PREPARATION AND CHARACTERISATION OF KENAF BAST FIBRE REINFORCED RECYCLED POLYPROPYLENE/RECYCLED POLYAMIDE 6 COMPOSITES

NUR LIYANA BINTI SURADI

UNIVERSITI TEKNOLOGI MALAYSIA

PREPARATION AND CHARACTERISATION OF KENAF BAST FIBRE REINFORCED RECYCLED POLYPROPYLENE/RECYCLED POLYAMIDE 6 COMPOSITES

NUR LIYANA BINTI SURADI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Polymer)

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2015

To my beloved mother (Noresah Md Seh), late father (Suradi Musa), and husband (Muhamad Ridhwan Abdullah) for your wonderful spirit, encouragement, and love

ACKNOWLEDGEMENT

I wish to express my sincere appreciate to my supervisors, Dr. Agus bin Arsad and Assoc. Prof. Dr. Abdul Razak bin Rahmat for your encouragement, guidance, and critics. Your energetic character has become motivation to me along this project. Standing with the continued supports from my supervisor and peoples around me, this thesis become reality.

A appreciation also for Department of Polymer Engineering laboratory staff (Mr.Azri, Mr.Izat, Mr.Nordin, Mr.Suhee Tan, Miss Zainab). The Sultanah Zanariah Library deserved special thanks for their efficient in providing relevant literature and terrific e-database services.

I am grateful to my siblings for their inspiration, support and patience. Special appreciation for my mother (Noresah binti Md Seh) and my late father (Suradi bin Musa) for their wonderful spirit, encouragement, and love that makes me stronger today. I also would like to express my gratitude and thank you to my friends for their continuous support. My sincere appreciation also extends to all who are not mentioned here who have provided assistance at various occasions. Their views and tips are useful indeed and may god bless everyone.

ABSTRACT

The purpose of this study was to investigate the effects of kenaf bast fibre (KBF) reinforced recycled polypropylene (rPP)/recycled polyamide 6 (rPA6) composites on mechanical, morphological, thermal and rheological properties. KBF was treated with alkaline treatment and then rPP and rPA6 were prepared by extruding using single screw extruder. Alkaline treated KBF was then reinforced with rPP/rPA6/ maleic anhydride grafted polypropylene (MAPP) blends and the mechanical, morphological, thermal and rheological properties were analysed. The amount of MAPP was fixed at 5 wt. % for all rPP/rPA6 blends. The blends ratios for rPP/rPA6/MAPP were 65/30/5, 45/50/5 and 25/70/5. The best mechanical properties of rPP/rPA6/MAPP blends ratios (25/70/5) then added with various amount of KBF compositions from 0 to 30 parts per hundred resin (phr). The addition of KBF caused the flexural strength and flexural modulus increased proportionally with increasing in its compositions in the composites. The tensile strength, Young's modulus, and hardness of composites remain unaffected with the increase in KBF composition. However, the elongation at break and impact strength of composites decreased with the increased in KBF compositions. From scanning electron microscope (SEM) micrograph, it was observed that the increase in the KBF compositions caused better dispersion, less interfacial gaps and void spaces. The melting temperature (T_m), crystallization temperature (T_c), degradation temperature (T_{deg}), and onset temperature (T_{onset}) decreased with the increase in KBF compositions in the composites. The melt flow index and rheological properties decreased with the increasing of KBF compositions in the composites. As for conclusion, KBF successfully functioned as reinforcement for rPP/rPA6/MAPP composites.

