J. Sahari[1, 2*],
S. M Sapuan[1, 2],
Z. N. Ismarrubie[2],
M. Z. A. Rahman[3]

Physical and Chemical Properties of Different Morphological Parts of Sugar Palm Fibres

[1)] Laboratory of Advanced Materials and Nanotechnology,
Institute of Advanced Technology,

[2)] Department of Mechanical and Manufacturing Engineering,

[3)] Department of Chemistry, Faculty of Science,
Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia

*E-mail: Kandhalawi_86@yahoo.com

Abstract
Recently, due to increased environmental concerns, scientists and technologists have placed great importance on the application of natural fibres, especially in biocomposites. The sugar palm tree is one of the most popular natural fibres used in engineering applications. A study on the fundamental properties of fibres from different morphological parts of the sugar palm plant, which are bunch, black sugar palm fibre, locally known as ijuk, trunk and frond was carried out in order to evaluate their potential as eventual raw materials for reinforced polymer composites. From this study, it wasd found that sugar palm frond (SPF) gives the highest tensile strength compared to the other parts, which is 421.4 N/mm^2. The tensile strength for sugar palm bunch (SPB), ijuk and sugar palm trunk (SPT) is 365.1, 276.6 and 198.3 N/mm^2, respectively. These results have been proven using those for their chemical compositions, where the highest cellulose content was obtained from SPF (66.5%), followed by SPB (61.8%), ijuk (52.3%), and SPT (40.6%). For water absorption testing, it was found that SPF also gave the highest percentage - 132.8%, followed by SPB, ijuk and SPT. Fourier transform infrared (FT-IR) spectroscopy was used in order to detect the presence of functional groups existing in sugar palm fibre.

Key words: *tensile properties, sugar palm, ijuk, bunch, trunk, frond.*

Introduction

In the past few decades, products made from natural fibre composites have yet to be seen in huge quantities. Due to the depletion of petroleum resources and awareness of global environmental problems, alternatives are being created for new green materials and products that are compatible with the environment [1]. These new biobased products, based on renewable plant and agricultural residues, are sustainable and eco-efficient products that can be used in various applications such as building, automotive furniture and packaging, which are currently dominated by products based on petroleum feedstock.

Natural fibre is now becoming a new alternative material that can replace petroleum based resources either alone or combined with another material to produce green composites. The advantages of natural fibres, such as low cost, low density, abundance, sustainability, recyclability and biodegradability make them more interesting to be applied in research in order to tap their full potential. Among important parameters that should be evaluated in natural fibres are tensile and chemical properties, as both parameters play a vital role in determinig the perfomance of fibres to be used for composites [2, 3].

The sugar palm tree, also known as *Arenga pinnata* , is one of the most famous plants in Malaysia and Indonesia. Sugar palm is suitable for producing renewable energy in the form of biofuels via a fermentation process derived from sugar collected from its bunch. Whereas for the African Palm, oil is extracted from both the pulp of the fruit and kernel as well. The variety of by-products of the sugar palm tree include foods and beverages, biopolymer, biocomposites, and it is a source of timber as well. The sugar palm tree is a member of the *Palmae* family and naturally a forest species [4]. Traditionally, the fibre has been used in various applications such as in brooms, rope, paintbrushes and roofs. The sugar palm is considered as one of the most diverse multi-purpose trees [5]. Almost all the parts of the tree can be used with important products such as sago, which is collected from the trunk. Besides that, vinegar, fresh juice and palm sugar can also be obtained from the sugar palm tree [6].

In order to enrich knowledge of sugar palm fibre reinforced polymer composites, understanding the basic mechanical properties of every part from the sugar palm tree is very important. Although the abundant source of sugar palm fibres is a waste of the plant It has great potential to be used as reinforcement for polymer composites. By-products from the sugar palm tree can be converted into high value products like composite materials [7]. Comprehensive research of its fundamental properties is necessary in order to completely evaluate the potential of sugar palm fibre for new applications [8].

The main objective of this research was to gain a better understanding and knowledge about the tensile and chemical composition (holocellulose, cellulose, hemicellulose, lignin, extractive and ash) of different morphological parts of the sugar palm plant and to explore their potential to be used as a new reinforcement in polymer composites.

