UNIVERSITI PUTRA MALAYSIA

MECHANICAL AND THERMAL PROPERTIES OF SHORT SUGAR PALM (Arenga pinnata MERR.) FIBRE-REINFORCED HIGH IMPACT POLYSTYRENE COMPOSITES

DANDI BACHTIAR

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By

DANDI BACHTIAR

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

May 2012

DEDICATION

My Father, (late) Bachtiar Amin
My Mother, Alima
My Wife, Cut Helida
and
My Children, Muhammad Hadid Ghifary
Muhammad Salman Alfarizi
Siti Maghfira Azzahra

also
My Brother, Lian Satria & family
My Sister, Yasmin Lilianti & family

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MECHANICAL AND THERMAL PROPERTIES OF SHORT SUGAR PALM (*Arenga pinnata MERR.*) FIBRE-REINFORCED HIGH IMPACT POLYSTYRENE COMPOSITES

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May 2012

Chairman: Professor Ir. Mohd. Sapuan Salit, PhD

Faculty: Engineering

Sugar palm fibre (SPF) is a promising natural fibre used in reinforcing polymer matrix composites. The fibre has good tensile properties and could also be suitable as reinforcing agents in composite materials. This research is important because no study has been conducted about the using of sugar palm fibre to reinforced high impact polystyrene (HIPS) composites previously. New natural composites of sugar palm fibre (SPF) reinforced high impact polystyrene (HIPS) matrix have been produced by using melt mixing and compression moulding method. Tensile, flexural, and impact tests were performed to determine the mechanical properties, while dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA) were performed to determine the thermal properties of SPF-HIPS composites by varying the sugar palm fibre contents. It was found that the increase in fibre loading on HIPS matrix enhanced the tensile and flexural modulus of the composites. However, tensile strength decreased with the increase in fibre loading due to poor compatibility of interface between fibre and polymer surfaces. The flexural strength also increased.

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However, all of the values of flexural strength of SPF-HIPS composites were lower than the pure HIPS matrix. The addition of short SPF decreased the impact strength of these composites. It was found that from the dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA) the SPF-HIPS composites showed better thermal stability than pure HIPS matrix. The moisture content of the SPF-HIPS composites increase and this behavior contribute to weakness in strength.

The major barrier in utilising natural fibres in reinforcing polymer composites is compatibility issue. It is because the weak interfacial bonding between hydrophilic fibres and hydrophobic polymers. The alkali treatment and compatibilizing agent were performed to the SPF-HIPS composites at the fibre content of 40%. The alkali treatment was performed by immersing fibres in 4% and 6% alkali solution, and the incorporation of 2% and 3% polystyrene-block-poly(ethylene-ran-butylene)-block-poly(styrene-graft-maleic-anhydride) were used as compatibilizing agent. Both alkali treatment and compatibilizing agent treatment increased the tensile strength of composites, while the alkali treatment at the 4% level showed the highest tensile strength, improvement of about 35% from untreated composites. Therefore, alkali treatment with 6% NaOH solution could improve the flexural strength, flexural modulus and impact strength of the composites from the untreated composites by 12%, 19% and 34% respectively. Compatibilizing agent showed the improvement on the impact strength, i.e 6% and 16% improvement for 2% and 3% MAH respectively, meanwhile, no enhancement of the composites properties when subjected to flexural properties testing. Finally, modification of the SPF-HIPS composites, using the compatibilizing agent and the fibres treated with alkali has brought a slight improvement to the peak temperature of decomposition of composites. It can be stated that the the modification of composites with alkaline

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treatment and compatibilizing agent on the high impact polystyrene composites resulted in higher thermal stability of the composites than the high impact polystyrene polymer alone.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIFAT-SIFAT MEKANIKAL DAN TERMAL DARIPADA KOMPOSIT POLISTIRENA IMPAK TINGGI DIPERKUAT GENTIAN PENDEK IJUK

oleh

DANDI BACHTIAR

Mei 2012

Pengerusi: Profesor Ir. Mohd. Sapuan Salit, PhD

Fakulti: Kejuruteraan

Gentian ijuk adalah gentian semulajadi yang boleh digunakan dalam memperkukuhkan matriks polimer komposit. Gentian ini mempunyai sifat tegangan yang baik dan juga mungkin sesuai sebagai ejen untuk mengukuhkan dalam bahan komposit. Kajian ini penting kerana tidak ada lagi kajian tentang penggunaan gentian ijuk yang dicampur dengan komposit polistirena impak tinggi. Komposit baharu semulajadi polistirena impak tinggi diperkuat gentian pendek ijuk telah dihasilkan dengan menggunakan kaedah pencampuran leleh dan pengacuan mampatan. Ujian tegangan, lenturan, dan impak yang telah dijalankan untuk menentukan sifat-sifat mekanik, manakala analisis dinamik mekanikal (DMA) dan analisis termogravimetri (TGA) telah dijalankan untuk menentukan sifat haba komposit dengan variasi kandungan gentian ijuk. Ia didapati bahawa peningkatan dalam kandungan gentian pada matriks HIPS mempertingkatkan modulus tegangan dan lenturan bagi komposit. Walau bagaimanapun, kekuatan tegangan menurun dengan peningkatan dalam kandungan gentian disebabkan keserasian lemah antara muka antara permukaan gentian dan polimer. Kekuatan lenturan juga

meningkat. Walau bagaimanapun, semua nilai kekuatan lenturan komposit adalah lebih rendah daripada matriks polistirena tulen. Penambahan gentian ijuk pendek mengurangkan kekuatan impak komposit. Didapati bahawa daripada analisis dinamik mekanikal (DMA) dan analisis termogravimetri (TGA) komposit menunjukkan kestabilan terma yang lebih baik daripada matriks tulen. Kandungan kelembapan komposit juga meningkat, dan tingkah laku ini menyumbang kepada kekuatan yang berkurangan.

Halangan utama dalam penggunaan gentian semulajadi dalam polimer adalah isu keserasian. Ini kerana ikatan yang lemah pada antarmuka gentian yang bersifat hodrofilik dengan polimer yang bersifat hidrofobik. Rawatan alkali dan ejen penyepadu telah dijalankan kepada komposit pada kandungan gentian sebanyak 40%. Rawatan alkali telah dilakukan oleh gentian dengan cara merendamkannya dalam 4% dan 6% larutan alkali; Manakala 2% dan 3% polystyrene-block-poly(ethylene-ran-butylene)-block-poly(styrene-graft-maleic-anhydride telah diguna-kan sebagai ejen penyepadu. Kedua-dua rawatan alkali dan rawatan ejen compatibilizing meningkatkan kekuatan tegangan komposit, manakala rawatan alkali di peringkat 4% menunjukkan tegangan yang tertinggi, peningkatan kira-kira 35% daripada komposit yang tidak dirawat. Oleh itu, rawatan alkali dengan larutan NaOH 6% boleh meningkatkan kekuatan lenturan, modulus lenturan dan kekuatan impak komposit daripada komposit tidak dirawat sebagai jumlah masing-masing 12%, 19% dan 34%. Ejen compatibilizing menunjukkan peningkatan pada kekuatan impak, iaitu 6% dan peningkatan 16% bagi masing-masing 2% dan MAH 3%, sementara itu, tiada peningkatan sifat komposit tertakluk kepada sifat-sifat ujian lenturan. Akhirnya, pengubahsuaian komposit, menggunakan ejen compatibilizing dan rawatan alkali telah membawa sedikit peningkatan kepada suhu puncak penguraian komposit. Ia boleh dinyatakan bahawa pengubahsuaian komposit dengan rawatan alkali dan ejen penyepadu pada komposit polistirena tinggi kesan menyebabkan kestabilan terma yang lebih tinggi bagi komposit daripada polimer polistirena berimpak tinggi sahaja.

