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Material Characterization of Roselle Fibre (*Hibiscus sabdariffa* L.) as Potential Reinforcement Material for Polymer Composites

DOI: 10.5604/12303666.1167413

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Abstract
Recently, in line with rising environmental concerns, researchers are now replacing synthetic fibres with natural ones as the main component in composites. Natural fibres are preferred to synthetic fibres because of several advantages such as biodegradable, light weight, low cost and good mechanical properties. Roselle is one of the plants found to be suitable to be used to produce natural fibres. In this work, we analysed the physical, thermal and mechanical characteristics of roselle fibre. Roselle fibre has good physical properties which lead to the dimensional stability of the composite product. The result obtained indicated that the moisture content of roselle fibre is 10.9%, while water absorption is 286.5%. Thermal gravimetric analysis (TGA) was conducted to understand the thermal stability of roselle fibre at high temperature. The results show that the initial degradation of roselle fibre starts at 225 °C and completes the decomposition of the lignocellulosic component at 400 4C. A tensile test was conducted to investigate the mechanical properties of roselle fibre. The tensile strength of roselle fibre is 130 - 562 MPa. On the basis of the properties of roselle fibres obtained, we concluded that roselle fibre is one of the good natural fibres that can be used as reinforced material for the manufacturing of polymer composites for different applications, while at the same time saving the cost required to manage the agro waste.

Key words: *Roselle fibre, physical properties, thermal properties, tensile test, mechanical properties.*

Introduction

Environmental issues are being addressed by many scientists and researchers nowadays. There is common agreement that these efforts are vital to ensure the survivability of mankind in the future. In order to be in line with this objective, material engineers have conducted studies to replace current synthetic fibres of reinforced materials with natural ones [1 - 4]. It is important for these replacement materials to be able to portray similar desired capabilities compared to their counterparts while introducing other 'green' characteristics. Natural fibres have been utilised for material reinforcement for more than 3000 years [5]. With the recent advancement in technology, they have been combined with polymers [6, 7]. Several types of natural fibres have been used for this purpose such as kenaf, roselle, jute, sugar palm, oil pump empty fruit bunch, sisal, pine apple leaf, rice husk, kapok, wood, barley oat coir and abaca [8].

Several reasons have attracted material engineers to use natural fibres to reinforce polymer composites such as a reduction of timber usage and the degradation of unused natural fibres. Other advantages include low cost, good mechanical properties, abundant availability, material renewability, biodegradability and abrasiveness in nature for ease of recycling [9 - 12]. These unused natural fibres can be processed into composite boards or other forms suitable for various applications while preserving the environment [1, 13]. Natural fibres can be found in southeast Asian countries such as Malaysia, Indonesia and Thailand [11]. Natural fibres such as roselle (*Hibiscus sabdariffa*) are found in abundance in nature and cultivated in Borneo, Guyana, Malaysia, Sri Lanka, Togo, Indonesia and Tanzania. The fruit of the roselle plant is commonly used in the medical [14 - 17] and food industries [18 - 20], as a textile [21 - 23] and is still under study as a reinforcement material for polymer composites [24, 25]. To this date, very limited studies have been done on the application of roselle fibres and its composites [26].

Roselle fibre is one of the natural fibres which have attracted researchers to explore their capability as a reinforcement material in composites. Some of the papers reviewed discussed the chemical and mechanical properties of roselle fibre in polymer composites [27, 28]. Roselle is a bast fibre from the Malvacae family [29]. It can grow annually and attain a height between 2 to 2.5 m [30]. The ro-

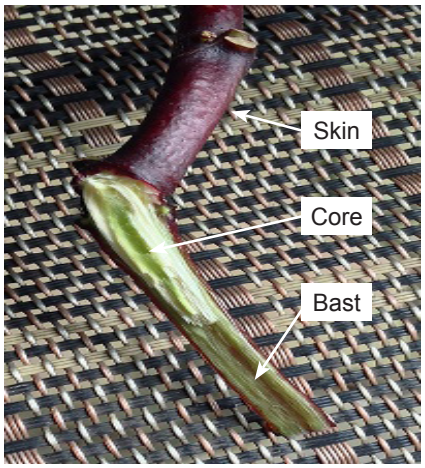

Figure 1. *Roselle stem.*

selle stem is red in colour, as illustrated in ***Figure 1***. In Malaysia, after a year, the roselle plant is cut and becomes a waste, which is because the quality of the roselle fruit is not suitable after a year. In order to use this plant efficiently, the fibre can be used as a reinforcement material for polymer composite. Roselle fibre can be extracted by water retting [31].

