

Chapter 2

Tropical Natural Fibres and Their Properties

Abstract In this chapter, a background of the importance of natural fibres is presented. The advantages and disadvantages of tropical natural fibres are listed. The chapter elaborates seven types of tropical natural fibres commonly being studied and used. The information about fibre extraction process, the application of fibres and other important topics are discussed.

Keywords Fibre extraction • Advantages of natural fibres • Natural fibre products • Tropical natural fibres • Kenaf fibres

2.1 Background

Natural fibre encompasses all forms of fibres from woody plants, grasses, fruits, agriculture crops, seeds, water plants, palms, wild plants, leaves, animal feathers, and animal skins. By-products of pineapple, banana, rice, sugarcane, coconut, oil palm, kenaf, hemp, cotton, abaca, sugar palm, sisal, jute and bamboo are among the fibres known to be used to make composites. Wool and silk are strong fibrous materials and wool had been used in textile industry dated back from 35,000 years ago and silk from at least 5,000 years [38]. The ancient Egyptians had been reported to have used natural fibre composites, made from straw and clay or mud around 3,000 years ago. But in this book, the study is restricted only to plant based fibres. In the recent years, there has been a growing interest in the application of natural fibres as reinforcements for polymer matrices. Natural fibre has good potential as reinforcement in thermoplastic and thermoset polymer composites mainly due to low density and high specific properties of fibres. Natural fibres have the properties, composition, structures and features that are suitable to be used as reinforcements or fillers in polymer composites.

The plant based fibres contain cellulose and non-cellulose materials such as hemicelluloses, pectin and lignin; thus they are also known as lignocellulosic or cellulosic fibres. Cellulose is semicrystalline polysaccharide found in natural fibres

and it is the reason for the natural fibres to demonstrate hydrophilic behaviour. It provides strength and rigidity to the fibres. Hemicellulose is an amorphous polysaccharide and its molecular weight is lower than cellulose. Fibres are held together by means of pectin. Pectin is a class of plant cell wall polysaccharide that can be found in a plants' cell wall. Lignin acts as a binder for the cellulose fibres and it adds strength and stiffness to the cell walls. Holocellulose contains mainly of *cellulose* and hemicelluloses and it is the total polysaccharide of natural fibres. It is obtained after removal of extractives and lignin from natural fibres. A Lumen is a cavity inside fibre cells. Ash and wax are normally contained in the fibers.

Natural cellulose fibres are extracted from lignocellulosic by-products using biological retting (bacteria and fungi), chemical retting (boiling in chemicals), mechanical retting (hammering, decortications), and water retting. Natural fibres can be used in the form of particulate or filler, short fibres, long fibres, continuous roving, woven fabric and non-woven fabric.

2.2 Advantages of Natural Fibres

Comparing to conventional reinforcing fibres like glass, carbon and Kevlar[®], natural fibres have the following advantages:

- Environmentally friendly
- Fully biodegradable
- Non toxic
- Easy to handle
- Non abrasive during processing and use
- Low density/light weight
- Compostable
- Source of income for rural/agricultural community
- Good insulation against heat and noise [24]
- Renewable, abundant and continuous supply of raw materials
- Low cost
- Enhanced energy recovery
- Free from health hazard (cause no skin irritations)
- Acceptable specific strength properties
- High toughness
- Good thermal properties
- Reduced tool wear
- Reduced dermal and respiratory irritation
- Ease of separation
- The abrasive nature of natural fibres is much lower compared to that of glass fibres, which offers advantages with respect to processing techniques and recycling [10].

2.3 Disadvantages of Natural Fibres

However, natural fibre suffered from the following drawbacks:

- Poor compatibility with hydrophobic polymer matrix
- The fibres degrade after being stored for a long period
- The inherent high moisture absorption
- The relatively high moisture absorption
- The tendency to form aggregates during processing [10]
- The low resistance to moisture [10]
- Low thermal stability [26]
- Hygroscopicity.

2.4 Types of Natural Fibres

In this section a review of various types of tropical natural fibres is made. Apart from general information about the fibres, typical applications of fibres are also presented.

