

**THE EFFECT OF FILLER LOADING AND COUPLING
AGENT ON PROPERTIES OF BENTONITE FILLED
RECYCLED HIGH DENSITY POLYETHYLENE
COMPOSITES**

MUHAMMAD ANAS BIN HUSNAN

UNIVERSITI MALAYSIA PERLIS

2014



**THE EFFECT OF FILLER LOADING AND COUPLING
AGENT ON PROPERTIES OF BENTONITE FILLED
RECYCLED HIGH DENSITY POLYETHYLENE
COMPOSITES**

by

MUHAMMAD ANAS BIN HUSNAN

(1331620829)

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

School of Materials

UNIVERSITI MALAYSIA PERLIS

Year

2014

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF DISSERTATION

Author's full name : MUHAMMAD ANAS BIN HUSNAN
Date of birth : 21 NOVEMBER 1989
Title : PROPERTIES OF BENTONITE AS FILLER FILLED
RECYCLED HIGH DENSITY POLYETHYLENE
COMPOSITES
Academic Session : 2013/2014

I hereby declare that the dissertation becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This dissertation is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)*
- OPEN ACCESS** I agree that my dissertation is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this dissertation in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE

891121-03-5501

(NEW IC NO. / PASSPORT NO.)

Date : _____

SIGNATURE OF SUPERVISOR

ASSOC. PROF. DR. SUPRI A. GHANI

NAME OF SUPERVISOR

Date : _____

NOTES : * If the dissertation is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

ACKNOWLEDGEMENT

Alhamdulillah, thank god for His graciousness and mercifulness has gave me the strength and ability to complete this thesis successfully.

I would like to express my utmost appreciation to my respectful supervisor, Assoc. Prof. Dr. Supri A. Ghani for his never ending guidance and support throughout the course of this work. His enthusiasm inspires me throughout the research period to strive as a student, researcher and also as a human. I also would like to extend my gratitude to my postgraduate coordinator, Dr Rozyanty Rahman for her cared and guidance on my study.

I also want to take this opportunity to express a deep sense of gratitude to Dean of School Materials Engineering, Dr. Khairul Rafezi Ahmad for all his support during my period of study. My sincere thanks also go to all the staff, technicians and PLV of School of Materials Engineering for their generous effort and assistance in the laboratory's work. I also want to thank to all my postgraduates colleagues for helping me to get through the difficult times, and for all the emotional support they provided. My days of research and thesis writing were easier with them around.

Last but not least, I record my gratitude to my lovely family especially my parents for their constant supports, understanding, loveliness and providing the financial support. I am also grateful to Universiti Malaysia Perlis for giving me the opportunity to be one of their MSc program students. Thank you very much.

TABLE OF CONTENTS

	PAGE
THESIS DECLARATION	i
ACKKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	ix
LIST OF SYMBOLS	xi
ABSTRAK	xii
ABSTRACT	xiii
CHAPTER 1 INTRODUCTION	
1.1 Background	1
1.2 Problem Statement	4
1.3 Objectives	5
1.4 Scope of study	6
CHAPTER 2 LITERATURE REVIEW	
2.1 Composites	7
2.1.1 Polymer Matrix Composites (PMC)	8
2.2 Recycled Plastic	9
2.3 Polyethylene	12
2.3.1 High Density Polyethylene (HDPE)	13

2.3.2	Properties of High Density Polyethylene (HDPE)	14
2.3.3	Application of High Density Polyethylene	15
2.4	Fillers	17
2.4.1	Properties of Natural Rubber (NR)	18
2.5	Inorganic Filler	19
2.5.1	Nano Composites	21
2.5.2	Nano Fillers	22
2.5.3	Bentonite	22
2.5.3.1	Structure of Clay Minerals	23
2.6	Coupling Agent	28
2.6.1	Polyethylene Grafted-Maleic Anhydride (PEgMAH)	29
2.6.2	Maleic Anhydride	30
2.7	Layered Particle in Nanocomposites	32
2.8	Filler-Matrix Interaction	34
2.9	Filler-Filler Interaction	35