Materials and methods

Preparation of sugar palm fibres

Sugar palm fibres were collected from Jempol, Negeri Sembilan, Malaysia. Fibre from different parts of the tree i.e trunk, *ijuk*, frond, and bunch were extracted. In order to obtain the fibre, every part of the sugar palm tree was shredded, separated and dried. Prior to that, the retting process was applied for one week to separate the stalk from the core of the sugar palm fibres. In this process, different parts of the sugar palm fibres were soaked separately in a water tank until the dirt vanished from the core section and the stalk was separated from the core. The fibres themselves remain relatively unchanged during this process.

Study of physical properties

An optical microscope - model Zeiss was used in order to determine the diameter of the fibres. Thirty fibres were measured and the average diameter calculated. A Water absorption test was carried out based on the ASTM D 750 standard, conducted to determine the hygroscopicity of the fibres when exposed to water. Samples from each mixture were placed in an oven at a temperature of approximately 105 °C for 24 hours or until a constant oven dry weight was achieved [9]. The samples were then put into a dessicator

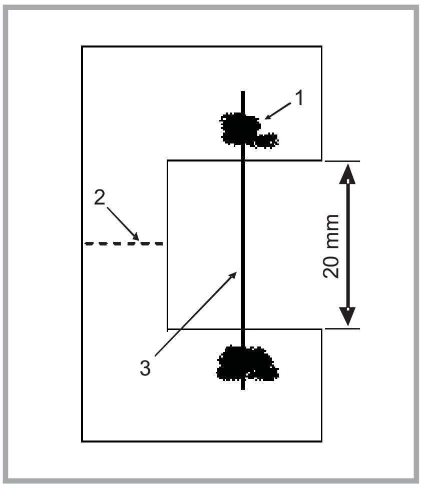

Figure 1. Specimen for single tensile test; 1 - adhesive, 2 - cutting line, 3 - fibre.

Table 1. Physical properties of fibres; ( ) refers to standard deviation.

Part	Water absorption, %	Diameter, μm
Sugar Palm Frond (SPF)	132.8 (25.8)	115.4 (6.5)
Sugar Palm Bunch (SPB)	123.7 (14.1)	254.7 (7.9)
Ijuk	103.8 (23.8)	221 (10.6)
Sugar Palm Trunk (SPT)	61.4 (11.1)	596.2 (7.4)

for 30 minutes and re-weighed for their oven dry weight. After that the reweighed samples were soaked in a beaker of water for 24 hours. On the following day, the samples were taken out from the water, dabbed dry and re-weighed once again to obtain the wet weight.

The percentage of water absorbed (WA) was calculated using Equation 1:

$$WA = (WW – OW)/OW \times 100\% \quad (1)$$

where,
WA - water absorbed in %
WW - wet weight in g
OW - oven dry weight in g.

Determination of tensile strength

A single fibre tensile test was conducted based on the ASTM D 3379 standard. Thirty specimens for each part were tested for their tensile strength with a 10 kN load-cell using an Instron tensile tester 5566. The gauge length was 20 mm, as shown in ***Figure 1***, and the crosshead speeds used were 1 mm/min and 2 mm/min.

Chemical composition

In order to obtain the chemical composition of the fibre, every part of the sugar palm tree was cut into chips and ground to pass through a BS 40 mesh sieve and be retained on a BS 60 mesh sieve. The fibre samples used in these experiments were roughly at equilibrium with the moisture of the air. The moisture was considered when determining the percentage of extractive, holocellulose, lignin and ash. Determination of the extractive, alpha-cellulose, lignin and ash content was undertaken following TAPPI standard methods: TS os-73, T 203 os, T 222 os-74 and T 15 os-58, respectively. The content of Hollocellulose was determined based on a previous method created by other researchers [10].