In order to produce fibre, it is desirable to have a long clean stem free of branches or fruiting stalks, which can interrupt the continuity of the fibre. This type of quality plant might be obtained only when it is grown in long sunny days for 3 to 4 months [32]. Since the production of quality fibre is dependent on an environment that promotes the continuous and rapid growth of the plant, 45.7 - 50.8 cm of rainfall during this 3 to 4 month period would seem to be desirable.

It is important to understand the properties of roselle before decisions can be made for its application. This paper studies in detail characteristics of roselle fibres which include physical, thermal, and mechanical properties.

Materials

Roselle plants were collected from Johor, Malaysia. Them roselle fibres were extracted by using the water retting process for 7 days. The retted stem of the roselle plant was washed in running water and fibres were removed manually. Next the fibres were cleaned and dried in sunlight. The roselle fibres were then prepared for several tests to study their potential as reinforcement materials in polymer composites.

Characterisation

Chemical composition

The chemical composition of roselle fibre is determine by using Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin.

Physical Properties

Diameter

The diameters of the roselle fibre were measured by using an optical microscope, the Zeiss model. produced by Carl Zeiss Microscopy, Singapore. Fifteen samples of single fibres were measured and the average diameter was obtained.

Density

The density of the roselle fibre was determined using a mathematical equation by dividing the mass over volume, as shown in ***Equation 1***. First the volume and weight of the container were measured. The volume of the container was determined by ***Equation 2***. Next the weight of the container was recorded as M_0. Roselle fibres were then prepared in powdered form by using a grinding machine. The powdered fibres were then put in the container. The container was then weighed as M_1.

$$Density = \frac{mass\ (M_1 - M_0))}{volume} \text{ in g/cm}^3 \quad (1)$$

$$Volume = height \times width \times depth \text{ in cm}^3 \quad (2)$$

Water absorption

The percentage of water absorption of roselle fibre was determined using ***Equation 3***. Seven samples were prepared and the average percentage of water absorption was calculated. The samples were weighed as M_0 first before being immersed in fresh water for 24 hours at room temperature. After 24 hours of immersion, the samples were then weighed again as M_1.

$$Water\ absorption = \frac{M_1 - M_0}{M_0} \times 100 \text{ in \%} \quad (3)$$

Moisture content

Seven samples were prepared for moisture content evaluation. The fibres were placed in normal climatic conditions at room temperature 27 ± 2 °C) with 65% relative humidity of air for 24 hours before weighing. Natural fibre is hydrophilic in nature, with its moisture absorption being strong related to the humidity of the air, e.g. the moisture content in fibres is higher in the case of the higher humidity of air. The percentages of moisture content of roselle fibre were determined using ***Equation 4***. The samples were heated in an oven for 24 hours at 105^0C[11]. Before heating the samples, the weight of fibre was measured as M_0. After 24 hours in the oven, the fibre was weighed again as M_1.

$$Moisture\ content = \frac{M_1 - M_0}{M_0} \times 100 \text{ in \%} \quad (4)$$

Morphology analysis

The morphology and cross section of the roselle fibre were observed under a scanning electron microscope (SEM), model Hitachi S-3400N, from Hitachi High Technologies, Singapore. Roselle fibre is very fine bast fibre, due to which it is difficult to obtain its cross section morphology . In order to overcome this problem, roselle fibres were immersed in liquid nitrogen to harden them and then gold coated in order to obtain a good quality of results.

Thermal properties

Thermogravimetric analysis (TGA)

Thermal characterisation of roselle fibre was performed using a Q series thermal analysis machine from TA Instrument , Malaysia. TGA measures weight changes in a material as a function of temperature (or time) under a controlled atmosphere. It is important to determine the degradation of natural fibre at high temperature before using it in polymer composites. About 4.8 mg of roselle fibre was placed in the chamber. An analysis was done in nitrogen atmosphere with a temperature range of 50 to 600 °C and heating rate of 10 °C/min.