2.4.1 *Banana Fibres*

Banana (*Musa*) is a high herbaceous plant (see Fig. 2.1) normally of 2–16 m high [6]. Although banana leaves (Fig. 2.2) were reported to be used as fibres in polymer composites, majority of work on banana fibres focused on the use of banana pseudo-stem (trunk) fibres (Fig. 2.3) as the reinforcement or filler in polymer composites. Pseudo-stem fibre is a bast fibre and it can be extracted after the fruit bunch was harvested by scrapping with a blunt knife or by using an extractor machine. Banana stem fibres are extracted by initially cutting into lengths of convenient size, and peeling layer-wise (see Fig. 2.4). The individual sheaths were dried under sun for 2 weeks (see Fig. 2.5) and then they were soaked in water for two more weeks. Once the lignin and cellulose were separated, the sheaths were dried again and the fibres were ripped off [42]. Typical density of banana fibre is 1,350 kg/m³, cellulose/lignin ratio is 64/5, modulus is 27–32 GPa, ultimate tensile strength is 529–914 MPa and water absorption is 10–11 % [7]. Joseph et al. [15] reported that the elongation and toughness of typical banana fibre were 3.0 % and 816 MN/m² respectively. Banana fibre has a non-mesh structure and has long filaments [29] Fig. 2.6 shows banana pseudo-stem fibres in woven mat form.

Bilba et al. [6] studied botanical composition, thermal degradation and textural observations of banana leaf and stem before they can be proposed as reinforcements in composites. Benítez et al. [5] investigated the effect of physical and

Fig. 2.1 Banana trees**Fig. 2.2** Banana leaf

chemical treatments of banana fibres in order to use them as reinforcements in polymer composites and the specimens were prepared using injection molding process. Guimarães et al. [12] carried out studies on chemical composition, X-ray

Fig. 2.3 Banana pseudo-stem



Fig. 2.4 Preparing of banana pseudo-stem fibres



powder diffraction analysis, morphological analysis and thermal behaviour of banana fibres. Thermal stability of the fibres was around 200 °C and decomposition of both cellulose and hemicelluloses in the fibres took place at 300 °C and above, while the degradation of fibres took place above 400 °C (Fig. 2.7).

Fig. 2.5 Drying of banana pseudo-stem fibres under the sun



Fig. 2.6 Woven banana fibres



Banana fibres are used to make high quality textile for generations and in Japan it was used to make famous Japanese dress called kimono. It was also reported that banana fibres were used as reinforcing fibres in polymer composites and in paper making [31]. The fibre can also be used as raw material for board and cellulose derivatives.

2.4.2 Coconut Fibres

Coconut (*Cocos nucifera*) is the plant of a species of palm. It is a tropical plant (Fig. 2.8) of the Areceae (Palmae) family. Coconut fibres are mainly taken from coirs (Figs. 2.9, 2.10 and 2.11), and to a lesser extent, coconut shell (Fig. 2.12) and

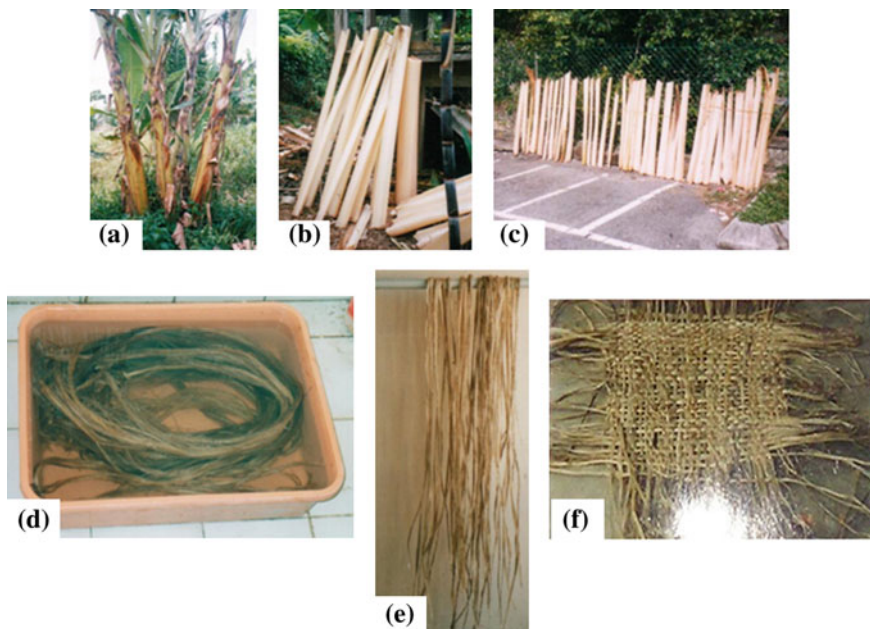


Fig. 2.7 Steps in preparation of banana fibres **a** banana plant **b** cutting **c** drying **d** soaking **e** re-drying **f** weaving

Fig. 2.8 A coconut plant



Fig. 2.9 Young coconut fruits



Fig. 2.10 Matured coconut fruit



spathe is used normally in the form of fillers. Coconut spathe, the covering of the coconut inflorescence, is an under-exploited material with considerable potential. This part of coconut tree is left out because demonstrates no good mechanical properties. Spathe is used as decorative (Fig. 2.13) as sold in gift shops in Kota Kinabalu, Sabah, Malaysia.