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APPROVAL

I certify that a Thesis Examination Committee has met on 28 May 2012 to conduct the final examination of Dandi Bachtiar on his thesis entitled "Mechanical and Thermal Properties of Short Sugar Palm (*Arenga pinnata* Merr.) Fibre-Reinforced High Impact Polystyrene Composites" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institution.

DANDI BACHTIAR

Date: 28 May 2012

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TABLE OF THE CONTENTS

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LIST OF TABLES

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LIST OF FIGURES

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LIST OF ABBREVIATIONS

CA	Cellulose acetate
CCF	Chicken Feather Fibre
CD	Compact Disk
CDA	Cellulose diacetate
CMC	Ceramic Matrix Composites
CTDIC	Cardanol derivative of toluene diisocyanate
DMA	Dynamic Mechanical Analysis
DSC	Differential Scanning Calorimetry
DTG	Derivative Thermogravimetry
DVD	Digital Versatile Disk / Digital Video Disk
EFB	Empty Fruit Bunch
EPS	Expanded Polystyrene
EVA	Ethylene vinyl acetate
FR	Fire Retardant
FRP	Fibre Reinforced Plastics
HDPE	High Density Polyethylene
HIPS	High Impact Polystyrene
HRR	Heat Release Rate
IC	Integrated Circuit
KOH	Kalium Hydroxide
LDPE	Low Density Polyethylene
LNR	Liquid natural rubber
MAH	Maleic Anhydride
MAPP	Maleated Polypropylene
MDI	Diphenylmethane diisocyanate
MMC	Metal Matrix Composites
NaOH	Sodium Hydroxide
NF	Natural Fibre
NMT	Natural fibre-mat-reinforced-thermoplastics
o-HBDS	o-hydroxybenzenediazonium
PBS	Polybutylene succinate
PEG	Polyethylene glycol
PHBV	Poly(hydroxybutyrate-co-valerate)
PLA	Polylactic Acid
PMC	Polymeric Matrix Composites
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane

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PVC	Poly(vinyl chloride)
RHF	Rice Husk Flour
RNP	Recycled newspaper
RTM	Resin Transfer Moulding
SEBS	Styrene-ethylene-buthylene-styrene
SEM	Scanning Electron Microscopy
SLS	Sodium laulryl sulfate
SMC	Sheet Moulding Compound
SPF	Sugar Palm Fibre
TGA	Thermogravimetris Analysis
TMA	Thermal Mechanical Analysis
TMTPA	Trimethylolpropane triacrylate
TPGDA	Tripropylene gylcol diacrylate
WF	Wood Flour

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CHAPTER 1

INTRODUCTION

1.1 Background

Polymer composite materials mostly nowadays use well-established fibres such as glass, carbon and aramid as the reinforcement. The use of polymer composites has grown at a phenomenal rate since the 1960s, and these materials now have an impressive and diverse range of applications in aircraft, spacecraft, boats, ships, automobiles, civil infrastructure, sporting goods and consumer products. The use of composites will continue to grow in future with emerging applications in large bridge structures, offshore platforms, engine machinery, computer hardware and biomedical devices. The greatest increases are occurring in the transport and construction markets, although the use of composites is also substantial in the corrosion protection (eg. piping), marine, and electrical/electronic markets (Mouritz and Gibson, 2006).

The use of composites in a broad of applications is due to their many excellent physical, thermal, chemical and mechanical properties. Key advantages of composites over many metal alloys include low density, high specific stiffness and specific strength, good fatigue endurance, excellent corrosion resistance, outstanding thermal insulation and low thermal expansion. However, there are several disadvantages with composites in particular to challenge the environmental issues. These inorganic fibres present disadvantages like their non-biodegradability, expensive, abrasive and non-renewable.

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Growing environmental awareness has resulted in a renewed interest in the use of natural material for many applications. This paradigm has forced industries like automotive, packaging and construction to search for new materials to make the conventional composite materials an environmentally friendly material. Natural fibre reinforced polymer composite materials have a number of benefits, including low density and bio-degradability, less abrasiveness, lower cost and renewable compare to inorganic fibres reinforced polymer composites. The substitution of the inorganic substances and synthetic fibres generally used as reinforcing fillers in plastics by natural fibres would be highly beneficial from the point of view of environmental protection, whereas inorganic materials such as glass fibre, carbon fibre, talc, clay and synthetic fibres do not have these benefits (Yang et al., 2007).

Many types of natural fibres have been employed in reinforcing the polymeric composites, such as kenaf, hemp, jute, flax, pineapple leaf, sisal and many more. Sugar palm or *Arenga pinnata* fibre is a promising source of natural fibre from sugar palm plant, a member of *Palmae* family. Traditionally application of this fibre cover wide range field such as rope, broom, paintbrush, filter, doormat, chair/sofa cushion and for roof because of its strength and durability (Suwartapradja, 2003). Geographical distribution of sugar palm covers the Indo-Malay archipelago and spread in all of tropical Southeast Asia countries, from Myanmar to the Philipines (Mogea et al., 1991). Moreover, this plant can also produce the bioethanol. Sugar palm plant has a highest production capability of the alcohol compared with other sources such as sweet sorghum, sugarcane, and cassava. This plant will become a promising source of biofuel in the future (de Boer, 2010; Widodo et al., 2009). Once

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the plantation of sugar palms is growing, there will be high availability of sugar palm fibres as the by-product.

Some investigations about reinforcement the thermoset material by sugar palm fibre have been studied (Sastra et al., 2005; Sastra et al., 2006; Suriani et al., 2006; Bachtiar et al., 2008; Bachtiar et al., 2009; Leman et al, 2008a; Ali et al., 2010). However, the characterization of the role of sugar palm fibres in the reinforcing of thermoplastic composites has not been studied yet.

One of the widely used thermoplastics is high impact polystyrene (HIPS). A study of residues from electrical and electronic equipment found that resin of high impact polystyrene (HIPS) accounts for 56% or more than half of all other plastic resin that were used (Fisher, et al., 2003). Major applications of HIPS include packaging, containers, appliance parts, house-wares and interior parts in household electronics. HIPS is a low cost plastic material, ease to machine and fabricate. HIPS usually specified for applications in particular for low strength structural with impact resistance, machinability and low cost are required.

1.2 Significance of Study

Mixing HIPS material with sugar palm fibres to form sugar palm fibre/HIPS composites is a promising alternative in optimization of good behaviors from both materials, fibres and matrix. Low cost, abundance and good mechanical properties of the sugar palm will contribute to the performance of composites with HIPS matrix. Characterization of sugar palm fibre reinforced HIPS composites also offer the new alternative in study on behavior of thermoplastic composites due to the limitation understanding about this

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composites previously. Extensive investigation on the behavior of sugar palm fibre reinforced high impact polystyrene composites is important in adding the highly contribution on natural composites researches fields.

