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Review

The Development of UAV Airframes Made of Natural Fibers: A Review

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Abstract: Natural fibers have been widely used as a reinforcing material for the construction of drones. The main goal of this review is to identify a biodegradable natural fiber material that can be built for Unmanned Aerial Vehicles (UAVs). The review shows that natural fibers such as kenaf and PALF can be used as an alternative composite material, particularly for multifunctional applications where their smaller weight and less expensive characteristics make them incredibly realistic. This review also discusses the mechanical properties, advantages and disadvantages, and fabrication of the composites.

Keywords: UAV; synthetic fibers; biocomposites; airframe; natural fibers; drones

1. Introduction

A UAV is a man-made machine or robot that has been widely used in military and civilian applications since the 20th century [1–4]. This vehicle has been named one of the futuristic technologies to help humans complete tasks efficiently. A drone can be categorized into mission, vehicle type, structures, a control system, and a propulsion system [5–10]. Multi-bolted connections [11–13] are most commonly used to connect the drone's components. One of the most important categories is the structure of the drones. The drone structure will support and lift the entire drone system in the air. So this structure should have enough strength to withstand the drone's weight and thrust, as is also the case with parts of other machines [14,15].

These structures are made of strong carbon fiber but are not environmentally friendly. The main problem with Carbon fiber is that it might fall and break when the drone experience accident. Those broken carbon fiber parts might fall into land, river, or sea. These items will never biodegrade and might harm animals or fish. However, the drone structure, its components can be made by using natural composite materials [16]. One of such natural composite materials, which can be used for making a drone frame kit, is a natural fiber. However, these components can be replaced by using a natural fiber drone frame kit. Natural fiber has many benefits compared to carbon fiber. Some of the benefits are biodegradability, renewability, and higher cost-effectiveness. Many natural fibers, like

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Kenaf and Pineapple Leaf Fibers (PALF), are available in Malaysia. The main goal of this review is to identify a biodegradable natural fiber material that can be built for drones.

2. Drone Frame Kit Material

The drone frame kits have evolved day by day. The structures to make the drone have been changing from Aluminium to Plastic, and then to Carbon fiber. Several research was done to get the best frame kit. Each of these frames has its advantages and disadvantages. The 2.1 part will clearly explain these materials.

2.1. Drone Frame Kit Materials

The purposes of drones also have beenexpanding in all industries, but one of the significant issues with the current drones is the material used to build the drone. Drones were constructed by using carbon fiber material which is a synthetic fiber. Researchers at Louisiana Tech University in the US are creating new drone technologies that could extend the durability, flying time, and cargo capacity of unmanned aerial vehicles (UAVs). The drone is an autonomous UAV that can be customized. It has a lightweight carbon fiber center plate and aluminum elements integrated into the frame design to maintain the platform during flight and stay sturdy [17].

The drone's frame kits also can be printed from 3D print machines [18]. The drone could be printed with carbon fiber-reinforced plastic filaments. The researcher from Ajou University made the ultrasonic fatigue analysis on a 3D-printed carbon fiber-reinforced plastic drone frame kit. This shows that the material of the drone can be 3D printed from carbon fiber filaments [19].

Research from Padang, Perdana et al. analyzed the alternative way to build a drone frame from Composite Waste Material Based Styrofoam, Bagasse, and Eggshell Powder. Styrofoam waste materials will be collected with chemicals like a Dioctyl Phthalate (DPO) stabilizer and acetone solution, making the material rigid. This material was tested with a flexural test to determine its suitability as a droneframe kit. The Bagasse and eggshell will react with the Styrofoam to make it more rigid. Then the material was oven dried and cut into a rectangle shape to be used forthe experiment. The percentage of the Bagasse and eggshell powder was varied in the research to find the best material composition with good mechanical strength. The result shows that the proposed composite material's highest bending strength and impact toughness were 11.01 MPa and 0.75 J/mm^2, respectively. The research concluded that drone frames could be made from composites comprised of waste materials like eggshell, bagasse, and stryrofoam [20].