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Materials	36
3.2	Compounding of RHDPE/Bentonite Composites with Coupling Agent	37
3.3	Compression Molding	38
3.4	Testing and Characterizations	39
3.4.1	Tensile Test	39
3.4.2	Swelling Behaviour	39
3.4.3	Scanning Electron Microscopy (SEM)	40
3.4.4	Fourier Transform Infrared Spectroscopy (FTIR)	40
3.5	Flow Chart of the Experiment	41

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Effect of Filler Loading on Properties of RHDPE/Bentonite Composites	43
4.1.1	Tensile Properties	43
4.1.2	Swelling Behavior	47
4.1.3	Morphology Analysis	48

4.1.4	Spectroscopy Infrared Analysis	50
4.2	Effect of PEGMAH on Properties of RHDPE/Bentonite Composites	51
4.2.1	Tensile Properties	51
4.2.2	Swelling Behavior	56
4.2.3	Morphology Analysis	58
4.2.4	Spectroscopy Infrared Analysis	59
4.3	Effect of Maleic Anhydride on Properties of RHDPE/Bentonite Composites	61
4.3.1	Tensile Properties	61
4.3.2	Swelling Behavior	65
4.3.3	Morphology Analysis	67
4.3.4	Spectroscopy Infrared Spectroscopy	68
CHAPTER 5 CONCLUSION AND SUGGESTION		
5.1	Conclusion	71
5.2	Suggestions	72
REFERENCES		73

LIST OF TABLES

NO.		PAGE
2.1	Common thermoplastic and their applications	10
2.2	Classification of polyethylene according to ASTM D 883-00	13
2.3	Different types of fillers	19
3.1	The formulations of RHDPE/Bentonite composites, RHDPE/Bentonite/PEgMAH composites and RHDPE/Bentonite/MAH composites	38
4.1	Weight swell percentage of RHDPE/Bentonite composites were immersed in toluene at room temperature for 46 hours	48
4.2	Weight swell percentage of RHDPE/Bentonite and RHDPE/Bentonite/PEgMAH composites were immersed in toluene at room temperature for 46 hours	57
4.3	Weight swell percentage of RHDPE/Bentonite and RHDPE/Bentonite/MAH composites were immersed in toluene at room temperature for 46 hours	66

LIST OF FIGURES

NO.		PAGE
2.1	Chemical structures of (a) ethylene and (b) polyethylene	12
2.2	Schematic of (a) linear and (b) branched arrangement	14
2.3	Common fillers particle shape	18
2.4	Tetrahedral sheet. The open circle are oxygens, the black circles tetrahedrally coordinated cations	24
2.5	Octahedral sheet. The filled black circled are OH and the filled grey circles octahedrally coordinated cations	25
2.6	Distribution of Al ³⁺ -ions in octahedral sheets with trans- and cis- vacant sites	26
2.7	Crystal structure of montmorillonite	28
2.8	Types of composites	33
3.1	Flow chart of the sample processing, testing, and characterizations	42
4.1	Tensile strength vs filler loading of RHDPE/Bentonite composites	44
4.2	Young's modulus vs filler loading of RHDPE/Bentonite composites	45
4.3	Elongation at break vs filler loading of RHDPE/Bentonite composites	46
4.4	SEM morphology of the tensile fracture surface of RHDPE/Bentonite-10 composites	49
4.5	SEM morphology of the tensile fracture surface of RHDPE/Bentonite-20 composites	49
4.6	SEM morphology of the tensile fracture surface of RHDPE/Bentonite-30 composites	50
4.7	Infrared spectroscopy spectrum of RHDPE/Bentonite-10 composite	51
4.8	Tensile strength vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/PEgMAH composites	53
4.9	Young's modulus vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/PEgMAH composites	54