1.3 Problem Statement

Usually, the major barrier in utilising natural fibres in reinforcing polymer composites is compatibility issue. It is because the weak interfacial bonding between hydrophilic fibres and hydrophobic polymers. The presence of hydroxyl and other polar groups on the surface and throughout natural fibre, moisture absorption can be high. It leads to poor wettability by the polymers. These problems were also faced by sugar palm fibres and HIPS matrix when the composites are developed. Some treatments have to conducted to break these drawbacks, such physical and chemical treatment sucjected to the fibres and matrix. Alkali treatment is usually used in fibre treatment and compatibilizing agent is used as chemical agent to upgrade the capability of matrix polymers when interact with natural fibres.

1.4 Objective of the Study

The objectives of this study are as follows:

1. To investigate the effect of fibre loading on the mechanical and thermal properties of sugar palm fibre reinforced high impact polystyrene composites.
2. To determine the influence of alkali treatment and compatibilizing agents on the mechanical and thermal properties of sugar palm fibre reinforced high impact polystyrene composites.

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3. To determine the influence of alkali treatment and compatibilizing agents on the moisture absorption behaviour of sugar palm fibre reinforced high impact polystyrene composites.

1.5 Scope and Limitation of the Study

The scope of present research is to study the potential of using a by- product of agriculture as a reinforcing of thermoplastic polymer. The fibre used in this study was sugar palm fibre obtained from tropical forest plant. High impact polystyrene (HIPS) resin was used to prepare composite in different amounts of sugar palm fibre (10%, 20%, 30% , 40% and 50% by weight) by internal mixer and compression moulding technique. These specimens were tested for their mechanical and thermal properties, by means of tensile, flexural, impact, dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA). Alkali treatment and compatibilizing agent (maleic anhydride) are used as chemical treatments to enhance the mechanical and thermal properties of the composites.

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REFERENCES

Agung, E.H., Sapuan, S.M., Hamdan, M.M., Zaman, H.M.D.K. and Mustofa, U. (2011). Study on abaca (*Musa textilis Nee*) fibre reinforced high impact polystyrene (HIPS) composites by thermogravimetric analysis (TGA). *International Journal of the Physical Sciences*. 6(8): 2100-2106.

Ahad, N.A., Parimin, N., Mahmed, N., Ibrahim, S.S., Nizzam, K. and Ho, Y.M. (2009). Effect of chemical treatment on the surface of natural fibre. *Journal of Nuclear and Related Technologies.* 6(1): 155-158.

Ahmad, S.H., Rasid, R., Bonnia, N.N., Zainol, I., Mamun, A.A., Bledzki, A.K. and Beg, M.D.H. (2011). Polyester-kenaf composites: effects of alkali fibre treatment and toughening of matrix using liquid natural rubber. *Journal of Composites Materials.* 45: 203-217.

Aiamsen, P., Paiphansiri, U., Sangribsub, S., Polpanich, D. and Tangboriboonrat, P. (2003). Toughness and morphology of radiation-crosslinked natural rubber modified polystyrene. *Polymer International*. 52:1198–1202.

Aji, I.S., Zainudin, E.S., Khalina, A., Sapuan, S.M., and Khairul, M.D. (2011). Thermal property determination of hybridized kenaf/PALF reinforced HDPE composite by thermogravimetric analysis. *Journal of Thermal Analysis and Calorimetry*. Article in press.

Akesson, D., Skrifvars, M. and Walkenstrom, P. (2009). Preparation of thermoset composites from natural fibres and acrylate modified soybean oil resins. *Journal of Applied Polymer Science*. 114: 2502–2508.

Akil, H.M., Omar, M.F., Mazuki, A.A.M., Safiee, S., Ishak, Z.A.M. and Bakar, A.A. (2011). Kenaf fibre reinforced composites: a review. *Materials and Design.* Article in press.

Alam, M.M., Ahmed, T., Haque, M.M., Gafur, M.A. and Kabir, A.N.M.H. (2009). Mechanical properties of natural fibre containing polymer composites. *Polymer-Plastics of Technology and Engineering*. 48: 110-113.

Alavudeen, A., Thiruchitrambalam, M., Venkateshwaran, N. and Athijayamani, A. (2011). Review of natural fibre reinforced woven composite. *Review of Advanced Materials Science.* 27: 146-150.

Alawar, A., Hamed, A. M., and Al-Kaabi, K. (2009). Characterization of treated palm tree fibre as composites reinforcement. *Composites: Part B*. 40: 601-606.

Alfarraj, A. and Nauman, E.B. (2004). Super HIPS: improved high impact polystyrene with two sources of rubber particles. *Polymer*. 45: 8435-8442.

Ali, A., Sanuddin, A.B. and Ezzeddin, S. (2010). The effect of aging on *Arenga pinnata* fibre reinforced epoxy composites. *Materials and Design*. 31(7): 3550-3554.

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Álvarez-Chávez, C.R., Edwards, S., Moure-Eraso, R. and Geiser, K. (2012). Sustainability of bio-based plastics: general comparative analysis and recommendations for improvement. *Journal of Cleaner Production*. 23: 47-56.

Alvarez, V.A., Ruscekaite, R.A. and Vazquez, A. (2003). Mechanical properties and water absorption behavior of composites made from a biodegradable matrix and alkaline-treated sisal fibres. *Journal of Composite Materials* 37(17): 1575-1588.

Antich, P. Vazquez, A., Mondragon, I. and Bernal, C. (2006). Mechanical behavior of high impact polystyrene reinforced with short sisal fibres. *Composites Part A: Applied Science and Manufacturing*. 37: 139-150.

Arbelaiz, A., Fernandez, B., Cantero, G., Llano-Ponte, R., Valea, A. and Mondragon, I. (2005). Mechanical properties of flax fibre/polypropylene composites. Influence of fibre/matrix modification and glass fibre hybridization. *Composites Part A: Applied Science and Manufacturing* 36(12): 1637-1644.

Ashori, A. and Shesmani, S. (2010). Hybrid composites made from recycled materials: moisture absorption and thickness swelling behavior. *Bioresource Technology*. 101: 4717-4720.

Bachtiar, D., Sapuan, S.M. and Hamdan, M.M. (2008). The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites, *Materials and Design*. 29: 1285-1290.

Bachtiar, D., Sapuan, S.M. and Hamdan, M.M. (2009). The influence of alkaline surface treatment on the impact properties of sugar palm fibre reinforced epoxy composites, *Polymer-Plastics of Technology and Engineering*. 48(4): 379-383.

Bachtiar, D., Sapuan, S.M. and Hamdan, M.M. (2010). Flexural Properties of Alkaline Treated Sugar Palm Fibre Reinforced Epoxy Composites, *International Journal of Automotive and Mechanical Engineering (IJAME)*. 1(1): 79-85.

Bertoti, A.R., Luporini, S. and Esperidião, M.C.A. (2009). Effects of acetylation in vapor phase and mercerization on the properties of sugarcane fibers. *Carbohydrate Polymers*. 77(1): 20-24.

Biagiotti, J., Puglia, D. and Kenny, J.M. (2004). A review on natural fibre composites – Part I: structure, processing and properties of vegetable fibres. *Journal of Natural Fibres*. 1(2): 37-68.

Bodros, E. and Baley, C. (2008). Study of the tensile properties of stinging nettle fibres (*Urtica dioica*). *Materials Letters*. 62: 2143-2145.

Bledzki, A. K. and Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science, 24*(2), 221-274.

© COPYRIGHT UPM

Bledzki, A.K., Mamun, A.A. and Faruk, O. (2007). Abaca fibre reinforced PP composites and comparison with jute and flax fibre PP composites. *Express Polymer Letters.* 1(11): 755-762.

