POTENTIAL REUSE OF RECOVERED NONMETALLIC PRINTED CIRCUIT BOARD WASTE AS SAND REPLACEMENT IN CONSTRUCTION MATERIALS

SITI SUHAILA BINTI MOHAMAD

A thesis submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Environmental)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MARCH 2014

DEDICATION…

A special dedication to my beloved mother, ***Faridah Zakaria*** and also to my father, ***Mohamad Hassan*** who often give encouragement, support and pray for my success during my Degree Master's study life.

Not to forget, my siblings, ***Siti Suria, Roslan, Amirudin and Nur Aqilah*** for always giving me support and attention in any situation i had faced.

Special thanks to my beloved future husband ***Mohd Rafizi AB Rahman @ Muhamad*** for the spirit and prayer to finishing the thesis.

Not least, my beloved lecturers, Assoc. Prof. Dr. Johan bin Sohaili and Prof. Ir. Dr. Mohd Warid bin Husin, and close friends Shantha Kumari who always being there during the time I need and their willingness to share knowledge, ideas, and opinion during study.

The sacrifice and loyalty that have been shown will not be forgotten until whenever. May all the said prayers will be getting blessings from Allah s.w.t. InsyaAllah...

Sincerely,
SITI SUHAILA BINTI MOHAMAD

ACKNOWLEDGEMENTS

Bismillahirahmanirrahim…

Alhamdulillah, I am grateful to Allah s.w.t for the blessings and grace, I managed to complete the thesis entitled *"Potential Reuse of Recovered Nonmetallic Printed Circuit Board Waste as Sand Replacement in Construction Materials"* properly and successfully.

The utmost and heartiest gratitude to my supervisor, Assoc. Prof. Dr. Johan b Sohaili, who always willing to share his invaluable and priceless knowledge and also giving advice, and enthusiastic support to my research. I am also grateful to him for spending his precious time to view and evaluate the thesis. A sincere thanks is accorded to my co-supervisor, Prof. Ir. Dr. Mohd Warid bin Husin for his guidance, and suggestions.

A million thanks to all the technicians in the Environmental, Structure and Materials Laboratory, Faculty of Civil Engineering for their guidance and helps shown during the laboratory works.

A special thanks to my thesis teammates, Shantha Kumari for willingness to share precious knowledge, information, and support for accomplish this research.

Finally, I wish to express my acknowledgement to University Teknologi Malaysia for providing sufficient and adequate materials, equipments and conditions in completing this research.

ABSTRACT

The study analyzed the treatment of nonmetallic printed circuit board (PCBs) by adding them into mortar cement and cement brick as sand replacement. This study aims to propose methods for reuse of nonmetallic PCBs waste. The leachability of raw nonmetallic PCBs was tested by performing crushed block leachability test (CBL). This test was conducted to determine the suitability of nonmetallic PCBs as a nontoxic material in terms of environmental. Mortar cement and cement brick specimens with nonmetallic PCBs ranging from 0% to 40% and 0% to 50% by weight of sand were prepared. The effectiveness of the treatment was evaluated by performing compressive strength as well as flexural strength, water absorption and whole block leaching (WBL) tests on the treated nonmetallic printed circuit board. The durability of mortar added 10% nonmetallic PCBs waste was also examined through acidic conditioning tests. The results indicated that the leaching of selected heavy metal ions from the cement matrix and raw nonmetallic PCBs are within the standard limits set by Department of Environment Malaysia (DOE). The analysis from TCLP test showed that almost all of concentration of metal ions detected in the CBL test (without treatment) was higher than the concentration of ion in WBL test (treatment). The compressive strength and flexural strength of the mortar added with nonmetallic PCBs was generally lower in the range of 10.1 N/mm2 to 31.9 N/mm2 for compressive strength and 3.5 N/mm2 to 7.7 N/mm2 for flexural strength than the control samples which is 33.5 N/mm2 and 8.0 N/mm2. The amount of nonmetallic PCBs to replace sand for optimum strength of mortar was about 28% with 95% confident level of ANOVA, and for brick the optimum proportion of nonmetallic PCBs is not more than 30%. From durability tests, weight and compressive strength both of mortars was decrease after soaking in acid solution. The total weight and compressive strength change is about 1.11% and 11.11% for mortar added with nonmetallic PCBs while 0.94% and 13.29% for control mortar. As a conclusion, the study shows that nonmetallic PCBs can be reused in profitable and environmentally friendly ways and has broad application prospects.

