International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(6): 399-406

Received: 08-09-2018
Accepted: 10-10-2018

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PINA: The environment friendly fibre

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Abstract
Natural fibre-based composites are under intensive study due to their eco-friendly nature and peculiar properties. The advantage of natural fibres are their continuous supply, easy and safe handling, and biodegradable nature. Although natural fibres exhibit admirable physical and mechanical properties, it varies with the plant source, species, geography, and so forth. Natural fibre especially pineapple leaf fibre (PALF) has so much to offer in the uprising world of industry. Pineapple leaf fibre (PALF) which is rich in cellulose, relatively inexpensive, and abundantly available has the potential for polymer reinforcement. A detailed study of chemical, physical, and mechanical properties will bring out logical and reasonable utilization of PALF for various applications. From the socioeconomic prospective, PALF can be a new source of raw material to the industries and can be potential replacement of the expensive and non-renewable synthetic fibre. The utilization of pineapple leaf fibre as reinforcements in thermoplastics and thermosetting resins in micro and Nano form for developing low cost and lightweight composites is an emerging field of research in polymer science and technology.

Keywords: Composites, eco-friendly, biodegradable, reinforcement, thermoplastics, thermosetting

Introduction

The ever-growing environmental pressure caused by the widespread consumption of petroleum-based polymers and plastics have spurred a thrust into the development of biodegradable or environmentally acceptable materials. Present-day research in the field of polymer science and technology has been focused on developing plastics, papers, adhesives, textile fibres, composites, blends, and many other industrial products from renewable resources, mostly the abundantly available agro-waste and lignocellulosic materials. Newer materials and composites that have both economic and environmental benefits are being considered for application in the automotive, building, furniture, and packaging industries. Growing environmental awareness, new rules, and regulations throughout the world for the creation of bio-based economy are challenging industry, academia, government, and agriculture. Within the past few years, there has been a dramatic increase in the use of natural fibres for composites. Recent advances in natural fibre development, genetic engineering, and composite science offer significant opportunities for improved materials from renewable resources with enhanced support for global sustainability. The potential of natural fibre-based composites using cellulose, wood, jute, kenaf, hemp, coir, sisal, pineapple, etc., as reinforcing fibres in both thermosetting and thermoplastic resins has received considerable attention among scientists all over the world for their excellent specific properties.

Lignocellulosic material is one of the most promising natural, abundant and renewable feedstock for application in several areas such as bio-fuels, animal feeding, fine chemicals and composites. Availability of inexpensive lignocellulosic natural fibres, such as pineapple leaf fibre (PALF) in tropical countries, provides a unique opportunity of exploring the possibility of their utilization for the synthesis of inexpensive biodegradable composites for various applications. The primary advantages of using these fibres as reinforcements in polymer composites are listed as follows: (1) low density, (2) low cost, (3) nonabrasive nature, (4) high filling level possible, (5) low energy consumption, (6) high specific properties, (7) biodegradability, and (8) generation of rural/agricultural-based economy. The structure and properties of these natural fibres depend upon several factors such as age, source, microfibrils, straightness, diameter, and chemical constituents. Since these fibres have small cross-sections and cannot be directly used in engineering applications, they are embedded in matrix materials to form fibre composites. The matrix serves as binder to bind the fibres together and transfers loads to the fibres. In order to develop and promote these natural fibres and their composites, it is necessary to understand their physico-mechanical properties.

Several reports have been published on the structures and properties of these natural fibres but a great deal of additional research is still needed in this area. The major constituents of natural fibres (PALF) are cellulose, hemicellulose, and lignin. The elementary unit of a cellulose macromolecule is anhydro-D-glucose, which contains three alcohol hydroxyls (–OH). These hydroxyls form hydrogen bonds inside the macromolecule itself (Intramolecular) and between other cellulose macromolecules (intermolecular) as well as with hydroxyl groups from the air. Therefore, PALF, like all vegetable fibres are hydrophilic in nature and their moisture content reaches about 11%. These fibres can act as effective reinforcements for polymer, rubber, gypsum, and cement matrices. However, PALF fibre-reinforced composites generally have poor interface and moisture resistance properties. The properties of composites depend on those of the individual components and on their interfacial compatibility. The adhesion between the fibre and the matrix is obtained by the mechanical anchoring of the fibre surface ends into the matrix. The absorption of moisture by untreated fibres, poor wettability, and insufficient adhesion between the polymer matrix and fibre leads in time to debonding. Without effective wetting of the fibre, strong interfacial adhesion cannot exist leading to internal strains, porosity, and environmental degradation. Therefore, the modification of the fibre is a key area of research at present to obtain optimum fibre-matrix properties. Properties of reinforcing fibre can be modified and tailored to different fashions and degrees by some chemical and physical methods.

