MECHANICAL AND FLAMMABILITY PROPERTIES OF HYBRID RECYCLED NEWSPAPER/SEPIOLITE POLYPROPYLENE COMPOSITES

MUSLIHA BINTI MOHAMED

UNIVERSITI TEKNOLOGI MALAYSIA

MECHANICAL AND FLAMMABILITY PROPERTIES OF HYBRID RECYCLED NEWSPAPER/ SEPIOLITE POLYPROPYLENE COMPOSITES

MUSLIHA BINTI MOHAMED

A dissertation submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Science (Polymer Technology)

FACULTY OF CHEMICAL ENGINEERING
UNIVERSITI TEKNOLOGI MALAYSIA

MARCH 2013

To my beloved Mother, Father, and brother and the ones who give me inspiration and support that made this work possible

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to Allah S.W.T for guiding me and give me a good condition of health to complete my research. There are a lot of challenges in order to finish this research.

Secondly, I would like to thank my supervisor, Dr. Zurina binti Mohamad for giving me very valuable knowledge, continuous support and motivation in order to finish this research. Sincere thanks to my co-supervisor, Prof. Dr. Azman bin Hassan for his helpful comments, ideas and advices. I also would like to thank to all the lecturers in the Departments of Polymer Engineering, the Quality Control staff of Universal Cable (M) Bhd and Idemitsu (M) Sdn. Bhd. Next would be my sincere thanks to technicians who have put special effort with valuable technical guidance during this project.

Next, I would like to express words of appreciation to my entire friends and course mates for believing in me and helping me weather through our stormy weathers. The experiences and knowledge I gained throughout the process of completing this research would prove invaluable to better equipment for the challenges which lied ahead.

Last but not the least to my parents and brother, I can never thank you enough for your love, and for supporting me throughout my studies in Universiti Teknologi Malaysia (UTM).

ABSTRACT

The goals of this study are to determine the effect of recycled newspaper (RNP) and sepiolite ratio on physical and mechanical properties and flammability properties of RNP/PP composites and RNP/Sepiolite PP composites respectively. In this research, RNP was collected from old newspaper piles and treated in laboratory. After that, it was being soaked with NaOH solution to remove impurities from it. Later, it was being dried in oven to remove moisture and was ground to get fine particles of RNP. Sepiolite was used as filler and can also work as flame retardant. PP composite was prepared by mixing PP pellets, RNP, Maleic anhydride polypropylene (MAPP) for the first stage. In the second stage, sepiolite was added into the formulation. After mixing, it was molded by hot pressing sample preparation. The properties of composites such as mechanical and flammability was investigated. The mechanical properties were studied on PP composites using tensile, flexural and impact test. Flammability properties were studied through limiting oxygen index (LOI) test. Tensile and flexural strength reduced as RNP content increased. Impact strength reduced during low amount of RNP presence. The presence of sepiolite can improve tensile, flexural and impact up to a maximum value before it starts to reduce. Percentage of LOI increased as RNP and sepiolite content increased.

ABSTRAK

Matlamat kajian ini adalah untuk menentukan kesan nisbah akhbar kitar semula (RNP) dan sepiolite pada sifat fizikal dan sifat kemudahbakaran RNP / PP komposit dan RNP / Sepiolite PP komposit.Dalam kajian ini, RNP telah diambil dari akhbar lama dan disediakan di dalam makmal. Sepiolite telah digunakan sebagai pengisi dan juga sebagai perencat api. Komposit PP telah disediakan dengan mencampurkan PP Pelet, RNP, Maleic anhydride polypropylene (MAPP) pada peringkat pertama. Pada peringkat kedua, sepiolite telah ditambah ke dalam campuran komposit PP. Selepas pencampuran, ia diikuti oleh acuan mampatan panas untuk menyediakan sample. Sifat – sifat komposit seperti mekanikal dan kemudahbakaran telah disiasat. Sifat mekanikal telah dikaji pada komposit PP dengan menggunakan ujian tegangan, lenturan dan hentaman. Sifat kemudahbakaran dikaji melalui ujian limit oksigen indeks (LOI). Kekuatan tegangan dan lenturan berkurangan kerana kandungan RNP meningkat. Kekuatan hentaman berkurangan pada kandungan RNP yang sedikit. Kehadiran sepiolite meningkatkan kadar tegangan, lenturan dan hentaman sehingga kepada nilai maksimum sebelum berkurangan. Peratus LOI meningkat apabila kanduangan RNP dan sepiolite meningkat.