Besides carbon fibers, glass fibers composites andAluminium drone frames are also commonly found in the market. Small and medium-sized UAVs are more frequently built with glass fiber composites. Composite materials are less heavy than metal components. The rigidity of the UAV kit will increase since glass fibers are employed as reinforcements. Glass fiber composites have high durability and will not break when struck or unintentionally dropped during drone flight operations. Glass fiber composites also have good processing capabilities. They can be processed into any shape due to their flexibility. Aluminum alloys are among the metal resources that fit the criteria for being lightweight and cost-effective. However, the significant issues with aluminum alloys are that they have low specific strength and are prone to bending deformation when exposed to external forces, which would cause balance instability during flight [21].

A drone's frame gives it shape and secures all of the subsystems. The most important material quality for the frame is strength because it performs a mechanical function. There was one research that used thermoplastic material to build the drone frame kit. Thermoplastics, such as nylon, polyester, and polystyrene, are common options for commercial drones because they are inexpensive to produce into intricate parts using injection moulding techniques [22–25]. Additionally, thermoplastics are strong and lightweight, with some variations having tensile strengths above 100 MPa and densities below 2 g/cm^3. Table 1 shows the summarized comparison of different drone frame kit development materials.

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Table 1. Comparison of the materials of the drone frame kit.

Composite Materials	Advantages	Disadvantages	Density (kg/m^3)	Tensile strength (MPa)	References
Carbon Fiber	High Tensile strength	Not Biodegradable	1171.5	3530	[18]
Aluminum	High Tensile strength	Not Biodegradable	2660	275	[18]
3D printed carbon fiber reinforced plastic	High Tensile strength	Not Biodegradable	1880	3799	[19]
Eggshell powder + Styrofoam	Biodegradable	Low Tensile strength	-	75	[20]
Fiberglass	High Tensile strength	Not Biodegradable	2.56	3445	[21]
Aluminum	High Tensile strength	Not Biodegradable	2660	275	[21]
Thermoplastic	Low	Not Biodegradable	2000	More than 100	[26]

The most significant gap in research that has been analysed is the biodegradability of the materials used to build the drone frame. These synthetic fiber materials are less environmentally friendly than natural fiber composites. Table 1 shows that the average tensile strength of materials used to develop the drone frame are around 1643 MPa.

2.2. Natural Fibers as Replacement for Synthetic Fibers

As the year passes, more people are motivated to find replacements for synthetic fibers and plastics. Although both materials are strong, they are not environmentally friendly. Researchers started to study the natural fibers that can be extracted from plant waste.For example, pineapple leaf wastes where the material will be burnt after harvesting pineapples. This method of disposal would cause problems such as water and air pollution. Therefore, researchers started to find a more environmentally friendly solution for waste management, where the wastes are collected and converted into valuable fibers to reinforce composites instead of being disposed of.

Extensive research is conducted on natural fibers to find their usefulness as a reinforcing material. New natural fibers and their properties are introduced yearly in the composites field. This is due to the unique properties of natural fibers, such as biodegradability, renewability, low density, and much more [27]. Table 2 compares the common natural fibers used in composites based on physical, chemical, and mechanical properties.

Table 2. Properties of natural fibers [27].

Fibers	Physical Properties			Chemical Properties			Mechanical Properties		
	Density [gm/cm3]	Diameter [um]	Length [mm]	Cellulose [wt.%]	Hemicellulose [wt.%]	Lignin [wt.%]	Tensile Strength [MPa]	Young's modulus [GPa]	Elongation [%]
Flax	1.4-1.5	40-600	5-900	70-75.2	8.6-20.6	2.2-5	345-900	27-80	1.2-1.6
Kenaf	1.2-1.45	12-37	4-110	45 - 57	21.5	8-13	295-930	53	1.6-6.9
Hemp	1.4-1.48	10-500	5-55	70-75.1	2-22.4	3.5-8	300-800	30-70	1.6
Jute	1.3-1.5	25-200	1.5 120	61-75.5	13.6-20.4	5-13	200-800	10-55	1.8
Sisal	1.2-1.5	8-200	900	47.6-78	10-17.8	8-14	100-800	9.4-28	2-3
Abaca	1.1-1.5	132-266	900	56-63.7	17.5	15.1	705-1041	9.8-14.8	3-12
Coir	1.1-1.46	10-460	20-150	32-43	<1	40-45	13-220	4-6	15-40

