COMPOSITE MATERIAL PRODUCTION OF NONMETALLIC PRINTED CIRCUIT BOARD WASTE WITH RECYCLED HIGH DENSITY POLYETHYLENE

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DEDICATION

This thesis is specially dedicated to my beloved mother, Rajakantham Govindarajoo and to my father, Muniyandi Narayanasamy, who often give encouragement, support and never fail to include me in their prayers for the successful completion of my PHD studies.

Not to forget, all my siblings, Sumitha, Sarogini, Thara, Ganesan and Devandra for always giving me supports, ideas and attention in any situation i had faced.

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Sincerely,

SHANTHA KUMARI MUNIYANDI

"Failure will never overtake me if my definition to succeed is strong enough"

(Dr APJ Abdul Kalam)

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ABSTRACT

This research is intended to develop a new potential reuse of recovered nonmetallic materials of printed circuit boards (PCBs) and plastic waste. Recycling of these wastes are being attempted in order to reduce its harmful effects on the environment. In fact, due to ever increasing environmental concerns and disposal costs, reuse and recycling of nonmetallic fractions from PCB wastes are considered as the best treatment practices. The study includes a process for encapsulation by combining dry nonmetallic PCB powder and recycled High Density Polyethylene (rHDPE) in an extruder to form a homogenous matrix and subsequently, compression molded into specimens in order to examine leachability, mechanical, morphological, thermal and weathering properties of the composites. The optimum nonmetallic PCB particle size with balanced mechanical properties was 0.07-0.09 mm. The leachability of raw nonmetallic PCB was tested by performing Toxicity Characteristics Leaching Procedure (TCLP) and Total Threshold Limit Concentration (TTLC). Subsequently, for rHDPE/PCB composites, the loadings of nonmetallic PCBs were varied from 10-50 wt%. Composites with 40 wt% nonmetallic PCB content showed the best balance of stiffness, strength and toughness with flexural modulus of 17.0 and 16.3 GPa and impact strength of 42.3 and 41.9 J/m for sample A and B, respectively. It was observed that, the addition of 6 phr maleated polyethylene (MAPE) has improved the flexural modulus and impact strength by 69% and 25%, respectively. Scanning electron microscopy (SEM) revealed that addition of compatibilizer improved the interfacial adhesion of the nonmetallic PCB material and polymer matrix. Encapsulation process has successfully entrapped and immobilized the residual metals from leaching out to the surrounding environment. After the nonmetallic PCB was filled in rHDPE composites with composition of 50 wt%, the concentration of Cu leached was far below the regulatory limit with 93.4% and 96% reduction for sample A and B, respectively, compared to raw nonmetallic PCB waste prior encapsulation process. Incorporation of nonmetallic PCB fillers in rHDPE reduced the thermal stability as the decomposition occured at lower temperature and melting temperature (Tm) also occured at lower temperature compared to the neat unfilled rHDPE. By adding 6 phr MAPE, Tm shifted to even lower temperature. The degree of degradation due to weathering increases with the time of exposure. Prolong exposure caused loss of mechanical properties of all the composites with and without compatibilizer. However, the rHDPE/PCB composites are more resistable to weathering attacks as compared to unfilled neat rHDPE. Water absorption of all the rHDPE/PCB composites reduced with addition of nonmetallic PCB material.