TABLE OF CONTENTS

2 LITERATURE REVIEW

3 MATERIALS AND METHODS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	-	American standard testing method
BFRP	-	Bamboo fiber reinforced polypropylene
BGRP	-	Bamboo-glass fiber reinforced polypropylene
CF	-	Cellulose fiber
CF	-	Cellulose fiber
CO	-	Carbon monoxide
GMA	-	Glycidylmethacylate
HDPE	-	High density polyethylene
LDPE	-	Low density polyethylene
LOI	-	Limiting oxygen index
MAPP	-	maleic anhydride grafted polypropylene
MFI	-	Melt flow index
MMT	-	Montmorillonite
M_w	-	Molecular weight
NaOH	-	Sodium hydroxide
PA	-	Polyamide
PALF	-	Pineapple leaf fiber
PLA	-	Polylactic acid
PLA	-	Polylactic acid
PP	-	Polypropylene
RNP	-	Recycled newspaper
TMP	-	thermomechanical pulp
TMP	-	Thermomechanical pulp

TOFA	-	Terol, tall oil fatty acid
UV	-	Ultra violet
WF	-	Wood flour
WP	-	Wastepaper
WP	-	Waste paper

LIST OF SYMBOLS

Δ	-	Delta
CH_3	-	Methyl group
G_m	-	Gibbs energy
H_m	-	Enthalpy
S_m	-	entropy
T_g	-	Glass transition temperature
Wt %	-	Weight percent
∂	-	delta

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of study

Generally composites consist of two phase which are polymer matrix and filler either synthetic or natural fibers. The traditional composites used man made filler such as aramid, glass and carbon fiber as reinforcing phase to take their advantage on tensile modulus (Gisele, 2011).The applications of natural fibers are increasing due to the low prices and the steadily rising performance of technical and standard plastics. More recently, the critical discussion about the preservation of natural resources and recycling has led to a renewed interest concerning natural materials with the focus on renewable raw materials (Wittig *et al.*, 1994). Furthermore, natural filler offers several advantages compared to manmade filler (Tajvidi, 2004):

- Plants fiber is more or less unlimited and it is renewable raw materials.
- The abrasiveness of natural fibers in term of process of composites material or material recycling is lower compared to glass fiber.
- The natural fiber reinforcement biodegradable polymer is the most environmental friendly as it can be composted at the end of their life.

In Asia country such as India, used natural fiber mainly jute fibers as reinforcement in the composites to produce panels, pipes and pultruded profiles with polyester matrices (Pal, 1984). Not only small part were been produced, India also promoted large projects where jute fibers reinforce polyester resin were used for building e.g. Madras house in 1978 (Winfield, 1979). Today, the use of natural fiber as reinforcement in technical application is taking place mainly in packaging and automotive industries.

Natural fibers are grouped mainly into three types which are seed hair, bast fibers and leaf fibers. For examples are sisal, abaca (leaf fibers), cotton, coconut (seed hair) and kenaf (bast fibers). Natural fiber consists of cellulose, hemicelluloses, pectin and lignin. The composition of each constituent varies depending on their type of fibers. Hemicellulose is responsible for biodegradation, thermal degradation and water absorption while lignin is responsible for UV degradation (Saheb *et al.*, 1999). New source of natural fiber is found such as fiber in the recycled newspaper. Recycled newspaper is one of the most materials collected by the recycling centre (Corbiere, 2001). It is increasingly recognized the usage of the recycled newspaper as the natural fiber source. Recycled newspaper consists of lignocellulosic fibers which are hydrophilic in nature and contain strongly polarized hydroxyl groups (Pradeep, 2012).

Hybrid composites consist of two or more reinforcing materials in the binder phase. More research is made by focusing the hybrid composites area because it offers better properties compared to traditional composites. By producing hybrid composites, the synergism effect can be achieved. Each type of fiber can complement with what the other are lacking. As a consequence, a balance in cost and properties can be achieved through proper material design. Hybrid of natural fiber and synthehic fiber such as glass fiber as reinforcement in composites can demonstrated a good mechanical performance (Abu Bakar *et al.*, 2005).Research done by Haijun *et al*. (2007) shows the mechanical properties such as tensile strength, modulus, and impact strength of notched or unnotched sample increase as the two different types of fibers which are glass fiber and thermomechanical pulp (TMP) are added into PP composites compared to neat PP. Adding hybrid natural fiber solely in polymer composites is less preferable as it has variable quality and offer low strength of composites. Huda *et al*. (2006) shows that, by using only natural fiber such

as recycled newspaper as reinforcing filler, it reduce the flexural strength and modulus of PLA. By adding talc as reinforcing filler, it increases flexural strength and modulus.

