.3 N, the propeller speed is 2957.1 RPM_1, and F_2 is asked to be how many N? The propeller speed is 7768.7 RPM_2.

Can be calculated:

$$F_2 = 13{,}3x \frac{(7768.7)^2}{(2957.1)^2}$$

$$F2 = 13{,}3 \text{ x } \frac{60352693.69}{8744204.41}$$

F2=13.3x6.8996

F=91.76 N

Which has been tested using a propeller made from mother-in-law's tongue plant material, so the total maximum thrust is 91,76 N x 0,102 kgf = 9,35952 kgf. The thrust results from the experiment.

4. CONCLUSION

This study demonstrates that Sansevieria trifasciata (snake plant) fibers as reinforcement in biocomposites have significant potential for developing environmentally friendly propellers for hybrid propulsion systems in aerospace applications. Mechanical tests show that this biocomposite material possesses a tensile strength of 40.7 N/mm², an elastic modulus of 1070.59 N/mm², and sufficient toughness for lightweight structural applications. Compression tests with a maximum load of 7,500 kgf and thrust tests producing 91.76 N further confirm the material's

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feasibility for use in non-structural aircraft components, particularly lightweight propeller parts.

The combination of hybrid propulsion technology and natural biocomposite materials can reduce the overall aircraft weight, improve fuel efficiency, and lower carbon emissions. Thus, this approach aligns with the principles of green aviation and supports the transition toward a sustainable aerospace industry.

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