A short review on the recent progress and properties of pineapple leaf fiber reinforced composite

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Abstract. Because of the increase in demand and the enhancement of environmental awareness, researchers are committed to the research and development of innovative, high-performance, andlow-cost green materials, especially since there is a large amount the study of natural fiber reinforced composite materials. An abundance of waste of pineapple leaves in Malaysia every year. If pineapple leaf fibers (PALF) can be extracted from the waste of pineapple leaves and made into green composites, it can not only solve the agricultural waste but also produce environment-friendly green composite materials to be applied in related industries. The main purpose of this review is to give an overview of recent developments in PALF reinforced composites as well as their properties. In this short review, the characteristics of PALF and its composites, the mechanical properties and the environmental impact of PALF reinforcedcomposite are studied. In the future, with the increasing research on PALF, selection of different composite materials and design of appropriate structures, the performance of PALF reinforced composites will significantly be improved, and thus has great potential to be widely used in product production and manufacturing.

1 Introduction

Attributable to significant developments in materials science and increasing environmental protection consciousness, there is a need for more environmentally friendly materials, which term "eco-composites" Natural fiber reinforced composites have gained a great deal of attention lately due to their advantages of low cost, lightweight, large dosage and eco- on their origin, natural fibers are categorized into three categories: animal, mineral, and plant. Plant fibers are the most widely used because they are limitless, inexpensive, and more widely available In Malaysia, there are approximately 15,000 hectares of pineapple plantations that provide abundant pineapple leaf fiber (PALF). On average, there are about 53,000 pineapples per hectare, producing 96 tons of fresh leaves. Nevertheless, the use of pineapple leaves is very limited thus there is huge agricultural waste every year The waste pineapple leaf often ends up in landfills, where much of the waste is transformed into methane and greenhouse gases, causing environmental problems [1-6] Therefore, if all the pineapple leaves can be extracted and make PALF composites for products, on the one hand, it can reduce agricultural waste and environmental pollution of pineapple leaves, on the other hand, it can further process and produce green products by making natural fiber composite materials and promote the harmonious development of industry and environment. In this literature review, comprehensive research was done on the recent developments in natural fiber reinforced composite. The characteristics of PALF and its composites were explored. The mechanical properties and the environmental impact of properties as well as the applications of PALF reinforced composite are studied. In the future, with more research on PALF, including the use of different composite materials, the design of reasonable material structures, and the selection of appropriate processing techniques, the application potential of PALF reinforced composite materials in product production and manufacturing is huge [7-9].

2 Pineapple leaf fiber

The non-climacteric tropical crop pineapple is one of the most important plants in the bromeliad family. PALF is a kind of relatively compatible multicellular lignocellulosic fiber with low density (0.8-1.6g/cm3) and good chemical composition, containing a lot of cellulose (67.12%-83%), lignin (4.4%-15.4%), hemicellulose (15%-20%), and some mineral chemicals, such as wax, pectin, fat, inorganic，anhydride [10,11]and so on Because wax content in the fiber is higher, PALF has a white, silky color and a softer surface than other natural fibers. Among various plant leaf fibers, the highest amount of cellulose content and low microfibrillar angle are found in PALF, which chiefly contribute to its superior tensile performance. Thus, PALF has a high tensile strength (180-1627Mpa), Young's Modulus (1.44-82.5Gpa), good rigidity, bending strength, good toughness, and can withstand loading conditions of extreme stress and strain 2022). In addition, the mechanical specificstrength and modulus of PALF are comparable to some glass fiber and it can be applied in the making of reinforced polymer composites In general, because of abundant raw materials, low price, good chemical composition, good mechanical properties and biodegradability PALF can be used as a good composite reinforcing material in various industries[12,13].

3 Recent progress of PALF reinforced composites

In recent years, people have been trying to use PALF to strengthen various matrix materials to develop green composite materials with higher mechanical strength and better degradability. In fiber- reinforced polymer materials, epoxy, polyester, and vinyl ester are common matrix materials Polyester is easy to manufacture, fast curing, inexpensive, and commonly used in tubes, containers, and high-performance components in transportation industries. However, it has limited properties in the structural application and extreme temperature conditions due to high hydrophilicity and poor corrosion resistance. Compared to polyester, vinyl ester has better corrosion resistance, excellent thermal stability, and good stretching resistance which is able to absorb greater impact energy without damage. But vinyl ester resin still has a certain water absorption and is not easy to combine with other structures different from itself. Among these matrix materials, epoxy has generally superior qualities [14]. Epoxy is known as a good adhesive, many two-component adhesives are