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji kesan gentian basta kenaf (KBF) yang bertetulang komposit polipropilena kitar semula (rPP)/poliamida (rPA6) kitar semula dari aspek mekanikal, morpologi, sifat terhadap haba dan sifat reologi. Dalam kajian ini, KBF telah dirawat dengan rawatan alkali dan kemudiannya rPP dan rPA6 diproses menggunakan penyemperitan skru tunggal. KBF yang telah dirawat kemudiannya digunakan untuk memperkukuh campuran rPP/rPA6/ maleik anhidrida yang dicangkuk dengan polipropilena (MAPP) dan aspek mekanikal, morpologi, sifat terhadap haba dan sifat reologi telah dianalisis. Penambahan ditetapkan pada 5 wt% MAPP pada semua campuran rPP/rPA6. Nisbah campuran bagi rPP/rPA6/MAPP dikaji adalah 65/30/5, 45/50/5 dan 25/70/5. Campuran rPP/rPA6/MAPP dengan sifat-sifat mekanikal terbaik (25/70/5) kemudiannya ditambah dengan komposisi KBF yang berbeza dari 0-30 bahagian dari seratus jumlah keseluruhan resin (phr). Dari kajian ini, penambahan KBF menyebabkan kekuatan lenturan dan lenturan modulus meningkat berkadaran dengan peningkatan komposisi KBF dalam komposit. Kekuatan regangan, modulus Young dan kekerasan komposit tidak berubah dengan peningkatan komposisi KBF dalam komposit. Bagaimanapun, sifat pemanjangan ketika putus dan kekuatan hentaman berkurangan dengan peningkatan komposisi KBF dalam komposit. Berdasarkan mikrograf mikroskop electron pengimbas (SEM), diperhatikan penambahan KBF menyebabkan penyebaran yang lebih baik, kurang ruang antara muka dan ruang lompang yang kelihatan. Suhu takat lebur (T_m), suhu penghabluran (T_c), suhu kemusnahan (T_{deg}), dan suhu permulaan (T_{onset}) berkurangan dengan peningkatan komposisi KBF dalam komposit. Indeks aliran leburan dan sifat-sifat reologi menurun dengan peningkatan komposisi KBF dalam campuran. Kesimpulannya, KBF berjaya bertindak sebagai pengukuh bagi campuran rPP/rPA6/MAPP.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APS	-	3-aminopropyltriethoxysilane
ASA	-	Acrylate-styrene-acrylonitrile
DSC	-	Differential scanning calorimetry
DTG	-	Derivative thermogravimetry
EPR-g-MA	-	Maleic anhydride-grafted-ethylene-propylene rubber
F-ASA	-	Functioned group acrylate-styrene-acrylonitrile
H_2SO_4	-	Sulphuric acid
KBF	-	Kenaf bast fibres
KCF	-	Kenaf core fibres
KF	-	Kenaf fibres
LNR	-	Liquid natural rubber
MAH	-	Maleic anhydride
MAPP	-	Maleic anhydride grafted polypropylene
MFI	-	Melt flow index
MFR	-	Melt flow rate
MVR	-	Melt volume rate
NaOH	-	Sodium hydroxide
NBR	-	Nitrile butyl rubber
OH	-	Hydroxyl
PA	-	Polyamide
PA6	-	Polyamide 6
PE	-	Polyethylene
phr	-	Part of resin
PP	-	Polypropylene
QReC	-	Quality Reagent Chemical
rPA6	-	Recycled polyamide 6
rpm	-	Rotation per minutes

rPP	-	Recycled polypropylene
SEBS	-	Styrene ethylene-butylene-styrene
SEBS-g-MA	-	Maleated styrene-ethylene-butylene-styrene
SMA	-	Styrene-co-maleic anhydride
T_c	-	Crystalline temperature
T_{deg}	-	Degradation temperature
TG	-	Thermogravimetry
T_g	-	Glass transition temperature
TGA	-	Thermogravimetric analysis
T_m	-	Melting temperature
T_{onset}	-	Onset temperature
UTM	-	Universal testing machine
v/v	-	Volume per volume
vol.%	-	Volume percents
w/v	-	Weight per volume
w/w	-	Weight per weight
wt.%	-	Weight percents
X_c	-	Crystalline percentages
X_c-rPA6	-	Crystallinity of rPA6
X_c-rPP	-	Crystallinity of rPP
ΔH_m	-	Heat of fusion