Pineapple is the second highest tropical fruit commercially produced in the world, around 25.1 million metric tonnes. Among various natural fibres, pineapple leaf fibres (PALFs) exhibit excellent mechanical properties. These fibres are multicellular and lignocellulosic. PALF is largely cultivated in tropical countries, mainly for its fruits. Its cultivation in India is substantial (about 2 250 000 acres of land is cultivated and is increasing; in the future a considerable increase in the production of the fibre is envisaged). The pineapple plant has a very short stem which first produces a rosette of leaves but which latter elongated and bear numerous spirally arranged fibrous leaves. The leaves are 3ft. long, 2 to 3-inch-wide sword shaped, dark green in color and bear spines of claws on their margins. The leaves of the pineapple plant yield strong, white fine silky fibres. Since the pineapple plant is a special crop, only limited quantity of fibre is available. Therefore, no attempt has been made to grade these fibres.

History

Pineapple is a native plant of America, first seen by Columbus and his companion in November 4, 1493, at an island of West Indies. When the new world was discovered, pineapple has been spread all over South America coastal region as well as in tropical regions. A Spanish government officer, De Oviedo, came to America in 1513; he handed over first written documents of some varieties of pineapple, and he added some Indies varieties also. The plant is called "pineapple" because of its fruit which look like pine cone. The native Tupi word for the fruit was *anana*, meaning "excellent fruit;" this is the source for words like *ananas*, common in many languages. The pineapple is an old emblem of welcome and can often be seen in stamped decorations. In 17th century Americans imported pineapple from Caribbean because of its apparently exotic features and rareness; pineapple began to be considered as an icon of wealthy people in America. The Portuguese contributed their important role in introducing the fruit throughout the whole tropical regions and major parts of world like south and east coast of Africa, Madagascar, south India, China, Java, Philippines, and Malaysia. Nowadays, varieties of pineapple plants are available which are used in various applications such as edible, medicinal, and industrial applications. For example, bromelain is an enzyme extracted from its leaves and helps in respiratory ailments. A mixture of pineapple juice and sand is powerful cleaner for boat decks. Dehydrated waste material of pineapple is used as bran feed for cattle, chicken, pigs, and so forth.

Pineapple Leaf Fiber

Pineapple leaf fibre is one kind of fibre derived from plants which is derived from the leaves of the pineapple plant. Pineapple which also has another name, that Cosmosus Ananas, (including the family Bromeliaceae), in general this is a crop plant season. Historically, this plant comes from Brazilian and brought to Indonesia by the Spanish and Portuguese sailors around 1599.

The pineapple leaf shape resembles a sword that taper at the ends with black and green colours on the edges of the leaves are sharp thorns. Depending on the species or type of plant, pineapple leaf length is between 55cm to75cm by 3.1cm to 5.3 cm wide and 0.18cm thick leaves of up to 0.27cm. In addition, pineapple species, spacing and distribution of sunlight will affect the growth of leaf length and strength properties of the resulting fibre. Distribution of sunlight is not too much (partly hidden) generally will produce a strong fibre, refined, and similar to silk. Pineapple leaf fibre intake is generally done at the age of 1 to 1.5 years. A fibre derived from the leaves of the young pineapple generally is not long and strong. For fibre produced from pineapple that is too old, exposed to sunlight without protection will produce short fibres, coarse, and brittle. Therefore, to obtain a strong fibre, soft and smooth, the selection should be done in pineapple leaves enough and protected from the sun.

Pineapple Leaf Extractor

Separation process or pineapple fibre from the leaves can be done in two ways, namely the manual and mechanical methods. The most common and effective is the manual method, the process is done by immersion. In this process, micro-organisms play an important role to separate or remove Gummy substance which surrounds the pineapple leaves and this process will cause fibre and decompose easily separated from each other. This process is done by soaking the leaves of the pineapple into the water in a certain period of time such as a week. The next process is the process of using a plate shown in Figure-1 or whittle with no sharp knife to remove the skin leaves still attached to the fibre surface shown in Figure-2. After that, the fibre is washed with water and dried under the sun or using the oven.

Fig 1: Process using a plate

Fig 2: Taking out the fibre

PALF is produced by novel technology invented as illustrated in Figure 3. PALF is extracted by a decortication machine named Pineapple Leaf Fibre Machine 1 (PALF M1). When most of the extractor or decorticator out there using crusher-like technology to extract PALF, this machine used blades to remove the waxy layer on the pineapple leaf instead of forcing it out by crushing. Furthermore, the blades' designs were unprecedented. The number of blades used, sizes and certain angle of the two blades needed to ensure that the leaf will not snap during the process plays crucial part of the extraction process. As shown in Figure 4, pineapple leaf is inserted between the two blades, blade 1 and blade 2. Upon entering the blades, the leaf will be sort of 'grind' and the outer waxy layer will be removed during this first step. During second step, when the leaf was being pulled off, yet again, the leaf will be grind for the second time that will remove the entire waxy layer, which was left during the first step. The extracted PALF is then being scoured and dried by using Pineapple Leaf Fibre Machine 2 (PALF M2) as in Figure 3(b). At this stage, the remaining green debris accumulated at PALF will be further cleaned and removed.