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epoxy-based. In addition, bio-resins are emerged and gradually replace the conventional resins to be the adhesives of natural fiber reinforced composite However, the biodegradable polymer composites are currently manufactured at a lower level, with higher costs and fewer practical applications in manufacturing, and still need to explore in the future Similar to most natural fibers, PALF has some disadvantages which influence the properties of its composite. PALF has poor thermal stability and poor durability. Moreover, the natural wax exists on the surface of PALF, and PALF has high hygroscopicity as well as low surface tension. Beyond that, the poor compatibility and wettability of PALF with resin result in weak bonding force which easily leads to crack propagation and failure. Thus, when PALF is used as a reinforcement material, itis important to eliminate the weak boundary layer in PALF in order to obtain appropriate composite properties. Fabrication methods, hybridization, and fiber treatment are independent factors for improving the performance of PALF reinforced composites.[7-11]

The characteristics of the material, especially the bonding of matrix and fiber, are substantially affected by fabrication methods. In the development of PALF reinforced composites, many fabricationmethods are evolved (Table 1). The composites fabricated by compression molding, autoclave, resin transfer molding and twin-screw extrusion have better interface bonding and relatively good mechanical properties but higher energy consumption and higher cost. Taking into account manufacturing efficiency and cost of production, manufacturers still use some traditional processing methods such as hand lay-up to fabricate fiber-reinforced composites for large-scale products[12,13]

Table 1. PALF reinforced composites and their fabrication methods.

Composites	Materials	Resins	Fabrication methods
PALF	PALF	phenol formaldehyde	Hand lay-up
	PALF	polypropylene	twin-screw extrusion
	PALF	epoxy	Hand lay-up
	PALF	polypropylene	compression molding
PALF+ other fibers	PALF+ kenaf+ palm	epoxy	Hand lay-up
	PALF+ glass fiber	Lannea Coromandelica Blender Epoxy matrix	Compression molding
	PALF+ coir fibers	polylactic acid	hot press
	PALF+ glass fiber +jute fiber	epoxy	Hand lay-up
	PALF+ kenaf fiber	phenol formaldehyde	hot press
PALF+ metal (FMLs)	PALF+ Aluminum 5052-H32 sheets	polypropylene	twin-screw extrusion
	PALF+ Aluminum5052-H32 sheets	polypropylene	hot compression molding

Hybrid PALF with other materials is a promising interest of researchers because it provides a wide range of combinations and properties. The hybrid composites combine the benefits of different materials while potentially reducing some of the drawbacks of each material, resulting in an improvement in overall performance. Until now, there have been developed various PALF reinforced composites, such as mixtures of different types of natural fibers, mixtures of PALF with synthetic fiber (eg: glass fiber), and combination of PALF with metal (especially the aluminum alloy) into FMLs, etc. (Table 1). After hybridization, various improved properties were observed which help to fabricate better PALF reinforced composites.[14].

3.1 Mechanical properties of PALF reinforced composites

Mechanical properties are the most important properties in material design. There are many parameters that will influence the mechanical property of natural fiber reinforced composites, such as the hybrid materials, fiber weight ratio (volume fraction), fiber orientation, fiber treatment, etc[15,16]

The mechanical property of hybrid PALF composite is relatively good compared with single fiber reinforced composite. During hybridization, the fiber volume fraction need to take into consideration. Kenaf fiber and PALF co-reinforced polyester composites with different weight percentages were prepared When the PALF content is increased to 50% (50% hemp, 50% PALF), the tensile modulus, tensile strength, impact strength and elongation of the material reach the maximum values of 246.8 MPa, 5482 MPa, 32 J/m^2 and 16.2% , respectively. At the same time, the toughness of the material has also increased, the maximum flexural modulus is 3216 and the flexural strength is 91.5 MPa.. [14] also observed the effects of fiber volume fractions on the mechanical performance of PALF/jute fiber/ glass fiber reinforced composites. The results also confirmed that the increase in fiber ratio can enhance the comprehensive mechanical properties of the hybrid composites, when the fiber content reaches the maximum value (42%), the flexural strength (239.37 MPa) and the tensile strength (71.66 MPa) of the composite material reach the maximum. SenthilKumar et al. investigated the mechanical characteristics of polyester (PE) reinforced by PALF. According to the free vibration test, the natural frequency of PE rises as fiber loading increases, and the natural frequency of 45 wt% PALF is the highest. These results show that appropriate fiber content gives good adhesion between PALF and the matrix, which might enhance the mechanical properties of the material. However, the fiber content should be controlled in a reasonable range in case the mechanical properties deteriorate due to inadequate fiber-to-matrix adhesion. Chrispin das et al. fabricated woven PALF reinforced phenol formaldehyde composites with 30%, 35%, 40% and 50% fiber content. In the mechanical test, it was found that when the fiber content was less than 40%, the mechanical properties of the composite enhanced with an increase in fiber volume ratio. However, when the fiber content exceeded 40%, the mechanical properties decreased.