4.10	Elongation at break vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/PEgMAH composites	55
4.11	SEM morphology of the tensile fracture surface of RHDPE/Bentonite/PEgMAH composites (a) RHDPE/Bentonite -10, (b) RHDPE/Bentonite -20, (c) RHDPE/Bentonite -30, (d) RHDPE/Bentonite/PEgMAH-10, (e) RHDPE/Bentonite/PEgMAH-20, (f) RHDPE/Bentonite/PEgMAH-30	59
4.12	Infrared spectroscopy spectra of RHDPE/Bentonite/PEgMAH composites	60
4.13	Proposed interaction of PEgMAH with Bentonite and RHDPE matrix	61
4.14	Tensile strength vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/MAH composites	63
4.15	Young's modulus vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/MAH composites	64
4.16	Elongation at break vs filler loading of RHDPE/Bentonite composites and RHDPE/Bentonite/MAH composites	65
4.17	SEM morphology of the tensile fracture surface of RHDPE/Bentonite/MAH composites, (a) RHDPE/Bentonite-10, (b) RHDPE/Bentonite-20, (c) RHDPE/Bentonite-30, (d) RHDPE/Bentonite/MAH-10, (e) RHDPE/Bentonite/MAH-20, (f) RHDPE/Bentonite/MAH-30	68
4.18	Infrared spectroscopy spectra of RHDPE/Bentonite/MAH-10 composites	69
4.19	Proposed interaction of MAH as coupling agent with Bentonite and RHDPE matrix	70

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
AT	Attapulgate
BPD	1,4-butandiol
CMC	Ceramic matrix composites
CNT	Carbon nanotube
DSC	Differential scanning calorimetry
EPDM	Ethylene propylene diene monomer
FTIR	Fourier transform infrared spectroscopy
HDPE	High density polyethylene
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
LPN	Layered polymer nanocomposite
MAH	Maleic anhydride
MAPE	Maleic anhydride-grafted-polyethylene
MAPP	Maleated polypropylene
MDPE	Medium density polyethylene

MMC	Metal matrix composites
MWNT	Multiwall carbon nanotubes
PBT	Polybutylene terephthalate
PCBs	Printed circuit boards
PE	Polyethylene
PEgMAH	Polyethylene grafted maleic anhydride
PPgMAH	Polypropylene grafted maleic anhydride
Phr	Part per hundred resins
PMC	Polymer matrix composites
PMMA	Poly (methyl methacrylate)
PP	Polypropylene
PS	Polystyrene
RHDPE	Recycled high density polyethylene
SEM	Scanning electron microscopy
SMA	Styrene-co-maleic anhydride
TGA	Thermogravimetric analysis
UHMWPE	Ultra-high molecular weight polyethylene
UPR	Unsaturated polyester resin
v-PP	Virgin isotactic polypropylene

LIST OF SYMBOLS

°C	Degree celcius
Al	Aluminium
BaSO ₄	Barium sulphate
Br	Bromine
C	Carbon
Ca	Calcium
CaCO ₃	Calcium carbonate
Cu	Copper
Fe	Ferum
g	Gram
H	Hydrogen
K	Potassium
Mg	Magnesium
Na	Sodium
O	Oxygen
OH	Hydroxide
Si	Silicon
W ₁	Weight of the dried sample
W ₂	Weight of the wet sample

Kesan Pembebanan Pengisi dan Agen Gandingan ke atas Sifat-Sifat Komposit Polietilena Ketumpatan Tinggi Kitar Semula Terisi Bentonit

ABSTRAK

Komposit polietilena ketumpatan tinggi kitar semula/bentonit (RHDPE/Bentonit) telah disediakan menggunakan Brabender Plasticorder pada suhu 160°C dan kelajuan rotor 50 rpm. Kesan pembebanan bentonit dan ejen gandingan ke atas sifat-sifat tegangan, sifat pembengkakan, morfologi, dan analisis spektroskopi inframerah (FTIR) komposit RHDPE/Bentonit telah dikaji. Keputusan menunjukkan bahawa dengan penambahan bentonit telah mengurangkan kekuatan tegangan, pemanjangan pada takat putus dan sifat pembengkakan, manakala modulus Young pula telah meningkat. Ejen gandingan seperti polietilena-anhidrida maleic (PEgMAH) dan anhidrida maleik (MAH) telah digunakan, di mana telah memberi kesan positif pada sifat-sifat mekanikal dan juga telah mengurangkan sifat pembengkakan komposit RHDPE/Bentonit. Komposit RHDPE/Bentonit/PEgMAH mempunyai kekuatan tegangan, modulus Young dan pemanjangan takat putus yang lebih tinggi tetapi lebih rendah peratus berat pembengkakan berbanding dengan komposit RHDPE/Bentonit/MAH. Analisis mikroskop pengimbas elektron (SEM) terhadap permukaan patahan tegangan untuk komposit RHDPE/Bentonit yang mempunyai ejen gandingan PEgMAH dan MAH menunjukkan bahawa interaksi antara muka antara bentonit dengan komposit RHDPE adalah lebih baik jika dibandingkan dengan komposit RHDPE/Bentonit tanpa kehadiran ejen gandingan.

