UNIVERSITI PUTRA MALAYSIA

MECHANICAL AND THERMAL PROPERTIES OF SURFACE TREATED SUGAR PALM FIBRE-REINFORCED EPOXY BIOCOMPOSITES

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By

AHMAD SYAHMI BIN MOHAMED LATIFF

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is gratefully dedicated to:
My beloved Mother and Father
Norzihan Binti Atan
Mohamed Latiff Bin Hj. Murad
And My Family
Thank you for your continuous support and effort towards the completion of this thesis.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Associate Professor Mohamad Ridzwan bin Ishak, PhD
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A number of chemical treatment processes of natural fibres such as jute, kenaf, sisal, flax etc have been practised to improve the structure of natural fibre in order to help them to form a strong bonding with resin in bio-composites making. However, as for sugar palm fibre there are not many treatments available due to limited research has been done on it. The only treatments that can be found for sugar palm fibre are sodium hydroxide (NaOH) and sea water treatments. This thesis focused on the study of new treatment for sugar palm fibre which is benzoylation (benzoyl chloride) treatment. The purpose of benzoylation is to reduce the hydrophilicity of sugar palm fibre and improve its chemical interlocking at the interface. This helps the fibre to be more compatible with polymer matrix and form a strong bonding. The mechanical properties of both untreated and treated sugar palm fibres were studied. The sugar palm fibres were being treated with sodium hydroxide and benzoyl chloride respectively to alter the composition of the fibre and to improve its properties. In single fibre testing, the highest improvement in tensile strength was observed in fibre treated with benzoyl chloride for 30 minutes soaking time with increment of 47.5 % compared to untreated fibre. The second highest was fibre treated with NaOH, showing increment of 35.1 % compared to untreated fibre. For sugar palm composite with 30 % fibre loading, the fibre treated with NaOH showed highest tensile strength with value of 54.8 MPa, followed by fibre treated with benzoyl chloride with 54 MPa and lastly untreated fibre with 38.3 MPa. For thermal properties, benzoylation process show significant improvement in all testing performed which are thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), thermomechanical analysis (TMA) and differential scanning calorimetry (DSC). This show that benzoylation process gives the fibre and its composites a better thermal stability than other composites. Based on the results obtained, it can be concluded that both benzoyl chloride and sodium hydroxide treatments improved the properties of sugar palm fibres and its composites.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIFAT-SIFAT MEKANIKAL DAN THERMAL SERAT POKOK ENAU YANG DIPERKUAT EPOKSI BIO-KOMPOSIT SETELAH DIRAWAT PERMUKAANNYA

Oleh

AHMAD SYAHMI BIN MOHAMED LATIFF

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Pengerusi : Profesor Madya Mohamad Ridzwan bin Ishak, PhD
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Beberapa proses rawatan kimia serat semulajadi seperti jut, kenaf, sisal, flux dan lain-lain telah diamalkan untuk memperbaiki struktur serat semulajadi itu untuk membantu ia membentuk ikatan yang kuat dengan resin dalam proses membuat bio-komposit. Walau bagaimanapun, bagi serat pokok enau tidak banyak rawatan yang tersedia kerana kurang kajian yang telah dilakukan terhadap serat pokok enau. Hanya sedikit sahaja kaedah rawatan yang boleh didapati untuk serat pokok enau iaitu dengan munggunakan natrium hidroksida (NaOH) dan rawatan air laut. Tesis ini memberi tumpuan kepada kajian rawatan baru untuk serat pokok enau yang merupakan rawatan benzoylation (benzoyl klorida). Tujuan benzoylation adalah untuk mengurangkan sifat hidrofililik dalam serat pokok enau dan memperbaiki ikatan kimia di permukaan serat. Ini membantu serat menjadi lebih serasi dengan matriks polimer dan membentuk ikatan yang kukuh. Sifat mekanikal bagi serat pokok enau yang dirawat dan juga serat yang tidak dirawat telah dikaji. Serat pokok enau dirawat dengan natrium hidroksida dan benzoyl klorida adalah bertujuan untuk mengubah komposisi serat dan untuk memperbaiki sifat-sifatnya. Dalam ujian serat tunggal, penambahbaikan tertinggi dalam kekuatan tegangan diperhatikan dalam serat yang dirawat dengan benzoyl klorida selama 30 minit waktu rendaman dengan kenaikan 47.5 % berbanding dengan serat yang tidak dirawat. Yang kedua tertinggi adalah serat dirawat dengan NaOH, menunjukkan kenaikan 35.1 % berbanding dengan serat yang tidak dirawat. Untuk komposit pula, dengan komposit 30 %, serat yang dirawat dengan NaOH menunjukkan kekuatan tegangan tertinggi dengan nilai 54.8 MPa, diikuti dengan komposit serat yang dirawat dengan benzoyl klorida dengan 54 MPa dan serat terakhir yang tidak dirawat dengan 38.3 MPa. Untuk sifat-sifat terma, proses benzoylation menunjukkan peningkatan yang ketara dalam semua ujian yang dijalankan iaitu analisis termogravimetrik (TGA), analisis mekanik dinamik (DMA), analisis termomekanik (TMA) dan kalori pengimbang perbezaan (DSC). Ini menunjukkan bahawa proses benzoylation memberikan serat dan kompositnya kestabilan terma