ABSTRAK

Kajian ini bertujuan untuk mengkaji potensi penggunaan semula bahan-bahan bukan logam yang terkandung di dalam papan litar bercetak (PCB) dan sisa plastik. Kitar semula sisa bertujuan untuk mengurangkan impak negatif terhadap alam sekitar. Disebabkan oleh peningkatan kesedaran alam sekitar dan kos pelupusan, pengunaan dan kitar semula bahagian bukan logam merupakan kaedah rawatan yang terbaik. Kajian ini merangkumi proses pengkapsulan dengan menggabungkan serbuk kering bahan bukan logam PCB dengan bahan buangan plastik polietilena berketumpatan tinggi (rHDPE) ke dalam penyemperit skru berkembar untuk membentuk matriks homogen dan seterusnya dibentuk kepada saiz spesimen ujikaji melalui proses pengacuan mampatan untuk mengkaji sifat kelarutresapan, mekanikal, morfologi, terma dan kesan cuaca terhadap bahan komposit. Saiz bukan logam PCB yang optimum dengan sifat-sifat mekanik yang seimbang adalah di antara 0.07-0.09 mm. Kelarutresapan bahan bukan logam PCB telah diuji dengan menggunakan ujian larut resap (TCLP) dan Total Threshold Limit Concentration (TTLC). Seterusnya, bagi komposit rHDPE/PCB, bahan bukan logam PCB telah diganti ke dalam komposit dalam komposisi 10 hingga 50%. Didapati bahawa komposit dengan 40% berat kandungan bahan bukan logam PCB menunjukkan kekuatan mekanikal yang baik dengan kekuatan modulus 17.0 dan 16.3 GPa dan kekuatan hentaman Izod 42.3 dan 41.9 J/m untuk sampel A dan B. Didapati bahawa, penambahan sebanyak 6 bahagian per ratus (phr) polietilena maleat (MAPE) berjaya meningkatkan ketahanan, kekuatan dan kekakuan bagi komposit berbanding komposit yang tidak mangandungi MAPE dengan peningkatan sebanyak 69% dan 25% bagi kekuatan modulus dan hentaman Izod. Mikroskop imbasan elektron (SEM) menunjukkan bahawa penambahan MAPE menambahbaik keserasian antara permukaan bahan PCB dan polimer matriks. Proses pengkapsulan berjaya memerangkap sisa logam daripada terlarut lesap ke alam sekitar. Setelah bahan bukan logam PCB digantikan ke dalam komposit rHDPE dengan komposisi 50 wt%, konsentrasi Cu yang terlarut resap berada jauh di bawah had peraturan yang ditetapkan dengan pengurangan sebanyak 93.4% dan 96% untuk sampel A dan B berbanding sampel sebelum proses pengkapsulan. Penambahan bahan ganti bukan logam PCB ke dalam rHDPE mengurangkan kestabilan terma kerana penguraian berlaku pada suhu yang lebih rendah dan suhu lebur (Tm) juga berlaku pada suhu yang lebih rendah berbanding dengan rHDPE. Manakala, dengan penambahan 6 phr MAPE, Tm beralih kepada suhu yang lebih rendah. Tahap hakisan akibat daripada kesan pendedahan kepada cuaca juga meningkat dengan peningkatan masa pendedahan. Pendedahan berlanjutan menyebabkan kemerosotan sifat mekanikal kesemua komposit dengan dan tanpa bahan penyerasi. Walau bagaimanapun, komposit rHDPE/PCB adalah lebih tahan terhadap serangan cuaca berbanding rHDPE tanpa bahan pengganti. Didapati kadar penyerapan air bagi komposit juga berkurangan dengan menggunakan bahan-bahan bukan logam PCB.

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
Ag	-	Silver
Al	-	Aluminium
Al_2O_3	-	Aluminium Oxide
APME	-	Association of Plastics Manufacturing in Europe
ATR	-	Attenuated total reflectance
As_2O_3	-	Arsenic Trioxide
ASTM	-	American Society for Testing and Materials
BaO	-	Barium Oxide
Be	-	Beryllium
Br	-	Bromine
BSI	-	British Standards Institution
C	-	Carbon
CaO	-	Calcium Oxide
Cd	-	Cadmium
CH_{32} CHOOH	-	Acid Acetic
CI	-	Carbonyl Index
Cl	-	Chlorine
CO_2	-	Carbon Dioxide
Cr	-	Chromium
Cr_2O_3	-	Chromium(III) Oxide
Cu	-	Copper
CuO	-	Copper Oxide
DOE	-	Department of Environmental
DSC	-	Differential Scanning Calorimetry