LIST OF SYMBOLS

°C	-	Degree Celsius
°C/min	-	Degree Celsius per minutes
µm	-	Micrometre
cm	-	Centimetre
g	-	Grams
g/10 min	-	Grams over 10 minutes
g/cm^3	-	Gram over cubic centrimetres
GPa	-	Giga Pascal
J	-	Joule
J/g	-	Joule per grams
J/m	-	Joule per metres
kg	-	Kilogram
m	-	Metre
mg	-	miligram
mm	-	Millimetre
mm/min	-	Milimetre per minutes
MPa	-	Megapascal
N	-	Newton

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Over the past few years, natural fibres have gained the interest of the researchers as substitute for the synthetic fibres (Yousif *et al.,* 2012). Natural fibres have many advantages over synthetic fibres such as good relative mechanical properties, lighter weight, and lower cost (Kassim *et al*., 2012). Other than that, natural fibres are abundant and renewable. Nowadays, the use of natural fibres is common in automotive, construction and furniture industries (Yousif *et al.*, 2012).

Kenaf fibre is included in the natural fibres category. Due to attractive features of kenaf fibres as reinforcing materials over others natural fibres, comprehensive studies of kenaf fibres were done (Ren *et al*., 2012). However, usually kenaf fibres face compatibility problems with the polymeric materials (El-Shekeil *et al*., 2012b). The hydrophilic nature of kenaf fibres is incompatible with hydrophobic polymeric materials (Kassim *et al*., 2012). Hence, researchers favoured the use of surface treatment on kenaf fibres to solve this problem. It was found that the alkaline treatment enhances matrix-fibres adhesion by increasing roughness and also removing impurities of the fibres (Yousif *et al*., 2012).

Kenaf fibres have two main components, the core and bast. In terms of mechanical properties, kenaf bast fibres (KBF) are found to have higher tensile, flexural, and impact properties than kenaf core fibres (KCF) (Ishak *et al.,* 2010). In this study, KBF has been chosen over KCF for its ecological advantages and its mechanical properties.

Kenaf fibre reinforced polymer composites are studied intensively by researchers (El-Shekeil *et al*., 2012b; Lee *et al.*, 2012). This is due to the increasing interest in the development of environmentally friendly material. Kenaf fibres has the potential to replace synthetic fibres due to its low cost, low density, acceptable specific strength properties, ease of separation, carbon dioxide sequestration and biodegradability.

At present, KBF has been used as reinforcement for conventional polymers such as polypropylene. Polypropylene (PP) is an important polymer in packaging, medical instrumentation, and automotive industries (Ezat *et al*., 2012). PP exhibits good strength, is easily processed, lightweight and economical. The mechanical properties of PP were improved with small amounts of filler (Khanjanzadeh and Tabarsa, 2012).

On the other hand, polyamide 6 (PA6) is well known as an engineering thermoplastic with excellent strength and stiffness, low friction, and chemical resistance (Liu *et al*., 2012). However, PA6 has drawbacks such as poor dimensional stability and high water absorption (Liao and Tjong, 2011). These drawbacks limit the industrial use of PA6. Hence, numerous efforts have been made to overcome these drawbacks such as the addition of inorganic filler.

PA6 are usually blended with PP to improve the properties of final products (Golfazani *et al.*, 2012). The poor processability and high moisture absorption of PA6 was compensated by the good processability and low moisture absorption of PP. Previously, researchers have suggested that the combination of PP and PA6 balances the properties of the final product (Chow *et al.*, 2005). Due to the excellent properties of PP/PA6 blends, researchers favour to use of these polymer combinations for their study (Wang *et al.*, 2012; Golfazani *et al*., 2012). However, due to the polarity differences and crystalline structure, the PP and PA6 were chemically immiscible (Jung *et al.*, 2007). Therefore to overcome the immiscible problems, the addition of maleic anhydride grafted polypropylene (MAPP) compatibilizer is necessary. The compatibilizer was use to reduces the interfacial tension of PP and PA6. Hence, it improves the interfacial adhesion between PP and PA6.

