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

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, and low-cost green materials, especially since there is a large amount of 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 environmentally-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 reinforced composite 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

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 specific strength 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 [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...
epoxy-based. In addition, bioresins 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, it is 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.

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 fabrication methods 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.

Table 1. PALF reinforced composites and their fabrication methods.

<table>
<thead>
<tr>
<th>Composites Materials</th>
<th>Resins</th>
<th>Fabrication methods</th>
</tr>
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<tbody>
<tr>
<td>PALF+other fibers</td>
<td>POLYPROPYLENE</td>
<td>Compression molding</td>
</tr>
<tr>
<td>PALF+kenaf+palm</td>
<td>POLYPROPYLENE</td>
<td>Twin-screw extrusion</td>
</tr>
<tr>
<td>PALF+epoxy</td>
<td>POLYPROPYLENE</td>
<td>Hand-lay-up</td>
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<tr>
<td>PALF+coir fibers</td>
<td>POLYPROPYLENE</td>
<td>Compression molding</td>
</tr>
<tr>
<td>PALF+glass fiber</td>
<td>POLYPROPYLENE</td>
<td>Hand-lay-up</td>
</tr>
<tr>
<td>PALF+glass+jute fiber</td>
<td>POLYPROPYLENE</td>
<td>Hand-lay-up</td>
</tr>
<tr>
<td>PALF+kenaf fiber</td>
<td>PHENOL FORMALDEHYDE</td>
<td>Hot press</td>
</tr>
<tr>
<td>PALF+metal (FMLs)</td>
<td>POLYPROPYLENE</td>
<td>Hot compression molding</td>
</tr>
<tr>
<td>PALF+Aluminum 5052-H32 sheets</td>
<td>POLYPROPYLENE</td>
<td>Twin-screw extrusion</td>
</tr>
<tr>
<td>PALF+Aluminum 5052-H32 sheets</td>
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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.
3.1 Mechanical properties of PALF reinforced composites

The mechanical properties of PALF reinforced composites were studied to understand the effect of fiber content on the performance of the composite. The results showed that the tensile strength and modulus of composite increase as fiber content increases. However, beyond a certain fiber content, the tensile strength and modulus start to decrease due to the agglomeration of fibers.

The flexural strength and modulus of the composite also increase with the increase in fiber content. At a fiber content of 40%, the flexural strength and modulus reach their maximum values. However, further increase in fiber content leads to a decrease in flexural strength and modulus due to the decreased fiber-matrix adhesion.

The impact strength of the composite also increases with the increase in fiber content. This indicates that the composite can effectively withstand impact loads.

The modulus of elasticity of the composite also increases with the increase in fiber content. This shows that the composite can withstand higher stresses without deformation.

In conclusion, the mechanical properties of the composite improve with the increase in fiber content. However, beyond a certain fiber content, the mechanical properties start to decrease due to the decreased fiber-matrix adhesion.
In addition, this sample had the lowest residual percentage at 700°C because the highest NaOH concentration (1wt%) had the highest degradation rate. The samples that experienced the longest alkaline couple (SAC) had the greatest thermal stability of natural fibers. Gnanasekaran, Nordin, Jamari, & Shariffuddin (2013) have carried out research showing that the value of thermal conductivity significantly decreases as the PALF content increases due to the non-conductive properties. However, PALF is a natural fiber that can absorb more water than synthetic fibers, leading to a decrease in mechanical properties.

One disadvantage of PALF composites is that the mechanical strength will decrease if the fiber ratio is higher than 30%. The fiber volume fraction influences the thermal performance of PALF reinforced composite. Researchers have tried to explore different methods to modify the PALF. From thermal stability tests, as the concentration of NaOH and the period of steam soaking increases, the main degradation temperature rises noticeably. The samples that experienced the longest treatment time had the highest NaOH concentration (1wt%) and the period of steam soaking.

3.2 Environment impact of PALF reinforced composites

Among these methods, alkalization, cyanoethylation, grafting, and dewaxing were proved to be effective methods. The fiber orientation range, increasing the mechanical property will decrease when fiber content exceeds the limit. The compressive strength of treated fiber composites is higher than untreated fiber, and the treated PALF shows better damping properties but poor adhesion of the fiber and the matrix. However, external reagents can make the surface of all treated PALF rough. Senthilkumar et al. investigated the effects of various chemical modification of PALF is the common method to enhance the adhesion between fiber and matrix. Najeeb et al. also confirmed the impact of these modifications. Studies have shown that NaOH can enhance the adhesion between PALF and the matrix.

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, affecting the impactful stress transfer between the resin and the PALF and having a certain adhesion of the fiber and the matrix can be considered to ensure that PALF reinforced composites can still work properly in environments.
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
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.

References