(a) (b)

Fig 3: (a) PALF M1; (b) PALF M2

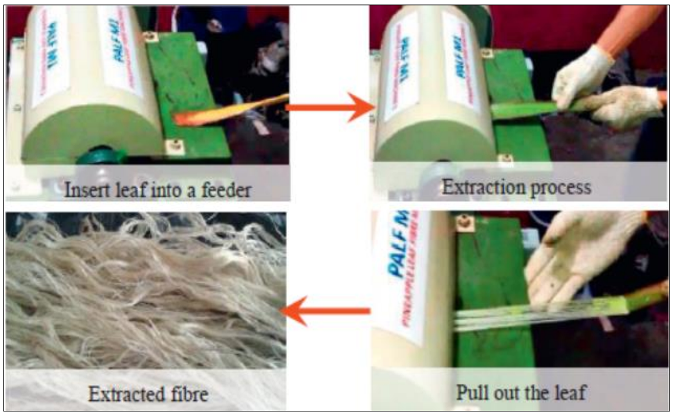

Fig 4: PALF M1 mechanism

Retting of pineapple leaves

In retting process, small bundles of scratched pineapple leaves are immersed in a water Tank which contains substrate: liquor in 1:20 ratio, urea 0.5%, or diammonium phosphate (DAP) for fast retting reactions. Materials in water tank are regularly checked by using finger to ensure fibre are loosened and can extract many chemical constituents like pentosans, lignin, fat and wax, ash content, nitrogenous matter, and pectin. After retting process, fibres are segregated mechanically, through washing in pond water. Extracted fibres are dried in hanging place by air. Both ball mill and disc mill can be used to extract PALF from chopped fresh pineapple leaf. The methods not only are simple but also provide higher fibre yield and smaller fibre than the conventional methods. Among the two mechanical grinding methods studied, wet ball milling is much slower but provides PALF with a greater number of elementary fibre.

Chemical Composition

Technical Association of Pulp and Paper Industry (TAPPI) standards reported that the chemical constituents and extractive like holocellulose, α-cellulose, lignin, and ash content of PALF were analysed from different source of fibres, age of fibres, and climatic conditions. The procedure to extract the fibres may attribute the factor of various types of chemical composition and cell wall structure. In a transmission electron microscopy, PALF cell wall shows distinct different layers as primary (P), secondary, and tertiary (S1, S2, and S3) layers. The chemical composition of PALF is depicted in Table1. Pineapple leaf fibres have many chemical constituents like α-cellulose, pentosans, lignin, fat and wax, pectin, nitrogenous matter, ash content, degree of polymerization, crystallinity of α-cellulose, and antioxidants. PALF has a large quantity of α-cellulose (81.27), low quantities of hemicelluloses (12.31%), and lignin content (3.46%). PALF has higher cellulosic content as compared to other natural fibres like oil palm frond, coir, and banana stem fibres. The higher quantity of cellulose in PALF supports the higher weight of the fruit. The chemicals composition fibre directly affects performance of fibres.

Table 1: Chemicals composition of PALF.

Cellulose content (%)	Hemicellulose (wt.%)	Lignin content (%)	Pectin (wt.%)	Holocellulose	Moisture content (wt.%)	Extractives	Ash (%)	Fat &wax
85	-	12		-	-	-	-	-
70-82	-	5-12	-	-	11.8	-	-	-
67.1- 69.3	-	14.5-15.4	-	-	-	-	1.21	-
68.5	18.8	6.04	1.1	-	-	-	0.9	3.2
69.5	-	4.4	1.2	-	-	-	2.7	4.2
69.5	-	4.4	1.1	-	-	-	0.9	3.3