The Effect of Filler Loading and Coupling Agent on Properties of Bentonite Filled Recycled High Density Polyethylene Composites

ABSTRACT

Recycled high density polyethylene/ bentonite (RHDPE/Bentonite) composites had been prepared using Brabender Plasticorder at temperature 160°C and rotor speed of 50 rpm. The effect of Bentonite loading and coupling agent on tensile properties, swelling behavior, morphology analysis, and spectroscopy infrared (FTIR) analysis on RHDPE/Bentonite composites were studied. The result showed that the addition of Bentonite reduced the tensile strength, elongation at break and weight swell percentage of composites, whereas the Young's modulus increased. Coupling agent such as polyethylene graft maleic anhydride (PEgMAH) and maleic anhydride (MAH) were used, which resulted in positive effect on mechanical properties, and reduce the weight swelling percentage of RHDPE/Bentonite composites. The RHDPE/Bentonite/PEgMAH composites have higher tensile strength, Young's modulus, and elongation at break but lower weight swell percentage compared to the RHDPE/Bentonite/MAH composites. The scanning electron microscopy (SEM) micrographs of tensile fractured surfaces for the RHDPE/Bentonite composites with coupling agents of PEgMAH and MAH indicated that the interfacial adhesion between Bentonite and RHDPE composites were better than the RHDPE/Bentonite composites without the coupling agents.

CHAPTER 1

INTRODUCTION

1.1 Background

Recycled polyethylene is the largest amount plastic manufactured in the world and extensively used polyolefin. Recycled polyethylene is produced in numerous polymeric forms, varying by their linearity and molecular weight, or branches, or presence of irregularities and many more. The density of the polymer is used as the principals classification features of polyethylene (Klyosov, 2007). Polyethylene exhibits a range of tensile strength and flexibilities, is generally tough, can be readily extruded or molded, and is relatively inexpensive. These characteristics guarantee that the various families of Polyethylene (PE) find major use as a commodity polymer.

The post-consumer plastics recycling stays one of the desired recycling options for ecological and energy reasons, as long as it stays economically profitable. The recycled post-consumer plastics are low in cost, due to the rising number of plastic waste produced daily in large cities around the world. Furthermore, the post-consumer plastics recycling offer the solution for landfill problem. The municipalities are becoming more concerned about the increasing of plastic waste generation every year (increasing at 25% per year) when the landfill area only capable to increase at 7.5% per year. It is estimated that by 2015, there will be out of disposal options for plastic waste.

High density polyethylene (HDPE) is a famous plastic type due to its versatility, having a wide range of applications such as consumer goods, containers and furniture. HDPE plastic has several properties that make it ideal as packaging and manufacturing product such as stronger than standard polyethylene, acts as an effective barrier against moisture and remain solid in room temperature. Post-consumer HDPE from bottles is a fascinating source of recycled material because, on one hand, it cannot be used again in alimentary applications and, on the other hand, its high melting viscosity makes direct transformation via injection moulding very difficult. Recycled HDPE can be used in an increasing amount of potential applications, as long as the mechanical, impact, and thermal properties of the material (recycled-virgin) is not far from each other (MasPOCH et al., 2005).

Polymer composites are the combinations of materials consisting reinforcing phase (fibers, particles or sheets) and the matrix phase (polymer, ceramic or metal). The main idea of filler into the composites is to improve certain properties and lower the cost of the composites (Manchado & Arroyo, 2002).

A commonly used polymer materials as the matrix for composite application is HDPE, that is widely exploited due its excellent properties such as easy to process, chemical resistance, electrical insulation properties and often compounded with natural mineral fillers to enhance its stiffness, toughness, dimensional stability and electrical insulation properties (Akinici et al., 2011; Osman & Atallah, 2007). Therefore, compounding organic and inorganic fillers into polymeric materials has been an interesting method to new engineering composite as the filler will give new characteristics to the polymer. The addition of fillers to polymer has been widely practiced in industry due to its economic value and favourably to modify certain properties based on the applications (Supri et al., 2010).