Fiber orientation also influences the mechanical property of composites. Temesgen Batu et al. [17] pointed out that better mechanical properties are provided by fiber orientation along the load direction (0° direction) than by other fiber directions. Todkar & Patil [18]compared the mechanical properties of material with short PALF randomly arranged along the length, and with long PALF that are unidirectional along the length. The previous sample can effectively withstand tensile loads, in which only a few parts of the fiber will be pulled out and debonding before fracture. For randomly oriented short PALF reinforced composite, more fibers werepulled out, split, and deboned due to poor bonding. Doddi, Chanamala, & Dora samples of hybrid PALF/ basalt reinforced epoxy composite with various pineapple leaf fiber orientations ranging from 0° to 90° and investigated the influence of PALF orientation on the dynamic mechanical properties. The results show that the PALF orientation at 0°, the damping performance, young's modulus and bending modulus are better, and the damping performance is worst at 60° PALF orientation. In addition, the glass transition temperature (Tg) shifts to the right as the angle of PALF increase.

The interfacial bonding of natural fiber with the matrix can be strengthened by fiber surface modification for improving mechanical strength. The modification methods such as alkalization, cyanoethylation, grafting, and dewaxing were proved to be effective methods. Among these methods, chemical modification of PALF is the common method to enhance the adhesion of PALF to the matrix. Najeeb et al used silane treated PALF with various soaking times (1h, 3h, 5h). X-ray diffraction analysis showed that Si element was found on the surface of all treated fibers, the crystallinity of treated fiber changed slightly compared with untreated fiber, and the treated fiber has the largest surface roughness and tensile strength. The mechanical properties are impacted by different kinds of chemical treatment reagents. Senthilkumar et al. investigated the different effects of NaOH and KOH on PALF in surface modification. Studies has shown that NaOH can enhances the adhesion between the fiber and the matrix but the damping property is poor, while the fibers treated by KOH have better damping properties but poor adhesion ofthe fiber and matrix. At the same time, the compressive strength of treated fiber composites is higher than that of untreated fiber composites.

In conclusion, synthetic fibers, other natural fibers and metal materials can be hybridized with PALF. Through hybridization, the advantages and disadvantages of different materials can be integrated and improve the mechanical properties of materials. Within a reasonable range, increasing the fiber ratio of PALF reinforced composites improves their mechanical properties, but the mechanical property will decrease when fiber content exceeds the limit. Increased fiber orientation will result in a change in the contact area between resin and PALF, affecting the impactful stress transfer between the resin and the PALF and having a significant impact on the mechanical properties.Fiber treatment can enhance the mechanical properties by enhance the adhesion between fiber and matrix.

3.2 Environment impact of PALF reinforced composites

Natural fiber reinforced composite usually has better biodegradable properties than conventional composites like synthetic fiber reinforced composite[19]. However, external environmental conditions, such as temperature, humidity, soil pH, and nutrient availability, can degrade the properties of bio-composites [20]. Thus, the environmental impact needs to take into consideration to ensure that PALF reinforced composites can still work properly and safely in a range of different environments.

One disadvantage of PALF composites is that the mechanical strength will decrease significantly at slightly higher temperatures. Although there are several works that have been done, the thermal degradation of PALF reinforced composites is still a pressing issue

Fiber volume fraction influences the thermal performance of PALF reinforced composite. Pujari Satish et al investigated the thermal properties of PALF/latex composites, and the research results show that the value of thermal conductivity decreases as the PALF content increases due to the non-conductive properties of PALF. When the fiber content is at the maximum volume fraction (30% PALF), the thermal conductivity of the composite is the lowest, at 0.33 W/mk. In addition, researchers try to explore different methods to improve thermal properties. Chemical treatment is a commonly used way to enhance the thermal stability of natural fibers. Gnanasekaran, Nordin, Jamari, & Shariffuddin utilized the steam-alkaline couple (SAC) [21-24] to modify the PALF. From thermal stability tests, as the concentration of NaOH and the period of steam increase, the main degradation temperature rises noticeably. The samples that experienced the longest SAC treatment (60 min) and the highest NaOH concentration (1wt%) had the highest degradation temperature (329.78°C). In addition, this sample had the lowest residual percentage at 700°C because the treated fiber has a smaller percentage of high molecular weight lignin. Rahman et al. explored the thermal characteristics of jute and PALF co-reinforced polymer. They found that the weight loss of the composite is affected by different irradiation doses at different temperatures and irradiation can make the composites more stable at high temperatures.