Pickering et al. also mentioned the difference between bast and leaf fibers. Bast fibers are plants with natural reinforcement to the stem, contributing to their higher tensile strength than leaf fibers. Examples of bast fibers are Kenaf, Flax, Hemp, Jute, and many more. Leaf Fibers are fibers that have high elongation percentage. High elongation percentage will give high material toughness. Examples of leaf fibers are Pineapple Leaf Fibers (PALF) and Abaca.

There was also research conducted on the characterization of natural fibers surfaces and natural fibers composites by Sgriccia et al. The main objective of this research was to study thedifferent types of natural fibers as a composite re to replace glass fiber composites. The result of the study was that the process of making natural fibers saves more energy than the process of making glass fibers. The research also showed that the Kenaf stalk contains more bast fibers (40%) than the hemp stalk (25%), which signifies higher tensile strength [28].

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Elanchezhian et al. (2016) also reviewed the mechanical properties of natural fibers where natural fiber composites like Abaca, jute, and sisal are used in many engineering applications because of their superior properties such as specificstrength, low weight, low cost, reasonably good mechanical properties, nonabrasive, eco-friendly and biodegradable characteristic. It was reported that Abaca has good mechanical properties in terms of its specific strength. Jute was reported to have the best flexural property among these materials, while Cisel showed the best hardness property. The research conducted shows that natural fibers generally have good mechanical properties to be used in engineering applications. Based on this research, it is possible to make drones using natural fibers [29].

Zhao et al. researched for an alternative material to replace plastic to reduce plastic pollution. Their research focuses on replacing plastics with natural fibers in the construction industry. The review reported that the production of plastics had been rapidly increasing annually. Three hundred million plastic waste was generated in 2015. Almost half of the waste was due to the construction industry. In the construction industry, the heat insulation material is made of used plastic. It was reported that the research aims to replace the heat insulation material with natural fiber. They concluded that natural fibers are sustainable and have excellent thermal performance. Therefore, natural fibers can also be used to manufacture drone frames that can withstand high temperatures. This feature would ensure that the equipment in the control panel would not overheat [30].

Some research uses natural fibers in other industries such as chemical, civil, mechanical, and many more. However, in the aerospace industry, natural fibers are rarelyused due to the high requirement of mechanical properties. However, as advanced natural composites' material mechanical properties have improved in recent years, the aerospace industry has also started to dabble with natural fiber composites—for example, drone frames made from natural fibers, propellers, and many more. Table 3 shows the summarized applications that have used natural fibers in their manufacturing stage.

Table 3. Natural fibers applications in other industries.

Natural Fibers	Industries	Applications	References
Flax, Sisal, Coir, Jute, Hemp, Kenaf	Automotive	Parcel shelves, door panels, instrument panels, armrests, headrests, and seat shells	[31]
Flax, Bamboo, Kenaf, Kenaf, Hemp	Furniture	Chair, Tables, Bags	[32]
Sisal, Jute PALF	Construction	Natural Fiber Cement, I-beam	[33]
Flax, Kenaf, Hemp, Banana	Sports	Tennis Racquet, Bicycle frame, Skateboard	[34]
Jute, Cotton, Flax, PALF	Fabric	Clothes, Thread, Bags	[35]

Previously, drone frame kits were usually made of plastic and carbon fibers. Plastic was cheaper but had low strength. Meanwhile, carbon fibers have high strength, high durability, and structural efficiency (strength-to-weight ratio) but are much more expensive. These carbon fibers and plastics have been widely used in aerospace, automotive, marine, and civil industries. Drones made from carbon fibers are lightweight, which helps the drone to have a longer flying duration.