70-80	-	5.0-12.7	-	-	11.8	-	-	3.3
74.33	-	10.41	-	80.68	-	6.68	4.73	-

Physical and Mechanical Properties

Reinforced natural fibres composite plays a huge share in bio composite and material science. PALF has been proved as a good substitute of synthetic fibres, because of its economical and renewable nature. Specific strength of natural fibres supports in enhancing the physical and mechanical strength of polymer matrix without using any additional processing. The superiority of PALFs mechanical properties is related with the high content of alpha-cellulose content and low microfibrillar angle (14∘). Due to extraordinary qualities of PALF, it can be used as reinforcing composite matrix. The physicomechanical properties of any natural fibres depend on fibre-matrix adhesion, volume fraction of fibre, aspect ratio, orientation, and stress transfer efficiency at interface. The result of PALF based polymer composites shows excellent stiffness and strength compared to other cellulose based composite materials. Strange characteristics of PALF are noticed; that is, a wet PALF bundle exhibits lower strength by 50%, but when it converts into yarn, its strength increases up to 13%. Table 2 shows the physical and mechanical strength of PALF. The PALF exhibits a modulus range from 34.5 to 82.51GN·m−2, tensile strength ranges from 413 to 1627MN·m−2, and an elongation at breakpoint ranges from 0.8 to 1.6%. PALF can sustain abrasiveness. Datta *et al*. studied many different types of properties and behaviour like morphology of surface structure, tensile behaviour, and dielectric property. PALF shows good elastic property in cellulose type I structure.

Table 2: Physical and mechanical strength of PALF.

Density (g/cm3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Specific Strength (GPa/g/cm3)	Specific modulus (GPa/g/cm3)	Elongation at break (%)	Dia. (μm)	Microfibril angle
1.52	413–1627	34.5- 82.51	0.3-1.1	22.7-54.3	1.6-3	20-80	-
1.526	170	62.10	1.1	40.70	3	-	-
1.44	413–1627	34.5- 82.51	-	-	1.6	-	-
1.526	413	62.10	-	-	1.6	50	-
1.07	126.60	4.405	-	-	2.2	-	-
	413–1627	34.5- 82.51	-	-	1.6	20-80	14
1.526	170	6.260	-	-	3	-	-
1.52	170	6.21	-	-	3	-	-
1.07	126.60	4.405	-	-	2.2	-	-
1.526	413	6.5	-	-	1.6	30-60	-
1.526	170	62.10	-	-	3	-	-
1.44	413-1627	34.5-82.51	-	-	-	20-80	8-14
1.44	413-1627	34.5-82.51	-	-	1.6	20-80	-
1.44	170	6.26	-	-	1.6	5-30	12
1.526	413	4.2	-	-	3.0-4.0	50	14
1.440	-	-	-	-	-	1.56-4.5	8-15
-	293.08	18.934	-	-	1.41	1.50-300	5

PALF fibre in non-woven mats

Ratio PALF/PP (%)	Tension Strength MPa	Tension Modulus GPa	Flexural Strength MPa	Flexural Modulus GPa
80/20	18.98	1.16	12.67	1.12
70/30	20.13	1.42	22.73	2.83
60/40	48.73	3.12	21.77	2.23
50/50	42.17	3.42	31.01	2.32

FTIR Spectra

FTIR spectroscopy is used to observe functional groups in natural fibres, such as hydroxyl group, carbonyl groups and vinyl groups, ketone group, and many more. It helps to identify the changes in chemical compound of natural fibres before and after the chemical treatments. Table 3 shows the typical FTIR spectra of various untreated natural fibres hemp, sisal, jute, kapok, kenaf, and oil palm fibre along with PALF. The characteristic of the O–H group is common for all, visible in between the intensity of 3338–3450 cm−1. The untreated fibres show common peaks corresponding C–H stretching and C–O stretching at 2924.2 and 1741.1 cm−1, respectively. According to Jonoobi, in kenaf, the broad peak at 3338 cm−1 which appears in spectra is attributed to the O–H frequency, whereas the peaks at 2899 cm−1 mainly take place from C–H stretching. Sreekala noted that the untreated oil palm fibre shows peaks corresponding C–O stretching at 770 cm−1 and C–H stretching at 2850 cm−1, whereas oil palm fibre shows another peak at 3450 cm−1 due to the –O–H stretching. FTIR spectra of holocellulose and α-cellulose samples free from extractive of PALF are presented in Figure 5. The peak 3343 cm−1 represents O–H groups in case of α- cellulose sample. In holocellulose and free-extractive samples, hydroxyl stretching frequency displayed at 3,296 cm−1 and 3327 cm−1, respectively. For α-cellulose sample, another peak frequency at 1725.25 cm−1 shows C–O bending frequency. While, in case of holocellulose and free extractive, the peak frequency at 1728 and 1733 cm−1 corresponds to the carbonyl peak frequencies, respectively. The sharp band observed at 1733 cm−1 is due to the absorption of carbonyl stretching of ester and carboxyl groups which is most abundant in pineapple leaf hemicelluloses.

Table 3: Infrared transmittance peaks (cm−1) of untreated natural fibres.