EFB	-	Empty Fruit Bunch
ELT	-	Equilibrium Leach Test
Fe	-	Iron
Fe_2O_3	-	Ferric Oxide
FR	-	Fiberglass Resin
FTIR	-	Fourier Transform Infrared Spectroscopy
GDP	-	Gross Domestic Product
GOS	-	Gravity Oil Separator
GR	-	Glass Fiber Resin
HDPE	-	High Density Polyethylene
H	-	Hydrogen
HBr	-	Hydrogen Bromide
Hg	-	Mercury
H_2O	-	Water
IDEM	-	Indiana Department of Environmental Management
IGES	-	Insitute for Global Environmental Strategies
IWM	-	Integrated Waste Management
K_2O	-	Potassium Oxide
LDPE	-	Low Density Polyethylene
LLDPE	-	Low Linear Density Polyethylene
MA	-	Maleic Anhydride
MAPE	-	Maleated PE
MAPP	-	Maleated Polypropylene
MEP	-	Multiple Extraction Procedure
MgO	-	Magnesium Oxide
MFs	-	Metallic Fractions
MOE	-	Modulus of Elasticity
MSW	-	Municipal Solid Waste
Na_2O	-	Sodium Oxide
NaOH	-	Sodium Hydroxide
NEMA	-	National Electrical Manufacturers Association
Ni	-	Nickel
NiO	-	Nickel Oxide
NMFs	-	Non-Metallic Fractions

O	-	Oxygen
ODEQ	-	Oregon Department of Environmental Quality
PAHs	-	Polycyclic Aromatic Hydrocarbons
Pb	-	Lead
PBDEs	-	Polybrominated Diphenyl Ethers
PbO	-	Lead (II) Oxide
PCB	-	Printed Circuit Board
PCBs	-	Polychlorinated Biphenlys
PCBA	-	Printed Circuit Assembly
PE	-	Polyethylene
PEEK	-	Poly Ether Ether Ketone
PEI	-	Poly(Ether Imide)
PET	-	Polyethylene Terephthalate
PETE	-	Polyethylene Terephthalate
PMC	-	Phenolic Moulding Compound
PMCGN	-	phenolic moulding compound glass nonmetals
P_2O_5	-	Phosphorus Pentoxide
PP	-	Polypropylene
PVC	-	Polyvinyl Chloride
PWB	-	Printed Wiring Board
rHDPE	-	recycled High Density Polyethylene
Sb	-	Antimony
SGPL	-	Structural-Grade Plastic Lumber
SEM	-	Scanning Electron Microscope
Si	-	Silica
SiO_2	-	Silicon Dioxide
Sn	-	Stannum
SnO_2	-	Stannum Dioxide
SO_3	-	Sulfur Trioxide
SPI	-	Society of the Plastics Industry
SrO	-	Strontium Oxide
TCLP	-	Toxicity Characteristics Leaching Procedure
TGA	-	Thermogravimetry Analysis
TiO_2	-	Titanium Dioxide

Tn	-	Tungsten
TTLC	-	Total Threshold Limit Concentration
UO_3	-	Uranium Trioxide
USEPA	-	United States of Environmental Protection Agency
UV	-	Ultraviolet
vHDPE	-	virgin High Density Polyethylene
WMC	-	Waste Management Center
WPC	-	Wood Plastic Compound
WRC	-	Water Research Commission
XRF	-	X-ray Fluorescence Spectrometry
Zn	-	Zinc
ZnO	-	Zinc Oxide
ZrO_2	-	Zirconium dioxide

LIST OF SYMBOLS

$+\Delta a$	-	color shift towards red
$-\Delta a$	-	color shift towards green
$+\Delta b$	-	color shift towards yellow
$-\Delta b$	-	color shift towards blue
C-C	-	Carbon Carbon bond
C-H	-	Carbon Hydrogen bond
C=O	-	Carbonyl stretching
ΔEab	-	difference of colour change
ΔHm	-	melting enthalpies
ΔH_o	-	heat of fusion
ΔL	-	changes in lightness
O-H	-	Hydroxyl group
Tc	-	Crystallization
Tm	-	Melting temperature
Ws	-	saturated weight of samples
Wd	-	weight of samples
Xc	-	Percentage of crystallinity

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CHAPTER 1

INTRODUCTION

1.1 Background

Solid waste disposal has become a serious issue for country and municipal governments throughout the nation. As available landfill space decreases and the cost of siting and building new landfills increases, local authorities are struggling to develop alternative means of meeting the waste disposal challenge. Currently, Malaysia is facing urban solid waste management issues as landfills are rapidly filling up, increasing amount of waste are generated, shortage of disposal land, resulting of serious environmental and human health impacts (Saeed et al., 2009). These circumstances happened due to the growing amount and the variety types of waste generated in relation with the rapid population and industrial growth, and also due to the rising in the standard of living of the people. Landfilling is the most widely used method for solid waste disposal, because it is the most economical and environmentally acceptable method throughout the world (Samsudin and Mashitah, 2013).