Tensile properties

The tensile test is a simple method to know the mechanical properties of natural fibre. Several significant mechanical properties can be obtained from a tensile test such as Young's modulus, tensile stress, maximum elongation, tensile strain and yield stress. The tensile properties of roselle fibre were determined using a Universal Testing Machine, model Instron 5556, from Intron, Singapore, as shown in ***Figure 2***. The ASTM D3379 standard was used for a single fibre tensile test [13]. The gauge length of the roselle fibre samples was 20 mm and the cross-head speed 1mm/min with a 5 kN load cell. The fibre was properly selected under an optical microscope before being

Figure 2. *Tensile test for roselle fibre.*

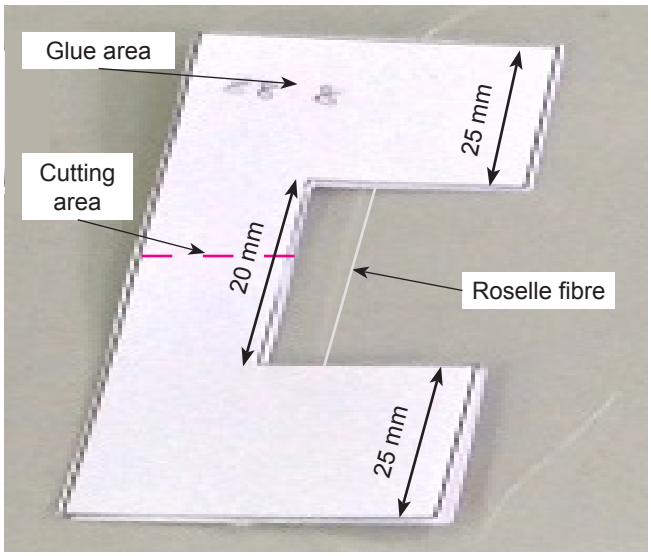

Figure 3. *Sample preparation for tensile test.*

tested to ensure that the specimen yields an accurate result. The fibre was glued onto the sample holder as shown in ***Figure 3***. Before testing was commenced, the sample holder needed to be cut in the middle. Fifteen samples of roselle fibre were prepared to perform a preliminary tensile test. Individual fibre breaking loads were recorded and their diameters measured using an optical microscope, type Lieca MS 5. The cross-sectional area of fibres in the area of failure was calculated as follows:

$$A = \pi d^2 \quad (5)$$

where, A - area, d - diameter

The tensile strength of the single fibre can be calculated using ***Equation 6*** [33].

$$\sigma_f = F/A \quad (6)$$

where, σ_f - tensile strenght of the fibre in Pa, F - maximum force at break in N, A - area of fibre cross section in m^2.

Results and discussion

Physical properties

The physical properties of natural fibre is one of the main factors which influences the properties of a composite product. Physical properties include the diameter of fibres, moisture content, density, water absorption and morphology. In this topic, details of roselle fibre properties will be discussed. It is clear from the results obtained that the diameter range of roselle fibre is 50 to 80 µm. ***Figure 4*** shows the substitute diameter measurement under an optical microscope at 400× magnification. The diameter measurement varies for each sample, which is due to the natural behaviour of the natural fibre, where it is hard to identify a single fibre with the naked eye. Technically, a single fibre consists of a bundle of fibres [34]. It is difficult to get a true dimension of roselle fibre. In contrast to synthetic fibre, the surface, smoothness, quality and shape of natural fibre is non uniform and inconsistent along the fibre length, which is a characteristic of natural fibre [35]. Diameter measurement of the fibre in this study is assumed to be circular in shape to simplify the calculation of the average diameter of the fibre [36]. Bodros et. al. describe that natural fibres are composed from plant cell walls and hollow cavity lumen. Based on their method, the fibres are assumed to be of a perfect cylindrical shape, and the lumens are not taken into account for practical reason. This is due to the difficulty of determining the dimension of lumen in practice, because of the inconsistent size of the scattered lumen in natural fibre. Similar approaches were practiced by several researchers to determine the diameter of the fibre for further calculation of the tensile properties of natural fibre [35 - 40]. In this study, we use a conventional method, following ASTM 3379 (tensile test for single fibre), where it is assumed that the fibre is cylindrically shaped, based on the previous work done by Bodros and Barley [36].

The density of roselle fibre is 1.41 g/cm^3, which is quite low. This feature is mainly caused by the natural presence of its lumen structure [41], which is hollow with thin walls, as depicted in ***Figure 5.a***. This physical characteristic contributes to natural fibre lightness. The results of roselle fibre water absorption are high - 286.5%. The lumen structure has great affinity towards water. As more lumen exists, more water is absorbed by roselle fibres, which is one of the distinct disadvantages of natural fibres. These phenomena also exist due to the cellulose content in natural fibres in general and roselle fibre in particular. A higher percentage of celloluse content increases free hydroxyl groups. Moreover natural fibres are hydrophilic. However, this disadvantage can be further improved by surface treatment.