yang lebih baik daripada komposit lain. Berdasarkan keputusan yang diperoleh, dapat disimpulkan bahwa kedua-dua rawatan melalui benzoyl klorida dan natrium hidroksida, ia dapat meningkatkan sifat-sifat serat pokok enau dan kompositnya.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
CTE	Coefficient of Thermal Expansion
DMA	Dynamic Mechanical Analysis
DSC	Differential Scanning Calorimetry
DP	Degree of Polymerization
EFB	Empty Fruit Bunch
FTIR	Fourier Transform Infrared Spectroscopy
IFSS	Interfacial Shear Strength
PE	Polyethylene
POM	Polarized Optical Microscopy
PP	Polypropylene
PVC	Polyvinyl Chloride
SPF	Sugar Palm Fibre
TGA	Thermogravimetric Analysis
TMA	Thermomechanical Analysis

LIST OF SYMBOLS

α	alpha
ρ	Density (g/cm^3)
ε	Strain (%)
σ	Stress (MPa)
ΔH	Heat of Fusion
%wt	Weight fraction
F	Force (kN)
E	Young's modulus (MPa)
L	Length (m)
D	Diameter (m)
P	Load (N)

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

With the ever-expanding technology in the composites industry, new research have developed in order to find new resource to replace conventional synthetic composites fibre that widely used in many applications [1] [2] with natural composites. With means of changing the method of preparing the composites, engineers can begin to look at the expansion of composites materials industry. The theory behind altering the composition of the mixture of plastic/resin/epoxy with natural resource, is that it will lead to improved properties and/or change the characteristic of the entire composites. The current systems used for composites are that manmade composites can be made from scratch and be form to any desirable properties and characteristic.

For the past few decades, there has been a great deal of research done in the area of composite materials to improve strength of building structures. These structures generally utilize strong materials to support its loads and for creating structures that can increase its lifetime. More recently, the application of natural composites on structures has been implemented in many field such as automotive, and construction site [3] [4] [5] with hopes of many benefits such as reduce the high cost of synthetic composites, improve in performance and reducing waste product of natural resources. The current need in composites industry is a material that can achieve high strength with less weight and less cost with limitless resource such as from recycle materials or waste product from nature. There are certain composite materials that use natural resources as its base (kenaf, flax and chaff) that currently has accomplished its properties, but have certain disadvantages associated with them. There are a few adaptive natural composites that attempt to replicate the properties and behaviour of synthetic composites, such as the high tensile strength, and high modulus of toughness.

Currently, natural fibres are trending among researchers as new resources that can replace synthetic based materials either by itself or with combination from other material to produce green composites. What make it interesting for researcher to applied research on natural fibres are the advantages of natural fibre itself, such as low density, abundance, sustainability, biodegradability, recyclability and low cost which make it more profitable [6]. In evaluating natural fibres, there are some important parameters that should be consider like tensile, thermal and chemical properties. These parameters important in determining the performance of the fibres to be used for composites. In this thesis, sugar palm fibres are used as base for natural composites materials.

1.2 Problem Statement

Man-made fibre known as synthetic fibre are being used widely in almost all industry as reinforcement for composite which have proved its effectiveness over the years. Despite its effectiveness as reinforce for composite, there are many downsides of using synthetic fibre for long term and also short term used of it. The use of synthetic fibre can cause harmful effect toward human and also environment. If someone inhale the synthetic fibre continuously which can happen during the preparation of the fibre itself or when preparing the composite can cause a serious respiratory problem in a long term and damage the lungs of the consumers. As the composite aren't being used or need anymore, the disposable synthetic fibre composite cannot be degraded those will cause pollution and harm the environment [7]. Other than causing damage to the environment and human, synthetic fibre also causing a significant damage to the industrial and corporates industry as the cost of materials and production involving synthetic fibre is very high. With disadvantages of synthetic fibre overwhelm its usefulness, it ignites the sparks of many personnel and also organization to start on new research of finding the replacement for synthetic fibre. The most significant findings from all these researches to replace synthetic fibre are plant fibres. There are many researches that has been done to find the plant fibre that best to replace synthetic fibre for certain use in industry. This is because each plant species produces different fibre thus it makes different properties when mixing with composite which later can be used for different purpose depend of the properties of the fibre composite. However, even with so many researches have been done on many plant fibre, there is one that have the potential to be use as bio fibre composite that have not been study much by researchers and that plant is sugar palm tree. Sugar palm tree or its scientific name refer as Arenga Pinnata has been used from the leaves to the trunk to make into daily product since ancient time. One of it is rope produced from the tree fibre, it being use to tie a small boat to jetty because of its high durability properties towards sea water [8] [9] [10] [11]. These findings have alerted some researcher to study more on the properties and characteristic of the fibre produced by the tree.