Recycling is one way to turn the waste products into different, yet usable products, keeping more waste out of the landfills. Plastics are one such product that can be recycled. With a big push for green products and to be environmentally friendly, plastic recycling is becoming big business. Recycling not only reduces the amount of waste material that enters landfills, but it also reduces carbon dioxide emissions and reduces oil usage.

Plastic manufacturing not only produces waste materials but also produces gases, such as carbon monoxide, nitrogen oxide, chlorine dioxide and sulfur hexafluoride, all of which ends up in our atmosphere and our water. By recycling also, we are using less energy than the energy needed in producing new plastic and the goods are just durable and useful. Post industrial plastics that are often sold for recycling are high density polyethylene (HDPE), polypropylene (PP), and acrylonitrile butadiene styrene (ABS). For instance, for every tonne of plastic, that is recycled, 2 metric tons of petroleum is saved, 30 yard of landfill space and over 650 gallons of oil will be saved. Over 7 metric tons of petroleum will be saved per every one tonne of HDPE that is recycled (PACIA, 2008).

Having this in mind, an Integrated Waste Management (IWM) strategy has to be implemented for conservation of natural resources as well as for protecting the environment in order to approach sustainable development. In order to achieve IWM strategy, Cradle to Cradle concept has caught the attention in many developing countries. Cradle to Cradle focuses on designing industrial systems so that materials flow in closed loop cycles, meaning that waste is minimized and waste products can be recycled and reused. All waste materials are productively re-incorporated into new production and use phase (Braungart and McDonough, 2002).

Although over the last decade, there has been a continuing effort by the plastic industry to recycle their products. One of the main issues with recycled plastics is how to achieve properties approaching virgin plastics. Frequently, waste streams contain dissimilar plastics which are incompatible and complicate the generation of useful materials.

For instance, according to PACIA (2008), the total amount of plastic recycled in Australia in 2007 were merely 261,109 tonnes, this value has not significantly increased despite the increases in consumption because poor mechanical properties and short life span limit the usage of products made from recycled plastic (Bertin and Robin, 2002). However, materials can be incorporated into the polymer matrix of recycled plastics to restore their mechanical properties and extend the life spans of the composites; these materials are often called fillers. Fillers are solid additives that are incorporated into the polymer matrix in order to improve its mechanical properties. The two most widely used types of fillers in these applications are extender and reinforcing fillers. The extender are generally used to increase polymer bulk and reduce the cost of final products, while reinforcing fillers, on the other hand, have the ability to improve mechanical and physical properties of polymer.

Reinforcing fillers, being much stiffer and stronger than the polymer, usually increases its modulus and strength. They are usually rigid materials, immiscible with the matrix in both molden and solid states, and as such, form distinct dispersed morphologies.

As for this study, nonmetallic fractions from printed circuit boards recycling waste have been utilized as filler material in recycled HDPE composites. The nonmetallic printed circuit board (PCB) waste was an industrial solid-waste byproduct from PCB recovery process obtained from two different local PCB recycling industries in Johor, Malaysia. This was in the form of powder and without electronic elements. In Malaysia, E-waste is categorized as scheduled wastes under the code of SW 110 of First schedule of the Environmental Quality (Scheduled Waste) Regulation 2005 (Appendix A). Under this regulation, the SW 110 waste are defined as wastes from the electrical and electronic assemblies containing components such as accumulators, mercury, glass from cathode-ray tube and other activated glass or polychlorinated biphenyl-capacitors, or contaminated with cadmium, lead, nickel, chromium, copper, manganese or silver.