Natural fibers composites is been receive great attention as an innovative materials in several sector application such as automotive, packaging, building and biomaterials. They offers great advantages but also have its own drawback which can affect the properties of the composites, generally leads to lower performance and thus limit their use. One of it is weak compatibility between fiber and polymer matrix. This happened because of poor adhesion between polar fiber and nonpolar polymer matrix and it can be overcome by using compatibilizer. There is various type of compatibilizer available in the industries such as Dodecanol, Terol, tall oil fatty acid (TOFA). Research done by Thanatiwat. 2007 shows that tensile strength and impact strength of maleic anhydride grafted polypropylene (MAPP) modified rossells-PP composites were higher than that of unmodified rossells-PP composite and slightly increased with increasing MAPP content. However, no significant difference of Young's modulus was found when the MAPP was added. Tensile strain at break slightly increased with increasing MAPP content. The MAPP increase the properties of rossells-PP composites by creating linkage between hydrophilic hydroxyl group of fiber and the carboxyl group of the compatibilizer that than link to the polymeric material (Rana *et al.*, 1998). In this project, commercial compatibilizer, MAPP were incorporate in the hybrid composites to avoid the compatibility issue.

Natural fiber composites also have poor fire resistance which is a major problem in certain application, for example transportation sector and aerospace. High content of cellulose tends to increase the flammability of the fiber (Chapple *et al.*, 2010). Many researchers treated the hybrid natural composites with the flame retardant prior incorporation in the matrix. Flame retardant can be divided into several categories which are antimony oxide, organic halogens, organic phosphate, inorganic phosphates, inorganic halides, alloys and reactive flame retardants. Research done by Sain *et al*. 2004 shows that by incorporation the flame retardant like magnesium hydroxide, the flammability of saw dust/rice husk filled polypropylene can be reduce by 50 %. To date, most of flame retardant used are halogeneous compound based with antimony trioxide. However, the rules and regulation limit the use of halogeneous compound as flame retardant as it release heavy smoke and toxic gasses during burning (Marosfoi *et al.*, 2008). To overcome this problem, inorganic filler such as sepiolite can be an alternative compound to be substitute

over these halogeneous compounds. Inorganic filler like sepiolite help to stop or inhibit the polymer combustion process by reducing the combustible product and alter the thermal conductibility and the viscosity of the resulting material depending on the nature and chemical structure of the polymer. Adding this flame retardant additive, it produces a layer of char during combustion (Lewin, 2006).In this research, sepiolite was used and the effect of the sepiolite content on the flammability properties of the composites was evaluated.

1.2 Problem statement

Recycling is important since it can produce new product from recycles material without sending it back to the landfill. In general, an estimated amount of 19100 tonnes of waste was generated every day in Peninsular Malaysia and 7 % of it was paper (Jaafar, 2006).To date, many researchers used natural fiber as the filler in their composites. The natural fiber range from kenaf, pineapple leaves, jute and hemp. Recent discovery shows recycle newspaper (RNP) also can be used as natural filler and has same component with others (cellulose, hemicellulose and lignin) (Osman *et al.*,). However, the development of RNP/PP composites is not yet been explore in detail. In this study, the RNP/PP composites and RNP/Sepiolite PP composites were produced with different ratio of RNP and sepiolite. Constant amount of compatibilizer are added to make sure no defect cause by compatibility issue to study the effect on mechanical properties.

Some of the advantages of recycling are it can prolong the life span of dump site and reduce the need of deforestation to get the raw materials hence it can reduce global warming. Research made by Kaseva *et al.*(1996) shows that in Dar esSalaam city, Tanzania out of 294 tonnes of study material such as paper, metal, plastics, glass and textiles only 4 tonnes are recovered and recycled. Global warming can cause fire very easily and natural composites are easily burn in fire because high content of cellulose (Gani *et al.*, 2007).Due to that reasons and new government regulations, flame retardant have experienced a tremendous growth.Different amount of flame retardant (sepiolite) concentration will be used in order to produce better properties of hybrid kenaf fiber/recycled newspaper polypropylene in term of flammability.