There are several researches that has been done on the mechanical properties of the sugar palm fibre composite. Those researches were mainly on the mechanical properties of untreated fibre composite of short, long and woven [7] [12] [13] [14] [15] [16]. Previous studies that had been carried out were using epoxy resin and unsaturated polyester as the matrix. Both matrix used show improvement in the properties of the fibre composite. However, epoxy resin is widely used in aerospace industry than unsaturated polyester due to its properties.

For any natural fibre composite to improve its properties, surface modifications of the fibre needed [17] [18] [19]. There are many available methods for natural fibre surface modifications out there but few only been tested for sugar palm fibre. In recent years, many researches unveil the potential of alkaline treatment and sea water treatment on sugar palm fibre properties. However, there is no research carried out to study the potential of using acid treatment on sugar palm fibre for its surface modification. The alkaline and sea water treatment had shown improvement on the tensile and flexural of the sugar palm fibre reinforced epoxy composite.

1.3 Research Objective

The general aim of this study is to determine the mechanical properties, and also thermal properties of treated sugar palm fibre reinforced epoxy composites.

The specific objectives of this study are;

i. To study the mechanical properties of sugar palm fibre such as tensile strength, and interfacial shear strength (IFSS). To analyse sugar palm fibre component using Fourier-transform infrared spectroscopy (FTIR).
ii. To investigate the effect of surface treatment using sodium hydroxide and benzoyl chloride on the mechanical and thermal properties of sugar palm fibre and it’s composite.
iii. To analyse the mechanical, and thermal properties of sugar palm fibre reinforced epoxy composite such as tensile properties, flexural properties, and also thermal stability of the composite by using thermogravimetric analysis (TGA), thermomechanical analysis (TMA), dynamic mechanical analysis (DMA) and differential scanning calorimetry (DSC).

1.4 Hypotheses

The hypotheses of these studies are;

i. There are significant effects of sugar palm fibre content to the mechanical and thermal properties of sugar palm fibre reinforced epoxy composite such as tensile, flexural, TGA, TMA, DMA, and DSC.
ii. There are significant effects of sodium hydroxide and benzoyl chloride to the mechanical, physical and chemical properties of sugar palm fibre reinforced epoxy composite such as tensile, flexural, TGA, TMA, DMA, and DSC.

1.5 Significance of Study

The significance of this study is to show good usage of resource that available. The available resource of natural fibre throughout this region would help developing the bio-composite products with low materials cost and production, partially biodegradable, and environmental friendly [20] [6]. It’s more important that the full potential of sugar palm tree haven’t been exploit by local people mainly on the tree fibre. Based on current knowledge, there are few commercialize product made of its fibres, fruits and leaves. The only product made out of the tree fibre by local people are ropes, brushes, brooms and handicrafts as their daily used and commercial product. In addition to that, the usefulness of sugar palm fibre as reinforcing materials for bio-composite will open up the opportunity to commercialize the sugar palm tree as multipurpose tree [21] [22] [23] [24] [25] [26]. This surely would increase the demand of the fibre and thus needing more labour in the field and this will open up more work opportunity for local people and increase their income as well [27].

Based on previous researched, sugar palm fibre showed a promising alternative as replacement for synthetic fibre as reinforcing materials in many composite applications such as furniture, doors, and buildings [28] [29] [30].

1.6 Scope and Limitation of Studies

This study focusses on the determination of the mechanical and thermal properties of sugar palm fibre reinforce epoxy composite. The fibre used was in form of unidirectional instead of woven which is its natural form of fibre. The woven fibre obtain from the supplier have to be wash and clean to remove impurities and substance from the fibre before it can be organized properly. The matrix used in this study was epoxy resins and amine hardener. The surface modification used was chemical treatment method by using alkaline and acid. The fibres was treated with alkaline solution using sodium hydroxide (NaOH) and acid solution, benzoyl chloride. The chemical properties in the fibre observed by using FTIR method. Interfacial shear strength (IFSS) were determined by using untreated and chemically treated fibre with the matrix used in the study. Mechanical, physical, and chemical testing were performed in order to determine the composite material properties base on standard requirement. The effect of fibre loading and chemical treatment to the properties of the composite are also studied.

1.7 Structure of Thesis

In this thesis, chapter 1 consist of the background of the study, problem statements, objectives, hypothesis, significance of the study, scope and limitation of the study and structure of the thesis. While for chapter 2 it represents the literature review base on the previous research work in numerous fields of study which are applicable for this research. The literature begins with mostly the latest and later literature survey on natural fibre and sugar palm fibre that are available. Followed by literature on composite and bio-composite. Reviews of its properties are also included in this chapter of study. Chapter 3 describe the methodology of this study in details. It presents the surface modification of sugar palm fibre by chemical treatments method. This chapter also consist of techniques and steps for preparing chemically treated fibre. Besides that, the techniques preparation of composites and determination of its properties (mechanical, physical, and chemical) of sugar palm fibre reinforced epoxy composite also presented in this chapter. Chapter 4 shows the results and discussion on the effects of fibre loadings and chemically treated fibre on the properties (mechanical, physical, and chemical) of the sugar palm fibre reinforced epoxy composites. Lastly, chapter 5 presented the conclusions and also recommendations of future works.

