PHYSICAL AND THERMAL PROPERTIES OF POLYPROPYLENE/RICE STRAW BIOCOMPOSITE FOAM

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PHYSICAL AND THERMAL PROPERTIES OF POLYPROPYLENE/RICE STRAW BIOCOMPOSITE FOAM

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Especially dedicated to my beloved husband, Mohd Zuhairi Bin Jaafar, my son, Muhammad Izz Marzuqi bin Mohd Zuhairi and my parents. Thanks for the encourage, love and support.

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"In the name of Allah SWT, the most gracious and the most merciful"

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ABSTRACT

Polymer foam biocomposites based on polypropylene/rice straw (PP/RS) were successfully prepared by using an extrusion foaming process. The compounding of PP and RS was performed in a twin-screw extruder which was blended with crosslinker; dicumyl peroxide (DCP), blowing agent; azodicarbonamide (AZ) and different compatibilizers; polypropylene maleic anhydride (PPMAH) and ULTRAPLAST^{TM} TP10. Compatibilizers were utilised to improve poor interfacial interaction between hydrophilic rice straw and hydrophobic matrix polypropylene. The foam biocomposite was extruded at temperatures of 180, 190, 190 and 200 °C respectively, which set from the feeder until the die zone. Each sample has five different series of formulations. The density test, water absorption test and gel content test were conducted to study the physical properties of PP/RS biocomposite foam. The thermal properties were also investigated by using differential scanning calorimetry (DSC) and thermal gravimetric analysis (TGA). Meanwhile, the morphologies of the biocomposite foams were observed through scanning electron microscopy (SEM). The incorporation of PPMAH or TP10 improved the compatibility and processability of PP/RS biocomposite foam. This formulation has produced a good cell structure, lower density of biocomposite, improved the water uptake resistance and exhibited the best crosslinking density.

ABSTRAK

Polimer busa biokomposit berasaskan polipropilena / batang padi (PP / RS) telah berjaya dihasilkan melalui proses penyemperitan berbusa. Pencampuran polipropilena batang padi telah dijalankan dengan menggunakan penyemperit skru berkembar dan digabungkan dengan bahan-bahan penyambung silang; dikumil peroksida (DCP), ejen pembusa; azodikarbonamida, (AZ) dan penyerasi yang berbeza; polipropilena maleik anhidrida (PPMAH) dan ULTRAPLAST^{TM} TP10. Penyerasi digunakan untuk meningkatkan kelemahan interaksi antara muka di antara batang padi yang bersifat hidrofilik dan polipropilena matriks yang bersifat hidrofobik. Busa biokomposit ini disemperit pada suhu 180, 190, 190 dan 200 °C yang ditetapkan dari zon penyuap sehingga zon dai. Setiap sampel berbeza-beza dari segi muatan atau kepekatan yang melibatkan lima siri formulasi. Ciri-ciri fizikal biokomposit polipropilena / batang padi berbusa dikaji melalui ujian ketumpatan, ujian penyerapan air dan ujian kandungan gel. Sifat-sifat haba juga dikaji dengan menggunakan kalorimeter pengimbasan pembezaan (DSC) dan analisis gravimetrik terma (TGA). Pencirian morfologi bagi biokomposit berbuih PP/RS diperhatikan dengan menggunakan mikroskop imbasan elektron (SEM). Penambahan PPMAH atau TP10 telah meningkatkan keserasian dalam pemprosesan biokomposit berbusa PP/RS. Formula ini telah menghasilkan satu struktur sel yang baik, ketumpatan biokomposit yang lebih rendah, meningkatkan rintangan serapan air dan ketumpatan sambungsilang yang terbaik.