Proper decision of the filler length, filler type, filler orientation and filler volume fraction is very crucial, since it influences the density, cost, and the composite properties such as tensile properties (Cao et al., 2012), thermal properties (Singha & Thakur, 2009), mass swell resistance (Abu Bakar et al., 2010). The strength and the stiffness of the composites are influenced by disorientation of fillers, fillers of non-uniform strength, discontinuous fillers, interfacial conditions and the residual stresses. For example, composites strength and stiffness will be reduced when the fibers or fillers are not parallel to the loading direction.

Natural fillers are extensively separated into three classes depending on their source: animal based, plant based, and mineral based. Plant-based fillers are ligno-cellulosic in nature consisted of lignin, hemicellulose and cellulose. On the other hand, animal based fillers are of proteins such as wool and silk. Generally, a mineral based composite is asbestos fiber and is only a naturally occurring mineral fiber (silicate based mineral). Natural fiber-reinforced polymer composites have captivated many research pursuits due to their possibility to replace synthetic fiber composites such as carbon or glass fiber composites (Bledzki & Gassan, 1999). This happens because of natural fibers exceed synthetic fibers in term of less damage to processing equipment, lower weight, lower cost, good relative mechanical properties, better surface finish of moulded parts composite and renewable resources (Corbiere-Nicollier et al., 2001; Joshi et al., 2004). However, despite the potential of replacing the synthetic fibers, natural fibers do have some problems at high fiber content due to the fiber-fiber interaction and fiber dispersion problems.

Moreover, fibers or fillers are also used to improve the working properties of thermoplastics, such as the strength, rigidity, durability, and hardness (Khunova et al., 1999). In this study, bentonite has been introduced in this research as a filler into

recycled high density polyethylene (RHDPE). It is a soft clay comprising smectite minerals with minor amount of feldspar, biotite and quartz and is also categorized as layered silicate. It is a kind of mineral which is a layered aluminium silicate with exchangeable cations and reactive OH groups on the surface.

1.2 Problem Statement

Plastics have become an indispensable ingredient of human life. They are non-biodegradable polymers of mostly containing carbon, hydrogen and few other elements such as chlorine, nitrogen etc. Thus, there is always an issue about environmental and economic issue that had been stressed out about the polymer materials specifically plastic materials. The increasing of awareness generate more practical studies to control the problem and one of the idea is by using post-consumer plastic combined with organic or inorganic fillers to make a new composite.

Recycled high density polyethylene (RHDPE) is a great example as it is among the most common recycled plastic. RHDPE is often used for juice bottles, milk jugs, shampoo bottles and laundry detergent bottles. It can be recycled into lunch trays, chairs, pens, truck cargo liners, drainage pipe, plastic lumber, floor tile and even bridges. The plastic is normally fabricated with chemicals to enhance strength which is much in demand for construction materials.

Bentonite is natural inorganic fillers, the incorporation of inorganic fillers into thermoplastics is a common practice in the plastics industry. The main objectives of producing these polymer composites are to reduce an industrial costs and also to

modify certain characteristics such as strength and stiffness. One of the disadvantages of using inorganic filler is the poor interfacial adhesion of the matrix-filler interaction. One way of compatibilizing RHDPE with inorganic particles is by using coupling agent such as polyethylene grafted maleic anhydride (PEgMAH) and maleic anhydride (MAH) to improved the interfacial adhesion between the filler and the matrix.

1.3 Objectives

The objectives of this research are:

1. To study the effect of filler loading on the tensile properties, swelling behavior, and morphology of recycled high density polyethylene/bentonite composites.
2. To study the effect of polyethylene grafted maleic anhydride (PEgMAH) as coupling agent on the tensile properties, morphology and swelling behavior of recycled high density polyethylene/bentonite composites.
3. To investigate the effect of maleic anhydride (MAH) as coupling agent on the tensile properties, morphology and swelling behavior of recycled high density polyethylene/bentonite composites.