REFERENCES

[1] X. Li, L. G. Tabil and S. Panigrahi, "Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review," *Journal of Polymers and the Environment* , vol. 15, no. 1, pp. 25-33, 2007.

[2] R. M. Rowell, "Property Enhanced Natural Fibre Composite Material Based on Chemical Modification.," *Science and Technology of Polymer and Advanced Material.,* pp. 717-732, 1998.

[3] M. Lavery, "Sealant in the automotive industry.," *International Journal of Adhesion and Adhesives,* vol. 6, no. 22, pp. 443-445, 2002.

[4] L. Y. Mwaikambo and E. T. N. Bisanda, "The performance of cotton-kapok fabric polyester composite.," *Polymer Testing,* no. 18, pp. 181-198, 1999.

[5] B. C. Suddell and W. J. Evans, "Natural fiber composites in automotive applications.," in *In Natural Fiers, Biopolymer, and Biocomposites,* Boca Raton, CRC Press, 2005, pp. 231-259.

[6] H. Y. Sastra, J. P. Siregar, S. M. Sapuan, Z. Leman and M. M. Hamdan, "Tensile properties of Arenga Pinnata fibre-reinforced epoxy composites," *Polym Plast Technol Eng.,* vol. 1, no. 8, p. 45, 2006.

[7] D. Bachtiar, S. M. Sapuan and M. M. Hamdan, "The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites," 2008.

[8] M. Ishak, Z. Leman, S. Sapuan, M. Salleh and S. Misri, "The Effect Of Sea Water Treatment On The Impact And Flexural Strength Of Sugar Palm Fibre Reinforced Epoxy Composites," *International Journal of Mechanical and Materials Engineering (IJMME),* vol. 4, no. 3, pp. 316-320, 2009.

[9] A. Othman and N. Haron, "Potensi Industri Kecil Tanaman Enau," *In FRIM Report No 60,* pp. 7-18, 1992.

[10] R. Miller, "The Versetile Sugar Palm," *Principes,* no. 8, pp. 115-146, 1964.

[11] P. Tomlison, "The leaf base in palms its morphology and mechanical biology," *Journal of the Arnold Arboretum* , no. 43, pp. 23-45, 1962.

[12] D. Bachtiar, M. S. Salit, E. Zainudin, K. Abdan and K. Z. H. M. Dahlan, "Effects of Alkaline Treatment and A Compatibilizing Agent on Tensile Properties of Sugar Palm Fibre-Reinforced High Impact Polystyrene Composites," *Sugar palm HIPS composite,* vol. 6, no. 4, pp. 4815-4823, 2011.

[13] D. Bachtiar, M. S. Salit, E. S. Zainudin, K. Abdan and D. K.Z.M., "The tensile properties single sugar palm (Arenga pinnata)," in *IOP Conference Series: Materials Science and Engineering*, 2010.

[14] H. Y. Sastra, J. P. Siregar, S. M. Sapuan, Z. Leman and M. H. M. Ahmad, "Flexural properties of Arega Pinnata fibre reinforce composites," *American Journal of Applied Sciences (Special Issue)*, pp. 21-24, 2005.

[15] H. Y. Sastra, J. P. Siregar, S. M. Sapuan, Z. Leman and M. M. Hamdan, "Tensile properties of Arega Pinnata fibre-reinforce epxy composites," *Polymer-Plastic Technology and Engineering* , no. 45, pp. 1-8, 2006.

[16] J. P. Siregar, Tensile and Flexural Properties of Arega Pinnata Filament (Ijuk Filament) Reinforce Epoxy Composites, MSc Thesis, Universiti Putra Malaysia, 2005.

[17] J. Biagiotti, D. Puglia, L. Torre, J. M. Kenny, A. Arbelaiz, G. Cantero, C. Morieta, R. Llano-Ponte and I. Mondragon, "A systematic investigation on the influence of the chemical treatment of natural fibres on the properties of their polymer composites.," *Polymer Composites*, vol. 2, no. 25, pp. 470-479, 2004.

[18] A. Gomes, K. Goda and J. Ohgi, "Effects of alkali treatment to reinforcement on tensile properties of curaua fibre green composites.," *JSME International Journal Series A* , vol. 4, no. 47, pp. 451-456, 2004.

[19] J. Rout, M. Misra, S. S. Tripathy and A. Mohanty, "The influence of fibre surface modification on the mechanical properties of coir-polyester composites.," *Polymer Composites*, vol. 4, no. 22, pp. 468-476, 2004.

[20] Li, X, Tabil, L. G and S. Panigrahi, "Chemical treatments of natural fibre for use in natural-reinforce composites: A review," *Polymer Environment*, no. 15, pp. 25-33, 2007.

[21] J. Dransfield, "Palms in everyday life of West Indonesia," *Principes*, no. 20, pp. 39-47, 1976.

[22] W. H. Hodge, "Palms-Principes of the plant world," *Principes*, vol. 1, no. 2, pp. 32-40, 1958.