The moisture absorption of natural fibre must be reduced to produce a high quality composite. In addition, fibre and matrix adhesion can be further improved by strengthening the composite. The moisture content of natural fibre is one of the most important criteria which needs to be considered in choosing natural fibre as reinforcement material as moisture content affects the dimensional stability, electrical resistivity, tensile strength, po-

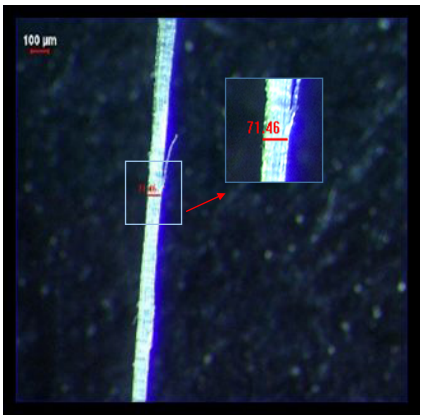

Figure 4. *Roselle fibre diameter measurement under optical microscope.*

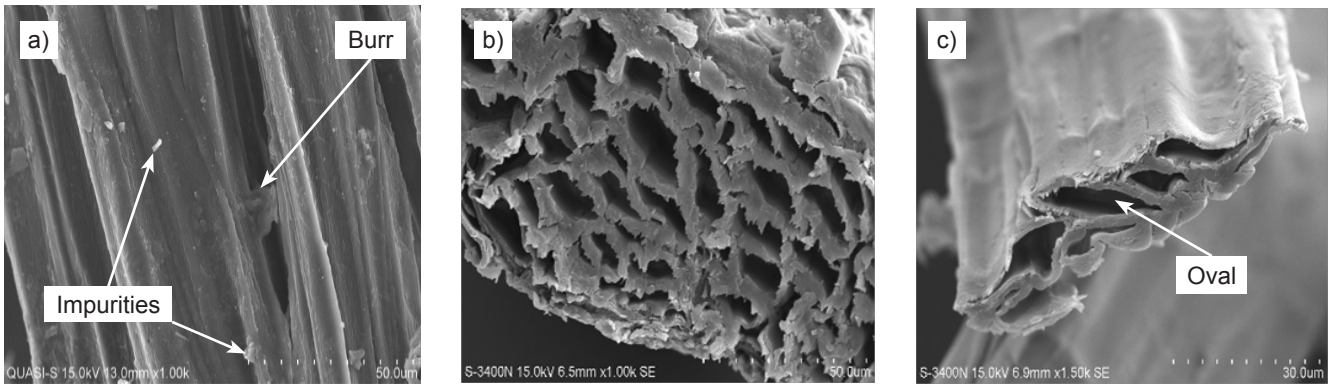

Figure 5. *(a) Surface of roselle fibre at 800× magnification, (b) cross section of roselle fibre at 1k magnification, (c) cross section of single fibre of rosell at 1.5k magnification.*

rosity and swelling behaviour of natural fibre in composite material [12]. From the literature published, it was found that the relatively low moisture content of the natural fibre is the most desirable criterion for polymer composites, which can overcome the problem mentioned above [12]. The average moisture content of roselle fibre is 10.9%.

Composites combined with fibre of less moisture content is less likely to decay in contrast to a composite combined with fibre of high moisture content. This is probably due to the absence of fibre ability to retain water within the composites, which may promote the degradation of the composites [42]. There are three major chemical components: cellulose, lignin and hemicelluloses in the fibre which effect the ability to attract and hold water molecules. From the research findings, lignin has lower attraction for water molecules and the hemicellulose structure - the highest. The attraction of cellulose for water is in the middle of these two components. The chemical content contributes to the major effect of the moisture content of natural fibre, which is because of the presence of hydroxyl bonding or OH group in the cellulose structure.

The need for quality enhancement of roselle fibre as a filler in a composite is necessary in order to avoid the instability of fibre properties. The properties of roselle fibre are similar to other common natural fibres. However, the main problem of roselle fibre is the high percentage of water absorption, as it is sensitive to the environment, which gives a moisture effect and poor adhesion on the interface between the fibre and polymer. This can be solved with chemical treatment which changes the surface properties and enhances the fibre quality. There are several potential chemical treatment methods that can be applied to roselle fibre, such as alkalisation, acetylation, a silane coupling agent, graft copolymers and benzoylation [43]. However, the moisture absorption of natural fibre is higher compared to synthetic fibre due the nature mechanism of plant based fibre.