ABSTRAK

Kajian ini adalah untuk menganalisis bahan sisa bukan logam papan litar pencetak (PCB) yang telah diolah dengan menambahnya ke dalam mortar simen dan batu bata simen sebagai pengganti pasir. Kajian ini bertujuan bagi mencadangkan kaedah untuk menggunakan semula bahan sisa bukan logam PCB. Ujian pengurasan blok hancur (CBL) telah dijalankan keatas bahan bukan logam PCB. Ujian ini dijalankan untuk mengkaji kesesuaian penggunaan bahan sisa bukan logam PCB sebagai bahan bukan toksik dari segi alam sekitar. Mortar simen dan batu bata simen yang telah ditambah dengan bahan sisa bukan logam PCB dengan jumlah penggantian antara 0% hingga 40% dan 0% hingga 50% mengikut berat pasir telah disediakan. Keberkesanan olahan sisa dinilai dengan melakukan ujian kekuatan mampatan, ujian kekuatan lenturan, ujian serapan air dan ujian pengurasan keseluruhan blok (WBL) ke atas mortar dan batu bata. Ketahanan mortar ditambah dengan 10% sisa bukan logam juga telah diperiksa melalui ujian rendaman asid. Keputusan menunjukkan bahawa larut lesap ion logam berat daripada mortar dan bahan sisa bukan logam PCB adalah dalam had yang ditetapkan oleh Jabatan Alam Sekitar Malaysia (JAS). Keputusan analisis juga menunjukkan bahawa hampir semua kepekatan ion logam yang dikesan dalam ujian CBL (tanpa olahan) adalah lebih tinggi daripada kepekatan ion logam dalam ujian WBL (telah diolah). Kekuatan mampatan dan kekuatan lenturan mortar yang ditambah bahan sisa bukan logam PCB adalah lebih rendah iaitu 10.1 N/mm^2 hingga 31.9 N/mm^2 bagi kekuatan mampatan dan 3.5 N/mm^2 hingga 7.7 N/mm^2 bagi kekuatan lenturan berbanding dengan kekuatan mortar kawalan iaitu 33.5 N/mm^2 dan 8.0 N/mm^2. Jumlah bahan sisa bukan logam PCB yang optimum untuk menggantikan pasir bagi mencapai kekuatan optimum mortar adalah kira-kira 28% dengan tahap kepercayaan sebanyak 95% berdasarkan ujian ANOVA. Manakala untuk batu bata, jumlah optimum bahan sisa bukan logam PCB yang boleh digunakan untuk menggantikan pasir adalah tidak lebih daripada 30%. Daripada ujian ketahanan pada asid, didapati bahawa berat dan kekuatan mampatan kedua-dua jenis mortar adalah menurun selepas direndam dalam larutan asid. Jumlah perubahan berat dan kekuatan mampatan adalah sebanyak 1.11% dan 11.11% bagi mortar ditambah dengan bahan bukan logam PCB manakala 0.94% dan 13.29% untuk mortar kawalan. Sebagai kesimpulan, kajian menunjukkan bahawa bahan sisa bukan logam PCB boleh digunakan semula dengan cara yang menguntungkan dan mesra alam dan mempunyai prospek aplikasi yang luas.

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LIST OF ABBREVIATIONS

Al_2O_3 - Aluminum Oxide
ASTM - American Standard on Testing Materials
As - Arsenic
Ag - Argentum
Ba - Barium
BaO - Barium Oxide
Br - Bromine
BS - British Standard
CaO - Calcium Oxide
CBL - Crushed Block Leaching
Cd - Cadmium
CH_{32} CHOOH Acid Acetic
Cr - Chromium
Cr_2O_3 - Chromium Oxide
CRT - Cathode Ray Tubes
Cu - Cuprum
CuO - Cuprum Oxide
DOE - Department of Environmental
ELT - Equilibrium Leach Test
Fe_2O_3 - Ferric Oxide
HCl - Hydrochloric Acid
HDPE - High Density Polyethylene
Hg - Mercury
ICT - Information and Communication Technology
IDEM - Indiana Department of Environmental Management

MEP - Multiple Extraction Procedure
MF - Metallic Fractions
MgO - Magnesium Oxide
MS - Malaysian Standard
Na_2O - Sodium Oxide
NaOH - Sodium Hydroxide
NEMA - National Electrical Manufacturers Association
Ni - Nickel
NMF - Non-Metallic Fractions
NMP - Nonmetallic Plate
OPC - Ordinary Portland Cement
Pb - Plumbum
PC - Personal Computers
PCB - Printed Circuit Board
PMCGN - Phenolic Moulding Compound Glass Nonmetals
PVC - Polyvinyl Chloride
PWB - Printed Wire Boards
Se - Selenium
SEM - Scanning Electron Microscope
SiO_2 - Silicon Dioxide
Sn - Stannum
SnO_2 - Stannum Dioxide
TCLP - Toxicity Characteristic Leaching Procedure
USEPA - United States of Environmental Protection Agency
WBL - Whole Block Leaching
WMC - Waste Management Center
XRF - X-ray Fluorescence Spectrometry
Zn - Zink