[23] Z. Mahmud, "Potensi dan pemasaran produk aren di Sulawensi Utara.," *Laporan bulanan Balitka*, pp. 1-8, Mei 1991.

[24] J. Mogea, B. Seibert and W. Smith, "Multipurpose palms: the sugar palm.," *Agroforestry Systems*, no. 13, pp. 111-129, 1991.

[25] G. Sumadi, "Arega Pinnata: A Palm for Agroforestry.," *In: Proceedings of an International Workshop held in Pataya, Thailand,* pp. 149-150, 2-5 November 1987.

[26] A. Sumitro, "Afroforestry development in Indonesia. In Mellink, W., Rao, Y.S and Muc Dicken, K.G. (eds).," in *Agroforestry in Asia and the Pasific.* , Winrock Int. Inst. Agric. Devlpmnt. Bangkok, 1991.

[27] F. M. Arshad, "Agriculture pertinent issues in Malaysia: Summary. In 50 Years of Malaysian Agriculture: Transformational Issues, Challenges, and Direction. eds. M.A., Fatimah, N.M.R., Abdullah, B. Khaur and A.M., Abdullah," UPM Press, Serdang, 2007.

[28] S. B. Abdullah and H. Y. Sastra, "Ijuk fibre as a material subtitution in manufacture of composite," *LPTR Unsyiah,* 1999.

[29] W. P. Sarjono and A. Wajono, "Pengaruh Penambahan Serat Ijuk Pada Kuat Tarik Campuran Semen-Pasir dan Kemungkinan Aplikasinya.," *Jurnal Teknik Sipil* , vol. 2, no. 8, pp. 159-169, 2008.

[30] J. P. Siregar, S. M. Sapuan, M. Z. A. Rahman and H. M. D. K. Zaman, "Characterization and chemical composition of short pineapple leaf fibres (PALF). In Postgraduate Seminar on Natural Fibre Composites.," UPM Press, Serdang , 2008.

[31] J. Preston, "Encyclopædia Britannica," 2015. [Online]. Available: http://global.britannica.com/technology/man-made-fiber. [Accessed 5 November 2015].

[32] A. K. Mohanty, M. Misra, L. T. Drzal and S. E. Selke, "Natural Fibers, Biopolymers, and Biocomposites: An Introduction," in *NATURAL FIBERS, BIOPOLYMERS, AND BIOCOMPOSITES*, Boca Raton; London; New York; Singapore, Taylor & Francis, 2005, pp. 2-6.

[33] "Fiber reinforced plastics used," Plast. News, 2002.

[34] P. Barghoorn, U. Stebani and M. Balsam, " Part 2: Applied macromolecular chemistry," *Trends in polymer chemistry 1997,* vol. 47, no. Acta Polymerica, pp. 266-267, 1998.

[35] A. K. Mohanty, M. Misra and G. Hinrichsen, "Biofibres, biodegradable polymers and biocomposites: An overview," *Macromolecular Materials and Engineering,* Vols. 276-277, no. 1, pp. 1-24, 2000.

[36] C. M. Clemons, R. M. Rowell, D. Plackett and B. K. Segerholm, "Wood/Nonwood Thermoplastic Composites," in *Handbook of Wood Chemistry and Wood Composites*, Boca Raton, CRC Press, 2013, pp. 473-508.

[37] A. Mohanty, M. Misra, L. T. Drzal, S. Selke, G. Hinrichsen and B. R. Harte, "Natural fibers, biopolymers, and biocomposites: An introduction," in *Natural fibers, biopolymers, and biocomposites*, Boca Raton, CRC Press, 2005, pp. 1-31.

[38] H. B. Florido and P. B. d. Mesa, "Sugar palm [Arenga pinnata (Wurmb.) Merr.]," *Research Information Series On Ecosystems,* vol. Volume 15, no. No. 2, p. 7, 2003.

[39] MR Ishak, "Effects of impregnation pressure on physical and tensile properties," Elsevier Ltd., Serdang, 2012.

[40] J. M. Sitorus, "Inilah Berbagai Fakta Menarik Mengenai Tuak," hipwee, 11 July 2015. [Online]. Available: http://www.hipwee.com/list/inilah-berbagai-fakta-menarik-mengenai-tuak-minuman-khas-orang-batak/. [Accessed 1 12 2015].

[41] RH Miller, "The versatile sugar palm," *Principes,* vol. 8, pp. 115-147, 1964.

[42] Z. Leman, S. M. Sapuan, M. Azwan, M. H. M. Ahmad and M. A. Maleque, "The effect of environmental treatments on fiber surface properties and tensile strength of sugar palm fiber-reinforced epoxy composite," *Polym Plast Technol Eng,* 2008.

[43] M. R. Ishak, S. M. Sapuan, Z. Leman, M. Z. A. Rahman and U. M. K. Anwar, "Characterization of sugar palm (Arenga pinnata) fibres," *Journal of Thermal Analysis and Calorimetry,* vol. 109, no. 2, pp. 981-989, 2011.