Spectroscopic characterisation

Fourier transform infrared (FT-IR) spectroscopy was used in order to detect the presence of functional groups existing in sugar palm fibre. Spectra of the fibre were obtained using an IR spectrometer (100 Series type, Perkin-Elmer). About 2 mg of the sample, which was in powder form, was mixed with potassium bromide (KBr) and pressed into a disc of about 1 mm thick. FT-IR spectra of the sample were collected in the range of 4000 - 200 cm^{-1}.

Results and discussion

Physical properties of the fibres

The diameter and percentage of water absorption of sugar palm fibres are shown in ***Table 1***. From the table, it can be seen that SPT fibre has the largest diameter, followed by SPB, *ijuk* and SPF. It was shown that SPF gave the highest percentage of water absorption, followed by SPB, *ijuk* and SPT, i.e. 132.8%, 123.7%, 103.8% and 61.4%, respectively. SPF and SPB absorbed more water compared to *ijuk* and SPT because of the fact that the height of SPF and SPB in the tree is greater than than that of *ijuk* and SPT. The higher the fibres, the younger their age will be, and they are more active in developing cells for the photosynthesis process. Similar findings have been reported, where water is an important factor in regulating the productivity of the plant [11].

Tensile stress-strain behaviour

Figure 2 show the stress–strain curves of fibres from different parts of the sugar palm tree. From both figures, it is observed that there is no significant difference between the results for 1 mm/min and 2 mm/min, indicating no effect of the strain rate on the tensile behaviour of the materials. The stress–strain curves for all types of fibres show a linear behaviour at low strains, followed by a drastic change in slope for SPF and SPB. However, for *ijuk* and SPT, the curves initially show linear behaviour up to approximately 5% of the strain, followed by non-linear behaviour up to 22 and 29%, respectively. Both curves show a nonlinear behaviour at a higher strain, maintained up to complete failure. The higher the strain, the more ductile the materials are. In the linear regions, the material which has the highest slope is considered to be the stiffest. Thus this phenomenon indicates that SPF is the stiffest, followed by SPB, *ijuk* and SPT.

Tensile strength

The tensile strength, modulus and strain of sugar palm fibre are given in ***Table 2***, which shows that the tensile strength of SPF is higher than that of the other sugar palm fibres, which is 421.4 N/mm^2. The tensile strength of SPB, *ijuk* and SPT is 365.1, 276.6 and 198.3 N/mm^2, respectively. Overall, the tensile strength for all the sugar palm fibres is almost the same as for oil palm, coir and kenaf fibres, which is in the range of 100 – 450 N/mm^2. It means that all parts of sugar palm fibre (SPF, SPB, *ijuk* and SPT) are suitable to be used as reinforcement in polymer composites. However, these tensile prop-

Table 2. Mechanical properties of sugar palm fibre and some other fibres; ( ) refers to standard deviation.

Natural fibre	Tensile strength, N/mm^2	Tensile modulus, kN/mm^2	Strain, %	Diameter, μm	Ref.
SPF	421.4	10.4	9.8	115.4 (6.5)	Current study
SPB	365.1	8.6	12.5	254.7 (7.9)	
SPT	198.3	3.1	29.7	596.2 (7.4)	
Ijuk	276.6	5.9	22.3	221 (10.6)	
Coir	138.7	6	10.5	396.9 (67.9)	[13, 14]
Kenaf	215.4	13-17	1.2 - 1.3	-	[15, 16]
Oil Palm Fibre	284.0	6.7	14	-	[17]
Kevlar	3000	60	2.5 - 3.7	-	[18]