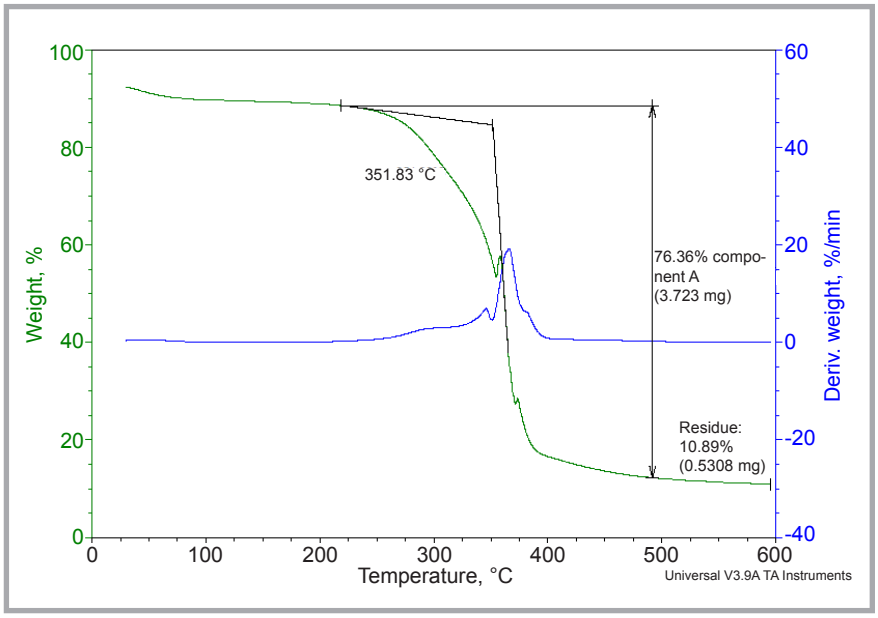

Figure 6. *TGA of roselle fibre.*

Figures 5.a, 5.b and ***5.c*** shows the morphology of roselle fibre and ***Figure 5.a*** - a longitudinal view of roselle fibre. The structure of a Roselle fibre consists of several elementary fibres (referred also to as ultimate fibres or cells) overlapped along the length of fibres and bonded firmly together by pectin and other non-cellulosic compounds that give strength to the bundle as a whole [35]. However, the strength of the bundle structure is significantly lower than that of the elementary cell. As seen in ***Figure 5.a***, there are impurities on the surface, and the surface structure has a lot of bur, which is due to the bare surface of the fibre without any treatment. The region at the interface of two cells is termed middle lamella, as shown in ***Figure 5.a*** . In common terminology the bundles of elementary fibres are referred to as technical fibres or single fibre. The shape of lumen is oval, which might be due to the stress applied while cutting the fibre for SEM sample preparation. ***Figures 5.b*** and ***5.c*** shows a cross section of roselle fibre at different magnifications, which are 1k and 1.5k, respectively, indicating a typical cross section of the lumen structure observed in roselle fibre.

Thermal properties

In order to study their thermal behaviour, further analysis must be conducted on natural fibres. Thermogravimetric analysis can be done to provide such information. This method is capable of providing precise information on thermal stability. The thermal stability or themal degrada-

tion of natural fibre is important as it is also affected while increasing the temperature in the manufacturing process with polymer/resin. It is crucial to confirm that the fibre used in the composite has the capability to withstand the temperature applied during the manufacturing process or application of the product. ***Figure 6*** indicates the curves for weight loss and differential weight loss for roselle fibres as the temperature rises. Generally there were 4 stages of main thermal degradation of the roselle fibre. The first is moisture evaporation, followed by the decomposition of hemicellulose, cellulose and lignin, and finally is its ash [37].

The first degradation of roselle fibres occurred between 40 to 110 °C, which is due to the evaporation of moisture content in the fibre. As the temperature of fibre increased while it was heated, the fibres became lighter because of the evaporation of bound water and volatile extractives. Although less volatile extractives are still in existence, they tend to move towards the outer part of the fibre stem surface. This movement of volatile extractive occurs due to water movement from the inner to the outer part of the fibre stem surface as the water available in the outer part evaporates. Eventually, the volatile extractives coalesce and migrate to the fibre surface (outer part of fibre stem). It can be seen that the lignocellulosic component was decomposed in the range of 200 to 400 °C, which is about 76% of weight loss. The second phase thermal degradation of roselle fibre is due to thermochemical change in the hemicellulose content in the fibre caused by cellular breakdown as the temperature was increased. Hemicelulose started to decompose in the range of 225 to 350 °C. Hemicellulose degrades earlier than the other lignocellulosic component, cellulose and lignin. The cellulose structure is more thermally stable compared to hemicellulose, which is due to the fact that the hemicellulose structure contains saccharides such as galactose, glucose, mannose and xylose. Saccharides are normally very amorphous in nature, which makes them easily migrate from main stem. Eventually saccharides become volatile at relatively lower temperatures [44]. The third stage is decomposition of the cellulosic structure.