E-waste contributed 52,978.13 metric tons which was 3.82% of the total quantity of scheduled waste generated by category in the year 2013. It is also being predicted by Department of Environmental (2009) in their inventory report that the amount of E-waste will increase by an average of 14% annually and by year of 2020, a total 1.17 billion units or 21.38 million tons of E-waste will be generated. By considering PCBs waste form about 3% by weight of the total amount of electronic waste, it can be concluded that approximately, 1589 metric tons of PCB waste was generated in the year 2013.

PCBs are essential electronic components. A PCB is used to connect electronic components without the need for conventional cables. The large amount of material used in circuit boards and the presence of high levels of pollutants make their recycling and disposal very problematic (Janz and Bilitewski, 2008). PCBs are in fact the generalized term representing the platform upon which microelectronic components such as semiconductor chips and capasitors are mounted. They are used to support the electronic components as well as to connect them using conductive pathways, tracks or signal traces etched from copper sheets laminated onto them. The components of waste PCBs can be divided into metallic fractions (MFs) and non-metallic fractions (NMFs) or non-conducting substrate or laminate, conductive circuits printed on or inside the substrate, and mounted components.

Muo et al (2004) had studied the characteristics of nonmetallic PCBs and concluded that the nonmetallic PCB powder mainly consists of resin and glass fibers, and their combined characteristics are very useful (Mou et al., 2004). To date, very limited research has been conducted to study the properties of nonmetallic PCB waste for the utilization as a filler material in thermoplastic products. A research done by Zheng et al. (2009) to study the nonmetallic PCB fraction as reinforcing fillers in polypropylene (PP) has proven to be an effective way to enhance strength and rigidity: particles 0.178 - 0.104mm, modified by a silane coupling agents, could be successfully added in PP composites as a substitute of traditional fillers.

The nonmetallic fraction of PCB can also be used with some effectiveness as a partial replacement of inorganic aggregates in concrete applications to decrease the dead weight of structures (Niu and Li, 2007). The glass fibers and resins powder contained in the nonmetallic fraction can also be used to strengthen the asphalt.

Despite the fact that nonmetallic PCB waste could be utilized as filler material in some practical thermoplastic products, it should be borne in mind that, the nonmetallic fractions from PCB wastes are still considered hazardous in certain countries and including Malaysia, because it contains a small amount of residual heavy metals such as Cu, Sn, Zn, Ni, Pb and etc (Cui and Forssberg, 2003). These nonmetallic materials are normally disposed of by combustion and disposal in landfill as the main method for treating, and it may cause secondary pollution and resource wasting too (Guo et al., 2010). However, according to EPA's guidelines, before disposal at approved disposal sites, hazardous waste must first be treated to immobilize the hazardous constituents. It is known that many attempts have been made in the past to render hazardous wastes harmless by immobilizing the waste against dispersion by ecological forces. One of the techniques to immobilize the waste against dispersion to environment is through solidification.

In this study, solidification using thermoplastics encapsulation technique has been employed. Generally, any type of thermoplastics can be used to create a coating or jacket over the nonmetallic PCB waste. However, in this study, recycled grade of High Density Polyethylene (rHDPE) waste is used. The rHDPE used was supplied by Metahub Industries Sdn Bhd, Johor and from post-industrial HDPE pipe waste. The HDPE pipe was recovered and shredded into small flakes with 8-10 mm sizes. It is well known that, polyethylene has been used as a binder for encapsulation of a wide range of waste types. In contrast to hydraulic cement and thermosetting polymer processes, the present HDPE encapsulation method does not require chemical reactions for solidification. The waste-binder interactions are also minimized. Previous studies have revealed that encapsulation would provide a high degree of control over release to the environment of unwanted quantity of hazardous wastes (Batstone et al., 1989). The polymer acts as barrier to prevent contaminants leaching into environment. A study done by Kalb et al. (1998) on encapsulation and stabilization of radioactive, hazardous and mixed wastes, had stated that in contrast to conventional binding agents, such as hydraulic cement the use of polyethylene as a binder has several distinct advantages. Solidification is assured on cooling because no curing chemicals reactions are required. A wide range of waste types are compatible with polyethylene because constituents present in the waste will neither inhibit nor accelerate solidification. It is also said that, polyethylene encapsulation results in higher loading efficiencies and better waste form performance when compared with hydraulic cements.