LIST OF SYMBOLS

A Area of mortar

Fc - Compressive Strength

P - Load when sample failed

Sf Flexural Strength

S1 - Compressive strength at initial curing

S2 - Compressive strength after immersion

Wd - oven-dry weight

Wi - Immersed weight

Ws - Saturated weight

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The change in government strategy from agriculture to industry, and the rapid economic development, had caused the government facing a few problems. One of these problems is the increasing quantity of electrical and electronic waste (E-waste) (Ibrahim, 1992). Malaysia produces a large amount of waste from E-waste. According to United Nations Environment Programme (2007), electrical and electronic equipments or components that are destined for recycling or recovery or disposal are considered as E-waste. The examples of E-waste are such as used television, motherboard, printed circuit board (PCB), waste of integrated circuit, and others. These wastes exist in a complex situation in terms of materials, design, components and original equipment manufacturing process.

The growth of electrical and electronic industries has increased 13% from year 2000 to 2008 (Johan et al., 2012). Department of Environment (2009) in their inventory report stated that the amount of E-waste will be increasing by an average of 14% annually and by the year of 2020, a total of 1.17 billion units or 21.38 million tons of E-waste will be generated. It is estimated a cumulative total of 403.59 million units of waste from electrical and electronic equipment have been generated in year 2008 and total of 31.3 million units has been discarded in the same year (Johan et al., 2012). In developed country such as China, Japan and Malaysia, the production of electrical and electronic equipment is being growing rapidly.

The disposal, storage, management, and environmental pollution becoming a big problem with the increased of E-waste (Zulkifli et al., 2010). Government and private sectors should take the initiative to reuse E-waste without giving adverse effect to the environment. However, E-waste is considered not safe to be reuse because it is categorized as scheduled wastes by Department of Environment (2010), because it is contains some contaminants that can be potentially hazardous, if improperly handled. For example, printed circuit boards contain heavy metals such as nickel, chromium, tin, lead, copper, brominated flame retardants and cathode ray tubes (CRTs) containing lead oxide.

Therefore the researchers have done various studies to find the possibility to reuse this type of waste. In the reuse of waste, one of the famous industry is the construction industry, in particular the concrete manufacturing industry. Several studies have been done by other developed countries to use and prove that the reuse of waste can improve the properties of the concrete. However, in Malaysia, there is still no any research has been done involving the reuse of E-waste especially printed circuit board in the manufacture of concrete.

1.2 Problem Statement

In recent years there has been increasing concern about the growing volume of E-waste in the country. These increasing volumes of E-waste will contribute problems leading to environmental pollution, threat to human health and constraints in handling waste (Cui and Forssberg, 2003). According to Menad et al. (1998), these problems occur mainly because E-waste is toxic and contains heavy metals which make the disposal process harder to tackle. E-waste that is disposed of in landfill produce highly contaminated leachate which caused environmental pollution especially to surface water and groundwater. For example, acids and sludge from melting computer chips, if disposed into the ground will cause acidification of soil and subsequently contamination of groundwater. They also stated that once E-waste is being filled, it will pose significant contamination problems at which the landfills will leach the toxins into the groundwater. Based on Theng (2008), E-waste also gives hazardous effects to human health. For examples, lead and cadmium in PCBs will give effects on brain development of children. Besides that, brominated flame retardants will interfere reproductive process and also cause immune system damage.

Printed Circuit Boards (PCBs) is one of the important components in electrical and electronic equipment. Electrical and electronic equipment cannot function without PCBs (Huang et al., 2008; Lee et al., 2004). At the end of life E-waste, PCBs will be recycled to get the valuable material such as metal (Hall et al., 2007; Li et al., 2007). The materials produced from recycled PCBs waste basically consist of metals and nonmetallic materials (Guo et al., 2008; Hall et al., 2007; Perrin et al., 2008). Metallic materials can be sold at a high price while the nonmetallic materials of PCBs are disposed in landfill even though without approval from the Department of Environment. Recycling of PCBs is an important subject not only from the recovery of the valuable materials, but also from reuse of nonmetallic materials (Guo et al., 2008; Hall et al., 2007).

The current problems are focused on nonmetallic material since it is being noted by Department of Environment Malaysia as scheduled waste and contain hazardous materials such as Cu, Cr and Br. Besides that, based on Department of Environment (2010), nonmetallic PCBs are required to be transported by licensed contractors or recycling plants to disposed of at Kualiti Alam Sdn. Bhd in Bukit Nanas, Negeri Sembilan. The problem of handling this scheduled waste includes cost of disposal of the waste is expensive compared to municipal solid waste. As stated by Kualiti Alam Sdn Bhd, one of the contractors licenced by the Department of Environmental for scheduled waste disposal and recycling, the cost of handling and disposal of nonmetallic PCBs is RM 150 per metric tonne. Because of this factor, nonmetallic PCBs waste is disposed of by industries illegally without permission from Department of Environmental. 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 others problems such as resources wasting, risks to human health and environmental pollution.