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LIST OF ABBREVIATIONS

AZ	-	Azodicarbonamide
CFC	-	ChloroFluoroCarbon
DCP	-	Dicumyl Peroxide
DSC	-	Differential Scanning Calorimetry
EPS	-	Expanded Polystyrene
PE	-	Polyethylene
PP	-	Polypropylene
RS	-	Rice Straw
PVC	-	Poly(vinylchloride)
SEM	-	Scanning Electron Microscope
TGA	-	Thermal Gravimetric Analysis
WPC	-	Wood Polymer Composites

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The combination of various synthetic reinforcing fillers with many polymer composites has been initiated during the past decades. The improvement of mechanical properties and obtained the demand characteristics in actual applications has become the main purposes in modification of composites. The Greenpeace groups and NGOs have addressed the bad impact of those synthetic reinforcing fillers on the environment which has become the global issue (Nourbakhsh *et al.*, 2011). As a result of growing awareness of global environment, the green products which have criteria such as the sustainability, eco-efficiency, industrial ecology, green chemistry and engineering is integrated into the development of new products. Hence, studies are proceeded to find ways in utilizing the natural fillers as the replacement of synthetic fibers as reinforcing fillers. The polymers are obviously involved into this tendency and numerous bio-polymer involving natural fibers such as jute, kenaf, sisal, wheat straw, rice husk and rice straw have been elaborated (Alemdar and Sain, 2008).

Natural fiber as reinforcement in plastics is very different than the other reinforcement due to its better properties itself such as flexibility, lightness, easier and safer in handling and working condition, easy to fabricate on intricate required shape with economic savings. They are broadly known and utilized in many areas such as building industry, transportation and consumer goods (Satyanarayana *et al.*, 1990).

The utilization of natural fibers in biocomposites grows rapidly as its abilities and latent qualities for various applications which was required nowadays. The biodegradable and renewable properties are really needed as reinforcing fillers in polypropylene composite (Nourbakhsh *et al*., 2011). Polypropylene added with rice straw fiber systems had comparable physico-mechanical properties and characteristics with those of wood composites. Chemically, lignocellulosic rice straw fiber has similar compositions as other natural fibers used in thermoplastics (Yao *et al.,* 2008). From Wu *et al.* (2012), the crystallinity of untreated and treated rice straw cellulose fibers recorded closed differences which are 71.3% and 72.9% separately and enhanced the elastic modulus of rice straw fibrils (RSF)/PP nanocomposites.

Recently, some progress has been made in the study regarding the foaming of the polymer biocomposites which has contributed to the synergism properties. The combination of the enhanced mechanical and physical elements has improved the specialty of properties on biocomposite foam products (Kiliaris and Papaspyride, 2010; Satyanarayana *et al.*, 2009).

Polymer foams can be generally classified as macro-cellular, micro-cellular and ultra-micro-cellular ones. Many advantages exhibit on foaming polymers over unfoamed polymers such as higher impact strength, higher toughness, and higher stiffness to- weight ratio, higher fatigue life, higher thermal stability, lower dielectric constant, and lower thermal conductivity (Xu *et al.*, 2007). Environmental concern of waste reduction helps to transfer the previous tradition of burning for disposal of natural fibers by utilizing them as fillers. Increasing the utilization of fibers, may solve the pollution problems. The improvement of foaming the polymer biocomposites really works because it will reduce the consumption of polymer's resins which can directly reduce the material costs and enhanced the physical properties such as lightness. Previously, many foaming researches have been done on the polymer biocomposite. It has result the improvement in mechanical and physical properties of the biocomposites as mentioned by the many researchers. Those researches normally focused on the effect of the formation or the existence of the bubbles nucleation and growth in the biocomposite. Lee *et al.* (2005) reported that the good dispersion of small amount of foaming agent which is called as denser matrix in thermoplastic tend to initiate the nucleation sites to ease the foam nucleation process thus encourage the macroscopic mechanical enhancement. Foaming polyethylene was widely accepted and done by researchers instead of polypropylene as reported by Abe and Yamaguchi (2000), where in their study of foaming crosslinked polyethylene, the degree of shrinkage reduced with the increasing of crystallization temperature Tc, due to the immediate crystallization.