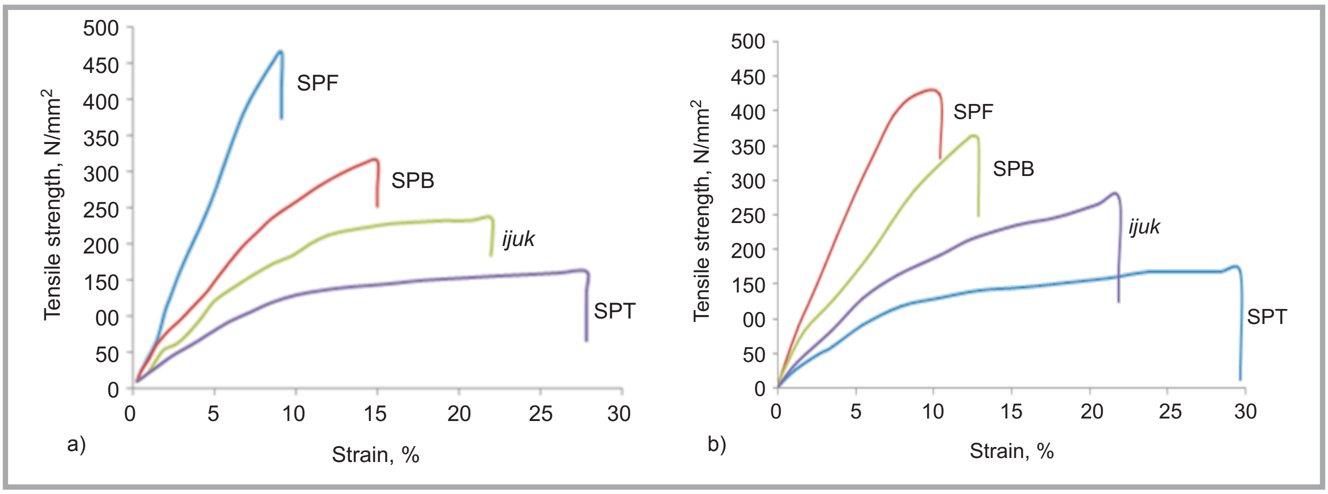

Figure 2. *Tensile stress-strain curve of fibres at: a) 1 mm/min and b) 2 mm/min.*

erties are much lower when compared to aramids, such as Kevlar [12].

The tensile modulus of SPF, SPB, *ijuk* and SPT are 10.4, 8.6, 5.9 and 3.1 kN/mm^2, respectively, showing that SPF demonstrates the highest stiffness among the sugar palm fibres tested. Compared with other established natural fibres (6 - 17 kN/mm^2), the tensile moduli obtained from all parts of sugar palm fibre are lower, meaning that the stiffness of sugar palm fibre is lower compared to other natural fibres.

For the strain analysis, it was found that all of the SPF, SPB, SPT and *ijuk* gave a high value compared to other fibres, from which we can conclude that sugar palm fibre is more flexible than other natural fibres. The sugar palm fibres which are SPF, SPB, SPT and *ijuk* exhibit a little bit of the same behaviour as that of oil palm and coir fibres in terms of physical and mechanical properties because they are of the same palmae family [13].

Chemical composition

Table 3 shows the results of the chemical composition of fibre from different parts of the sugar palm tree. Plant fibres are composite materials designed by nature. Basically, most plant fibres consist of cellulose, hemicellulose, lignin, extractive and ash [18]. The major component in most plants is cellulose, being the main element that provides strength and stability to the fibre [19]. From ***Table 3***, it is shown that SPF has the highest cellulose content compared to the others - 66.5%, whereas the cellulose content for SPB, *ijuk* and SPT are 61.8, 52.3 and 40.6%, respectively, proving the fact that the mechanical properties of sugar palm frond (SPF) are strongly influenced by the cellulose content [20]. Cellulose is the main structural component that provides strength and stability to the plant cell walls and fibres [21]. The results obtained have good agreement with those attained previously, where the cellulose content of *ijuk* collected from Indonesia was approximately 50%, while hemi-cellulose, lignin, ash, and moisture contents were 7, 45, 3 - 7, and 9.5%, respectively [22]. However, these results are slightly different from those of the current study due to variation in the growth area of the fibres.

From ***Table 3***, it was found that extractives and ash are minor components, with the table giving 2 - 7% for extractives and 2 - 5% for ash. The existence of extractive material, espeacially in wood, influences the odour and colour of the plant. As far as lignin is concerned, SPT has the highest content of lignin - 46.44%, proving that lignin is the compound that gives rigidity to the plants [1]. It also adds to the wood's toxicity and makes it more resistant to decay caused by attacking insects.