Substantial research has been carried out on coconut coir fibre and coconut shell filler and their composites. Coir is the seed-hair fibrous material found between the hard, internal shell and the outer coat (endocarp) or husk of a coconut. Coir fibre is a coarse, stiff and reddish brown fibre and is made up of smaller threads, consists of lignin, a woody plant substance, and cellulose [21]. Coir has been used for making twine, mats and brooms. It was also used in hydroponic growing [20].

Fig. 2.11 Coir fibres



Fig. 2.12 Coconut shells



Fig. 2.13 Coconut spathe



Fig. 2.14 Kenaf plant
(Courtesy of Mr. Wan Mohd
Haniffah Wan Husain)



2.4.3 Kenaf Fibres

Kenaf (*Hibiscus cannabinus L.*) was a native of West Africa and had been cultivated from around 4000 B.C. [3]. It is a member of the Hibiscus gene and a family of Malvacea which is similar to cotton and okra [28]. Kenaf is a warm season plant, which requires a short period of sunlight. It has been grown for several 1,000 years for fibre and food. It is a common wild plant of tropical and sub-tropical Africa and Asia. It is a high carbon dioxide absorbent plant. Kenaf is a fast growing tree and could be harvested in just 4–5 months. It has very short life cycle and cultivation of kenaf produced high biomass output [35]. Kenaf stalk is made up of a soft inner core and a fibrous outer bast surrounding the core (Fig. 2.14).

Kenaf bast fibre is longer than soft wood fibre, i.e. 10 mm for the former [18] and 5 mm for the latter [32]. The diameter of the bast fibre bundles is smaller than that of softwood, but the tensile strength is three times greater. The kenaf bast fibre has the potential as a reinforcing fibre in thermoplastic composites because of its superior toughness and high aspect ratio in comparison with other fibres.

Fig. 2.15 Long kenaf fibres



Fig. 2.16 Random short kenaf fibres



Fig. 2.17 Kenaf filler

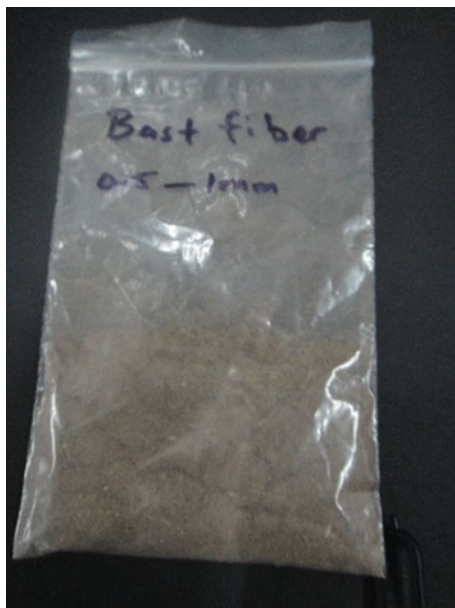


Fig. 2.18 Woven kenaf fibres



Fig. 2.19 A typical pulverizer to produce fillers (Courtesy of Innovative Pultrusion Sdn. Bhd, Seremban, Negeri Sembilan, Malaysia)



According to Karnani et al. [17], a single fibre of kenaf can have a tensile strength and modulus as high as 11.9 and 60.0 GPa respectively. These properties can vary depending on the source, age and separating techniques of the fibre. Figures 2.15, 2.16, 2.17 and 2.18 show long kenaf fibres, random short kenaf fibres, kenaf filler, and woven kenaf fibres respectively. Kenaf is a light weight material, and its density is approximately 0.15 g/m^3 . This material can easily be crushed to form fillers. Figure 2.19 shows a typical pulverizer to produce fillers. Its cellulose and lignin contents are approximately 32 and 25 %, respectively. Kenaf core has higher hemi-cellulose content than wood.