Thus, an effort need to be taken in realizing this study by compounding the rice straw (RS) and polypropylene (PP) matrix followed by foaming process, in order to investigate the performance of the PP/RS biocomposite foam.

1.2 Problem Statement

The utilization of natural filler as reinforcement in thermoplastics is widely known among researchers in order to enhance or improve the mechanical and physical properties of biocomposites. Rice straw is one of the most arising natural fiber utilized as the filler in thermoplastics due to its good thermal stability than the others natural fiber (Nallis, 2009). The utilization of rice straw also giving the additional advantages where it is easily crushed into chips or particles and had the similarity to wood fibers (Buzarovska *et. al.*, 2008). Previously, the abundance of rice straw after the paddy field harvested has worried or giving many potential difficulties to environmental problems all over the world (Nallis, 2009). Thus, many efforts have been done from researcher to reduce the waste of this rice straw.

Nowadays, the foamed plastics are stronger than their non-foamed plastics because of the lightness in weight, clearly noticeable cost-to-performance and favorable strength-to-weight ratios (Thorne, 1996). Due to these special and unique properties, microcellular or foamed plastics can be used in many applications either in automotive and aerospace industries, containers, sporting goods and thermal and electrical insulators. If the biocomposites can be foamed effectively with intended results, the utility of materials can be enhanced by having the good foam cell-structures in the composite (Rizvi *et al.,* 2000). The modification on mechanical properties and density especially, has encouraged the utilization of foaming agent in the production of biocomposites foam. In certain case, it would be very difficult to obtain the demanded properties in the biocomposite, thus the foaming technology has been contributed in realizing it. The techniques become more economically attractive as the lower density can be achieved (Han *et al.,* 1976). In this research, the investigation more focused on the loading of rice straw as filler, azodicarbonamide as foaming agent and dicumyl peroxide as crosslinker on the PP/RS biocomposite foam.

1.3 Objectives of Study

The overall objective of this study was to investigate the properties of foamed PP/RS crosslinked with dicumyl peroxide via in-situ process whereby foaming agent, crosslinker and compatibilizer were added simultaneously together during extrusion to foam products. These objectives were subdivided into:

1) To investigate the effect of rice straw filler loading on the properties of PP/RS biocomposite foam such as morphology, thermal stability, density, thermal properties and water absorption.
2) To study the effect of foaming agent loading on the properties of PP/RS biocomposite.
3) To determine the effect of dicumyl peroxide crosslinker on the properties of PP/RS biocomposite foam.
4) To analyze the effect of compatibilizers on the properties of PP/RS biocomposite foam.

1.4 Scope of Study

This study focused on the in-situ compounding and foaming processes in the extruder. The investigation involved the gas bubbles formation in the polymer melt biocomposite. Materials used in this study were polypropylene (PP), rice straw (RS), azodicarbonamide (AZ)**,** dicumyl peroxide (DCP) and two types of compatibilizers; maleic anhydride polypropylene (PPMAH) and Ultra-plust TP10. Every series was compounded together and extruded through the twin screw extruder with the fixed temperature for every zone at the extruder.

Compositions of materials used are as follow:

(a) Rice straw in a powder form was used at different loading; 0 wt% to 50 wt%.

(b) Azodicarbonamide in a granule form was used at different phr; 1.5 phr to 3.0 phr.

(c) Dicumyl peroxide in a powder form was used at different phr loading; 0.5 phr to 2.5 phr.

(d) Compatibilizers (PPMAH and TP10) in a granule form were used at different phr; 0 phr to 10 phr.

The compositions of materials were taken variously in order to study the effects, the degree of foaming, types of cells formed and distribution of the gas bubbles in the polymer melt. SEM micrographs were used to characterize the pattern and types of foam cell structures produced in composites. The thermal properties and crystallinity of biocomposite foam were studied by using the differential scanning calorimetry (DSC) while thermogravimetric analysis (TGA) was used to measure thermal stability in a material as a function of temperature (or time) under a controlled atmosphere.