1.3 Objectives of research

The aims of this study are to produce a balance stiffness, toughness, strength and low flammability of polypropylene (PP) natural fiber composites material name recycled newspaper (RNP) /PP composites. Recycled newspaper were bleached with sodium hydroxide (NaOH) and used as filler. PP, compatibilizer (MAPP), flame retardant (sepiolite) and RNP are used as a raw material in compounding process to produce RNP/PP composites via twin screw extruder.

The objectives of this study are:

i) To determine the effect of RNP ratio on physical and mechanical properties and flammability properties of RNP/PPcomposites.

ii) To investigate the effect of sepiolite on the mechanical and flammability properties of RNP/Sepiolite PP composites

1.4 Scopes of study

In order to achieve the objectives of the research, the following activities were carried out:

1. Recycled newspaper preparation

    i) Recycled newspaper was purified though bleaching method.

2. PP natural composites preparation

    In this research project, PP natural composites were prepared via melt extrusion blending method. This involved:

    i) Compounding of PP, natural filler, flame retardant and compatibilizer using twin screw extruder.

    ii) Hot pressing to prepare test specimens according ASTM standard.

3. Physical and mechanical analysis

    i) Tensile test

    ii) Flexural test

    iii) Izod impact test

4. Flammability study

    i) Limiting oxygen index (LOI) test

REFERENCES

Abdul Khalil, H. P. S., Hanida, S., Kang, C. W., & Nik Fuaad, N. A. (2006). Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. Journal of Reinforced Plastics and Composites, 26(2), 203–218.

Abu Bakar, A., Hariharan, & Khalil, H. P. S. A. (2005). Lignocellulose-based hybrid bilayer laminate composite: Part I – Studies on tensile and impact behavior of oil palm fiber–glass fiber-reinforced epoxy resin. Journal of Composite Materials, 39(8), 663–684.

Acosta, J. L.,Ojeda, M. C., Morales, E., Linares, A. (1986). Journal of Applied Polymer Science , 31, 2351.

Alvarez, A., Santare´n, J., Pe´rez Castells, R., Casal, B., Ruiz-Hitzky, E., Levitz, P., et al. (1987).Surfactant adsorption and rheological behaviour of surface-modified sepiolite. In: Proc. Int. Clay Conf. Denver, 1985. The Clay Minerals Society, Bloomington, IN, 370–374.

Athijayamani, A, Thiruchitrambalam, M., Natarajan, U., & Pazhanivel, B. (2009). Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite. Materials Science and Engineering A, 517(1–2), 344–353

Blatz P. S. (1964). French Patent 1964;1,355,064. Cited in: Lyons JW. The chemistry and uses of fire retardants, Wiley–Interscience, New York, London, Sydney, Toronto; 1970

Bledzki, A. K., Reihmane, S., & Gassan, J. (1996). Properties and modification methods for vegetable fibers for natural fiber composites. Journal of Applied Polymer Science, 59(8), 1329–1336..

Chaigneau M, Le Moan G. (1982). Toxicity of products resultingfrom the cold combustion of polypropylene. Comptes Rendus des Seances de l'Academie des Sciences.Serie III. Sciences de la Vie 1982;295(3):223–5.

Chang, P.R., Jian, R., Zheng, P., Yu, J., Ma, X., (2007). Preparation and properties of glycerol plasticized-starch (GPS)/cellulose nanoparticle (CN) composites. Carbohydrate Polymer 79, 301–305.

Christian S. D. (1983). Suggested flammability performance requirements for the contents of public buildings. Journal of Society of Dyers and Colour, 1983;99:78–85.

Dale BT. (1995) Compounding processed old news print with recycled high density polyethylene to make a substitute lumber product. Annual Technical Conference SPE, no53/ v.3,4232–6.

Einsele U, Koch W, Herlinger H. (1984). Investigations into the development of heat when textiles burn in air. Melli and Textil berichte 1984;65(3):200–6.

Gleixner G. (2001). Flame retardant PP fibres-lateat developments.Chem Fibers Int 2001;51:422–4. Tankard CJ. Flame retardant systems for polypropylene. MPhil Thesis, University of Manchester, Manchester, UK; 1995.