Fig. 2.20 Beg from kenaf fibre (Courtesy of National kenaf and Tobacco Board, Malaysia)



In Malaysia, National kenaf and Tobacco Board (NKTB), Kubang Kerian, Kota Bharu, Kelantan established in April 2010 under the National kenaf and Tobacco Board Act 2009 [34]. It is now the policy of the government to replace tobacco with kenaf. Kenaf can be used as high quality bedding, woven and non-woven textiles, animal feed, oil absorption, fibre composite boards and paper [36] and bag (see Fig. 2.20).

2.4.4 Oil Palm Fibres

Oil palm (*Elaeis guineensis*) (see Fig. 2.21) is reported to originate from tropical forests in West Africa and it was introduced in Malaysia in 1870 [4]. Oil palm empty fruit bunch (EFB) (Fig. 2.22), oil palm frond (OPF), oil palm trunk (OPT), kernel shell, pressed fruit fibre (fruit mesocarp) and palm oil mill effluent (POME) generated from oil palm industry are regarded as waste and unutilized. These products normally caused major environmental pollution [14]. Lignocellulosic fibres can be extracted from OPT, OPF, fruit mesocarp and EFB [37]. Oil palm fibre (OPF) is extracted from EFB by retting process. The available retting processes are mechanical retting (hammering), chemical retting (boiling with chemicals), steam/vapour/dew retting and water/microbial retting [37]. Water retting is the most popular process among all those processes [30].

Fig. 2.21 Oil palm tree



Fig. 2.22 Empty fruit bunch (EFB) after palm oil extraction process



Oil palm fibre is hard and tough. However the presence of hydroxyl group made the fibres hydrophilic, leading to poor interfacial bonding with hydrophobic polymer in composites. This in turn, results in poor physical and mechanical properties of the composites [30].

Fig. 2.23 Sugar palm tree

2.4.5 Sugar Palm Fibres

Sugar palm (*Arenga pinnata*) is native to Indo-Malayan archipelago, it can be found in tropical South East and South Asia, Guam, Papua New Guinea [25]. Sugar palm (*Arenga pinnata*) is called by different names such as *kabung* or *enau* in Malaysia, *aren* in Indonesia and *gumoti* in India. Sugar palm fibre is a kind of natural fibre (in textile form) that comes from *Arenga pinnata* plant; a forest plant that can be found enormously in Southeast Asia like Indonesia and Malaysia. This fibre seems to have properties like other natural fibres, but the detail properties are not generally known yet. In Malaysia, sugar palm trees can be found in Bruas and Parit in Perak, Raub in Pahang, Jasin in Melaka and Kuala Pilah in Negeri Sembilan [27]. There are approximately 809 ha of sugar palm plantation found in Tawau, Sabah and 50 ha found in Benta, Pahang [33]. Figure 2.23 shows a sugar palm tree.

Generally, sugar palm fibre called *ijuk* in Malaysia has desirable properties like strength and stiffness and its traditional applications include paint brush, septic tank base filter, clear water filter, door mat, carpet, rope, cushion, roof material, broom, chair/sofa cushion, and for fish nest to hatch its eggs [39]. In certain regions in Indonesia, traditional application of sugar palm fibre includes handcraft for *kupiah* (Acehnese typical headgear used in prayer) and roofing for traditional house in Mandailing, North Sumatra, Indonesia. The sugar derived from the sugar palm tree is called palm sugar and it is one of the local delicacies widely consumed by Asians for making cakes, desserts, food coatings or mixed with drinks. It is



Fig. 2.24 Bali lamp from sugar palm fibre

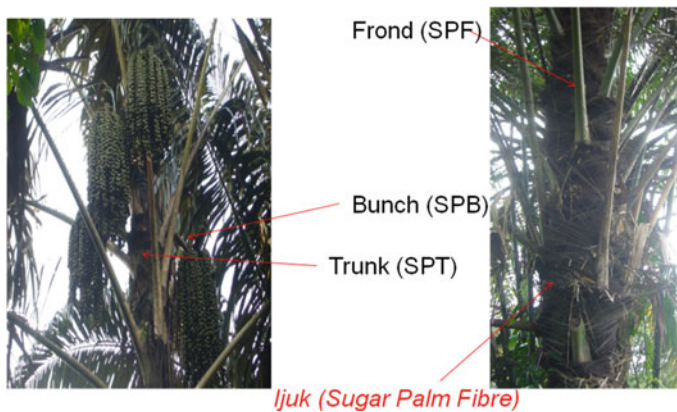


Fig. 2.25 Sources of sugar palm fibres

produced by heating the sap derived from the sugar palm tree [13]. Sugar palm is proven to be acid and salt water resistant that made it feasible for use as rope used fisherman and domestic septic tank base filter. Figure 2.24 shows the use of sugar palm fibres in lamp in Bali, Indonesia. In fact, not only *ijuk* (natural woven cloth fibre) can be a useful source of fibres; other parts in sugar palm tree like sugar palm front (SPF), sugar palm bunch (SPB) and sugar palm trunk (SPT) can be used as fibres as shown in Fig. 2.25.