Bond/stretching	PALF (cm−1)	Hemp (cm−1)	Sisal (cm−1)	Jute (cm−1)	Kapok (cm−1)	Kenaf (cm−1)	Oil palm fibre (cm−1)
–OH	3349.9	3448	3447.2	3447.9	3419.7	3338	3450
C–H	2903.8	2920.5	2924.2	2918.8	2918.1	2899	2850
C=O	1737.4	-	1736.5	1737.2	1741.1	1736	1735
C=C	1608.3	1654	1653.9	1653.8	1596.1	-	1606
C–H	1374.4	1384.1	1384.1	1384.1	1383.6	-	-
C–H	-	-	1259.9	1255.6	1245.5	-	-

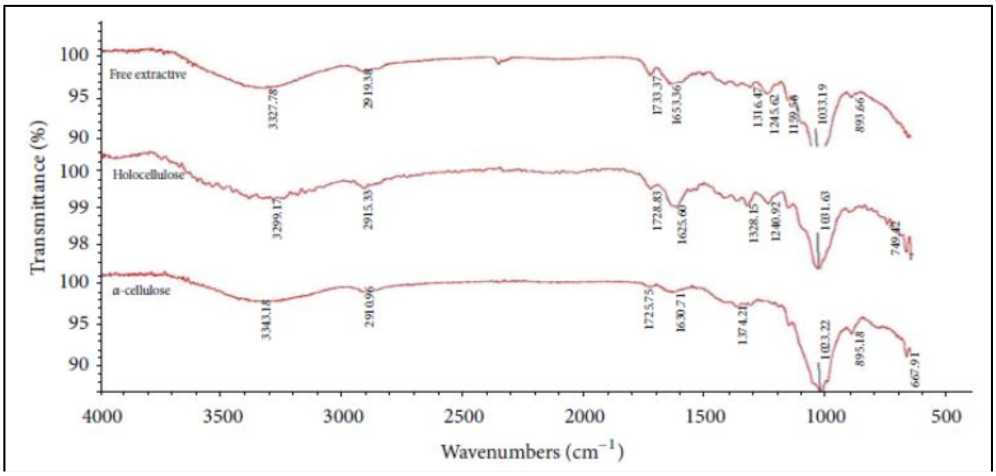

Fig 5: FTIR spectra of pineapple leaf fibre in various forms.

Challenges for PALF as Reinforcement

PALF shows lower degree of compatibility with hydrophobic polymers due to its hygroscopic nature. Existence of natural waxy substance on surface of fibre layer provides low surface tension, which does not allow a strong bond with polymer matrix. However, the literature suggests various methods to improve the fibre surface to make it suitable for good interfacial fibre/matrix bonding. Natural fibres reinforced polymers are susceptible to humidity and water absorption that causes a physical degradation of final product. High moisture content in fibre can cause swelling or dimensional defect at the time of composites preparing that affect the physical and mechanical property of the final product. At low temperature, water molecule faces obstacle by stiffness of polymer chain segments. Moisture diffusion into polymer depends on various factors such as molecule structure, polarity, crystallinity and the hardeners used in composite making.

PALF Based Composite

Natural fibres are focused study among researchers and industries, as a replacement of glass fibres to natural fibres. The rapid growth in research on environmental issues is acceleration factors to utilise natural fibres in coming decades. Recently, PALF is being utilised effectively in polymer matrix to develop composites with improved mechanical strength. The outstanding mechanical properties of individual PALF are reflected in its ultimate product. Various research has been done to reinforce PALF with thermoset, thermoplastic, biodegradable plastics, and natural rubber.

1. Epoxy Based PALF Reinforced Composite.

Epoxy resin has excellent properties like adhesion, strength, low shrinkage, corrosion protection, and many other properties. Although it is expensive resin, its mechanical and chemical properties are very good. Natural fibres like jute, flax, sisal, and bamboo fibres with epoxy reinforced have been studied. In case of PALF there is no work done yet. PALF has a major problem related to adhesion with many polymer matrices. PALF is hydrophilic in nature and it does not have good compatibility with hydrophobic polymer. PALF contains waxy substance on its surface causing low surface tension which negatively affects the bonding with polymer matrix. To overcome this issue PALF surface is modified to improve bonding. In surface modification process reagents make fibres hydrophobic in nature and graft the fibres surface with resin matrix and some compatible polymers. A number of researches have been carried out to improve the adhesion between PALFs and matrix, for example, cyanoethylation, alkalization, dewaxing, and grafting of acrylonitrile monomer. These methods have been proved to be a very effective modification to enhance the adhesion property of PALFs with polymer matrix. Benzoylated PALF with alkali treatment are used to enhance the adhesion and tensile properties. The alkalization process makes the fibres surface rough and improved mechanical hold. A rough surface improves the affinity of epoxy matrix and interfacial adhesion made strong due to deposition of DGEBA resin on fibres surface. Furthermore PALF-epoxy composites will exhibit a positive result in interfacial bonding when combination of alkalization and DGEBA solution will be used. Such kinds of surface modification will enhance the flexural, tensile, and impact properties of epoxy composite.