The amount of nonmetallic materials is enormous, but economic value of nonmetallic materials is very low. Besides that, recyclers have to incur additional expenses when handling and disposing of nonmetallic materials. PCBs recyclers have to pay fee when nonmetallic materials are sent to the landfill sites or waste incineration plants, which would reduce the recycler’s net revenue. So these study focus on alternative method of how nonmetallic PCBs could be reuse without giving the negative effect to human health and environmental.

1.3 Research Objective

The objectives of this research are:

i. To investigate the suitability of nonmetallic PCBs as a nontoxic material in terms of environmental quality.

ii. To determine the effectiveness of waste treatment processes on nonmetallic PCBs in term of mechanical properties of mortar and cement brick.

iii. To determine the effect of nonmetallic PCBs contents as a sand replacement in mortar in terms of leachability.

1.4 Scope of Research

In this study, all of experiments were carried out in the laboratory. The experiments had been done in several laboratories such as environmental engineering, science, mechanical and structure and material. Nonmetallic PCBs were taken from two electronic waste recycling factories. The samples are divided into two different types of PCBs namely nonmetallic glass fiber reinforced epoxy resin and nonmetallic cellulose paper reinforced phenolic resin. Mortar cubes and cement bricks were prepared using nonmetallic PCBs as sand replacement.

To achieve all the objectives of this study, several experiments have been done, such as:

i. Scanning Electron Microscope (SEM) on raw material of nonmetallic PCBs and mortar cubes. This test was conducted to determine the pattern of microstructure surface, size and particles arrangement of raw nonmetallic PCBs powder and mortar.

ii. X-ray Fluorescence Spectrometry (XRF) on raw material of nonmetallic PCBs and cement to identify and determine the chemical composition.

iii. Toxicity Characteristic Leaching Procedure (TCLP) Test on raw material of nonmetallic PCBs and mortar cubes were conducted to evaluate and determine the concentration of heavy metals leached from the raw nonmetallic PCBs waste and mortar cubes.

iv. Compressive strength, Water adsorption, Flexural strength, and Durability test on mortar and cement brick were conducted to determine mechanical properties of mortar and cement brick.

1.5 Significance of the Research

This research is significant to identify that the nonmetallic PCBs is safe to the environmental and can be reused by means of production of nonhazardous product that is safe in terms of the environmental, human health and publicly acceptable. The success of this research also very significant in reducing waste disposal cost and resource wasting by making full use of nonmetallic PCBs waste from being dump into landfill. Since nonmetallic PCBs are considered as waste, and it has no value, hence this research is seen important to save the production cost of mortar and cement brick by using nonmetallic PCBs as sand replacement. The success of this project will widen the applications of nonmetallic PCBs especially as sand replacement in making mortar and cement brick.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Rapid development in Malaysia is a positive step towards progress as planned by the government. The high rate of economic development in Malaysia causes problems such as the vast generation of waste especially scheduled waste. According to the Department of Environment, (2007) scheduled wastes are substances that are highly flammable, corrosive, and toxic and easily react or cause explosion when mixed with other substances. In Malaysia, under the Environmental Quality (Scheduled Waste) Regulation 2005 (amendment 1989) defined scheduled wastes as any waste falling within the categories of waste listed in the first scheduled, which included 77 scheduled waste code categories (Department of Environment, 2005). Based on Zulkifli et al. (2010) the definition of scheduled wastes varies from one country to another. At the international level it is called toxic and hazardous waste.

The increment of scheduled waste generation rates, disposal cost, environmental and health concern and limited landfill space give significant impacts on waste management efforts. In Malaysia, based on notification received by the Department of Environment, a total of 1,880,929 metric tonnes of scheduled wastes were generated in 2010 as compared to 1,705,308 metric tonnes in 2009. It shows the slight increasing of the waste amount within one year. Based on the quantity of scheduled waste generated in Malaysia from 2006 to 2010 (Figure 2.1), E-waste registered the second highest percentage with 8.68 percent (Department of Environment, 2010).