The better mechanical properties of composites show with MAPP rather than others compatibilizer (Jung e*t al.*, 2007). It is due to the compatibilizing effects between maleic anhydride (MA) with amide group in PA6. The applications of MAPP in the PP/PA6 system was not a new issue since it has been studies previously by Takahashi (2002) and Li *et al*. (2010). Even though, PP/PA6 system has been studied intensively, but the studies on recycled PP/PA6 system remain unexplored.

At present, the applications of non-biodegradable PP and PA6 become common. The widespread consumption of these plastics in industries has implications to the environment (Khanjanzadeh and Tabarsa, 2012; Lee *et al.,* 2012). Environment problems have been created environmental problems due to excessive consumption of these polymers (Lee *et al.,* 2012). Finally, the excessive consumption of these polymers ends up in landfills. In response to these problems, the industrial applicator added a small amount of recycled polymers with virgin polymers in their industrial process. However, this practice is not sufficient to overcome these problems. Hence, instead of virgin PP and PA6, recycled PP and PA6 were chosen in this study. The purpose of this study is to suggest a solution of these environmental problems.

1.2 Problems Statement

Even though intensive studies on PP/PA6 system have been carried out, but the problems caused by these non-biodegradable polymers are still not resolved. Hence, the use of virgin PP and PA6 was replaced with recycled polymers to reduce these environmental problems. Since, PP/PA6 system is incompatible, MAPP compatibilizer was added to ensure optimum compatibilization effects of recycled PP (rPP) /recycled PA6 (rPA6) blends. KBF was added as reinforcement agents. The research questions that need to be answered are as follows;

i. What is the rPP/rPA6 ratio that provides the best mechanical and thermal properties?
ii. What are the effects of the KBF ratio on mechanical, morphological, thermal, and rheological properties of composites?
iii. What is KBF ratio that provides the best mechanical, morphological, thermal, and rheological properties of composites?

1.3 Objectives of Study

The objectives of this study are to produce composites of rPP /rPA6/MAPP reinforced KBF.

i. To determine rPP/rPA6 ratio that gives the best mechanical and thermal properties.
ii. To investigate the effects of KBF ratio on mechanical, morphological, thermal, and rheological properties of composites.
iii. To determine the best KBF ratio that gives the best mechanical, thermal, and rheological properties of composites.

1.4 Scope of Study

i. Literature reviews were done on the related study of KBF, chemical modification of KBF, properties of PP and PA6.

ii. The study was involved the following steps:

a) Alkaline treatment of KBF.
b) Preparation of rPP and rPA6, MAPP was fixed at 5 phr for all rPP/rPA6/MAPP blends.
c) Blending of KBF reinforced rPP/rPA6/MAPP, maximum KBF ratio fixed at 30 parts per hundred (phr) based on total polymer blend weight.
d) Sample characterizations, by comparing the properties with and without KBF using:

1) Mechanical characterisations using tensile test, flexural test, hardness test, and izod impact test.
2) Thermal characteristic using Differential scanning calorimetric (DSC) and thermogravimetric analysis (TGA) methods.
3) Morphological characterization using scanning electron microscope (SEM).
4) Rheological characteristic were investigated using Melt flow index (MFI) and capillary rheometer.

e) Data analysis by comparing mechanical, thermal, morphological and rheological study.

iii. The best KBF ratio that gives the best mechanical, thermal, and rheological properties of composites were determined by analyst and verified the best blends compositions.

iv. Report writing.

REFERENCES

Agrawal, R., Saxena, N.S., Sharma, K.B., Thomas, S. and Sreekala, M.S. (2000). Activation Energy and Crystallization Kinetics of Untreated and Treated Oil Palm Fibre Reinforced Phenol Formaldehyde Composites. *Materials Science and Engineering.* A277, 77-82.

Akil, H.M, Omar, M.F., Mazuki, A.A.M, Safiee, S., Ishak, Z.A.M. and Abu Bakar, A. (2011). Kenaf Fiber Reinforced Composites: A Review. *Journal Materials and Design.* 1-15.

Anuar, H. and Zuraida, A. (2010). Improvement in Mechanical Properties of Reinforced Thermoplastic Elastomer Composite with Kenaf Bast Fibre. *Composites: Part B*. 42, 462–465.