2. Polyethylene Based PALF Reinforced Composites.

A pineapple leaf fibre reinforced with polyethylene exhibits high performance composites. In comparison to other natural fibres, pineapple leaf fibre (PALF) shows excellent mechanical and physical properties but the hydrophilic nature of PALF causes a negative impact. Thus, a chemical treatment such as alkali, isocyanate, saline, and permanganate were carried out to improve the water resistance. Peroxide modification is very helpful to reduce the hygroscopicity of fibres.

3. Polypropylene Based PALF Reinforced Composites.

Pineapple leaf fibres (PALF) are renounced as possible and plentiful substitutes for the high-priced and non-renewable synthetic fibres. PALF enhances the mechanical properties of the polymer matrix through its own high specific strength. PALF is multicellular, lignocellulosic and has very good mechanical properties. In study of stress behaviour of PALF reinforced polyethylene composite, stress is inversely proportional fibre content. Mechanical properties of polypropylene pineapple leaf fibre reinforced composites are reported. The tensile and flexural properties of composites are depending on volume fraction. The recent study showed very useful composites with high-quality strength. PALF is being used as a reinforced agent in polyropylene matrix in the place of pure resin, to improve the mechanical properties. Flexural modulus and flexural stress are directly related to the volume fraction. Though, value is insignificant due to fibre-to-fibre repulsion and dispersion problems. Researchers are mainly focused on improving the mechanical properties of PALF-PP composites and interfacial relation.

4. Vinyl Ester Based PALF Reinforced Composites.

Now natural fibres are widely used in the research as a substitute of glass fibre (GF) in fibre reinforced plastics (FRP). In comparison to glass fibre, these natural fibres have lower densities, are economical, consume lesser energies during production, cause less or no abrasion to machines, and are not hazardous to health when inhaled. In spite of these properties, pineapple leaf fibres are untouched in research areas especially for reinforcing plastics although this application is now becoming an important research area. Now polymers composite is focused on using pineapple leaf fibres for developing value added applications. Despite several merits, PALF possesses inherent demerits such as poor interfacial fibre matrix adhesion and absorbing water. In the last two decades, a lot of researches have been carried out to optimize the problem of the interfacial adhesion between natural fibres and polymer matrices. There is not much literature available on PALF-vinyl composites. Vinyl esters are strong, flexible, and less hydrophilic in nature. Moreover, interfacial shear stress (IFSS) is the measurement of fibre-matrix adhesion which is always higher for natural fibre-vinyl ester compared to those of other matrices. Most of the work on PALF-reinforced thermoset composites used hand lay-up method in sample preparation and very few if any reported the use of liquid compression moulding process. As reinforced matrix, both untreated and bleached PALF are using in the form of random and unidirectional PALF mats.

5. Polyester Based PALF Reinforced.

PALF is obtained from the pineapple plant's leaves. Major compounds of PALF are cellulose (70–80%), lignin (5–12%), and ash (1.1). The recent study proved that by using different surface modified pineapple leaf fibres as reinforcing material can be used for polyester matrix. PALF fibre loading up to 30% by weight with polyester showed significant increment in flexural strength, tensile strength, and impact strength. Toughness of composite material is reached up to the benchmark of engineering materials. Surface modification by chemical treatment can enhance the strength of individual fibres and it can help to develop better mechanical strength PALF/polyester composite for commercial purpose.

6. Polycarbonate Based PALF Composite.

A poor contact between PALF and matrix are prone to moisture intake and ultimately degradation through insects and pests. Thus, fibre surface modification is an important and necessary step to reduce the polarity of fibre. There are many methods like alkaline treatment, grafting with maleic anhydride copolymer, saline coupling agent such as c-amino propyl trimethoxy silane (Z-6011) and c methacrylate propyl trimethoxy saline (Z-6030). Polycarbonate (PC) is an amorphous thermoplastic resin. It provides numerous vital and important characteristics such as lucidity, dimensional strength, high impact strength, and high heat resistant and flame resistance. Though there are some limitations of using the PALF in some applications. At low temperatures, it becomes softer and easy to remove from mould. There are very few research works published on the PALF reinforced with polymers.

7. Low Density Polyethylene Based PALF Composite.

Melt mixing and solution mixing techniques have been used in preparation of PALF reinforced LDPE composites. Solution mixed technique shows a better tensile strength than melt mixed technique. Relation of fibre size, loading %, and orientation with mechanical properties has been studied. Through fibre distribution curve and scanning electron micrographs, it is possible to analyse fibre rupture and damage during composite making. Fibre length of 6mm length was found to be suitable for PALF reinforced with LDPE. Mechanical properties are found to be improved and elongation at break is inversely proportional to fibre loading. In comparison to random and transverse orientation, longitudinal orientation of fibres showed better mechanical properties of composites. PALF LDPE composites are eco-friendly, biodegradable and exhibit superior performance than any other cellulose-fibre reinforced LDPE systems.