Unlike synthetic fibers, natural fibers are cheaper, renewable, biodegradable, corrosion resistive, abundant, and non-toxic. Natural fibers are reinforcement materials environmentally superior because:

1. The production of natural fiber will have lower environmental impacts compared to other synthetic materials
2. Natural fibers have low carbon footprints where the carbon it produces when decomposing will be very low
3. Easy to handle due to its non-toxic property. There was no need to wear masks, gloves, or protective clothes while extracting the fibers

Focusing on natural fibers composites that are economical and environmentally benign is urgently required. One environmentally beneficial material that has drawn researchers worldwide is sugarcane bagasse (SCB). From the chemical composition of SCB, its main components include cellulose, hemicellulose, lignin, ash, and wax. This research investigates the viability of using

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sugarcane bagasse fiber-reinforced composites for manufacturing drone frames. This research focuses more on enhancing material strength rather than drone frame-making. It was reported that the weight of the fiber dropped by 43% after alkali treatment, principally due to the removal of cellulose and hemicellulose from the fiber. According to the investigation results, specimens made entirely of epoxy have superior qualities to those made with sugarcane bagasse fiber. Also, it was observed that the tensile and flexural strength of samples with 1, 2, and 3 weight percentage of fiber shows a declining trend, and those with 4% of fiber weight show an increasing trend. The gaps created by air particles or bubbles during casting and fiber aggregation may be responsible for the specimens with bagasse fiber composites with inferior characteristics [36].

Based on previous research, sugarcane bagasse has also been used in droneframe-making. However, based on the mechanical properties, PALF and kenaf were identified as the most robust material among natural fibers. The mechanical properties of these two materials are shown in Table 4. Both of these natural fibers have high mechanical properties. PALF and kenaf can also be procured easily, making developing the drone frame kit easier.

Table 4. Tensile strength comparison of PALF, Moris Gajah, Josapine, and Sarawak PALF.

type of PALF	tensile strength/MPa
Yankee	400
Moris Gajah	175
Josapine	275
Sarawak	145

2.3. Pineapple Leaf Fibers (PALF) composites

Pineapple leaf fiber was chosen to reinforce the composite made for the drone frame kit. The main reason for this is its abundant supply. The part below will explain the current research done on the PALF.

Najeeb et al. investigate properties of the new Malaysian pineapple variety, namely, Yankee pineapple's leaf fibers (PALF) bio-fillers in composite applications. There were a few steps done starting from the extraction of the PALF, composition analysis, scanning electron microscopy (SEM)/energy-disperse X-ray (EDX), Attenuated total reflection (ATR), X-ray diffraction (XRD), Thermogravimetric analysis (TGA), Atomic force microscope (AFM) till the Single fibers test. Yankee's PALF has a much higher tensile strength than Moris Gajah, Josapine, and Sarawak's PALF. Moreover, the surface roughness in three dimensions shows that pineapple fibers have a rough surface, making them suitable for fiber reinforcement in a composite matrix to improve interlocking bonding [37].

Moreover, Najeeb et al. (2019) also analyzed Malaysian Yankee pineapple leaf fibers/epoxy composite. The processed PALF material will be arranged in X horizontally and Y vertically. When the fiber was mixed with epoxy, a composite produced from fibers in the Y-direction improved maximum stressby 93.7 percent. This demonstrates that PALF aids in the more effective transfer of load in the Y-axis throughout the composite, contributing to the composite's overall strength. The vertically cut Y PALF should be used to build the drone frame kit [38].