Cellulose started to decompose at a temperature of 350 °C, completely decomposed at 375 °C, and finally the lignin element descomposed starting at

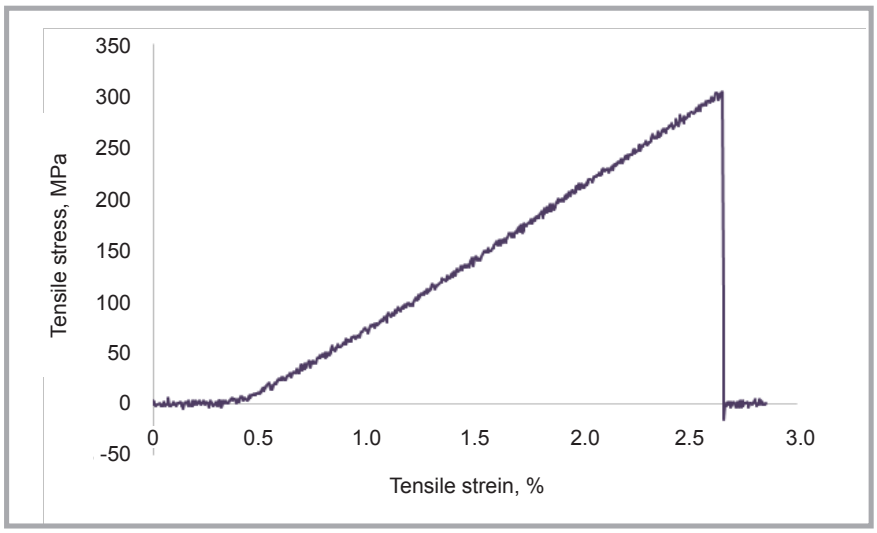

Figure 7. *Stress strain curve.*

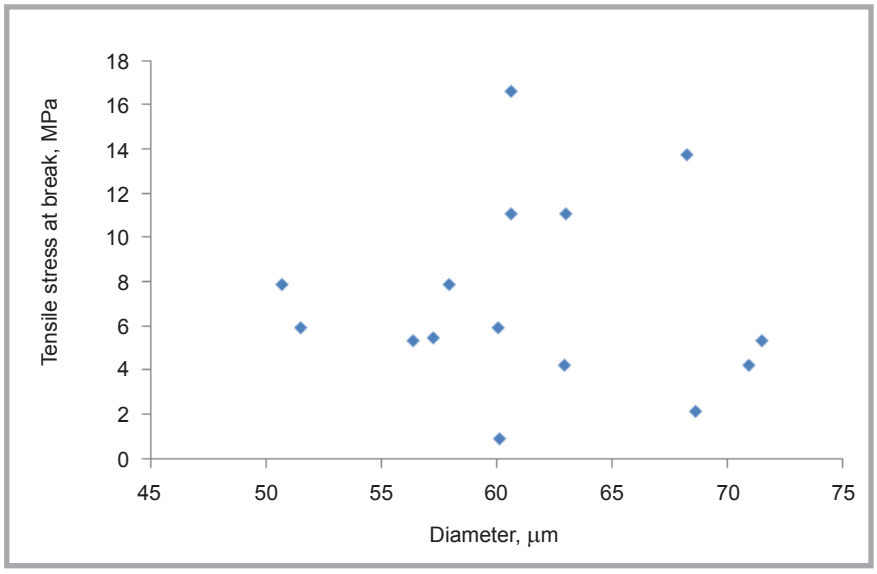

Figure 8. *Tensile stress at break of roselle fibre versus diameter.*

375 to 400 °C. Lignin was the last element to be decomposed because its structure was relatively complex. The complexity is further defined with the presence of aromatic rings with various possible branches. ***Table 1*** shows the thermal properties of roselle fibre in comparison with other bast fibres. It can be seen that roselle fibres have a good thermal stability compared with other established bast fibres such as kenaf and jute.