Butylina, S., Martikka, A. and Kärki, T. (2011). Physical and Mechanical Properties of Wood Polypropylene Composites Made with Virgin and/or Recycled Polypropylene. *Polymer-Plastics Technology and Engineering*. 50, 1040–1046.

Bourmaud, A., Duigou, L.D. and Baley, C. (2011). What is the Technical and Environmental Interest in Reusing a Recycled Polypropylene Hemp Fibre Composite. *Polymer Degradation and Stability*. 96, 1732-1739.

Cassagnau, P. and Barres, C. (2010). Rheological Behavior of Rubber Nanocomposites. Thomas S. and Stephen R. *Rubber Nanocomposites: Preparation, Properties and Applications.* (pp. 353-390). India: John Wiley & Sons (Asia) Pte. Ltd

Chong, E.L., Ahmad, I., Dahlan, H.M. and Abdullah, I. (2010). Reinforcement of Natural Rubber/High Density Polyethylene Blends with Electron Beam Irradiated Liquid Natural Rubber-Coated Rice Husk. *Radiation Physics and Chemistry*. 79, 906-911.

Chow, W.S., Abu Bakar, A., Mohd Ishak, Z.A., Karger-Kocsis, J. and Ishiaku, U.S. (2005). Effect of Maleic Anhydride-Grafted Ethylene-Propylene Rubber on the Mechanical, Rheological and Morphological Properties of Organoclay Reinforced Polyamide 6/Polypropylene Nanocomposites. *European Polymer Journal*. 41, 687-696.

Chow, W.S. and Mohd Ishak, Z.A. (2006). Mechanical, Morphological and Rheological Properties of Polyamide 6/Organo-Montmorillonite Nanocomposites. *eXPRESS Polymer Letters.* 1 (2) ,77–83.

Edeerozey, A.M.M., Akil, H.M., Azhar, A.B. and Ariffin, M.I.Z. (2007). Chemical Modification of Kenaf Fibers. *Materials Letter.* 61, 2023-2025.

El-Shekeil, Y.A., Sapuan, S.M., Khalina, A., Zainudin, E.S. and Al-Shuja'a, O.M. (2012a). Effect of Alkali Treatment on Mechanical and Thermal Properties of Kenaf Fiber-Reinforced Thermoplastic Polyurethane Composite. *Journal of Thermal Analysis and Calorimetry*. 109,1435–1443.

El-Shekeil, Y.A., Sapuan, S.M., Khalina, A., Zainudin, E.S. and Al-Shuja'a, O.M. (2012b). Influence of Chemical Treatment on the Tensile Properties of Kenaf Fiber Reinforced Thermoplastic Polyurethane Composite. *eXPRESS Polymer Letters*. 6 (12), 1032–1040.

Ezat, G.S., Kelly, A. L., Mitchell, S.C., Youseffi, M. and Coates, P.D. (2012). Effect of Maleic Anhydride Grafted Polypropylene Compatibilizer on the Morphology and Properties of Polypropylene/Multiwalled Carbon Nanotube Composite. *Polymer Composites.* 33 (8), 1376-1386.

Gao, H., Xie, Y., Qu, R. and Wang, Q. (2011). Grafting Effects of Polypropylene/Polyethylene Blends with Maleic Anhydride on the Properties of the Resulting Wood-Plastics Composites. *Composites: Part A.* 43, 150-157.

Ghahri, S., Najafi, S.K., Mohebby, B. and Tajvidi, M. (2010). Impact Strength Improvement of Wood Flour–Recycled Polypropylene Composites. *Journal of Applied Polymer Science.*

Gregorova, A., Kosikova, B. and Stasko, A. (2007). Radical Scavenging Capacity of Lignin and Its Effect on Processing Stabilization of Virgin and Recycled Polypropylene. *Journal of Applied Polymer Science.* 106, 1626-1631.