The testings and analyses involved in this study are density measurement for various formulations which were recorded by density Mettler Toledo. ASTM D2842 were used to determine water absorption of rigid cellular plastics and ASTM D2765 were used to determine the gel content or crosslinked density of crosslink foam plastics by extracting the samples with solvents such as decahydronaphthalene or xylenes.

1.5 Significance of Study

Polypropylene/rice straw foam based on chemical foaming agent give a quite similar function as synthetic wood which will replace the usage of the wood in construction and manufacturing based on wood (furniture) industries around the world. In enhancing the properties of products with remain original properties, the same products with new properties can be realized. In addition, the foaming agent enhanced the light weight of the material to suit the order of consumer needs.

REFERENCES

Abe, S. and Yamaguchi, M. (2001). Study on the Foaming of Crosslinked Polyethylene. *Journal of Applied Polymer Science*. **79:** 2146–2155.

Ahmad, M. (2004). Thermoplastic Microsphere as Foaming Agents for Wood Plastics. *Expancel Inc.* Composite. Presented at WPC 2004 Conference, Vienna, Austria. 1-13.

Alemdar, A. and Sain, M. (2008). Biocomposites from Wheat Straw Nanofibers: Morphology, Thermal and Mechanical properties. *Composites Science and Technology*. **68:** 557–565.

Almanza, O., Rodriguez-Perez, M.A. and De Saja, J.A. (2001). The Microstructure of Polyethylene Foam Produced by a Nitrogen Solution Process. *Polymer*. **42:** 7117-7126.

Ave´rous, L. and Le Digabel, F. (2006). Properties of Biocomposites Based on Lignocellulosic Fillers. *Carbohydrate Polymers*. **66:** 480–493.

Balasuriya, P. W., Ye, L. and Mai, Y. W. (2001). Mechanical Properties of Wood Flake – Polyethylene Composites. *Composites: Part A.* **32:** 619-629.

Basfar, A. A. and Ali, Z. I. (2011). Physico-Chemical Properties of Low Density Polyethylene and Ethylene Vinyl Acetate Composites Cross-linked by Ionizing Radiation. *Radiation Physics and Chemistry*. 80: 257–263.

Bledzki, A. K. and Faruk, O. (2004). Creep and Impact Properties of Wood Fibre–Polypropylene Composites: Influence of Temperature and Moisture Content. *Composites Science and Technology*. **64:** 693–700.

Bledzki, A.K. and Faruk, O. (2006). Injection Moulded Microcellular Wood Fibre–Polypropylene Composites. *Composites: Part A*. **37:** 1358–1367.

Bledzki, A. K., Zhang, W. and Faruk, O. (2005). Microfoaming of Flax and Wood Fibre Reinforced Polypropylene Composites. *HolzalsRoh- und Werkstoff*. **63:** 30–37.

Bledzki, A. K., Faruk, O. and Huque, M. (2002). Physico-Mechanical Studies of Wood Fiber Reinforced Composite. *Polymer-Plastics Technology and Engineering*. **41.3:** 435-45.

Brahmakumar, M., Pavithran.C. and Pillai, R. M. (2005). Coconut Fibre Reinforced Polyethylene Composites: Effect of Natural Waxy Surface Layer of the Fibre on Fibre/Matrix Interfacial Bonding and Strength of Composites. *Composites Science and Technology*. **65:** 563–569

Buzarovska, A., Bogoeva-Gaceva, G., Grozdanov, A., Avella, M., Gentile, G., and Errico, M. (2008). Potential Use of Rice Straw as Filler in Eco-composite Materials. *Australian Journal of Crop Science.* **1(2):** 37 – 42.

Chang, S. Y., Ismail, H. and Ahsan, Q. (2012). Effect of Maleic Anhydride on Kenaf Dust Filled Polycaprolactone / Thermoplastic Sago Starch Composites. *BioResources.* **7(2):** 1594 – 1616.