Spectroscopic characterisation

FT-IR spectroscopy is one of the powerful tools used to evaluate the specificity of funtional groups that exist in each morphological region. ***Figure 3*** (see page 24) shows the FT-IR spectra for all 4 types of sugar palm fibre i.e. SPB, SPF, *ijuk* and SPT. From the figure, it is shown that the spectra were almost the same among the 4 types of fibre. There are also no major differences observed when compared with other established fibres.

The intense peaks at 3200 - 3500 cm^{-1} ,shown in ***Figure 3*** (see page 24), indicated the presence of O-H groups in all parts of the fibres, due to hydroxyl groups found in celluloces, hemicelluloses and lignin. Peaks at 1600 - 1800 cm^{-1} represent carbonyl groups (C=O) in hemicelluloces and lignin [23]. The strong peaks at 2850 - 3000 cm^{-1} and 1000 - 1300 cm^{-1}, assigned to C-H stretching and C-O groups, resectively, are also present in all 4 types of fibres. The peaks at 1475-1600 cm^{-1} correspond to the stretching of the aromatic groups present in lignin [24, 25].

Conclusions

From this investigation, the tensile and chemical properties of single fibres from different parts of the sugar palm tree i.e. SPF, SPB, SPT and *ijuk* have been evaluated. The results show that the highest tensile properties (tensile strength, tensile

Table 3. *Chemical composition of fibres*

Description	Sugar Palm Frond (SPF)	Sugar Palm Bunch (SPB)	Ijuk	Sugar Palm Trunk (SPT)
Moisture, %	2.7	2.7	7.4	1.5
Extractive, %	2.5	2.2	4.4	6.3
Holocellulose, %	81.2	71.8	65.6	61.1
Cellulose, %	66.5	61.8	52.3	40.6
Lignin, %	18.9	23.5	31.5	46.4
Ash, %	3.1	3.4	4.0	2.4

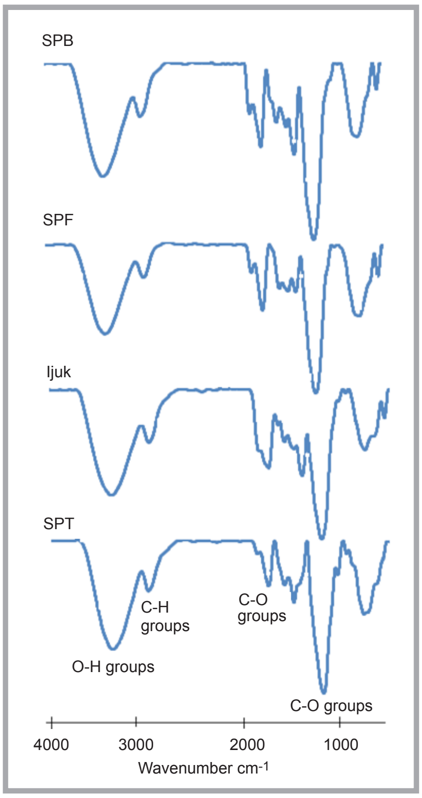

Figure 3. *FT-IR spectra of sugar palm fibres.*

modulus and elongation at break) were obtained from SPF i.e. 0.421, 10.4 kN/mm^2, and 9.8%, respectively, followed by SPB (0.365, 8.6 kN/mm^2, and 12.5%, respectively), *ijuk* (0.277, 5.9 kN/mm^2, and 22.3%, respectively), and SPT (0.198, 3.1 kN/mm^2, and 29.7%, respectively). These results have been proven using those of their chemical compositions, where the highest cellulose content was obtained from SPF (66.5%), followed by SPB (61.8%), *ijuk* (52.3%), and SPT (40.6%). For water absorption testing, it was found that SPF also demonstrated the highest percentage i.e. 132.80%, followed by SPB, *ijuk* and SPT. Finally, FT-IR spectroscopy was used to prove the specificity of funtional groups existing in each morphological region. Overall, the tensile and chemical properties of sugar palm fibre (SPF, SPB, SPT and *ijuk*) show almost the same results as other established natural fibres used as composite reinforcement, meaning that all parts of fibres from the sugar palm tree have the potential to be developed as new green composite products.

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