Godshall, D., White, C. and Wilkes, G.L (2000). Effect of Compatibilizer Molecular Weight and Maleic Anhydride Content on Interfacial Adhesion of Polypropylene–PA6 Bicomponent Fibers. *Journal of Applied Polymer Science.* 80 (130-141).

Golfazani, M.E.H., Nazockdast, H., Rashidi, A., and Yazdanshenas, E. (2012). The Role of Nanoclay Partitioning on Microfibril Morphology Development in Polypropylene/Polyamide 6 Nanocomposite Fibers. *Journal of Macromolecular Science, Part B: Physics.* 51, 956–967.

Holbery, J. and Houston, D. (2006). Natural-Fiber-Reinforced Polymer Composites in Automotive Applications. *Jom.*58 (11), 80-86.

Holsti-Miettinen, R.M., Perttila, K.P., Seppala, J.V. and Heino, M.T. (1995). Oxygen Barrier Properties of Polypropylene/Polyamide 6 Blends. *Journal of Applied Polymer Scien*ce. 58,1551-1560.

Hong, S.M., Hwang, S.S., Jeon, B.H., Choi, J.S., Kim, H.B., Lim, S.T. and Choi, H.J. (2005). Polypropylene/Polyamide 6 Blends Based on Commingled Plastic Wastes. *Journal of Materials Science*. 40, 3857-3859.

Huda, M.S., Drzal, L.T, Mohanty, A.K., and Misra, M. (2007). Effect of Fiber Surface-Treatments on the Properties of Laminated Biocomposite from Poly(lactic acid) (PLA) and Kenaf Fibers. *Composites Sciences and Technology*. 68, 424-432.

Ishak, M.R., Leman, Z., Sapuan, S.M., Edeerozey, A.M.M. and Othman, I.S. (2010). Mechanical Properties of Kenaf Bast and Core Fibre Reinforced Unsaturated Polyester Composites. *IOP Conference Series: Materials Science and Engineering.* 11 (1).

Jaziri, M., Barhoumi, N., Massardier, V. and Melis, F. (2007). Blending PP with PA6 Industrial Wastes: Effect of the Composition and the Compatibilization. *Journal of Applied Polymer Science.* 107, 3451-3458.

Jose, J., Nag, A. and Nando, G.B. (2010). Processing and Characterization of Recycled Polypropylene and Acrylonitrile Butadiene Rubber Blends. *Journal of Polymer Enviroment.* 18, 155-166.

Jung, C.H., Choi, J.H., Lim, Y.M., Jeun, J.P., An, S.J., Kang, P.H. and Nho, Y.C. (2007). Preparation of Polypropylene Compatibilizer by Radiation Grafting and Its Effect on PP/Nylon 6 Blend. *Macromolecule Symposia*. 249-250, 573-579.

Kalia, S., Kaith, B.S and Kaur, I. (2009). Pretreatment of Natural Fibers and Their Application as Reinforcing Materials in Polymer Composites-A Review. *Polymer Engineering and Science.* 49 (7), 1253-1268.

Kartalis, C.N., Poulakis, J.G., Tsenoglou, C.J. and Papaspyrides, C.D. (2001). Pure Component Recovery from Polyamide 6/66 Mixtures by Selective Dissolution and Reprecipitation. *Journal of Applied Polymer Science.* 86, 1924–1930.

Kassim, M.A., Crosky, and Ruys, D. (2012). Water Absorption and Modification of Kenaf and Flax Fibres. *Advanced Materials Research.* 545, 342-347.

Khanjanzadeh, H. and Tabarsa, T. (2012). Effect of Montmorillonite and Maleic Anhydride Grafted Polypropylene Content on Polypropylene/Wood Flour Composites. *Applied Mechanics and Materials*. 110-116, 596-599.

Kiliaris, P., Papaspyrides, C.D., Xalter, R. and Pfaendner, R. (2012). Study on the Properties of Polyamide 6 Blended with Melamine Polyphosphate and Layered Silicates. *Polymer Degradation and Stability*.97, 1215-1222.

Law, T.T and Mohd Ishak, Z.A. (2010). Water Absorption and Dimensional Stability of Short Kenaf Fiber-Filled Polypropylene Composites Treated with Maleated Polypropylene. *Journal of Applied Polymer Science*. 120, 563–572.