Chivrac, F., Pollet, E. and Ave'rous, Luc. (2009). Progress in Nano-Biocomposites Based on Polysaccharides and Nanoclays. *Materials Science and Engineering*. 117.

Chodak, I. and Matisovfi-Rychlfi, L. (1986). Thermooxidative Stability of Crosslinked Polypropylene. *Polymer Degradation and Stability*. **16**: 213–220.

Crookston, K. A., Young, T. M., Harper, D. and Guess, F. M. (2011). Statistical Reliability Analyses of Two Wood Plastic Composite Extrusion Processes. *Reliability Engineering and System Safety*. **96:** 172–177.

de la Fuente, J. L., Ruiz-Bermejo, M., Menor-Salván, C. and Osuna-Esteban, S. (2011). Thermal Characterization of HCN Polymers by TG-MS, TG, DTA and DSC Methods. *Polymer Degradation and Stability*. **96:** 943-948.

Di Landro, L., Sala, G. and Olivieri, D. (2002). Deformation Mechanisms and Energy Absorption of Polystyrene Foams for Protective Helmets. *Polymer Testing*. **21:** 217-228.

Eaves, D. (2004). *Handbook of Polymer Foams*. UK: Rapra Technology Limited.

El-Dessouky, H. M., Mahmoudi, M. R., Lawrence, C. A., Yassien, K. M., Sokkar, T. Z. N. and Hamza, A. A. (2009). On the Physical Behavior of Isotactic Polypropylene Fibers Extruded at Different Draw-Down Ratios. I. Optical Properties and Cold-Drawing. *Polymer Engineering and Science*. **49:**2116–2124.

Energy Research Group UCD (2002). *A Detailed Guide to Insulating Your Home*. Sustainable Energy Ireland. 1 – 24.

English, B., Youngquist, J.A. and Krzysik, A.M. (1994). Lignocellulosic Composite. *Cellulosic Polymers, Blends and Composites*. **6:** 115-130.

Farsheh, A. T., Talaeipour, M., Hemmasi, A. H., Khademieslam, H., Ghasemi, I. and Masoomi, Z. (2011). Development of Fine-Celled Wood Fiber – PVC Composite Foams Using Multi-Walled Carbon Nanotubes. *World Applied Sciences Journal*. **13(2):** 269 – 276.

Frisch, K.C., Reegen, S.L. and Robertson, E.J. (1967). The Effect of Chemical Structure on Environmental Properties of Polyurethanes. *Cellular Plastics*. 75-95.

Gendron, R. and Vachon, C. (2003). Effect of Viscosity on Low Density Foaming of Poly(Ethylene-Co-Octene) Resins. *Journal of Cellular Plastics*. **39:** 71-85.

Grozdanov, A., Buzarovska, A., Bogoeva-Gaceva, G., Avella, M., Errico' M. E. and Gentille, G. (2006). Rice Straw as an Alternative Reinforcement in Polypropylene Composites. *Agronomy for Sustainable Development*. **26:** 251-255.

Han, C. D., Kim, Y. W. and Malhotra, K. D. (1976). A Study of Foam Extrusion Using a Chemical Blowing. *Journal of Applied Polymer Science*. **20:** 1583 – 1595.

Haq, M., Burgueno, R., Mohanty, A.K. and Misra, M. (2009). Bio-based Unsaturated Polyester/layered Silicate Nanocomposites : Characterization and Thermo-Physical Properties. *Composites: Part A*. **40:** 540-547.

Hohne, G. W. H., Hemminger, W. F. and Flammersheim, H. –J. (2003). Differential Scanning Calorimetry (Second Edition): An Introduction of Practitioners. Springer-Verlag Berlin Heidelberg New York.

Iswanto, A. H. and Febrianto, F. (2005). The Role of Dicumyl Peroxide (DCP) in the Strengthening of Polymer Composites. *Peronema Forestry Science Journal*. **1:** 46-49.