Wang et al. (2010) had studied the functional groups of nonmetallic PCB fractions. He stated that the polarity of the waste was due to the presence of hydroxide groups, carbonyl groups, acetal groups and silanol groups on the particle surface. It is well known that blending of non-polar polymer such as recycled HDPE with polar components like nonmetallic PCB creates materials with poor mechanical properties, unstable morphology and lack of surface adherence, making it necessary their compatibilization.

A research done by Guo et al. (2010) revealed that increasing amount of glass fibers in nonmetallic PCBs also can decreased the flow ability of composites and reduced the dipersion of ingredients which may lead to poor interfacial adhesion. In order to improve the interfacial adhesion between rHDPE matrix and nonmetallic PCB, maleated PE (MAPE) compatibilizer has been introduced to the blend system, which can significantly improve the performances of the composites. Compatibilizers can be used to improve properties to the point where recycled polymers more closely resemble the virgin material.

It is therefore, the main concern of this study is to recycle the nonmetallic PCB waste in a safe and environmentally sound manner by applying encapsulation technique in preparing composites made from nonmetallic PCB and recycled HDPE (rHDPE). Previously, several studies were conducted to study methods to reuse the nonmetallic waste as a filling material in some practical products, such as bricks, composite boards and modified polypropylene filled with nonmetallic PCBs (Mou et al., 2007; Zheng et al., 2009). However, based on literature search, there is no research has been conducted to study the HDPE encapsulation technique using nonmetallic PCB waste modified with MAPE compatibilizer.

1.2 Problem Statement

In recent years through out the world including Malaysia, there has been increasing concern about the growing volume of end of life electronics and the fact that much of it is consigned to landfill without any attempt being made to recycle the nonmetallic materials it contains. A large amount of nonmetallic materials in PCBs are disposed of by combustion and disposal in landfill as the main method for treating nonmetals in PCBs, but it may cause secondary pollution and resource wasting. The problem is generally focused on the non metallic materials since it is being noted by Department of Environment as hazardous and being listed under SW 501/ SW 110 of the Environmental Quality (Scheduled Waste) Regulations 2005. Since it contains chemical hazards (Cui and Forssberg, 2003), hence it needs to be disposed at licensed scheduled waste disposal site which is Kualiti Alam Sdn. Bhd. The problems arise as the cost of disposal of these hazardous residues is so expensive. Kualiti Alam Sdn. Bhd charge RM150 / tonne of PCB together with other charges including cost of packaging, segregation, transportation and others. Moreover, these residues are capable to give risk to the human health and surrounding environment if it is not being properly managed (Cui and Forssberg, 2003). Menad et.al. (1998) cited that once PCBs are being filled, it will poses significant contamination problems at which the landfills will leach the toxins into the groundwater.

Because of the expensive cost of disposal, some industries tend to dipose the nonmetallic PCB illegally without permission from DOE. There are also industries that just keep nonmetallic PCBs waste in premises without any initiative to recycle them. This situation is directly causing the increasing of the storage problem to industries. Based on Cui and Forssberg (2003), if not managed properly, the disposal of nonmetallic PCBs will give the negative effect and cause other problems such as resource wasting, risks to human health and environmental pollution.

On the other hand, economic growth and changing consumption and production patterns are resulting into rapid increase in generation of waste plastics worlwide. The world’s annual consumption of plastic materials has increased from around 5 million tonnes in the 1950s to nearly 100 million tonnes; thus, 20 times more plastic is produced today than 50 years ago (Ebenezer et al., 2013). This implies that, more resources are being used to meet the increased demand of plastic, at the same time more plastic waste is being generated. In Asia and the Pacific, as well as many other developing regions, plastic consumption has increased much more than the world average due to rapid urbanization and economic development (Kreith, 1994). Waste plastics are becoming a major stream in solid waste due to the increase in generation. After food waste and paper waste, plastic waste is the third major contribution at municipal and industrial waste in cities (UNEP, 2009). Even the cities with low economic growth have started producing more plastic waste due to increased use of plastic packaging, plastic shopping bags, PET bottles and other goods/appliances using plastic as the major component. The increase has caused major challenge for local authorities, responsible for solid waste management and sanitation. Due to lack of integrated solid waste management, most of the plastic waste is neither collected properly nor disposed of in appropriate manner to avoid its negative impacts on environment and public health and waste plastics are causing littering and choking of sewerage system. Due to extremely long periods required for natural decomposition, waste plastic is often the most visible component in waste dumps and open landfills. Plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand. Plastic waste recycling also has a great potential for resource conservation and grenn houses gases emissions reduction, such as producing fuel from plastic waste.