Water absorption is one of the leading factors to the deterioration of agricultural fiber reinforcedcomposites properties and influencing the long-term durability of material PALF will expand in all dimensions with the increase of hygroscopicity. At the same time, the interaction between the matrix and PALF will be adversely impacted by the water molecules and promote bacterial growth. The addition of PALF will faster the degradability of composites in any media such as in soil and seawater environments. Armynah et al. added PALF into cassava starch/chitosan/ZnO composite for increasing degradation performance. The results demonstrated that adding PALF to plastics increases the proportion of water absorption, which easily degrades for 18 days in seawater and 21 days in ordinary soil. Furthermore, the study confirmed that the hydrophilicity increased with the increase of PALF due to the high cellulose content of PALF. Chrispin das et al. compared the water absorption properties of woven PALF/ phenolic composites with different fiber loads of 30%, 35%, 40%, and 50%. The rate of water absorption of the sample with a fiber content of 50% is significantly higher than that of other samples. Researchers pointed out that hybridization and fiber treatment can decrease the water absorption of PALF reinforced composite. Siakeng et al. fabricated hybrid coir fibers (CF) / PALF/ poly lactic acid (PLA) composites. PALF has lower moisture absorption than CF due to the lower porosity and hollowness of PALF, and the CF/ PALF co-reinforced PLA has a medium water absorption amount. Rinawa et al., investigated the effects of fiber modification on the PALF/nano rice husk powders/ epoxy composites. Experimental results show that the lowest percentage of water uptake was found in the composite with 24 wt% treated PALF, which means the treatment can decrease water absorption. Mittal & Chaudhary studied the effect of alkaline treatment on the biodegradability of hybrid coir fiber/ PALF/ epoxy composites in natural soil. The study revealed that compared to single fiber reinforced composites, the biodegradability and mechanical strength of hybrid material both deteriorate rapidly. Furthermore, the composites with treated PALF lose more weight and exhibit a greater decrease in mechanical properties than the untreated sample.

In summary, external environmental conditions have a significant impact on PALF reinforced composites. The fiber volume fraction should be reasonably controlled to prevent the composites from deteriorating in extreme temperature conditions. The thermal stability of PALF reinforced composites can be improved by hybridization, fiber treatment, gamma radiation, etc. The addition of PALF will enhance the moisture absorption and worsen the properties of the bio-composites. The surface treatment and hybridization will improve the interfacial adhesion between PALF and resin, which minimizes the environmental impact on the composites.

4 Applications of PALF reinforced composites

Modern society is more environmentally conscious and designers are constantly developing more sustainable products. At present, PALF is mainly used in textiles, leather substitutes, automobile decorations, papermaking, furniture and so on In the textile industry, PALF has been the preferred material for textiles for decades PALF is the fifth generation of natural fiber following cotton, wool, silk and bast fibers. It has a white appearance, softer, smoother and finer texture than other plant fibers, absorbing sweat and breathable. PALF fabrics are easy to dye and have high color fastness, and can be blended with other natural or synthetic fibers. Its strength and toughness are stronger than the traditional cotton fiber after processing, so the PALF fabric is more crisp, can be made into senior dress, shirt, suit and so on. In addition, some PALF have a texture similar to leather, and can be dyed and printed like canvas to produce different textures that are both aesthetic and practical. Therefore, PALF is also an excellent substitute to leather for making clothing, furniture, accessories, and automobile seats, and other products. In Malaysia, PALF is also used in the relatively new paper industry, which has developed products such as paper cups, boxes, wrapping materials, etc. Compared with other natural fibers, PALF has higher tensile strength, good mechanical properties and sustainability, which make PALF composite materials can also be used in building materials, automotive parts and furniture. Meanwhile, studies have shown that PALF nanocomposites can also be used in chemical products such as cosmetics and medicine. Due to the unique performance, PALF will be applied more and more in various existing industries such as textile, leather ware, furniture, daily necessities, automobile and aerospace industry, and fabricated more complex products in the future with further research and development.

5 Conclusion

Many early-stage studies were included in this short review. The characteristics of PALF and its composites were explored. The mechanical performance and the environmental impacts of PALF reinforced composite are also studied. From research, interfacial adhesion between PALF and matrix is crucial for PALF reinforced composites. Many parameters determined the final properties of PALF composites like fiber orientation, fiber volume ratio, fiber treatment, etc. Among these, the fiber content needs to be thoughtfully designed, the effect of reinforcement is insufficient when fiber content is too low, while the performance of the composite will deteriorate if the fiber content is excessive; Hybridization is a significant method for preparing bio-composites because it can combine the benefits of different materials and improve the properties of materials; In addition, fiber surface modification can improve the interface binding between PALF and resin, thereby improving its mechanical, thermal, and reliability properties.

However, the development of PALF composites is still in the preliminary stage. For novel design,there still have many hybrid methods that need to be researched, for example, hybrid PALF with metal into FMLs is rare in research, and the use of bio-polymer is lack consideration. Additionally, there hasn't been much research done on a thorough assessment of the mechanical properties, thermal properties, reliability, and biodegradability of hybrid PALF composites. With further research and optimized properties of PALF and its composites, the application range will expand, and it will be an important part of the development and production of green products in the future.

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