Bledzki, A.K., Reihmane, S. and Gassan, J. (1996). Properties and modification methods for vegetable fibres for natural fibre composites. *Journal of Applied Polymer Science*. 59: 1329-1336.

Bledzki, A.K., Reihmane, S. and Gassan, J. (1998). Thermoplastics reinforced with wood fillers: a literature review. *Polymer-Plastics of Technology and Engineering*. 37(4): 451-468. 59: 1329-1336.

Callister, W. D. (2007). *Materials Science and Engineering: An Introduction* (7 ed.). New York: John Wiley & Sons.

Carrarher, C.E. (2010). *Introduction to Polymer Chemistry 2nd eds*. NewYork: CRC Press.

Chanda, M., Roy, S.K. (2009). *Industrial Polymers, Speciality Polymers, and their Applications*. London: CRC Press.

Chang, S., Xie, T. and Yang, G. (2007). Effects of shell thickness of polystyrene-encapsulated $Mg(OH)_2$ on flammability and rheological properties of high-impact polystyrene composites. *Polymer International.* 56: 1135-1141.

Cheng, S., Lau, K.T., Liu, T., Zhao, Y., Lam, P.M. and Yin, Y. (2009). Mechanical and thermal properties of chicken feather fibre/PLA green composites. *Composites: Part B.* 40: 650-654.

Cheung, H.Y., Ho, M.P., Lau, K.T., Cardona, F. and Hui, D. (2009). Natural fibre-reinforced composites for bioengineering and environmental engineering applications. *Composites: Part B.* 40: 655-663.

Chow, W. S., and Ooi, K. H. (2007). Effects of maleic anhydride graft polystyrene on the flexural and morphological properties of polystyrene/organo-montmorillonite nanocomposites. *Malaysia Polymer Journal* 2(1): 1-9.

Cohen, J.T., Carlson, G., Charnley, G., Coggon, D., Delzell, E., Graham, J.D., Greim, H., Krewski, D., Medinsky, M., Monson, R., Paustenbach, D., Petersen, B., Rappaport, S., Rhomberg, L., Ryan, P.B. and Thompson, K. (2002). A comprehensive evaluation of the potential health risks associated with occupational and environmental exposure to styrene, *Journal of Toxicology and Environmental Health*. Part B, 5:1-2, 1-263.

Dalibard, C. (1995). Overall view on the tradition of tapping palm trees and prospects for animal production. *International Relations Service*, Ministry of Agriculture, Paris, France.

Daniel, I. M. and Ishai, O. (1994). *Engineering Mechanics of Composite Materials*. New York: Oxford University Press.

© COPYRIGHT UPM

d'Almeida, A.L.F.S., Calado, V., Barreto, D.W. and d'Almeida, J.R.M. (2011). Effect of surface treatments on the dynamic mechanical behavior of piassava fibre–polyester matrix composites. *Journal of Thermal Analysis and Calorimetry*. 103: 179-184.

de Boer, I.E.M. (2010). Planting sugar palm as means to offset the CO_2 load of Apenhaul Primate Park, Appeldoorn, the Nederland. *International Zoo Yearbook*. 44: 246-250.

Devi, L.U., Bhagawan, S.S. and Thomas, S. (1997). Mechanical properties of pineapple leaf fibre-reinforced polyester composites. *Journal of Applied Polymer Science*. 64: 1739-1748.

Doan, T.T.L., Brodowsky, H. and Mader, E. (2007). Jute fibre/polypropylene composites II. Thermal hydrothermal and dynamic mechanical behaviour. *Composites Science and Technology*. 67: 2707-2714.

Doroudiani., S. and Kortschot, M.T. (2004). Expanded wood fibre polystyrene composites: processing–structure–mechanical properties relationships. *Journal of Thermoplastic Composite Materials*. 17:13-30.

Dweib, M.A., Hu, B., Shenton III, H.W. and Wool, R.P. (2006). Bio-based composite roof structure: manufacturing and processing issues. *Composite Structures*. 74: 379–388.

Ebskamp, M.J.M. (2002). Engineering flax and hemp for an alternative to cotton. *Trends in Biotechnology*. 20 (6): 229-230.

Edeerozey, A.M.M., Akil, H.M., Azhar, A.B. and Zainal Ariffin, M.I.Z. (2007). Chemical modification of kenaf fibres. *Materials Letters*. 61: 2023–2025.

Efriyohadi, A. (2011). Characterisation and optimisation of mechanical, physical and thermal properties of short abaca (musa textile nee) fibre reinforced high impact polystyrene composites, PhD thesis, Universiti Putra Malaysia.

Ehrenstein, G.W. (2001). *Polymeric Materials*. Munich: Carl Hanser Verlag.

Eichhorn, S.J. and Young, R. (2004). Composites micromechanics of hemp fibres and epoxy resin microdroplets. *Composites Science and Technology*. 5: 767-772.

Elberson, W. And Oyen, L. (2010). Sugar palm (*Arenga pinnata)*: Potential of sugar palm for bio-ethanol production, brosur prepared by FACT Foundation, Netherlands.

Felix, J.M. and Gatenholm, P. (1991). The nature of adhesion in composites of modified cellulose fibers and polypropylene. *Journal of Applied Polymer Science*. 42: 609-620.

© COPYRIGHT UPM

Ferdiansyah, T. and Razak, H.A. (2011). Mechanical properties of black sugar palm fibre-reinforced concrete. *Journal of Reinforced Plastics and Composites*. In Press.

Fisher, M., Biancaniello, J., Kingsbury, T., Headly, L. (2003). *Ten facts to know about plastic from consumer electronics*. Paper presented at the meeting of the International Symposium on Electronics & the Environment (ISEE). Institute for Electrical and Electronics Engineers, Inc.'s (IEEE).

Ganan, P. and Mondragon, I. (2003). Thermal and degradation behavior of fique fibre reinforced thermoplastic matrix composites. *Journal of Thermal Analysis and Calorimetry*. 73: 783-795.

Ganan, P., Garbizu, S., Ponte, R.L. and Mondragon, I. (2005). Surface modification of sisal fibres: effects on the mechanical and thermal properties of their epoxy composites. *Polymer Composites.* 26: 121-127.

Gassan, J. and Bledzki, A.K. (2001). Thermal degradation of flax and jute fibres. *Journal of Applied Polymer Science*. 82: 1417–1422.

Gassan, J., Gutowski, V.S. and Bledzki, A.K. (2000). About the surface characteristics of natural fibres. *Macromolecular Materials and Engineering*. 283: 132-139.

Gay, D. and Hoa, S. V. (2007). *Composite Materials: Design and Applications* (2nd ed.). New York: CRC Press.

George, J., Joseph, K., Bhagawan, S. S., and Thomas, S. (1993). Influence of short pineapple-leaf fibre on the viscoelastic properties of low-density polyethylene. *Material Letters.* 18: 163-170.

George, J., Sreekala, M.S. and Thomas, S. (2001). A review on interface modification and characterization of natural fibre reinforced plastic composites. *Polymer Engineering and Science.* 41(9): 1471-1485.

Gupta, M.C. and Gupta, A.P. (2005). *Polymer Composite*. New Delhi: New Age International (P) Limited Publishers.

Hapuarachchi, T.D., Ren, G., Fan, M., Hogg, P.J. and Peijs, T. (2007). Fire retardancy of natural fibre reinforced sheet moulding compound. *Applied Composite Materials*. 14: 251–264.