Fig. 2.26 Sugarcane trees

2.4.6 Sugarcane Fibres

Sugarcane (*Saccharum Officinarum*) is one of the major crops in Tropical region (Fig. 2.26). Total plantation area of sugar cane in Malaysia is nearly 34,500 acres [22]. Total plantation area of sugar cane in Malaysia is nearly 34,500 acres [22]. Sugarcane stalk (Fig. 2.27), from which bagasse fibres are derived, consists of an outer rind and an inner pith. Bagasse fibres are obtained after the extraction of the sugar-bearing juice from sugarcane [41]. Extracting sugar cane fibres from the plant stalks was considered to be a difficult and costly task [9]. Figure 2.28 shows a decortication machine to extract sugarcane juice from sugarcane juice maker in Malaysia. Residue of this sugarcane milling process gathered is a good source of sugarcane fibres.

Bagasse or sugar cane pulp fibres (sometimes called sugarcane bagasse) should be alkalinised, dried (Fig. 2.29), and milled before they can be used as high quality fibres [23]. Chiparus [9] reported that fibres in bagasse consist mainly of cellulose, pentosans, and lignin while [40] reported that chemical contents of bagasse are cellulose (35–40 %), natural rubber (20–30 %), lignin (15–20 %) and sucrose (10–15 %). Typically, the tensile strength of bagasse fibres is 70.85 MPa [8].

Utilization of sugarcane bagasse may contribute to environmental and economic development. Effort has been made to commercialize sugar cane fibres as useful products. Malaysia Airlines declared in 2012 that the meal box served on board from short haul flights to domestic and regional destinations are made from 100 % recyclable sugar cane fibre [1]. Bagasse has been used as a combustible

Fig. 2.27 Sugarcane stalk-
source of bagasse fibres



Fig. 2.28 Sugarcane
decortication machine



material for energy supply in sugar cane factories as in thermal power station in Guadeloupe (the French West Indies). Bagasse was also reported to be used in pulp and paper industries and for board materials [11]. Bagasse ash form bagasse fibres can be used as secondary filler in silica or carbon black filled natural rubber compound as reported by Kanking et al. [16].

Fig. 2.29 Drying of bagasse fibres



Fig. 2.30 Pineapple tree



2.4.7 Pineapple Leaf Fibres

The scientific name of pineapple plant is *Ananas comosus* L. Pineapple is a long-leaf desert plant (Fig. 2.30) that can be grown in dry condition belonging to the Bromelicea family. The plant is normally grown in nurseries for the first year or so

Fig. 2.31 Fibre extraction by scraping (Courtesy of Dr. Januar Parlaungan Siregar, Universiti Malaysia Pahang)



Fig. 2.32 Separating fibres from soft covering material (Courtesy of Dr. Januar Parlaungan Siregar, Universiti Malaysia Pahang)



and matures about 12–20 months old. The width of each leaf is about 50–75 mm. The fibres are contained in the spiky leaf of plant. Pineapple is a fibrous plant and it was reported that its fibres was as reinforcement or filler in composites. The majority of the research work carried out on pineapple leaf fibre (PALF) composites has been done in India and some South East Asian countries like Malaysia and Thailand. This could be due to the fact that the raw materials can be obtained there very cheaply, and so there is a great potential to commercialize this product and to enhance the quality of life of the people living in rural areas [2].

Conventional methods for PALF extraction include scraping (Fig. 2.31), retting and decorticating with a decorticator start from long fresh leaf and use mechanical force to remove soft covering material to provide long fibres (Figs. 2.32 and 2.33). In general, it is observed that, these methods produced low yield of coarse fiber bundles and up-scaling process is not easy to perform. Kengkhetkit and Amorn-sakchai [19] have come up with a new extraction method called mechanical milling. Apart from being used as reinforcement for composites, PALF was used as sound and thermal insulations. In Indonesia, PALF was used as raw material in textile industry (Fig. 2.34).

Fig. 2.33 White and silky luster of PALF fibres
(Courtesy of Dr. Januar Parlaungan Siregar, Universiti Malaysia Pahang)



Fig. 2.34 Shirt from pineapple leaf fibre



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