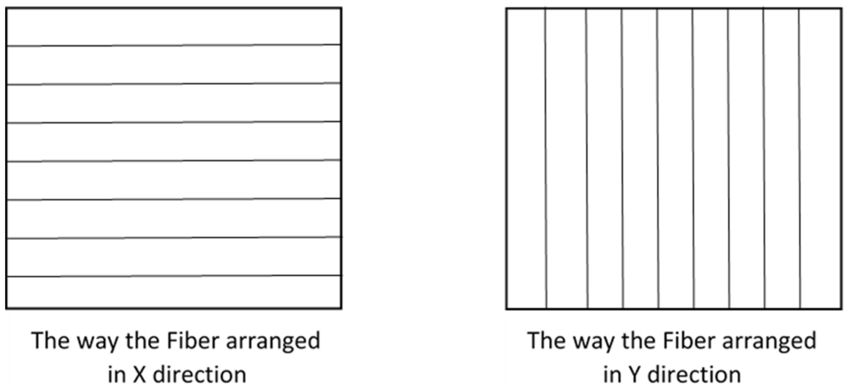

Figure 1. Fiber arrangement in PALF composites.

PALF has been researched in many ways, making it easier for people to understand its behavior and characteristics. This makes it to be used as the frame kit. After the fibers are extracted from the machine, the fibers will be processed into a composite board. From that board frame kit could be built. The essential parameters for the PALF have been identified from several kinds of research, as shown in Table 5.

Table 5. Mechanical Properties of PALF.

Density (g/cm^3)	Young's Modulus (GPa)	Tensile Strength(MPa)	Flexural Strength (MPa)	Elongation at break (%)	Ref.
1.07	127	6.51	21	-	[39]
1.53	5.83	290.61	-	3	[40]
1.44	34.5	413	-	1.6	[41]

2.4. Kenaf Fiber Composites

Kenaf has been chosen to be reviewed as it is also one of the most popular natural fibers worldwide. This material is very lightweight compared to other natural fibers. Kenaf has been widely used now for material replacements in all industries. Al-Ghazali Noor Abbas et al. researched Kenaf fibers suitable for building industries. The Kenaf has been processed to make it into a cement-type material. Kenaf is a cost-effective and environmentally friendly alternative to traditional fibers that can be utilized to improve the mechanical properties and durability of cementitious composites [42].

Kenaf fibers have been used in a polymer composite that can be used in many fields. The material was also materialized into a 3D print filament, where we can 3D print the complex design that cannot be obtained using thehand layout method [43]. The essential parameters for the Kenaf fibers had been identified from all past research, as shown in Table 6.

Table 6. Mechanical properties of Kenaf material.

Density (g/cm^3)	Young's Modulus (GPa)	Tensile Strength(MPa)	Specific strength (kNm/kg)	Elongation at break (%)	Ref
1.22	51.98	504.78	413.1	-	[44]
1.4	4.30	250	-	-	[45]
1.45	53	933	-	1.6	[46]

Like PALF, Kenaf gives different values of mechanical properties due to different extraction methods. Kenaf fibers have received massive attention as a replacement for glass fibers composite and have largely replaced it as an eco-friendly composite over the past few years. This makes it a desirable option. However, a comprehensive characterization is crucial for improving its features in various applications. As a result,numerous studies have been carried out in recent years on the characteristics of Kenaf fiberand its composites [47].

Besides that, M Noraini et al. (2019) analyzed a material using a statisticaltechnique to determine the relationship between the physical andmechanical properties of the natural plant. A type of plant fiber's variety wouldshow a wide range of material characteristics. When the critical factors arerecognized sooner, the prediction of material characterization is optimized. The measurements of physical and mechanical parameters from experimental work, suchas flexural strength and flexural modulus of the composites, are used to calculate thePearson correlation coefficient. A Pearson correlation ruler determined the degree of correlation between the variables. A strong negative relationship and a strong positive relationship have a correlation level between them [48].

Apart from that, there needs to be more research on the structural analysis of products using Kenaf fiber composites. This was because other research discusses experimenting on the composite samples more than studying the product itself. The structural analysis could be done by designing the frame kit where the parameters of Kenaf can be the input data.