Heijenrath, R. and Peijs, T. (1996). Natural fibre-mat-reinforced thermoplastic composites based on flax fibre and polypropylene. *Advanced Composites Letters.* 5(3): 81-85.

Hill, C.A.S., Khalil, H.P.S.A. and Hale, M.D. (1998). A study of the potential of acetylation to improve the properties of plant fibres. *Industrial Crops and Products.* 8: 53-63.

© COPYRIGHT UPM

Hornsby, P. R., Hinrichsen, E., and Tarverdi, K. (1997). Preparation and properties of polypropylene composites reinforced with wheat and straw fibres. *Journal of Materials Science* 32: 1009-1015.

Ibrahim, N.A., Hadhiton, K.A. and Abdan, K. (2010). Effect of fibre treatment on mechanical properties of kenaf fibre-ecoflex composites. *Journal of Reinforced Plastics and Composites*. 29(14): 2192-2198.

Idicula, M., Malhotra, S.K., Joseph, K. and Thomas, S. (2005). Dynamic mechanical analysis of oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites. *Composites Science and Teachnology*. 65: 1077-1087.

Idicula, M., Sreekumar, P.A., Joseph, K. and Thomas, S. (2009). Natural fibre hybrid composites – a comparison between compression molding and resin transfer molding. *Polymer Composites*. 30: 1417-1425.

Ishak, M.R., Leman, Z., Sapuan, S.M., Salleh, M.Y. and Misri, S. (2009). 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)*.4(3): 316-320.

Ishak, M.R. (2009). Mechanical Properties of Woven Sugar Palm Fibre Reinforced Unsaturated Polyester Composites. *Master of Science Thesis*. Universiti Putra Malaysia.

Ishak, M.R., Sapuan, S.M., Leman, Z., Rahman, M.Z.A. and Azwar, U.M.K. (2011) Characterization of sugar palm (*Arenga pinnata*) fibres: tensile and thermal properties. *Journal of Thermal Analysis and Calorimetry*, DOI 10.1007/s10973-011-1785-1.

Ismail, H., Norjulia, A.M. and Ahmad, Z. (2010). The effects of untreated and treated kenaf loading on the properties of kenaf-fibre-filled natural rubber compounds. *Polymer-Plastics Technology and Engineering*. 49(5): 519-524.

Jacob, M., Thomas, S. and Varughese, K.T. (2004). Mechanical properties of sisal/oil palm hybrid fibre reinforced natural rubber composites. *Composites Science and Technology*. 64: 955-965.

Jayaramudu, J., Reddy, K.O., Maheswari, C.U., Reddy, D.J.P. and Rajulu, A.V. (2009). Tensile properties and thermal degradation parameters of *Polyalthia cerasoies* natural fabric reinforcement. *Journal of Reinforced Plastics and Composites*. 28(18): 2177-2181.

Jensen, W.B. (2008). The Origin of the Polymer Concept. *Journal of Chemical Education*. 85(5): 624.

Joffe, R., Andersons, J. and Wallstrom, L. (2003). Strength and adhesion characteristics of elementary flax fibres with different surface treatments. *Composites Part A: Applied Science and Manufacturing*. 34: 603–612.

© COPYRIGHT UPM

Joffe, R. and Andersons, J. (2008). Mechanical performance of thermoplastic matrix natural-fibre composites, in Kim. L. Pickering (eds.), *Properties and performance of natural-fibre composites* (p. 402-459). England: Woodhead Publishing Limited.

John, M.J. and Anandjiwala, R.D. (2008). Recent developments in chemical modification and characterization of natural fibre-reinforced composites. *Polymer Composites*. 29: 187–207.

John, M.J. and Anandjiwala, R.D. (2009). Chemical modification of flax reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing*. 40: 442–448.

John, M. J. and Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers. 71*(3): 343-364.

Joseph, K., Thomas, S. and Pavithran, C. (1996). Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites. *Polymer*. 37(23): 5139-5149.

Joseph ,P.V., Joseph, K., Thomas, S., Pillai, C.K.S., Prasad, V.S., Groeninckx, G. and Sarkissova, M. (2003). The thermal and crystallization studies of short sisal fibre reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing*. 34(3): 253.

Kabir, M.A., Huque, M.M. and Islam, M.B. (2010a). Mechanical properties of jute fibre reinforced polypropylene composite: effect of chemical treatment by benzenediazonium salt in akaline medium. *Bioresources.* 5(3): 1618-1625.

Kabir, M.A., Huque, M.M., Islam, M.B. and Bledzki, A.K. (2010b). Jute fibre reinforced polypropylene composite: effect of chemical treatment by benzenediazonium salt in neutral medium. *Journal of Reinforced Plastics and Composites*, 29(20): 3111-3114.

Kabir, M.M., Wang, H., Aravinthan, T., Cardona, F. and Lau, K.T. (2011). Effects of natural fibre surface on composite properties: a review. *Proceedings of EDDBE2011*, pp. 94-99.

Kaboorani, A. And Faezipour, M. (2009). Effects of wood preheat treatment on thermal stability of HDPE composites. *Journal of Reinforced Plastics and Composites*, 28(24): 2945-2955.

Kalaprasad, G., Francis, B., Thomas, S., Kumar, C.R., Pavithran, C., Groeninckx, G. and Thomas, S. (2004). Effect of fibre length and chemical modifications on the tensile properties of intimately mixed short sisal/glass hybrid fibre reinforced low density polyethylene composites *Polymer International*. 53:1624–1638.

© COPYRIGHT UPM

Kalia, S., Kaith, B.S. and Kaur, I. (2009). Pretreatment of natural fibres and their application as reinforcing material in polymer composites: a review. *Polymer Engineering and Science*. 49: 1253-1272.

Kelley, S.S., Rowell, R.M., Davis, M., Jurich, C.K. and Ibach, R. (2004). Rapid analysis of the chemical composition of agricultural fibres using near infrared spectroscopy and pyrolysis molecular beam mass spectrometry. *Biomass and Bioenergy*. 27: 77-88.

Khalid, M., Ratnam, C.T., Chuah, T.G., Salmiaton, A. and Choong, T.S.Y. (2008). Comparative study of polypropylene composites reinforced with oil palm empty fruit bunch fibre and oil palm derived cellulose. *Materials and Design*. 29(1): 173-178.

Khan, M.A., Khan, R.A., Haydaruzzaman, Ghoshal, S., Siddiky, M.N.A and Saha, M. (2009). Study on the physic-mechanical properties of starch-treated jute yarn-reinforced polypropylene composites: effect of gamma radiation. *Polymer-Plastics Technology and Engineering*. 48: 542-548.

Kim, H.S., Yang, H.S., Kim, H.J. and Park, H.J. (2004). Thermogravimetric analysis of rice husk flour filled thermoplastic polymer composites. *Journal of Thermal Analysis and Calorimetry*. 76: 395–404

Kim, H.S., Yang, H.S., Kim, H.J., Lee, B.J. and Hwang, T.S. (2005). Thermal properties of agro-flour-filled biodegradable polymer bio-composites. *Journal of Thermal Analysis and Calorimetry*. 81: 299–306.

Kim, J.T. and Netravali, A.N. (2010). Mercerization of sisal fibres: effect of tension on mechanical properties of sisal fibre and fibre-reinforced composites. *Composites Part A: Applied Science and Manufacturing*. 41: 1245-1252.