PALF Based Hybrid Composites

Various combinations of natural lignocellulosic composite are promising interest of researchers. It provides wide range of results and properties which is very difficult to achieve through a single type of reinforcement. This type of matrix is generally used for the fibre having good interaction between matrix and fibres and together gives a better mechanical performance. Thus, hybrid composite is the mixture of two different types of fibres reinforced into a matrix. It has various improved qualities which help to make it best composite. Individual strength of fibres is combined to achieve improved composite with better efficiency. Many researches are in progress for partially or fully replacement to glass fibres (GF) by natural fibres. GF has very good quality of reinforcement along with natural fibres like sisal, jute, pineapple, hemp, and so forth. Composites and hybrid composites with PALF are shown in Table 4. Mechanical characteristic of hybrid composite and GF is studied by Thomas *et al*., Idicula *et al*. studied the well mixed random orientation of banana/sisal hybrid fibre reinforcement with polyester composite. Transformation maximum stress between fibres and matrix has been calculated for the composite of banana and sisal fibre ratio 3:1, showing lowest impact strength. There is another composite of natural fibre reinforced with short carbon and kenaf fibre hybrid system. On the basis of these studies, the aim of this research is to develop a high-performance, cost-effective, and lightweight pineapple leaf fibres and GF as the reinforcement-based hybrid composites. Utilization of pineapple leaf with disposable chopsticks is very popular. Pineapple leaf fibre (2.3–3.9 mm) and recycled disposable chopstick fibres were integrated into PLA and PBS. The optimum ratio and content of the hybrid fibres were investigated in order to obtain the best thermal and mechanical properties.

Table 4: PALF bio composites and hybrid composites with thermosets and thermoplastics

Natural fibre	Resin
PALF	Vinyl ester
PALF	Epoxy
PALF	Polycarbonate
PALF	Polypropylene
PALF	Polyester
PALF	Low density polyethylene
PALF	polyethylene
PALF + banana	Epoxy resin
PALF+ disposable chopstick hybrid fibre	PLA & poly butylene succinate (PBS)
PALF + Kenaf	HDPE
PALF + glass fibre	Polyester

PALF Applications and Future Prospects

PALF is generally used in making threads for textile fabrics from several decades. A future prospect of diversified application of PALF is presented in Figure 6. Present application of PALF for various purposes is textile, sports item, baggage, automobiles, cabinets, mats, and so forth. Surface modified PALF is introduced for making machinery parts like belt cord, conveyor belt cord, transmission cloth, air-bag tying cords, and some cloths for industry uses. PALF is very good for carpet making because of its chemical processing, dyeing behaviour, and aesthetically pleasing fabric. The use of pineapple leaf fibre can be considered relatively as new in the paper manufacturing industry in Malaysia. PALF can be suitable for various other applications such as cosmetics, medicine, and biopolymers coating for chemicals. The pineapple leave fibre is one of the natural fibres, having highest cellulosic content nearly 80%. Its density is similar to the other natural fibres while Young's modulus shows highest tensile strength when compared to other natural fibres. These properties are suitable for its application as building and construction materials, automotive components, and furniture. From this review it is clear that limited work has been done on thermal, electrical, dynamic, and mechanical properties. Till now, PALF has been studied as being reinforced with PP and unsaturated polyester only, so it is required to understand its behaviour with other resins also in relation to fabricated biocomposites and hybrid composites. PALF is widely accepted in textile sector and already used in our daily life materials but we attribute that further study will enhance the application in various other exiting products.