Guggenheim, S., Adams, J.M., Bain, D.C., Bergaya, F., Brigatti, M.F., Drits, V.A., et al. (2006). Summary of recommendations of nomenclature committees relevant to clay mineralogy: report of the association internationale pour l´etude des argiles (AIPEA) nomenclature committee for 2006. Clays Clay Miner. 54 (6), 761–772.

Gurniak U, Kohlhaas O. (1993). The effect of backing materials on the combustion behaviour of tufted carpets. Melli and Textil berichte 1993;74:632–3.

Horrocks AR. (2003). Flame-retardant finishes and finishing. In: Heywood DH, editor. Textile finishing. Bradford: Society of Dyers and Colourists; 2003, 214–50.

Huda, M. S., Drzal, L. T., Mohanty, A. K. and Misra, M. (2006). Chopped glass and recycled newspaper as reinforcement fibers in injection molded poly(lactic acid) (PLA) composites: A comparative study, Composites Science and Technology, 62(3), 339–353.

Jawaid, M., Abdul Khalil, H. P. S., Noorunnisa Khanam, P., & Abu Bakar, A. (2011). Hybrid composites made from oil palm empty fruit bunches/jute fibres: Water absorption, thickness swelling and density behaviours. Journal of Polymers and the Environment, 19(1), 106–109.

John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. Carbohydrate Polymers, 71(3), 343–364.

Jones, F. R. (1994). Handbook of polymer composites. England: Longman Scientific and Technical

Joshi, S. V., Drzal, L. T., Mohanty, A. K., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? Composites Part A: Applied Science and Manufacturing, 35(3), 371–376.

Karger-Kocsis, J. (2000). Reinforced polymer blends. In D. R. Paul, & C. B. Bucknall (Eds.), Polymer blends (p. 395). New York: John Wiley & Sons.

Karian, H. G. (1999). Handbook of Polypropylene and Polypropylene Composites, Second Edition, Revised and Expanded, England: Longman Scientific and Technical

Kurt, A.O.(2004). Nanosized fine particles and fibers as reinforcing materials synthesised from sepiolite. In: Guceri, S., Gogotsi, Y.G., Kuznetsov, ve V. (Eds.), Nanoengineered Nanofibrous Materials. NATO Science Series, II. Mathematics, Physics and Chemistry, vol. 169. Kluwer Academic Publishers1-4020-2549-1,443–449.

Lewin, M. (2006). Reflections on migration of clay and structural changes in nanocomposites. Polymer Advance Technology 17, 758–763.

Liu, Y., Zhao, J., Deng, C. L., Chen, L., Wang, D. Y. and Wang, Y. Z. (2011). Flame-Retardant Effect of Sepiolite on an Intumescent Flame-Retardant Polypropylene System, Composites Science and Technology 65 (2011) 1289–1294

M. Jawaid, H.P.S. and Abdul Khalil. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers 86 (2011) 1– 18.

Marosfoi, B. B., Garas, S., Bodzay, B., Zubonyai, F., Marosi, G. (2008). Flame retardancy study on magnesium hydroxide associated with clays of different morphology in polypropylene matrix. Polymer Advance Technology, 19:693–700.

Mohanty A., Misra M. andHinrichesn G. (2000).Biofibers, Biodegradable Polymers and Biocomposites: An Overview, Macromolecule Material Engineering , 1: 276–277.

Morales, E., White, J.R.(2009). Effect of ageing on the mechanical properties and the residualstress distribution of hybrid clay–glass fibre–polypropylene injection mouldings. Journal Material Science, 44, 4734–4742.

Myers C. (1994). Moisture effects on compounded recyclable high density polyethylene and post-consumer paper wastes. Annual Technical Conference—SPE, no52/v.3, 2861–4.

Nohales, A., Solar, L., Porcar, I., Vallo, C. I. and Go´mez, C. M. (2006). Morphology, flexural, and thermal properties of sepiolite modified epoxy resins with different

curing agents on properties of hybrid fiber biocomposites. Composites Part A: Applied Journal Application Polymer Science 109.

Pal PK .(1984). Performance of Hybrid Phenol-Formaldehyde-Based Composites. Plastics Rubber Process Application, 1984;4:215–219.