Koziol, M., Wlodek, A.B., Myalski, J. Wieczorek, J. (2011). Influence of wet chemistry treatment on the mechanical performance of natural fibres. *Polish Journal of Chemical Technology*. 13(4): 21-27.

Lai, W.L. and Mariatti, M. (2008). The properties of woven betel palm (*Areca catechu*) reinforced polyester composites. *Journal of Reinforced Plastics and Composites.* 27(9): 925-935.

Lee, C.K., Cho, M.S., Kim, I.H., Lee, Y.K. and Nam, J.D. (2010). Preparation and physical properties of the biocomposites, cellulose diacetate/kenaf fibre sized with poly(vinyl) alcohol. *Macromolecular Research.* 18(6): 566-570.

Lee, S.M., Cho, D., Park, W.H., Lee, S.G., Han, S.O. and Drzal, L.T. (2005). Novel silk/poly(butylene succinate) biocomposites: the effect of short fibre content on their mechanical and thermal properties. *Composites Science and Technology*. 65: 647-657.

Leman, Z., Sapuan, S.M., Azwan, M., Ahmad, M.M. and Maleque, M.A. (2008a). The effect of environmental treatments on fiber surface properties and tensile

© COPYRIGHT UPM

strength of sugar palm fiber-reinforced epoxy composites. *Polymer-Plastics Technology and Engineering*. 47(6): 606-612.

Leman, Z., Sapuan, S.M., Saifol, A.M., Maleque, M.A. and Ahmad, M.M. (2008b). Moisture absorption behavior of sugar palm fibre reinforced of epoxy composites. *Materials and Design.* 29(8): 1666-1670.

Li, X., Tabil, L.G. and Panigrahi, S. (2007). Chemical treatment of natural fibre for use in natural-fibre-reinforced composites: a review. *Journal of Polymer and Environment*. 15:25-33.

Lim, T.K. (2012). Arenga pinnata. In T.K. Lim. *Edible Medicinal and Non-Medicinal Plant: Volume 1*(pp. 280-284). London New York: Springer Dordrecht Heidelberg.

Lubin, G. (1982). *Handbook of Composites*. New York. Van Nostrand.

Luo, S. and Netravali, N. (1999). Interfacial and mechanical properties of environment-friendly "green" composites made from pineapple fibres and poly(hydroxybutyrate-co-valerate) resin. *Journal of Materials Science.* 34: 3709-3719.

Maldas, D., Kokta, B.V., Raj, R.G. and Daneault, C. (1988). Improvement of the mechanical properties of sawdust wood fibre-polystyrene composites by chemical treatment. *Polymer*. 29: 1255-1265.

Malkapuram, R., Kumar, V. and Negi, Y.S. (2009). Recent development in natural fibre reinforced polypropylene composites. *J. Reinforced Plastic and Composites*. 28: 1169-1189.

Mihai, M., Huneault, M.A. and Favis, B.D. (2007). Foaming of polystyrene/thermoplastic starch blends. *Journal of Cellular Plastics*. 43: 215-236.

Miller, R.H. (1964). The versatile sugar palm. *Principes*. 8: 115-147.

Misri, S., Leman, Z., Sapuan, S.M. and Ishak, M.R. (2010). Mechanical properties and fabrication of small boat using woven glass/sugar palm fibre reinforced unsaturated polyester hybrid composites. *IOP Conference Serie: Materials Science and Engineerin.* 11(1): 012015.

Mogea, J., Seibert, B. and Smits, W. (1991). The multipurpose palms: the sugar palm (Arenga pinnata (Wurmb) Merr.). *Agroforestry Systems*. 13: 111-129.

Mohamed, A.R., Sapuan, S.M. and Khalina, A. (2010). Selected properties of hand-laid and compression molded vinyl ester and pineapple leaf fibre (PALF)-reinforced vinyl ester composites. *International Journal of Mechanical and Materials Engineering (IJMME)*. 5(1): 68-73.

© COPYRIGHT UPM

Mohanty, A. K., Misra, M., Drzal, L., Selke, S. E., Harte, B. R., and Hinrichsen, G. (2005). Natural fibres, biopolymers, and biocomposites: An introduction. In A. K. Mohanty, M. Misra & L. Drzal (Eds.), *Natural Biofibers, Biopolymers, and Biocomposites*. Boca Raton, FL: CRC Press.

Mohanty, A.K., Misra, M. and Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: an overview. *Macromolecular Materials and Engineering*. 276/277: 1-24.

Mortezaei, M., Famili, M.H.N. and Kokabi, M. (2010). Influence of the particle size on the viscoelastic glass transition of silica-filled polystyrene. *Journal of Applied Polymer Science*. 115: 969–975.

Mouritz, A.P. and Gibson, A.G. (2006). Fire Properties of Polymer Composite Materials.

Mutje, P., Lopez, A., Vallejos, M.E., Lopez, J.P. and Vilaseca, F. (2007). Full exploitation of *Cannabis sativa* as reinforcement/filler of thermoplastic composite materials. *Composites Part A: Applied Science and Manufacturing*. 38: 369-377.

Mwaikambo, L.Y. and Ansell, M.P. (1999). The effect of chemical treatment on the properties of hemp, sisal, jute and kapok for composite reinforcement. *Die Angewandte Makromolekulare Chemie* 272: 108–116.

Nair, K.C.M., Diwan, S.M. and Thomas, S. (1996). Tensile properties of short sisal fibre reinforced polystyrene composites. *Journal of Applied Polymer Science*. 60: 1483-1497.

Nair, K.C.M., Kumar, R.P., Thomas, S., Schit, S.C. and Ramamurthy, K. (2000). Rheological behavior of short sisal fibre-reinforced polystyrene composites. *Composites Part A: Applied Science and Manufacturing*. 31: 1231-1240.

Nair, K.C.M., Thomas, S. and Groeninckx, G. (2001). Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres. *Composites Science and Technology*. 61: 2519–2529.

Niranjan, K. (2009). *Fundamentals of Polymers: Raw Materials to Finish Products*. New Delhi: PHI Learning Private Limited.

Ochi, S. (2006). Development of high strength biodegradable composites using Manila hemp fibre starch-based biodegradacle resin. Composites: Part A Applied Science and Manufacturing. 37: 1879-1883.

Ochi, S. (2008). Mechanical properties of kenaf fibres and kenaf/PLA composites. *Mechanics of Materials.* 40: 446-452.

Osman, H., Ismail, H. and Mariatti, M. (2009). Electron beam irradiation of recycled newspaper filled polypropylene/natural rubber composites: effect of crosslink

© COPYRIGHT UPM

promoters. Proceedings of 17th International Conference of Composites Materials (ICCM17), Edinburgh, UK, July 27-3. (D9-5).

Osman, H., Ismail, H. and Mariatti, M. (2010). Effects of maleic anhydride polypropylene on tensile, water absorption, and morphological properties of recycled newspaper filled polypropylene/natural rubber composites. *Journal of Composite Materials*. 44(12): 1477-1491.

Othman, A.R. and Haron, N.H. (1992). Potensi industri kecil tanaman enau. *FRIM Report*. 60: 7-18.

Owen, M. J. Middleton, V. and Jones, I.S. (Eds.) (2000). *Integrated design and manufacture using fibre-reinforced polymeric composites* New York: CRC Press.