There is an urgency to resolve the environmental pollution associated with the waste materials and the need to adopt a more sustainable approach to the problems associated with end of waste life. Thus, this research is intended to develop a new potential reuse of recovered nonmetallic materials of PCBs and plastic waste. From environmental point of view, recycling of these wastes are being attempted in order to reduce its harmful effects on the environment. In fact, due to ever increasing environmental concerns and disposal costs, reuse and recycling the nonmetallic fractions from PCB wastes are considered as the best treatment practices and can generate economy too by commercializing the products made from the rHDPE and PCB composites.

1.3 Objectives of the study

One of the most important aspects of materials development in thermoplastics engineering is to achieve a good combination of mechanical properties and processability at low or moderate cost. As far as mechanical properties are concerned, the main target is to strike a balance of stiffness, strength and toughness without violating the environment. No study on recycled HDPE and nonmetallic PCB composites modified with MAPE compatibilizer has been reported yet. Thus, the aim of the research is to develop an environmentally friendly polymer composite with enhanced properties. The main aim of this research is to study the effectiveness of encapsulation technique using recycled HDPE as binder material to encapsulate nonmetallic PCB waste. The main objective can further be divided as the followings:

i. To determine chemical composition and toxicity of nonmetallic PCB materials through X-ray Fluorescence Spectrometry (XRF), Fourier Transform Infrared Spectroscopy (FTIR), Total Threshold Limit Concentration (TTLC) and Toxicity Characteristics Leaching Procedure (TCLP).
ii. To determine the optimum size of nonmetallic PCB particles to be used as filler material in recycled high density polyethylene (rHDPE) with best mechanical properties.
iii. To determine the effect of various nonmetallic PCB contents on the mechanical, thermal, water absorption and morphological properties of rHDPE/PCB blends.
iv. To investigate the effects of compatibilizer (MAPE) on the mechanical, thermal, water absorption and morphological properties of rHDPE/PCB composites with and without compatibilizer.
v. To evaluate weathering properties of rHDPE/PCB composites in terms of mechanical properties, water absorption, color measurement and carbonyl index.

1.4 Scope of Research

The focused of this study was mainly on the toxic nonmetallic fractions obtained from PCB recovery and recycling process, that can be treated by encapsulation process with recycled HDPE for composite material production. Chemical composition and toxicity analysis of the nonmetallic PCB waste and its composites were determined. Physical, mechanical and thermal properties of rHDPE/PCB composites were also determined in this research project. Lastly, weathering properties of the composites were studied to investigate the UV resistance of composites made of nonmetallic PCB materials. The tests were conducted in two different environments namely, outdoor natural weathering and accelerated xenon arc-lamp weathering.

1.5 Significance of Research

The main concern of this study is to recycle the nonmetallic PCB waste in a safe and environmentally sound manner by applying encapsulation technique in preparing composites made from nonmetallic PCB and recycled HDPE (rHDPE). The research expects to develop a toughened composite with balanced mechanical properties without violating the environment. The success of this research will contribute to many potential specific application in the future. As for this research, the composite made from nonmetallic PCB waste and recycled HDPE can best be used in plastic lumber applications. While, from economic point of view, the use of waste materials can significantly reduce waste disposal cost and resource wasting by making full use of the waste material from being dump into landfill. Moreover, since nonmetallic PCBs are considered as waste and has no value, hence this research is seen important to save the production cost of composites by using it as filler material.

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