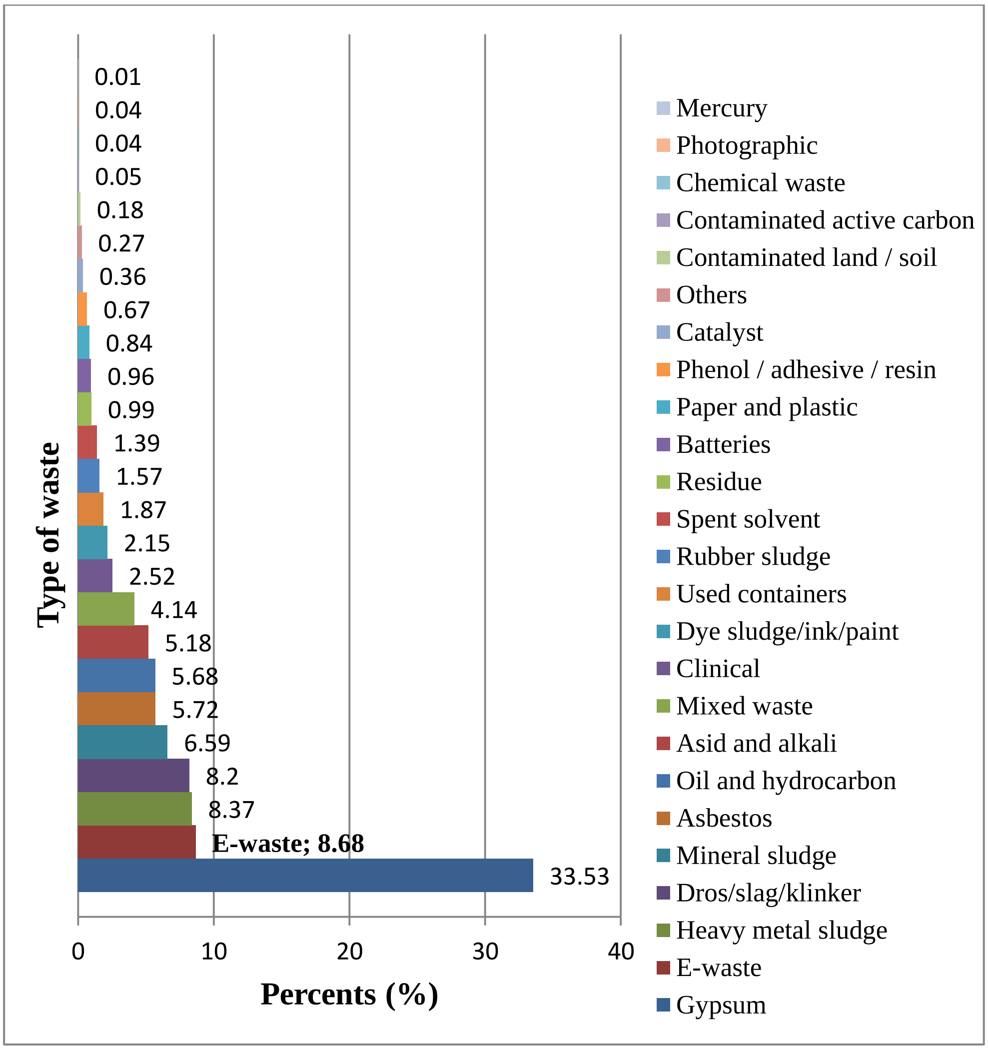

Figure 2.1: Percentage of scheduled waste generated by category (Department of Environment, 2010)

2.2 Management of Hazardous Waste in Malaysia

The control of toxic and hazardous waste disposal has been implemented through the provisions contained in clause 51 of the Environmental Quality Act 1974. In this provision, the law was designed to prohibit or control the discharge of materials such as toxic and hazardous waste to the environment. Based on Norazlina (2010), the purpose of this act is to prescribe the method of waste management to avoid the environmental pollution. The Department of Environment (DOE) is responsible for the enforcement of these rules. However, DOE is the only law enforcement agency rather than an organization that is providing and managing landfills. Therefore, the task of detailed planning, construction and operation of disposal sites should actually be implemented by other parties such as local authorities and the private sector in collaboration with the DOE. The consolidation of wastes management system is important for industrial countries to ensure cleanliness and environmental safety is assured.

Theng (2008) conducted a study on waste management in Malaysia. As show in Figure 2.2, the findings indicated that the junkshops, recycling centres and scrap collectors play an important role in bridging the gap between the waste generators and recyclers, by collecting E-wastes generated from various sources and sending these to E-waste recyclers. Currently there are 20 full recovery facilities and 132 partial recovery facilities licensed by DOE in Malaysia. All of the recovery facilities are owned by private companies (Department of Environment, 2012). These plants play a role to collect E-wastes from various middlemen, collectors and recycling centres. Materials such as plastics and metals will be recycled at these plants. Besides that, these recycling plants also extract precious metals such as gold, platinum, silver and lead from the circuit boards of the E-wastes. After recycling process, the reusable parts such as precious metals are returned back to the industry or market for reuse, while toxic components such as nonmetallic printed circuit board (PCBs) are send to Kualiti Alam Sdn Bhd for disposal.