Paiva, M.C., Ammar, I., Campos, A.R., Cheikh, R.B. and Cunha, A.M. (2007). Alfa fibres: Mechanical, morphological and interfacial characterization. *Composites Science and Technology*. 67: 1132-1138.

Panigrahi, S. (2006). Industrial Processing of Agricultural Fibre Composite: A Prairie Success Story. Bio-logical Futures III Conference. 16-17 October. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. http://198.169.133.105/presentations/Satya%20Panigrahi.pdf)

Perez, J., Munoz-Dorado, J., de la Rubia, T. and Martinez, J. (2002). Biodegradation and biological treatments of cellulose, hemicellulose and lignin: an overview. *International Microbiology*. 5: 53-63.

Rashdi, A.A.A., Sapuan, S.M., Ahmad, M.M.H.M. and Khalina, A. (2010). Combined effects of water absorption due to water immersion, soil buried and natural weather on mechanical properties of kenaf fibre unsaturated polyester composites (KFUPC). *International Journal of Mechanical and Materials Engineering (IJMME)*. 591): 11-17.

Ray, D., Sarkar, B.K., Das, S. And Rana, A.K. (2002). Dynamic mechanical and thermal analysis of vinyl-ester-resin-matrix composites reinforced with untreated and alkali-treated jute fibres. *Composites Science and Technology*. 62: 911-917.

Reddy, K.O., Maheswari, C.U., Rajulu, A.V. and Guduri, B.R. (2009). Thermal degradation parameters and tensile properties of *Borassus flabellifer* fruit fibre reinforcement. *Journal of Reinforced Plastics and Composites*. 28(18): 2297-2301.

Reddy, K.O., Maheswari, C.U., Shukla, M. and Rajulu, A.V. (2012) Chemical composition and structural characterization of Napier grass fibres. *Materials Letters*. 67: 35–38.

Reddy, N. and Yang, Y. (2005). Biofibres from agricultural byproducts for industrial applications. *Trends in Biotechnology*. 23 (1): 22-27.

© COPYRIGHT UPM

Reed, A.R. and Williams, P.T. (2004) Thermal processing of biomass natural fibre wastes by pyrolysis. *International Journal of Energy Research*,.28: 131-145.

Riedel, U. and Nickel, J. (1999). Natural fibre-reinforced biopolymers as construction materials – new discoveries. *Die Angewandte Makromolekulare Chemie*. 272: 34–40.

Rong, M.Z., Zhang, M.Q., Liu, Y.,Yang, G.C. and Zeng, H.M. (2001). The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. *Composites Science and Technol*ogy. 61: 1437-1477.

Rosa, I.M.D., Kenny, J.M., Puglia, D., Santulli, C. and Sarasini, F. (2010). Morphological, thermal and mechanical chracterization of okra (*Abelmoschus esculentus*) fibres as potential reinforcement in polymer composites. *Composites Science and Technology*. 70: 116-122.

Rowell, R.M. (2008). Natural fibres: type and properties. In K.L. Pickering (Eds.) *Properties and Performance of Natural-Fibre Composites.* (pp.3-66). Cambridge: Woodhead Publishing Limited.

Rozman, H.D., Tay, G.S., Abubakar, A. and Kumar, R.N. (2002). A preliminary study on oil palm empty fruit bunch-polyurethane composites. *International Journal of Polymeric Materials*. 51: 1087-1094.

Saheb, N. D., and Jog, J. P. (1999). Natural fibre polymer composites: A review. *Advanced Polymer Technology*. 18: 351-363.

Sanadi, A.R., Caulfield, D.F., Jacobson, R.E. and Rowell, R.M. (1995). Renewable agriculture fibres as reinforcing fillers in plastics: mechanical properties of kenaf fibre-polypropylene composites. *Ind. Engineering Chemistry Research*.34: 1889-1896.

Sanadi, A.R., Caulfield, D.F. and Jacobsen, R.E. (1997). Agro-fibre thermoplastic composites. In R.M. Rowell, R.A. Young and J.K. Rowell (editors). *Paper and Composites from Agro-based Resources*. New York: CRC Press.

Sastra, H.Y., Siregar, J.P., Sapuan, S.M. and Hamdan, M.M. (2006). Tensile properties of *Arenga pinnata* fibre reinforced epoxy composites. *Polymer-Plastics Technology and Engineering*. 45(1): 149-155.

Sastra, H.Y., Siregar, J.P., Sapuan, S.M., Leman, Z and Hamdan, M.M. (2005). Flexural properties of *Arenga pinnata* fibre reinforced epoxy composites. *American Journal of Applied Science*. Special issue: 21-24.

Seki, Y., Sarikanat, M., Kutlay, S., Sever, K. Erden, S. and Gulec, H.A. (2010). Effect of the low and radio frequency oxygen plasma treatment of jute fibre on mechanical properties of jute fibre/polyester composite. *Fibers and Polymers*. 11(8): 1159-1164.

© COPYRIGHT UPM

Sever, K. (2010). The improvement of mechanical properties of jute fibre/LDPE composites by fibre surface treatment. *Journal of Reinforced Plastics and Composites*. 29(13): 1921-1929.

Sghaier, S., Zbidi, F. and Zidi, M. (2009). Characterization of doum palm fibres after chemical treatment. *Textile Research Journal*. 79(12): 1108-1114.

Sgriccia, N and Hawley, M.C. (2007). Thermal, morphological, and electrical characterizarion of microwave processed natural fibre composites. *Composites Science and Technology*. 67: 1986-1991.

Shokoohi, S., Arefazar, A. and Khosrokhavar, R. (2008). Silane coupling agents in polymer-based Reinforced composites: a review. *Journal of Reinforced Plastics and Composites*. 27: 473-485.

Singha, A. S., and Thakur, V. K. (2008). Mechanical properties of natural fibre reinforced polymer composites. *Bulletin of Materials Science* 31(5): 791-799.

Siregar, J.P. (2005). Tensile and flexural strength of Arenga pinnata filament (ijuk filament) reinforced epoxy composites. *Master of Science Thesis*. Universiti Putra Malaysia.

Siregar, J.P., Sapuan, S.M., Rahman, M.Z.A. and Dahlan, K.Z.H.M. ((2011). Thermogravimetric analysis (TGA) and differential scanning calorimetric (DSC) analysis of pineapple leaf fibre (PALF) reinforced high impact polystyrene (HIPS) composites. *Pertanika Journal of Science and Technology*. 19(1): 161-170.

Smits, W. (2008). Arenga palm sugar: Overview of the Tomohon Masarang sugar palm factory. www.masarang.org. (accessed on 10th April 2009).

Sreekumar, P.A. and Thomas, S. (2008). Matrices for natural fibre reinforced composites. In K.L. Pickering (Eds.). *Properties and Performance of Natural Fibre Composites*. (pp. 67-126). Cambridge: Woodhead Publishing Limited.

Srinivasababu, N., Rao, K.M.M., Kumar, J.S. (2010). Tensile properties characterization of okra woven fibre reinforced polyester composites. *International Journal of Engineering*. 3(4): 403-412.

Staaij, J.V.D., Bos, A.V.D., Hamelinck, C., Martini, E., Roshetko, J. and Walden, D. (2011). *Sugar Palm Ethanol: Analysis of Economic Feasibility and Sustainability*. Utrecht. Ecofys Netherland BV.

Staudinger, H. and Fritschi, J. (1922). Über die Hydrierung des Kautschuks und über seine Konstitution. *Helv. Chim. Acta*. 5: 785–806.