Tensile strength of roselle fibre

Figure 7 shows a typical stress strain curve from one of the roselle fibre samples. The gauge length of all samples is 20 mm with a 1 mm/min cross-head speed. From the results obtained, there are different tensile properties among

Table 1. *Thermal properties of bast fibre in comparison with others; *IDT - Initial decomposition temperature, **FDT - Final decomposition temperature.*

Fibres	Degradation temperature, °C		Char residue, %	Reference
	T_{IDT}*	T_{FDT}**		
Roselle	220	400	10.9	Current study
Kenaf	247	455	11.4	[50]
Jute	205	340	21.0	[51]
Okra	220	359	7.6	[35]
sisal	222	415	5.0	[52]

Table 2. Comparison of tensile strength of roselle fibre with kenaf and jute fibres.

Fibre	Tensile Strength, MPa	Reference
Roselle	150 - 400	Current study
Kenaf	18 - 180	[53]
Hemp	300 - 800	[54]
Jute	340 - 384	[55]
Flax	500 - 900	[54]
Okra	281.68	[35]

the same batches of fibres, which is due the variation in roselle fibre structures, such as the lumen size of the fibre, and that in the diameter and wall thickness of the fibres [45]. The stress strain curve indicated that all samples failed in a brittle manner, after the yield point. The tensile strength of roselle fibre is in the range of 130 - 562 MPa. ***Figure 8*** shows the tensile stress at break of roselle fibre with respect to the diameter of the fibre. It can be seen that there is no correlation between the fibre diameter and tensile stress at break. The other study from literature published also found the same conclusion: there is no influence of the area on the tensile stress [45].

Table 2 shows the tensile strength of natural fibre, and from the table it can be conclude that roselle fibre is comparable with other natural fibres. Hence the capability of roselle fibre as reinforcement material for composites is in good agreement with other fibres. The study of tensile properties of fibres is important because the load applied to composites was transferred to the fibre first. The fibre helped to sustain the load applied, and once the fibre failed, then only the composite failed. The structure of bast fibre is almost similar for all type of fibres [13]. The differences between plant fibres are their compositions, i.e., the ratio between cellulose and lignin/hemicellulose, and in the orientation or spiral angle of the cellulose microfibril [13]. Elementary fibres contain cellulose, lignin and hemicellulose. Usually the tensile strength and Young's modulus of fibres increased as the cellulose content increased. The ductility of plant fibres depends on the orientation of microfibrils to the fibre axis, where if it is spiral, it is ductile, while if it is parallel, it is rigid, inflexible, and has high tensile strength.

Table 3 shows the chemical composition of roselle fibre compared with other established bast fibre. From the results obtained, it can be seen that the roselle fibre chemical content is comparable with other bast fibre. The chemical composition is the most significant factor that influences tensile properties, although there are many others [37]. This is because the content of cellulose, which is a chemical substance, determines the stability of the stem plant wall and strength with respect to the fibre. Another factor that effects the properties is the fibre defect. The fibre used as reinforcement material must have a minimum defect, where if it is present in the structure, the failure will start at the weak point (defects). Thus a detail inspection under a microscope needs to be performed in order to determine the quality of a fibre.

From the results obtained, it can be seen that the physical, thermal, and mechanical properties of roselle fibre have comparative properties with established bast fibre. Thus roselle fibre has the capability to be a reinforcement material for a polymer composite. Roselle fibre can also be used in reinforcement material with vinyl ester [46], epoxy [47], polyester [31] and phenol fomaldehyde [48]. Furthermore the author strongly believes that roselle fibre can also be put in the reinforced polymer composite used in automotive parts and accessories[49] as well as in the biomedical and aerospace industries.

Conclusions

Roselle is a type of bast fibre which has a high cellulose content, leading to high tensile properties of the fibre. The percentages of the moisture content of roselle fibre is better than other natural fibres, which leads to better dimensional stability, reduced porosity and also improved adhesion between the fibre and matrix. In terms of mechanical properties, roselle fibre has maximum tensile stress and elongation at break, which can provide good mechanical properties to the composite product. Although the water absorption of roselle fibre is quite high, it can be improved with fibre surface treatment. Upon further investigation oof its thermal properties, it was found that roselle fibre starts to degrade at a temperature of 200 °C. With all the good combinations of roselle fibre characteristics, it has great potential to be used as reinforcement material in composites.

Table 3. Chemical content of roselle fibre and other bast fibre.