In Malaysia, Kualiti Alam Sdn Bhd was built to address management problems of scheduled waste. Kualiti Alam Sdn Bhd is a center established by the Waste Management Center (WMC) in Bukit Nanas Negeri Sembilan. Nonmetallic PCBs from E-wastes which are categorized as scheduled wastes in Malaysia will be transported by licensed contractors to disposed off in the centralized scheduled waste treatment and disposal facility in Kualiti Alam Sdn Bhd (Theng, 2008). WMC also provides treatment for scheduled wastes listed in the Environmental Quality (Scheduled Waste) Regulations 1989. The laboratories available in WMC are like burning plant, physical or chemical treatment plant, solidification or stabilization and landfill (Rabitah, 2000).

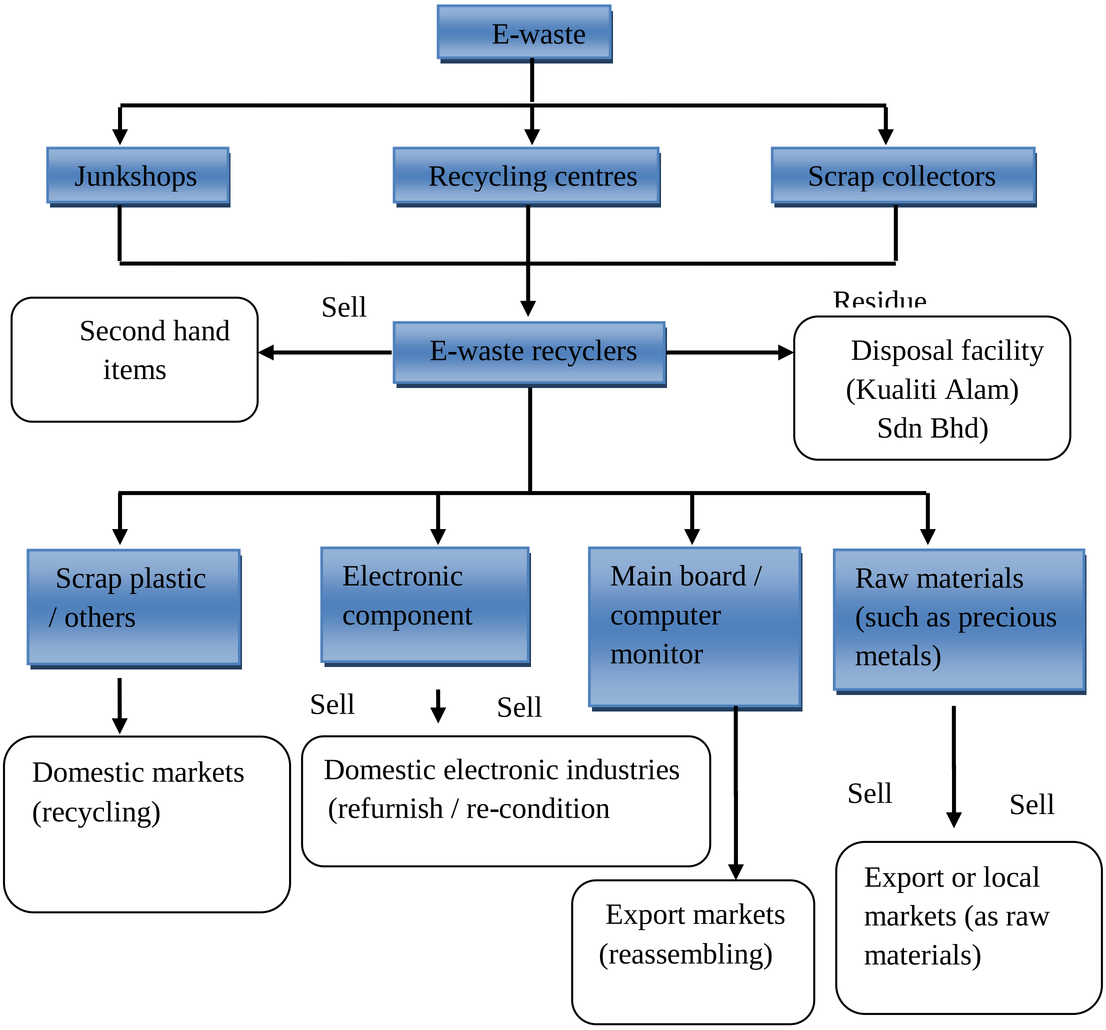

Figure 2.2: Material flow of E-wastes in Malaysia (Theng, 2008)

2.3 Electrical and Electronic Waste

Based on He (2006) the discarded and end-of-life electrical and electronic products are called as electrical and electronic waste (E-waste). E-waste comprises of wastes generated from used electronic devices and household appliances which are not fit for their original intended use and are destined for recovery, recycling or disposal. Electrical and electronic products include computers, Information and Communication Technology (ICT) equipment, home appliances, audio and video products and all of their peripherals (Rakesh, 2008; Li et al., 2007). According to Martin (2002), E-waste contain over 1000 different substances, many of which are toxic and potentially hazardous to environment and human health, if these are not handled in an environmentally sound manner.