Sudesh, K. and Iwata, T. (2008). Sustainability of biobased and biodegradable plastics. *Clean*. 36 (5–6): 433 – 442.

Suizu, N., Uno, T., Goda, K. and Ohgi, J. (2009). Tensile and impact properties of fully green composites reinforced with mercerized ramie fibers. *Journal of Materials Science*. 44(10): 2477-2482.

Suwartapradja, O.S. (2003). *Arenga pinnata*: a case study of indigenous knowledge on the utilization of a wild food plant in West Java. http://www.geocities.com/inrik/opan.htm

Swanson, S. R. (1997). *Introduction to Design and Analysis with Advanced Composite Materials*. Upper Saddle River, N.J.: Prentice Hall.

Taj, S., Munawar, M.A. and Khan, S. (2007). Natural fibre-reinforced polymer composites. *Proceedings of Pakistan Academy Science*. 44(2): 129-144.

Tajvidi, M. And Takemura, A. (2010). Thermal degradation of natural fibre reinforced polypropylene composites. *Journal of Thermoplastic Composite Materials*. 23: 281-298.

Thiruchitrambalam, M., Alavudeen, A., Athijayamani, A., Venkateshwaran, N. And Perumal, A.E. (2009). Improving mechanical properties of banana/kenaf polyester hybrid composites using sodium laulryl sulfate treatment. *Materials Physics and Mechanics*. 8: 165-173.

Thiruchitrambalam, M., Athijayamani, A., Sathiyamurthy, S. and Thaheer, A.S.A. (2010). A review on the natural fibre-reinforced polymer composites for the development of roselle fibre-reinforced polyester composites. *Journal of Natural Fibers*. 7(4): 307-323.

Ticoalu, A., Aravinthan, T. and Cardona, F. (2010). A review of current development in natural fibre composites for structural and infrastructure applications. *Proceedings of Southern Region Engineering Conference*. Toowoomba, Australia. 11-12 November, pp. 1-5.

Tomczak, F., Satyanarayana, K.G. and Sydenstricker, T.H.D. (2007a). Studies on lignocellulosic fibres of Brazil: Part III – morphology and properties of Brazilian curaua fibres. *Composites Part A: Applied Science and Manufacturing*. 38: 2227-2236.

Tomczak, F., Sydenstricker, T.H.D. and Satyanarayana, K.G. (2007b). Studies on lignocellulosic fibres of Brazil. Part II: Morphology and properties of Brazilian coconut fibres *Composites Part A: Applied Science and Manufacturing*. 38: 1710-1721.

Vilaplana, F., Ribes-Greus, A. and Karlsson, S. (2007) Analytical strategies for the quality assessment of recycled high-impact polystyrene: A combination of thermal analysis, vibrational spectroscopy, and chromatography. *Analytica Chimica Acta*. 604(1): 18-28.

© COPYRIGHT UPM

Vilaseca, F., Lopez, A., Llauro, X., Pelach, M.A. and Mutje, P. (2004). Hemp strands as reinforcement of polystyrene composites. *Chemical Engineering Research and Design*. 82(A11): 1425-1431.

Wallace, A.R. (1869) *The Malay Archipelago: the land of orang-utan and the bird of paradise*. New York: Harpers and Brothers Publishers.

Wambua, P., Ivens, J. and Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics? *Composites Science and Technology*. 6: 1259-1264.

Wang, W., Sain, M. and Cooper, P.A. (2006). Study of moisture absorption in natural fibre plastic composites. *Composites Science and Technology*. 66: 379-386.

Weyenberg, I.V., Truong, T.C., Vangrimde, B. and Verpoest, I. (2006). Improving the properties of UD flax fibre reinforced composites by applying an alkaline fibre treatment. *Composites Part A: Applied Science and Manufacturing*. 37: 1368-1376.

Widodo, T.W., Elita, R. and Asari, A. (2009). Sugar palm (*Arenga pinnata Merr*) plantation for bioethanol production, sustainable development and environmental conservation. Presentation paper for *Research Workshop on Sustainable Biofuel Development in Indonesia, Progress so Far and Future Applied Research Opportunities.* 4-5 Feb., Sultan Hotel, Jakarta, Indonesia.

Widyawati, N. Tohari, Yudono, P. and Soemardi, I. (2009). The Permeability and Germination of Sugar Palm Seeds (Arenga pinnata (Wurmb.) Merr.). in Indonesian. *Jurnal Agronomi Indonesia*. 37(2): 152-158.

Wielage, B., Lampke, T., Marx, G., Nesler, K. and Starke, D. (1999). Thermogravimetric and differential scanning calorimetric analysis of natural fibres and polypropylene. *Thermochimica Acta*. 337: 169-177.

Xu, Y., Jiang, L., Xu, J. and Li, Y. (2012). Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick. *Construction and Building Materials*. 27: 32-38.

Xu, Y., Wu, Q., Lei, Y., Yao, F. and Zhang, Q. (2008). Natural fibre reinforced poly(vinyl chloride) composites: effect of fibre type and impact modifier. *Journal of Polymer and Environment.* 16: 250-257.

Yang, H., Yan, R., Chen, H., Lee, D.H. and Zheng, C. (2007). Characteristics of hemicellulose, cellulose and lignin pyrolisis. *Fuel*. 86: 1781-1788.

Yang, H.S., Wolcott, M.P. Kim, H.S. and Kim, H.J. (2005). Thermal properties of lignocellulosic filler-thermoplastic polymer bio-composites. *Journal of Thermal Analysis and Calorimetry*. 82: 157–160.

Yang, H.S., Wolcott, M.P. Kim, H.S., Kim, S. and Kim, H.J. (2007). Effect of different compatibilizing agents on the mechanical properties of lignocellulosic

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material filled polyethylene bio-composites. *Composites Structures.* 79: 369-375.

Yusuf, D. (2007). Kampung Naga a Traditional Sunda Village. http://dieny-yusuf.com/kampung-naga-a-traditional-sunda-village (access on 26 December 2011).

Zabihzadeh, S.M. (2010). Influence of plastic type and compatibilizer on thermal properties of wheat straw flour/thermoplastic composites. *Journal of Thermoplastic Composite Materials*. 23: 817-826.

Zafeiropoulus, N.E., Dijon, G.G. and Baillie, C.A. (2007). A study of the effect of surface treatments on the tensile strength of flax fibres. Part I. Application of Gaussian statistics. *Composites Part A: Applied Science and Manufacturing*. 38(2): 621-628.

Zainudin, E.S., Sapuan, S.M., Abdan, K. and Mohamad, M.T.M. (2009a). Mechanical properties of compression molded banana pseudo-stem filled unplasticized polyvinyl chloride (UPVC) composites. *Polymer-Plastics Technology and Engineering*. 48: 97–101,

Zainudin, E.S., Sapuan, S.M., Abdan, K. and Mohamad, M.T.M. (2009b). Thermal degradation of banana pseudo-stem filled unplasticized polyvinyl chloride (UPVC) composites. *Materials & Design*, 30(3): 557-562.

Zampaloni, M., Pourboghrat, F., Yankovich, S.A., Rodgers, B.N., Moore, J., Drzal, L.T., Mohanty, A.K. and Misra, M. (2007). Kenaf natural fibre reinforced polypropylene composites: a discussion on manufacturing problems and solutions. *Composites Part A: Applied Science and Manufacturing*. 38: 1569-1580.

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