[44] P. A. Khudhur, O. S. Zaroog, B. A. Khidhir and Z. S. Radif, "Fracture Toughness of Sugar Palm Fiber Reinforced Epoxy Composites," *International Journal of Science and Research (IJSR),* vol. 2, no. 12, pp. 273-279, 2013.

[45] A. Ticoalu, T. Aravinthan and F. Cardona, "Experimental investigation into gomuti fibres/polyester composites," In: 21st Australasian Conference on the Mechanics of Structures and Materials (ACMSM 21), Melbourne, 2011.

[46] J. George, M. S. Sreekala and S. Thomas, "A Review on Interface Modification and Characterization of Natural Fiber Reinforced Plastic Composites," *POLYMER ENGINEERING AND SCIENCE,* vol. 41, no. 9, pp. 1471-1485, 2001.

[47] D. Ray, B. K. Sarkar, A. K. Rana and N. R. Bose, "Effect of alkali treated jute fibres on composite properties," *Bulletin of Materials Science,* vol. 24, no. 2, pp. 129-135, 2001.

[48] L. Y. Mwaikambo, N. Tucker and A. J. Clark, "Mechanical Properties of Hemp Fibre Reinforced Euphorbia Composites," *Macromolecular Materials and Engineering,* vol. 292, no. 9, pp. 993-1000, 2007.

[49] P. Joseph, Studies on short Sisal fibre reinforced isotactic Polypropylene Composites. PhD Thesis, India: Mahatma Gandhi University, 2001.

[50] B. Wang, S. Panigrahi, L. G. Tabil and W. Crerar, "Pre-treatment of Flax Fibers for use in Rotationally Molded Biocomposites," *Journal of Reinforced Plastics and Composites,* vol. 26, no. 5, pp. 447-463, 2007.

[51] A. Valadez-Gonzalez, J. M. Cervantes-Uc, R. Olayo and P. J. Herrera-Franco, "Chemical modification of henequén fibers with an organosilane coupling agent," *Composites Part B: Engineering,* vol. 30, no. 3, pp. 321-331, 1999.

[52] Y. Seki, "Innovative multifunctional siloxane treatment of jute fiber surface and its effect on the mechanical properties of jute/thermoset composites," *Materials Science and Engineering: A* , vol. 508, no. 1-2, pp. 247-252, 2009.

[53] M. S. Sreekala, M. G. Kumaran, S. Joseph, M. Jacob and S. Thomas, "Oil Palm Fibre Reinforced Phenol Formaldehyde Composites: Influence of Fibre Surface Modifications on the Mechanical Performance," *Applied Composite Materials,* vol. 7, no. 5-6, p. 295–329, 2000.

[54] R. M. Rowell and J. Rowell, Paper and Composites from Agro-based Resources, Florida: CRC Press, 2000.

[55] S. Mishraa, A. K. Mohanty, L. T. Drzal, M. Misra, S. Parija, S. K. Nayak and S. S. Tripathy, "Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites," *Composites Science and Technology,* vol. 63, no. 10, pp. 1377-1385, 2003.

[56] K. C. M. Nair, S. Thomas and G. Groeninckx, "Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres," *Composites Science and Technology,* vol. 61, no. 16, pp. 2519-2529, 2001.

[57] K. Joseph, S. Thomas and C. Pavithran, "Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites," *Polymer,* vol. 37, no. 23, pp. 5139-5149, 1996.

[58] M. P. A. Leonard and Y. Mwaikambo, "Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization," *Journal of Applied Polymer Science,* 2002.

[59] S. Sockalingam, J Gillerspie Jr and M. Keef, "Detailed modeling and analysis of single-fiber microdroplet test using cohesive zone approach," *Society of the Advancement of Material and Process Engineering,* 2013.

[60] M. N. Norizan, A. Khalina, S. M. Sapuan, A. M. D. Laila and M. Rahmah, "Curing behaviour of unsaturated polyester resin and interfacial shear stress of sugar palm fibre," *Journal of Mechanical Engineering and Sciences,* vol. 11, no. 2, pp. 2650-1664, 2017.

[61] J. Gassan and A. K. Bledzki, "The influence of fibre-surface treatment on the mechanical properties of jute-polypropylene composite," *Composite Part A: Applied Science and Manufacturing,* no. 28, pp. 1001-1005, 1997.

[62] J. Gassan and A. K. Bledzki, "Possibilities of improving the mechanical properties of jute/epoxy composites by alkaline treatment of fibres," *Composites Science and Technology,* no. 59, pp. 1303-1309, 1999.

[63] C. S. Hassan, S. M. Sapuan, N. A. Aziz and M. Z. M. Yusof, "Effect of Chemical Treatment on The Tensile Properties of Single Oil Palm Empty Fruit bunch (OPEFB) Fibre," *Trends in Textile Engineering & Fashion Technology,* vol. 3, no. 2, pp. 1-7, 2018.

[64] A. K. G. Bledzki, "Composites reinforced with cellulose based fibers," *Progress in Polymer Science,* vol. 2, no. 24, pp. 221-274, 1999.