Referring to the Environmental Quality Act 1974, E-waste is defined as waste of used electrical and electronic assemblies. E-waste is categorized as scheduled wastes under the code of SW 110 of First schedule of the Environmental Quality (Scheduled Waste) Regulation 2005. 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.

According to Rakesh, (2008) and Vincenzo et al., (2013)**,** E-waste has been categorized into three main categories which are large household appliances, IT and telecom, and consumer equipment. Refrigerator and washing machine represent large household appliances, personal computer, monitor and laptop represent IT and telecom, while televisions represent consumer equipment. Based on Brigden et al. (2005) each of E-waste items has been classified with respect to twenty-six common components, which could be found in them. These components form the building blocks of each item and therefore they are readily identifiable and removable. These components are metal, motor, ferrous, non-ferrous metals, cooling, plastic, insulation, glass, rubber, wiring, batteries, and printed circuit board.

2.4 Printed Circuit Boards

Printed circuit board is categorized as one of the component of E-waste. Printed circuit board (PCBs) is a piece of plastic material on which electronic components can be mounted for mechanical support. PCBs also defined as an electrically interconnects all the components by means supports of a pattern of metal tracks on its outer surfaces and sometimes on inner layers (Rakesh, 2008). PCBs are used to connect electronic components without the need for conventional cables. Circuit boards are estimated to make up about 3% of the electronic scrap (Scarlett, 1984). PCBs normally consist of a substrate onto which components have been soldered. Martin (1997) stated that, the parts of waste PCBs are consists of 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.

2.4.1 Non-Metallic Fractions

Based on Scarlett (1984), nonmetallic fractions are called nonmetals, nonmetallic materials, glass fiber resin powder (GR powder), glass nonmetals, and epoxy resin compounds. The two main types of base laminate or nonmetallic fractions used are phenolic paper and epoxy glass (Dalrymple et al., 2007). As stated by the American NEMA (National Electrical Manufacturers Association), FR-2 phenolic paper is known as FR-2 and epoxy glass is FR-4.

FR-2 is the grade specified for synthetic resin bonded paper where a composite material was widely used to build low-end consumer electronic equipment. The FR-2 is used mainly for non through-plated boards for the domestic and simpler industrial markets. The main advantages of FR-2 over FR-4 in these areas are its lower cost and the ease with which it can be punched. However, the electrical properties of FR-2 are inferior to those of FR-4 and its higher moisture absorption makes it unsuitable for plated-through hole work (Gary, 2009). Besides that, the mechanical strength of FR-2 is less than that of FR-4. FR-2 are distinguishable from FR-4 by their colour, which is usually a deep purple, brown or black (Martin, 1997).

While FR-4 is the grade for circuit boards made of woven fiberglass cloth with an epoxy resin binder that is flame resistant (self-extinguishing). According to Joseph (2006), FR-4 is most commonly used as an electrical insulator due to their zero water absorption and considerable mechanical strength. Besides that, FR-4 offer better dimensional stability than FR-2, but neither material is truly stable. FR-4 with a chopped strand glass reinforcement can be used where properties such as moisture absorption are critical, and better electrical properties are required than can be achieved with a FR-2 (Joseph, 2006; Gary, 2009). However, they are not widely used and most of their possible uses are met by epoxy or woven glass laminates which are readily available and has better electrical properties and strength. FR-4 are available, but are used only in special cases where a FR-2 would have inadequate properties but the paper base considered desirable. Based on Martin (1997) the usual colours for FR-4 are pale, translucent green or brown. Rigid laminates for specialized applications are available on base materials such as irradiated polyethylene, melamine, triazine, polysulphone, silicone and polyimide resins, some of which may be reinforced.

2.5 Material Composition of Printed Circuit Board

Guo et al. (2008) stated that, Printed Circuit Board (PCBs) are forms about 3% by weight of the total amount of E-waste. Generally, waste PCBs contains approximately 30% metals and 70% nonmetals (Guo et al., 2008; Goosy and Kellner, 2002). According to study conducted by He et.al (2006) and Veit et al. (2006), they found out that PCBs scrap generally contains approximately 40% metals, 30% organic and 30% ceramics. The nonmetallic PCBs consist of two type materials, which is thermoset resins and reinforcing materials (Hall et al., 2007; Perrin et al., 2008). An organic material of PCBs usually consists of plastic. Plastics often contain flame retardants and paper. Plastic is made up from various types such as C-H-O and halogenated polymers. Sometimes Nylon and polyurethane are also used in the PCBs, but only in small amounts. PCBs structure contains large quantities of base metals. Among the metals that exist in the PCBs are such as Cu, Fe, Al and Sn, rare and precious metals such as Tn, Ga, Pt, Ag, and Pd. In addition, hazardous metals such as Cr, Pb, Be, Hg and Cd are also present in PCBs. These metals are very harmful to the environment and also to human health if not managed in the right way. While ceramic element that exists in the PCBs are Si, Al, alkaline earth oxides, barium titanate ($BaTiO_3$) and mica.