Jackson, M. G. (1977). Review article: The alkali treatment of straws. *Animal Feed Science and Technology*. **2:** 105 – 130.

Jayaraman, K. (2003). Manufacturing Sisal-Polypropylene Composites with Minimum Fibre Degradation. *Composites Science and Technology*. **63:** 367-374.

John, M.J. and Thomas, S. (2008). Biofibers and Biocomposites. *Carbohydrate Polymer*. **71:** 343-364.

Kamel, S. (2004). Preparation and Properties of Composites Made From Rice Straw and Poly(Vinyl Chloride) (PVC). *Polymers for Advanced Technologies*. **15:** 612–616.

Kholodovych, V. and Welsh, W. J (2007). Densities of Amorphous and Crystalline Polymers. *Physical Properties of Polymers Handbook*. 611 – 617.

Kiliaris, P and Papaspyrides, C. D. (2010). Polymer/layered silicate (clay) nanocomposites: An overview of flame retardancy. *Progress in Polymer Science*. **35:** 902–958.

Kim, D. H and Kim, S. C. (1984). Dicumyl Peroxide-Initiated Croslinking Reaction of Low Density Polyethylene. *Polymer (Korea)*. **8:** 44 - 52.

Kong, Y and Hay, J. N (2002). The Measurement of the Crystallinity of Polymer by DSC. *Polymer*. **43:** 3873-3878.

Kunert, K. A., Ranachowski, J., Chodak, I., Soszyfiska, H. andPi~lewski, N. (1981). Physico-Mechanical Investigation of Crosslinked Polypropylene. *Polymer*. **22:** 1677-1682.

Lee, C.H., Jun, K., Jeong, L.G. and Kim, S.W. (1999). Growth of Gas Bubbles in the Foam Extrusion Process. *Advances in Polymer Technology*. **19:** 97-112.

Lee, L.J., Zeng, C., Cao, X., Han, X., Shen, J. and Xu, G. (2005). Polymer Nanocomposite Foam. *Composites Science and Technology*. **65**: 2344–2363.

Lee, S. T., (2004). *Introduction: Polymeric Foams, Mechanism, and Materials.* New York: CRC Press.

Li, D. C., Liu, T., Zhao, L., Yuan, W. K. (2011). Foaming of linear isotactic polypropylene based on its non-isothermal crystallization behaviors under compressed CO2. *Journal. of Supercritical Fluids*. **60:** 89– 97.

Longo, C.,Savaris, M., Zeni, M.,NicheleBrandalise, R, Maria CoulonGrisa, A. (2011). Degradation Study of Polypropylene (PP) and Bioriented Polypropylene (BOPP) in the Environment. *Materials Research*. **14(4):** 442-448.

Maffei, M. (2006). Characterization of Foaming Phenomena of Polypropylene Filled With Azodicarbonamide and Silica. Msc Polymer Thesis. University of Akron.

Mahendrakar, S. (2010). Maleic Anhydride Grafted Polypropylene Coatings on Steel: Adhesion and Wear. Master of Science. University of North Texas.

Maier, C. and Calafut, T. (1998). Polypropylene: The Definitive User’s Guide and Databook. **8**:69-73.

Matuana, L. M., Park, C. B. and Balatinecz, J. J. (1997). Processing and Cell Morphology Relationships for Microcellular Foamed PVC/Wood - Fiber Composites. *Polymer Engineering and Science*. **37**: 1137-1147.

Mills, N.J. (2007). *Polymer Foam Handbook*. Elsevier Limited. 1-18.

Najib, N. N., Ariff, Z. M., Manan, N. A., Bakar, A. A. and Sipaut, C. S. (2009). Effect of Blowing Agent Concentration on Cell Morphology and Impact properties of Natural Rubber Foam. *Journal of Physical Science*. **20 (1):**13-25.