1.4 Scope of study

Tensile test has been carried out to measure the tensile properties which are tensile strength, Young's modulus, and elongation at break of RHDPE matrix filled 10 phr, 20 phr and 30 phr of Bentonite with and without 6 phr of coupling agents. Coupling agents used in this study are PEGMAH and MAH. All the samples of the composites were prepared by using Brabender Plasticorder at 160°C of temperature and 50 rpm of rotor speed. Besides that, swelling behavior test had been conducted by immersed the sample into the toluene for 46 hours and morphology analysis were performed by using scanning electron microscope (SEM) to study the interfacial adhesion and interaction between bentonite and RHDPE. In order to obtain the detailed functional groups information and examine the bond interactions between bentonite, coupling agents (PEGMAH or MAH) and RHDPE matrix, spectroscopy infrared (FTIR) test has been conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Composites

In engineering practice, composite is formed by two or more components that beneficially combined to make best use of the more encouraging properties of the components while mitigating the effects of some of the less desirable characteristics. The principle utilizes to all types of chemical and mechanical, properties-physical, and a matter of importance to the scientist and engineers (Gupta & Gupta, 2005). Thomas et al. (2012) however defined composites as mixture of two or more materials deriving from the combination of basic structural material into a second substance, which is the matrix.

The combination material can appear in various morphologies such as particles, whiskers, fibers, or lamellae but always shared the same task, which to impart its own advantageous mechanical characteristics to the matrix. The reinforcing component can be discontinuous (whiskers, flakes, discontinuous short fibers) or continuous (long fibers and sheets). The most commonly used reinforcing components are in particulates or fibers (Akovali, 2001). On the other hand, matrix used in composites may be broadly classified to polymer matrix composites (PMC), metal matrix composites (MMC),

ceramic matrix composites (CMC) and carbon and graphite matrix composites (Mohammad, 2007).

2.1.1 Polymer Matrix Composites (PMC)

Polymer matrix composites (PMCs) incorporate a variety of continuous or short fibers bound together by an organic polymer matrix. The reinforcement in PMC offers high strength and stiffness unlike a ceramic matrix composite (CMC), where the reinforcement is mainly used to improve the fracture toughness. The function of the matrix in the system is to bond the fibers together so that loads could be transferred between them. PMC have low thermal conductivities such that temperature gradient is presented for a long period of time when subjected to heat flux (Gu & Asaro, 2010). The matrix of PMC can be divided into thermoplastic and thermoset (Campbell, 2003; Mohammad, 2007). The thermoplastic such as polyethylene, polypropylene, and nylon do not cross-link to form a rigid network as thermoset does thus can be recycled. The most widely used reinforcement materials cover fiberglass, carbon fiber, Kevlar and natural fibers. PMC have found a wide range of applications including sports, transportation and military.

There have been several researches on carbon nanotube and layered silicates reinforced polymer nanocomposites, where the fillers have high aspect ratios. However, particulate-polymer nanocomposites containing filler with lower aspect ratios have been clearly overlooked. Fu et al. (2008) studied the effects of particle size, particle loading on the stiffness, and particle/matrix interface adhesion on the strength, stiffness and toughness of such particulate-polymer composites. It is revealed that composite

toughness and strength are largely affected by all the factors, especially particle/matrix adhesion. However, the stiffness of composites depends significantly on particle loading since the fillers have much bigger modulus than the matrix.

2.2 Recycled Plastic

Plastic is a polymeric material that can be cast or molded into different shapes. It is made from petroleum by incorporating compounds in different proportions. About one ton of recycled plastics reserve 16.3 barrels of oils and 5,774 kilowatt-hours of energy. Moreover, it also reserve 30 cubic yards of landfill space. In addition, recycling plastic bottle could save up to 50% - 60% of the energy needed to make new ones. Plastic is used in various household items such as food wrappers, food containers, electrical equipment and even mobile phones.

The recycling of post-consumer materials is a crucial task for the plastic industry. Although the quantity of plastics in the waste is relatively low (around 7%-8% by weight), the low specific gravity turns waste visible (around 18%-20% by volume). Unfortunately, the high environmental resistance of the plastic materials means they could survive in the environment for a long time. The recycling of plastics can be considered as a crucial economic tool as the material and energy can be re-used. This contributes to a small use of energy, minor use of natural resources, and a reduced disposal of waste in the environment while gives an economic saving (Mantia & Mantia, 2002). Table 2.1 shows the common thermoplastic and their applications.