Lee, C.K., Cho, M.S., Kim, I.H. and Lee, Y. (2010). Preparation and Physical Properties of the Biocomposite, Cellulose Diacetate/Kenaf Fiber Sized with Poly(vinyl alcohol). *Macromolecular Research*. 18 (6), 566-570.

Lee, J.M., Mohd Ishak, Z.A., Mat Taib, R., Law, T.T. and Ahmad Thirmizir, M.Z. (2012). Mechanical, Thermal and Water Absorption Properties of Kenaf-Fiber-Based Polypropylene and Poly(Butylene Succinate) Composites. *Journal of Polymers and the Enviroment.*21 (1), 293-302

Li, X., Tabil, L.G. and Panigrahi, S. (2007). Chemical Treatment of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review. *Journal of Polymer Enviroment*. 15, 25-33.

Li, Y., Wang, D., Zhang, J.M. and Xie, X.M. (2010). Influences of Component Ratio of Minor Phases and Charge Sequence on the Morphology and Mechanical Properties of PP/PS/PA6 Ternary Blends. *Polymer Bulletin.* 66, 841-852.

Liao, C.Z. and Tjong, S.C. (2011). Mechanical and Thermal Behaviour of Polyamide 6/Silicon Carbide Nanocomposites Toughened with Maleated Styrene–Ethylene–Butylene–Styrene Elastomer. *Fatigue & Fracture of Engineering Materials & Structure* .35, 56-63.

Lin, Z., Chen, C., Guan, X., Tan, S. and Zhang, X. (2010). A Compatibilized Composite of Recycled Polypropylene Filled with Cellulosic Fiber from Recycled Corrugated Paper Board: Mechanical Properties, Morphology, and Thermal Behavior. *Journal of Applied Polymer Science.* 122, 2789-2797.

Liu, Z., Deng, Y., Han, Y., Chen, M., Sun, S., Cao, C., Zhou, C. and Zhang, H. (2012). Toughening of Polyamide-6 with a Maleic Anhydride Functionalized Acrylonitrile-Styrene-Butyl Acrylate Copolymer. *Industrial & Engineering Chemistry Research.* 51, 9235-9240.

Mariam, A. A., Kahraman, R., Khanama, P.N. and Madi, N. (2012). Date Palm Wood Flour/Glass Fibre Reinforced Hybrid Composites of Recycled Polypropylene: Mechanical and Thermal Properties. *Journal of Materials and Design.* 42, 289–294.

Mishra, S., Misra, M., Tripathy, S.S., Nayak, S.K. and Mohanty, A.K. (2001). Graft Copolymerization of Acrylonitrile on Chemically Modified Sisal Fibers. *Macromolecule Material Engineering*. 286 (2), 107-113.

Mishra, S., Mohanty, A.K., Drzal, L.T., Misra, M., Parija, S., Nayak, S.K. and Tripathy, S.S. (2003). Studies on Mechanical Performance of Biofibre/Glass Reinforced Polyester Hybrid Composites. *Composites Science and Technology*. 63, 1377-1385.

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.

Nasir, A., Yasin , T. and Islam, A. (2010). Thermo-Oxidative Degradation Behavior of Recycled Polypropylene. *Journal of Applied Polymer Science*. 119, 3315-3320.

Omonov, T.S., Harrats, C. and Groeninckx, G. (2005). Co-continuous and Encapsulated Three Phase Morphologies in Uncompatibilized and Reactively Compatibilized Polyamide 6/Polypropylene/Polystyrene Ternary Blends Using Two Reactive Precursors. *Polymer.* 46, 12322-12336.

Osman, H., Ismail, H. and Mariatti, M. (2012). Polypropylene/Natural Rubber Composites Filled With Recycled Newspaper: Effect of Chemical Treatment Using Maleic Anhydride-Grafted Polypropylene and 3-Aminopropyltriethoxysilane. *Polymer Composites.* 33(4), 609-618.