Nallis, K. (2009). Comparative Study on the Properties of Rice Straw/Polypropylene and Micaceous Clay/Polypropylene Composites. Master of Science. Universiti Sains Malaysia.

Nourbakhsh, A., Baghlani, F. F. and Ashori, A.(2011). Nano-SiO_2 Filled Rice Husk/Polypropylene Composites: Physico-Mechanical Properties. *Industrial Crops and Products*. **33:** 183–187.

Okroafor, M.O. and Frisch, K.C. (1995). *Introduction to Foams and Foam Formation.* Handbook of Plastic Foams. William Andrew Inc. 1-10.

Othman, N., Ismail, H. and Mariatti, M. (2006). Effect of Compatibilisers on Mechanical and Thermal Properties of Bentonite Filled Polypropylene Composites. *Polymer Degradation and Stability*. **91:** 1761-1774.

Park, C.B. Lee, J.W.S. Wang, J. (2007). *Advances in Structural Foam Molding Technology. UKC, Korean-American Scientists and Engineers' Conference.* Washington DC. August 9-12. Paper #982.

Petchwattana, N. and Covavisaruch, S. (2011). Influences of particle sizes and contents of chemical blowing agents on foaming wood plastic composites prepared from poly(vinyl chloride) and rice hull. *Materials and Design*. **32:** 2844–2850.

Quinn, S. (2001). Chemical Blowing Agents: Providing Production, Economic and Physical Improvements to a Wide Range of Polymers. *Plastics Additives & Compounding.* **3:** 16 – 21.

Ramakrishna, S., Huang, Z. M., Kumar, G. V., Batchelor, A. W. and Mayer, J. (2004). An Introduction to Biocomposites. *Biomaterials and Bioengineering*. **1**: 9-13.

Rizvi, G., Matuana, L. M. and Park, C. B. (2000). Foaming of PS/Wood Fiber Composites Using Moisture as a Blowing Agent. *Polymer Engineering and Science*. **40**: 10.

Sanip, S. M. and Katun, M. D. N. (1996). Interpenetrating Polymer Network Between Natural Rubber and Polymethyl Methacrylate: Effect of Crosslink Densities on Their Mechanical and Physical Properties. *Jurnal Teknologi: Science and Engineering, UTM*. **25:** 1-10.

Satyanarayana, K.G., Arigaza, G.G.C. and Wypych, F. (2009). Biodegradable Composites Based on Lignocellulosic Fibres – An Overview. *Progress in Polymer Science*. **34**: 982-1021.

Satyanarayana, K.G., Sukumaran, K., Mukherjee, R.S., Pavithran, C. and Piuai, S.G.K. (1990). Natural Fibre-Polymer Composites. *Cement & Concrete Composite*. **12**: 117-136.

Sauceau, M., Fages, J., Common, A., Nikitine, C., and Rodier, E. (2011). New Challenges in Polymer Foaming: A Review of Extrusion Processes Assisted by Supercritical Carbon Dioxide. *Progress in Polymer Science.* **36**: 749–766.

Sauceau, M., Nikitine, C., Rodier, E. and fages, J. (2007). Effect of Supercritical Carbon Dioxide on Polystyrene Extrusion. *Journal of Supercritical Fluids*. **43**: 367-373.

Sirisinha, K. and Kamphunthong, W. (2009). Rheological Analysis as a Means for Determining the Silane Crosslink Network Structure and Content in Crosslinked Polymer Composites. *Polymer Testing.* **28:** 636–641

Soest, P. J. V. (2006). Rice Straw, the Role of Silica and Treatments to Improve Quality. *Animal Feed Science and Technology*. **130:** 137–171.

Stark, N. M. and Rowlands, R. E. (2002). Effects of Wood Fiber Characteristics on Mechanical Properties of Wood/Polypropylene Composites. *Wood and Fiber Science.* **35(2):** 167-174.

Struktol (2000). *The Effects of Various Additives on the Processing and Physical Properties of Wood-Filled PVC*. Wood-Plastic Conference Baltimore, MD. December 5.