2.5. Advantages and Disadvantages of Natural Fiber and Synthetic Fiber

Synthetic fibers like carbon fibers and glass fibers have always been much more robust than natural fibers. The working principle of any mechanical material does not need greater strength. If the force applied is more, the synthetic fibers can be used without hesitation. Natural fibers can be used when the payload is low, and the force applied to the material is small. The main reason is the ability to biodegrade and having unlimited resources. Table 7 shows the advantages and disadvantages of using natural fibers in composites, and Table 8 compares natural fibers and synthetic fibers.

Table 7. Advantages and disadvantages of natural fibers [29].

ADVANTAGES	DISADVANTAGES
Natural fibers have low carbon footprints where the carbon it produces when decompose will be significantly less	The process of making the material will be much higher but still cheaper compared to synthetic fibers
Having bio-degradable properties	It is not water-proof as natural fibers can absorb water
Easy to obtain as it can be planted	Not widely available as the market is still very low
Easy to handle as it is not chemical, there was no need to wear masks, gloves and clothes while obtaining the fibers	Susceptible to insects attacks, fungal growths

Table 8. Comparison of Natural fibers with Synthetic fibers [49].

Aspects/ Properties	Natural fibers	Synthetic fibers
Price	Low	High
Weight	Low	High
Energy Consumption	Low	High
Tensile strength	Moderate	High
Mechanical Properties	Moderate	High
Moisture Sensitivity	High	Low
Resource	Unlimited	Limited
Production	Low	High
Recycle-ability	Yes	No

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2.6. Fabrication of the Natural Fiber Composite Materials

Some fabrication research hasbeen done to understand the proper way of fabricating natural fiber composites. There are many ways to fabricate natural fibers. One of the ways is the resin transfer molding process, also known as resin infusion molding. Both times, the resin is heated before being placed into the mold. The fibers are positioned and cured until the final composite structure is formed. In order to prevent voids from forming owing to air bubbles in the system and to aid in the movement of resin infusion into the mold cavity, the system must be connected to a vacuum system. A flexible membrane replaces a double mold with one face for resin infusion.This membrane is squeezed down over a surface with the desired composite shape, and then liquid resin will be injected to make the composite board. The mold is typically an open mold for resin transfer [50].

Another way will be the simplest and least expensive method for producing thermoset composites is hand layup. The composite could be fabricated after planning the sequence and orientation of the fiber material used. The composite board will be formed by manually layering multiple fiber mats using a brush or roller to disperse the resin in the fibers. The orientation of the fibers may be regulated using this technology, which also enables controlled composite construction. Following construction, the composite board was removed from the mold and cured at an appropriate temperature (standard or high temperature [51]. Then the board will be obtained after the material is oven dried to cure the composite panel completely. Table 9 shows the comparison between different fabrication methods.

Table 9. Comparison of the Fabrication methods.

	Hand Lay-up	Compression Molding	Resin Transfer Molding
Advantages	– Very simple method with affordable tooling. – Suitable for huge sizes	– Can do mass production with low cost – Very high-quality composite as the material – High dimensional accuracy	– Entire shape will have a good surface – Any fiber and matrix can be used
Disadvantages	– Safety precautions are needed because the fabrication deals with chemicals – Not economical – Low viscosity resins	– The equipment is expensive – Only for 1 part material – Shape is very limited	– Expensive – Limitation of matrix

3. Conclusion

Based on this brief review's analysis, natural fiber-based composites could be an alternative composite material, particularly for multifunctional applications wheretheir smaller weight and less expensive characteristics make them incredibly realistic. Natural fiber materials like PALF and kenaf should replace carbon fiber to achieve sustainability. These materials can compete with Carbon fiber due to their unique characteristic: biodegradability and cost-effectiveness.

The drone industry should consider the natural fiber frame kit, which could reduce costs. One of the pieces of equipment on the drone is the tray frame kit which holds the entire drone equipment. From this review, it can be concluded that natural fibers such as kenaf and PALF can be used as an alternative composite material for the drone's structure. Besides, the agricultural waste produced in plantations can also be reused to its full potential.

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