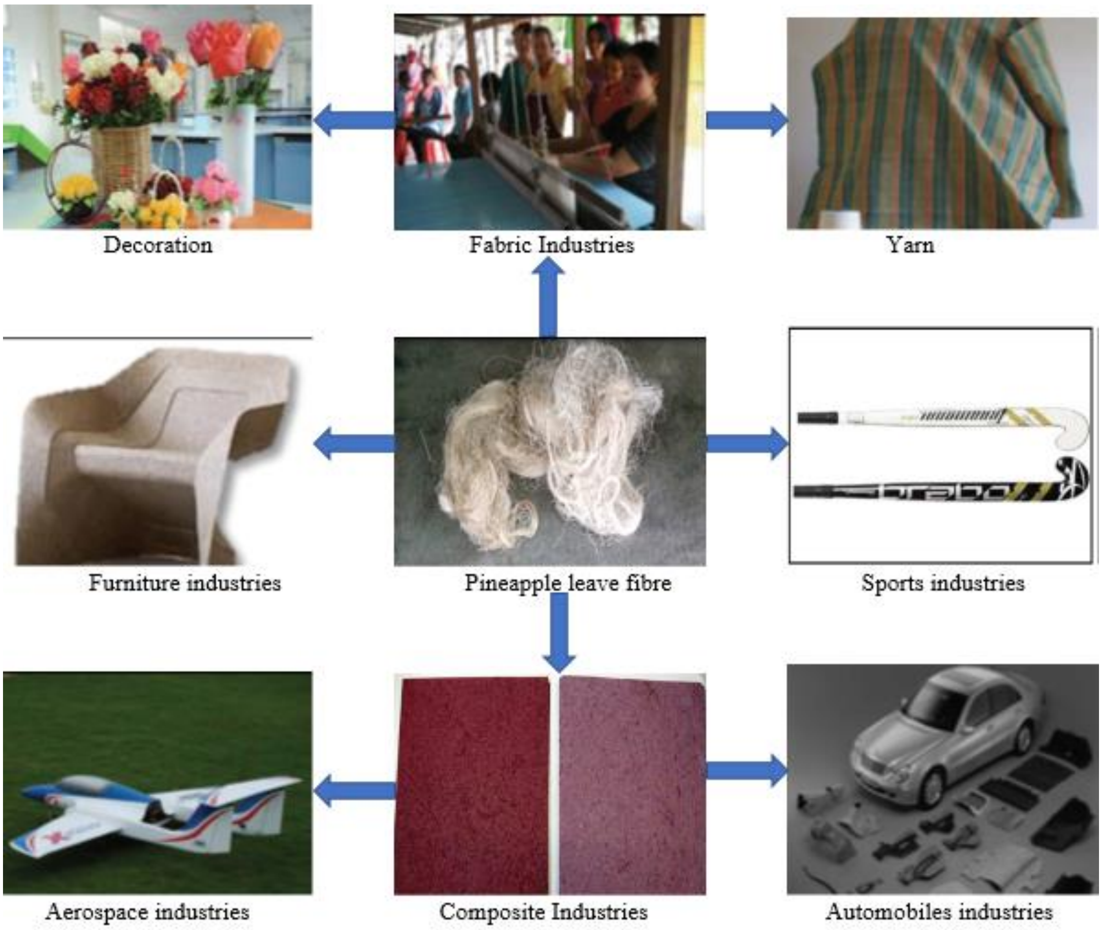

Fig 6: Various present and future applications of pineapple leaves.

Conclusion

Pineapple leaf fibre is very common in tropical regions and very simple to extract fibres from its leaves. The utilization of pineapple leaf fibre in composite material is a new source of materials which can be economic, eco-friendly, and recyclable. Synthetic fibres can be replaced or partially substituted with PALF in fabrication of composite products for different applications. Pineapple is one of the natural fibres having highest cellulosic content nearly 80%. Density of PALF is similar to other natural fibres while Young’s modulus is very high, and tensile strength is highest among the related natural fibres. These properties are suitable for its application as building and construction materials, automotive components, and furniture. PALF fibres can be used as reinforcements in various thermoset, thermoplastic, rubber, and cement resin matrices. These fibres can also be used in the preparation of hybrid composites with synthetic fibres such as glass fibre. PALF is widely accepted in textile sector and already used in our daily life materials but we attributed that further study will enhance its application in development of various existing products.

References

1. Asim M, Abdan K, Jawaid M, Nasir M, Dashtizadeh Z, Ishak MR, *et al*. A Review on Pineapple Leaves Fibre and Its Composites. International Journal of Polymer Science, 2015.
2. Leao AL, Souza SF, Cherian BM, Frollinin E, Thomas S, Pothan LA, *et al*. Pineapple Leaf Fibers for Composites and Cellulose. Molecular Crystals and Liquid Crystal. 2010; 522:336-341.
3. Prado KS, Pinacé MAS. Characterization of Fibers from Pineapple’s Crown, Rice Husks and Cotton Textile Residues. Materials Research. 2015; 18(3):530-537.
4. Yusof Y, Yahya SA, Adam A. Novel technology for sustainable pineapple leaf fibers productions. Procedia CIRP. 2015; 26:756-760.
5. Mishra S, Mohanty AK, Drzal LT, Misra M, Hinrichsen G. A Review on Pineapple Leaf Fibers, Sisal Fibers and Their Biocomposites. Macromolecular Materials and Engineering, 2004, 955-974.
6. Adam A, Yusof Y, Yahya A. Extraction of Pineapple Leaf Fibre: Josapine and Moris. ARPN Journal of Engineering and Applied Sciences. 2016; 11(1):161-165.
7. Liu W, Misra M, Askeland P, Drza LT, Mohanty AK. Polymer. 2005; 46:2710-2721.
8. Devi LU, Bhagawan SS, Thomas S. Mechanical Properties of Pineapple Leaf Fiber-Reinforced Polyester Composites, 1996, 1739-1748.