Summers, D. M. (2000). *Fundamental Properties of Rice Straw in Comparison with Softwoods.* ESPM 286: Physical Properties of Wood.

Tang, H., Liu, Z. Y., Piao, I. H., Chen, X. F., Lou, Y. X. and Liz, S. H. (2003). Electrical Behavior of Carbon Black-Filled Polymer Composites: Effect of Interaction Between Filler and Matrix. *Journal of Applied Polymer Science*. **51:** 1159 – 1164.

Thorne, J. L. (1996). *Thermoplastic Foams*. Sherwood Publishers, Hinckley, Ohio. 579 – 583.

Torres, F.G. and Cubillas, M. L. (2005). Study of the Interfacial Properties of Natural Fibre Reinforced Polyethylene. *Polymer Testing*. **24**: 694–698.

Xu, X. Park, C.B. Lee, J.W.S. and Zhu, X. (2008). Advanced Structural Foam Molding Using a Continuous Polymer/Gas Melt Flow Stream. *Journal of Applied Polymer Science.* **109:** 2855-2861.

Xu, Z-M., Jiang, X-L., Liu, T., Hu, G-H., Zhao, L., Zhu, Z-N.and Yuan, W-K. (2007). Foaming of Polypropylene with Supercritical Carbon Dioxide. *Journal of Supercritical Fluids*. **41**: 299-310.

Yao, F., Wu, Q., Lei, Y. and Xu, Y. (2008). Rice Straw Fiber-Reinforced High-Density Polyethylene Composite: Effect of Fiber Type and Loading. *Industrial Crops and Products*. **28**: 63–72.

Willett, J.L. and Shogren, R.L. (2002). Processing and Properties of Extruded Starch/Polymer Foams. *Polymer*. **43**: 5935–5947.

Wu, Y., Zhou, D., Wang, S., Zhang, Y., and Wu, Z. (2012). Polypropylene Nanocomposite Reinforced with Rice Straw Fibril and Fibril Aggregates. *Polypropylene.* 329 – 345.

Yamsaengsung, W. and Sombatsompop, N. (2009). Effect of Chemical Blowing Agent On Cell Structure and Mechanical Properties of EPDM Foam, and Peel Strength and Thermal Conductivity of Wood/NR Composite–EPDM Foam Laminates. *Composites: Part B.* **40**: 594–600.

Yao, F., Wu, Q., Lei, Y. and Xu, Y. (2008). Rice Straw Fiber-Reinforced High-Density Polyethylene Composite: Effect of Fiber Type and Loading. *Industrial Crops and Products*. **28**: 63–72.

Yazdani, H., Morshedian, J. and Khonakdar, H. A. (2006). Effects of Silane Coupling Agent and Maleic Anhydride-Grafted Polypropylene on the Morphology andViscoelastic Properties of Polypropylene–Mica Composites. *Polymer Composite*. **27:** 491-496.

Zakaria, Z. (2007). Characterization of Polyethylene Foam and its Structure PropertiesRelationship in Shock Absorbing Application. M. Sc. Dissertation, Universiti Sains Malaysia, Pulau Pinang, Malaysia.

Zhang, Z. X., Lu, B. X., Xin, Z. X., Kang, C. K., and Kim, J. K. (2011). Effect of Flame Retardants on Mechanical Properties, Flammability and Foamability of PP/Wood-Fiber Composites. *Composites Part B: Engineering*. **43:**150-158.

Zhao, R., Huang, J., Sun, B. and Dai, G. (2001). Study of the Mechanical Properties of Mica-Filled Polypropylene-Based GMT Composite. *Journal Applied Polymer Science.* **82:**2719-2728.

Zou, Y., Huda, S. and Yang, Y. (2010). Lightweight Composites from Long Wheat Straw and Polypropylene Web. *Bioresource Technology*. **101**: 2026–2033.