[65] J. Ke and K. Yu, "Fibre-reinforced Cellulose Acetate Composites," 2007. [Online]. Available: http://www.odec.ca/projects/2007/yuka7k2/tensile.html. [Accessed 17th April 2019].

[66] M. Z. Rong, M. Q. Zhang, Y. Liu, G. C. Yang and H. M. Zeng, "The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites," *Composites Science and Technology,* vol. 61, no. 10, pp. 1437-1447, 2001.

[67] A. Mohanty, M. Misra and L. T. Drzal, "Surface modifications of natural fibers and performance of the resulting biocomposites: An overview," *Composite Interfaces,* pp. 313-343, 2001.

[68] U. Nirmal, S. T. W. Lau and A. J. Hashim, "Interfacial Adhesion Characteristics of Kenaf Fibres Subjected to Different Polymer Matrices and Fibre Treatments," *Journal of Composites,* 2014.

[69] M. J. John and S. Thomas, "Biofibres and biocomposites," *Carbohydrate Polymers,* vol. 71, no. 3, pp. 343-364, 2008.

[70] A. Shalwan and B. Yousif, "In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibres," *Materials & Design*, vol. 48, pp. 14-24, 2013.

[71] G. V. Reddy, S. V. Naidu and T. S. Rani, "Impact Properties of Kapok Based Unsaturated Polyester Hybrid Composites," *Journal of Reinforced Plastic and Composite*, 2008.

[72] A .Shalwan and B.F. Yousif, "In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibres," *Materials & Design*, no. 48, pp. 14-24, 2013.

[73] G. V. Reddy, S. V. Naidu and T. S. Rani, "Impact properties of kapok based unsaturated polyester hybrid composites," *Journal of Reinforced Plastics and Composites,* no. 27, pp. 1789-1804, 2008.

[74] U. Nirmal, S. T. W. Lau and J. Hashim, "Interfacial adhesion characteristics of kenaf fibres subjected to different polymer matrices and fibre treatments," *Journal of Composites,* pp. 1-12, 2014.

[75] M. John and S. Thomas, "Biofibres and biocomposites," *Carbohydrate Polymers,* no. 71, pp. 343-364, 2008.

[76] R. A. Khan, M. A. Khan, H. U. Zaman, S. Pervin, N. Khan and S. Sultana, "Comparative studies of mechanical and interfacial properties between jute and e-glass fiberreinforced polypropylene composites," *Journal of Reinforced Plastics and Composites,* no. 29, pp. 1078-1088, 2010.

[77] V. Vilay, M. Mariatti, R. M. Taib and M. Todo, "Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber–reinforced unsaturated polyester composites," *Composites Science and Technology,* no. 68, pp. 631-638, 2008.

[78] W. Liu, A. K. Mohanty, P. Askeland, L. T. Drzal and M. Misra, "Influence of fiber surface treatment on properties of Indian grass fiber reinforced soy protein based biocomposites," *Polymer,* vol. 45, no. 22, pp. 7589-7596, 2004.

[79] M. R. Ishak, Z. Leman, M. S. Salit and M. K. A. Uyup, "Characterization of sugar palm (Arenga pinnata) fibres," *Journal of Thermal Analysis and Calorimetry,* 2012.

[80] C. Merlini, V. Soldi and G. M.O.Barra, "Influence of fiber surface treatment and length on physico-chemical properties of short random banana fiber-reinforced castor oil polyurethane composites," *Polymer Testing,* vol. 30, no. 8, pp. 833-840, 2011.

[81] S. Aboul-Fadl, S. Zeronian, M. Kamal, M. Kim and M. Ellison, "Effect of Mercerization on the Relation Between Single Fiber Mechanical Properties and Fine Structure for Different Cotton Species," *Textile Research Journal*, 1985.

[82] L. Y. Mwaikambo and M. P. Ansell, "Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization," *Journal of Applied Polymer Science* , 2002.

[83] M. A. Abbas., D. Bachtiar, J. P. Siregar and R. Rejab, "Effect of sodium hydroxide on the tensile properties of sugar palm fibre reinforced thermoplastic polyurethane composites," *Journal of Mechanical Engineering and Sciences*, vol. 10, no. 1, pp. 1765-1777, 2016.

[84] M. Haameem, M. A. Majid, M. Afendi and F. Idris, "Alkaline treatment and thermal properties of Napier grass fibres," *International Journal of Automotive and Mechanical Engineering*, p. 3238, 2016.

[85] N. Mohanta and S. Acharya, "Fiber Surface Treatment: Its Effect on Structural, ,Thermal, and Mechanical Properties of Luffa Cylindrica Fiber and Its Composite," *Journal of Composite Materials*, 2015.

[86] E. B. Larsen, Pressure Bag Molding: Manufacturing, Mechanical Testing, Non-Distructive Evaluation and Analysis, MSc Thesis, Montana State University , 2004.

[87] R. A. Sanadi, J. F. Hunt, D. F. Caulfield, G. Kovacsvolgyi and B. Destree, "High fiber low-matrix composites: kenaf fiber/polyprophylene," in *6th International Conference on Woodfibre-Plastic Composites*, Madison, 2001.