Type of fibre	Celulose	Hemicellulose	Lignin	Ash	References
Roselle	65.49	20.46	5.41	0.53	Current study
Kenaf	31.0 - 63.5	17.6 - 23.0	12.7 - 19.0	2.0 - 5.0	[43, 56]
Jute	45.0 - 71.5	13.6 - 21.0	13.0 - 26.0	0.5 - 2.0	[43, 57]
Hemp	57.0 - 77.0	14.0 - 22.4	3.7-13.0	0.8	[43]
Flax	64.0 - 71.9	16.7 - 20.6	2.0 - 2.2		[58]

Acknowledgements

The authors would like to thank University Putra Malaysia for providing a research grant (ERGS 5527190) and the facility support to carried out the experiment.

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Received 07.07.2014 Reviewed 23.02.2015

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES
INSTYTUT BIOPOLIMERÓW I WŁÓKIEN CHEMICZNYCH

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Director of the Institute: *Danuta Ciechańska Ph.D., Eng.*

The Institute of Biopolymers and Chemical Fibres *was consolidated with the Pulp and Paper Research Institute in 2007.*

The research subject *of IBWCH is conducting scientific and development research, as well as implementing their results into praxis in the following fields:*

- *processing, modifying, and application of biopolymers,*
- *techniques and technologies of manufacturing, processing, and application of chemical fibres and other polymer materials and related products,*
- *techniques and technologies connected with manufacturing, processing and application of products of the pulp and paper industry and related branches*

R&D activity *includes the following positions, among others:*

- *biopolymers – modifying and processing,*
- *functional, thermoplastic polymers,*
- *biodegradable polymers and products from recovered wastes,*
- *industrial biotechnology, e.g. bioprocesses for modifying and processing polymers and fibres, and biosyntheses of nanobiomaterial polymers,*
- *biomaterials for medicine, agriculture, and technique,*
- *nano-technologies, e.g. nano-fibres, polymer nano-coatings, nano-additives for fibres.*
- *processing of polymer materials into fibres, films, micro-, and nano- fibrous forms, and nonwovens,*
- *paper techniques, new raw material sources for manufacturing paper pulps,*
- *environmental protection,*

The Institute is active *in implementing its works in the textile industry, medicine, agriculture, plastic processing, filter and packing materials manufacturing, as well as in the cellulose and paper industries.*

The Institute has *the following five laboratories, which have accreditation certificates PCA:*

- *Laboratory of Microbiology*
- *Laboratory of Biodegradation*
- *Laboratory of Environment Protection*
- *Laboratory of Metrology*
- *Laboratory of Paper Quality*

The Institute's offer of specific services *is wide and differentiated, and includes:*

- *physical, chemical and biochemical investigations of biopolymers and synthetic polymers,*
- *physical, including mechanical investigation of fibres, threads, textiles, and medical products,*
- *tests of antibacterial and antifungal activity of fibres and textiles,*
- *investigation in biodegradation,*
- *investigation of morphological structures by SEM and ESEM*
- *investigation and quality estimation of fibrous pulps, card boards, and paper products, including paper dedicated to contact with food, UE 94/62/EC tests, among others.*
- *Certification of paper products.*

The Institute is member *of domestic and international scientific organisations, the following, among others: EPNOE Association-European Polysaccharide Network of Excellence, Polish Chitin Society, Centre of Advanced Technology of Human-Friendly Textiles 'PROHUMANOTEX', Polish Platform of Textile Technology, Polish Platform of the Forest-Wood Technology Sector, International Scientific Network 'Environment versus Technology' ENVITECH-NET.*

The Institute participates *in the following strategic research projects: KEY PROJECT: 'Biodegradable fibrous goods', BIOGRATEX – PO IG 01.03.01-00-007/08; FORESIGHT PROJECT: 'Modern technologies for textile industry. A Chance for Poland' – UDA – PO IG 01.01.01-00-005/09-00 (as a leader); STRATEGIC PROJECT: 'Technology for the preparing of biodegradable polyesters using renewable raw materials', BIOPOL – PO IG 01.01.02-10-025/09; STRATEGIC PROJECT: 'Application of biomass for production of environmentally friendly polymeric materials', BIOMASS – PO IG 01.01.02-10-123/09.*

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The Institute is active *in international cooperation with a number of corporation, associations, universities, research & development institutes, and companies from Austria, Germany, Finland, France, Sweden and the United States among others.*

The Institute is publisher *of the scientific journal 'Fibres & Textiles in Eastern Europe'; the journal is since 1999 on the 'Philadelphia List' of the Institute for Scientific Information.*

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