Rana, A.K., Mandal, A.,Mitra,B. C., Jacobson, R., Rowell, R.,and Banerjee, A. N. (1998). Short Jute Fiber-Reinforced Polypropylene Composites: Effect of Compatibilizer. resin-Fire performance and background—Part I. Polymer Degradation Stability 92, 2223–2230.

Richardson, T. L., and Lokensgard, E. (1997). Industrial plastics: theory and application. (3rd). USA: Delmar publishers, inc

Ruiz-Hitzky, E. (2001). Molecular access to intracrystalline tunnels of sepiolite. Journal Material Chemical.11, 86–91.

Ruiz-Hitzky, E.(1974). Contribution a` l'e´tude des re´actions de greffage de groupements organiquessur les surfaces mine´rales. Greffage de la sepiolite. Ph.D. Thesis, Universite´ Catholique de Louvain, Leuven, Belgium.

Ruiz-Hitzky, E., Van Meerbeek, A. (2006). Development in clay science. In: Bergaya, F., Theng, B.K.G., Lagaly, G. (Eds.), Clay Mineral- and Organoclay Polymer nanocomposite. Handbook of Clay Science. Elsevier, Amsterdam, 583–621.

Sa´nchez del Rı´o, M., Sua´rez, M., Garcı´a-Romero, E., Alianelli, L., Felici, R., Martinetto, P., et al. (2005). Mg K-edge XANES of sepiolite and palygorskite. Nuclear Instruments and Methods in Physics Research B. 238, 55–60.

Sarkissov, A., Meijer, H., Fischer, H. (2005). Influence of the particle morphology on the micro and macromechanics of nano-reinforced materials. Material Responsible Society Symposium Program vol. 856E. BB4.4.1-6.

Shakeri, A. and Raghimi, M. (2009).Studies on Mechanical Performance and Water Absorption of Recycled Newspaper/Glass Fiber-reinforced Polypropylene Hybrid Composites. Journal of Reinforced Plastics and Composites 2010 29: 994.

Shemwell BE, Levendis YA. (2000). Particulates Generated From Combustion of Polymers (Plastics). Journal of Air Waste Management Association 2000;50(1):94–102

Shen, L., Lin, Y., Du, Q., Zhong, W. (2006). Studies on structure–property relationship of polyamide-6/attapulgite nanocomposites. Composites Science Technology, 66, 2242–2248.

Sreekala, M. S., George, J., Kumaran, M. G., & Thomas, S. (2002). The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibres. Composites Science and Technology, 62(3), 339–353.

Sreekumar, P. A. (2008). Matrices for natural-fibre reinforced composites. In K. L. Pickering (Ed.), Properties and performance of natural-fibre composite (p. 541). UK: Brimingham, Woodhead Publication Limited.

Thwe, M. M., & Liao, K. (2003a). Durability of bamboo–glass fiber reinforced polymer matrix hybrid composites. Composites Science and Technology, 63(3–4), 375–387.

Toldy, A., Anna, P., Csontos, I., Szabo, A., Marosi, Gy. (2007). Intrinsically flame retardant epoxy resin-Fire performance and background—Part I. Polymer Degradradation Stabilization, 92, 2223–2230.

Van Meerbeek, A., Ruiz-Hitzky, E. (1979). Mechanism of the grafting of organosilanes on mineral surfaces. II. Secondary reactions during the grafting of alkenylchlorosilanes. Colloid Polymer Science, 257, 178–181.

Wambua, P.,Ivens, J. and Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics?. Composites Science and Technology 63 (2003) 1259–1264

Wang, C.H., Auad, M.L., Marcovich, N.E., Nutt, S. (2008). Synthesis and characterization of organically modified attapulgite/polyurethane nanocomposites. Journal Applied Polymer Science, 109,2562–2570.

Wishman M, Hagler G. E. (1985). Handbook of fire science and technology. Fibre chemistry, vol. 5.NewYork: Marcel Dekker Inc.; 1985. p. 382.

Wittig, W. (1994). Einsatz von Naturfasern. In Kfz-Bauteilen. Kunststoffe im Automobilbau. Düsseldorf: VDI Verlag.

Xie, S., Zhang, S., Wang, F., Yang, M., Se gue la, R., Lefebvre, J.M. (2007). Preparation, structure and thermomechanical properties of nylon-6 nanocomposites with lamella-type and fiber-type sepiolite. Composite Science Technology, 67, 2334–2341.