[88] M. F. Ashby, Michael Ashby, London: Butterworth-Heinemann , 2011.

[89] H. Yang, R. Yan, H. Chen, D. H. Lee and C. Zheng, "Characteristics of hemicellulose, cellulose and lignin pyrolysis," *Fuel*, Vols. 12-13, no. 86, pp. 1781-1788, 2007.

[90] K. C. M. Nair, S. Thomas and G. Groeninckx, "Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres," *Composites Science and Technology*, no. 61, pp. 2519-2529, 2001.

[91] D. Bachtiar, K. Abdan, S. M. Sapuan and E. S. Zainudin, "The Flexural, Impact and Thermal Properties of Untreated Short Sugar Palm Fihre Reinforced High Impact Polystyrene (HIPS) Composites," *Polymers and Polymer Composites*, vol. 20, no. 5, pp. 493-502, 2012.

[92] B. Rashid, M. Jawaid, M. R. Ishak, and M J Ghazali, "Physicochemical and thermal properties of lignocellulosic fiber from sugar palm fibers: effect of treatment," *Cellulose*, vol. 23, no. 5, pp. 2905-2916, 2016.

[93] M. R. Ishak, S. M. Sapuan, M. Z. A. Rahman, U. M. K. Anwar and J. P. Siregar, "Sugar palm (Arenga pinnata): Its fibres, polymers and composites," *Carbohydrate Polymers,* vol. 91, no. 2, pp. 699-710, 2013.

[94] D. Ray, B. K. Sarkar, S. Das and A. K. Rana, "Dynamic mechanical and thermal analysis of vinylester-resin-matrix composites reinforced with untreated and alkali-treated jute fibres," *Composites Science and Technology,* vol. 62, no. 7, pp. 911-917, 2002.

[95] X. Li, L. G. Tabil and S. Panigrahi, "Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review," *Journal of Polymers and the Environment* , vol. 15, no. 1, pp. 25-33, 2007.

[96] B. R. Mohammed, Z. Leman, M. Jawaid, M. J. Ghazali and M. R. Ishak, "Dynamic Mechanical Analysis of Treated and Untreated Sugar Palm Fibre-based Phenolic Composites," *Palm phenolic composites,* vol. 12, no. 2, pp. 3448-3462, 2017.

[97] M. J. M. Ridzuan, M. S. A. Majid, M. Afendi, M. N. Mazlee and A. G. Gibson, "Thermal behaviour and dynamic mechanical analysis of Pennisetum purpureum/glass-reinforced epoxy hybrid composites," *Composite Structures,* vol. 152, pp. 850-859, 2016.

[98] M.Jawaid, H. P. S. A. Khalil, A. Hassan, R. Dungani and A. Hadiyane, "Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites," *Composites Part B: Engineering,* vol. 45, no. 1, pp. 619-624, 2013.

[99] B. K. Goriparthi, K. N. S. Suman and N. M. Rao, "Effect of fiber surface treatments on mechanical and abrasive wear performance of polylactide/jute composites," *Composites Part A: Applied Science and Manufacturing,* vol. 43, no. 10, pp. 1800-1808, 2012.

[100] S. M. Lee, D. Cho, W. H. Park, S. G. Lee, S. O. Han and L. T. Drzal, "Novel silk/poly(butylene succinate) biocomposites: the effect of short fibre content on their mechanical and thermal properties," *Composites Science and Technology,* vol. 65, no. 3, pp. 647-657, 2005.

[101] M. W. Lee, S. O. Han and Y. B. Seo, "Red algae fibre/poly(butylene succinate) biocomposites: The effect of fibre content on their mechanical and thermal properties," *Composites Science and Technology,* vol. 68, no. 6, pp. 1266-1272, 2008.

[102] Z. M. Hafiz, A. A. Bakar and H. M. Akil, "Predicting the Coefficient of Thermal Expansion of Pultruded Composites," *Mechanics of Composite Materials,* vol. 50, no. 5, pp. 603-612, 2014.

[103] G. Korb, J. Koráb and G. Groboth, "Thermal expansion behaviour of unidirectional carbon-fibre-reinforced copper-matrix composites," *Composites Part A: Applied Science and Manufacturing,* vol. 29, no. 12, pp. 1563-1567, 1998.

[104] D. Sampathkumar, R. Punyamurthy, B. Bennehalli, R. P. Ranganagowda and S. C. Venkateshappa, "NATURAL ARECA FIBER: SURFACE MODIFICATION AND SPECTRAL STUDIES," *Journal of Advances in Chemistry,* vol. 10, no. 10, pp. 3263-3273, 2014.

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LIST OF PUBLICATIONS

Journal Paper

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Chapter in book

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Chapter 5: Preparation and Characterization of Sugar Palm Fibres, Book: *Sugar Palm Biofibres, Biopolymers, and Biocomposites*, 2019, Published by CRC Press Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, ISBN 978-1-4987-5302-9.

Conference proceeding

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