Ray, D., Sarkar, B.K., Rana, A.K. and Bose, N.R. (2001). Effect of Alkali Treated Jute Fibers on Composite Properties. *Bulletin of Material Science*. 24 (2), 129-135.

Ren, X., Qiu, R., Fifield, L.S., Simmons, K.L. and Li, K. (2012). Effects of Surface Treatments on Mechanical Properties and Water Resistance of Kenaf Fiber Reinforced Unsaturated Polyester Composites. *Journal of Adhesion Science and Technology.* 26, 2277-2289.

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 Technology*. 61, 1437-1447.

Rosch, J. and Mulhaupt, R. (1994). The Role of Core/Shell-Micro Particle Dispersions in Polypropylene Polyamide-6 Blends. *Polymer Bulletin*. 32, 697-704.

Scaffaro, R. and Mantia, F.P.L. (2002). Characterization of Monopolymer Blend of Virgin and Recycled Polyamide 6. *Polymer Engineering and Science.* 42 (12), 2412-2417.

Soroudi, A. and Skrifvars, M. (2012). Electroconductive Polyblend Fibers of Polyamide-6/Polypropylene/Polyaniline: Electrical, Morphological, and Mechanical Characteristics. *Polymer Engineering and Science.* 52 (7), 1606-1612.

Takahashi, T. Effect of Maleic Anhydride Grafted Polypropylene on Structure of Polypropylene/Polyamide 6 Blend Fiber (2002). *Sei Gakkaishi.* 58 (60).

Valadez-Gonzalez, A., Cervantes-Uc, J.M., Olayo, R. and Herrera-Franco, P.J. (1999). Chemical Modification of Heneque ´n Fibers with an Organosilane Coupling Agent. *Composite: Part B*. 30, 321-331.

Vallim, M.R., Araujo, J.R., Spinace, M.A., De Paoli, M.A. (2009). Polyamide-6/High-Density Polyethylene Blend Using Recycled High-Density Polyethylene as Compatibilizer: Morphology, Mechanical Properties, and Thermal Stability. *Polymer Engineering and Science.* 49 (10), 2005-2014.

Wang, L., Guo, Z.X. and Yu, J. (2011). Cocontinuous Phase Morphology for an Asymmetric Composition of Polypropylene/Polyamide 6 Blend by Melt Mixing of Polypropylene with Premelted Polyamide 6/Organoclay Masterbatch. *Journal of Applied Polymer Science.* 123, 1218–1226.

Wang, Q., Jiang, Y., Li, L., Wang, P., Yang, Q. and Li, G. (2012). Mechanical Properties, Rheology, and Crystallization of Epoxy-Resin-Compatibilized Polyamide 6/ Polycarbonate Blends: Effect of Mixing Sequences. *Journal of Macromolecular Science R, Part B: Physics*. 51, 96–108.

Weyenberg, I.V.D., Ivens, J., Costerb, A.D., Kino, B., Baetens, E. and Verpoest, I. (2003). Influence of Processing and Chemical Treatment of Flax Fibres on Their Composites. *Composites Science and Technology*. 63, 1241-1246.

Yousif, B.F., Shalwan, A., Chin, C.W. and Ming, K.C. (2012). Flexural Properties of Treated and Untreated Kenaf/Epoxy Composites. *Materials and Design.* 40, 378–385.

Yussof, A. A., Massoumi, L. and Hassan, A. (2010). Comparison of Polylactic Acid/Kenaf and Polylactic Acid/Rice Husk of Composites: The Influence of Natural Fibers on Mechanical, Thermal and Biodegrability Properties. *Journal of Polymer Enviroment*. 18, 422-429.

Zampaloni, M., Pourboghrat, F., Yankovich, S.A., Rodgers, B.N., Moore, J., Drzal, L.T. Mohanty, A.K. and Misra, M. (2007). Kenaf Natural Fiber Reinforced Polypropylene Composites: A Discussion on Manufacturing Problems and Solutions. *Composites Part A: Applied Science and Manufacturing.*38 (6), 1569-1580.