According to Hino et al. (2009), the PCBs contained approximately 30% of metallic materials such as Cu and Fe, approximately 25% of organic resin materials containing elements such as C and H, and approximately 30% of glass materials used as resin reinforcing fibers. From studies that have been conducted by (Gao et al., 2002; Goosey and Kellner, 2003), they revealed that in term of metals the Cu, had the biggest content at 14.6 mass%. The others metals found in PCBs components are Sn at 5.62 mass%, Fe at 4.79 mass%, Pb at 2.96 mass%, Ni at 1.65 mass%, and Cr at 0.35 mass%. While in terms of the precious metal composition, Au, Ag, and Pd were found at small concentrations of 450, 200, and 220 ppm, respectively. Br is classified as nonmetal compositions and it was found at a content of 5.07 mass%. Sb was found at a content of 0.45 mass%, and is also being used in PCBs nonmetal because it has a flame-retardant efficacy through combination with a halide flame-retardant. For inorganic glass fiber materials, SiO_2 was found at a content of 24.7 mass%, followed by Al_2O_3 at 6.20 mass%, CaO at 3.36 mass%, and MgO at 0.081 mass%, and BaO at 0.0022 mass%.

2.6 Morphology and Structure of Nonmetallic PCBs

Scanning Electron Microscope (SEM) is a standard technique for the characterization of microstructure of a substance. SEM analysis is particularly suitable to study the details of the structure because the microscope can do magnification up to thousands of times the size of the original sample. In this study, SEM is used to determine the microstructure and physical condition such as the surface morphology, shape, and particle size (Oner, 2000).

Generally, the structure of nonmetallic PCBs has typically been established using Scanning Electron Microscopy observation. Wang et al. (2010) had successfully studied the fracture surface of the nonmetallic PCBs. From their observation, they found that the nonmetallic PCBs powders are mostly in irregularly shaped granules. In this test, a small amount of glass fibers and fiber bundles are also observed. As illustrated in Figure 2.3, the fibers (point a) are mainly consist of silicon, while the irregularly shaped particles (points b and c) are mainly consist of carbon. From observation, it can be concluded that the fibers are glass fibers, while the irregularly shaped particles are thermoset resin or paper composite.

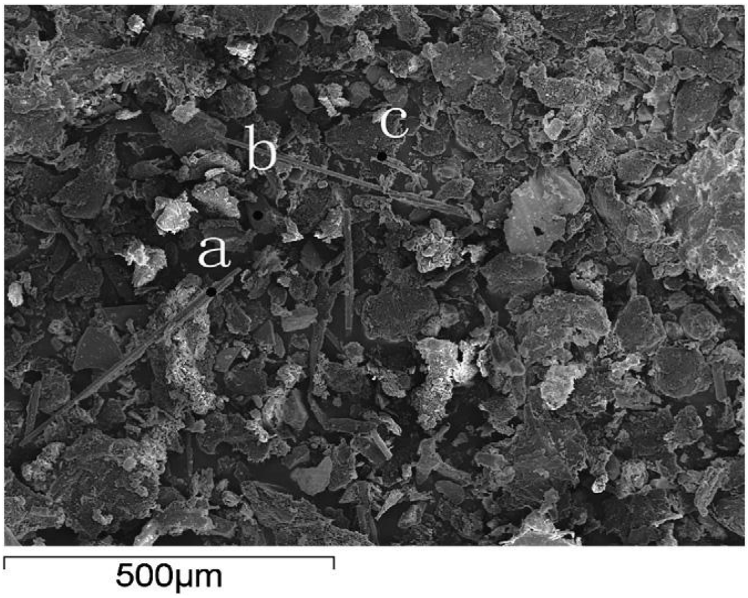

Figure 2.3: SEM image of nonmetallic PCBs (Wang et al., 2010)

Zheng et al. (2009) also studied details about microstructure of nonmetallic PCBs. From microscopic observation (Figure 2.4) they concluded that the majority of coarse nonmetallic PCBs consist of fiber particulate bundles, with the predominantly of fibers being encapsulated in thermosetting resin. While, the single glass fibers and thermosetting resin powders were not seen. It also shows thermosetting resin gets stuck inside the glass fibers, forming a large fiber-particulate bundle of loosely entangled fibers. For the medium nonmetals, it contains single glass fibers, thermosetting resin powders and fiber-particulate bundles. While, fine nonmetals PCBs mainly consist of single glass fibers and resin powders.

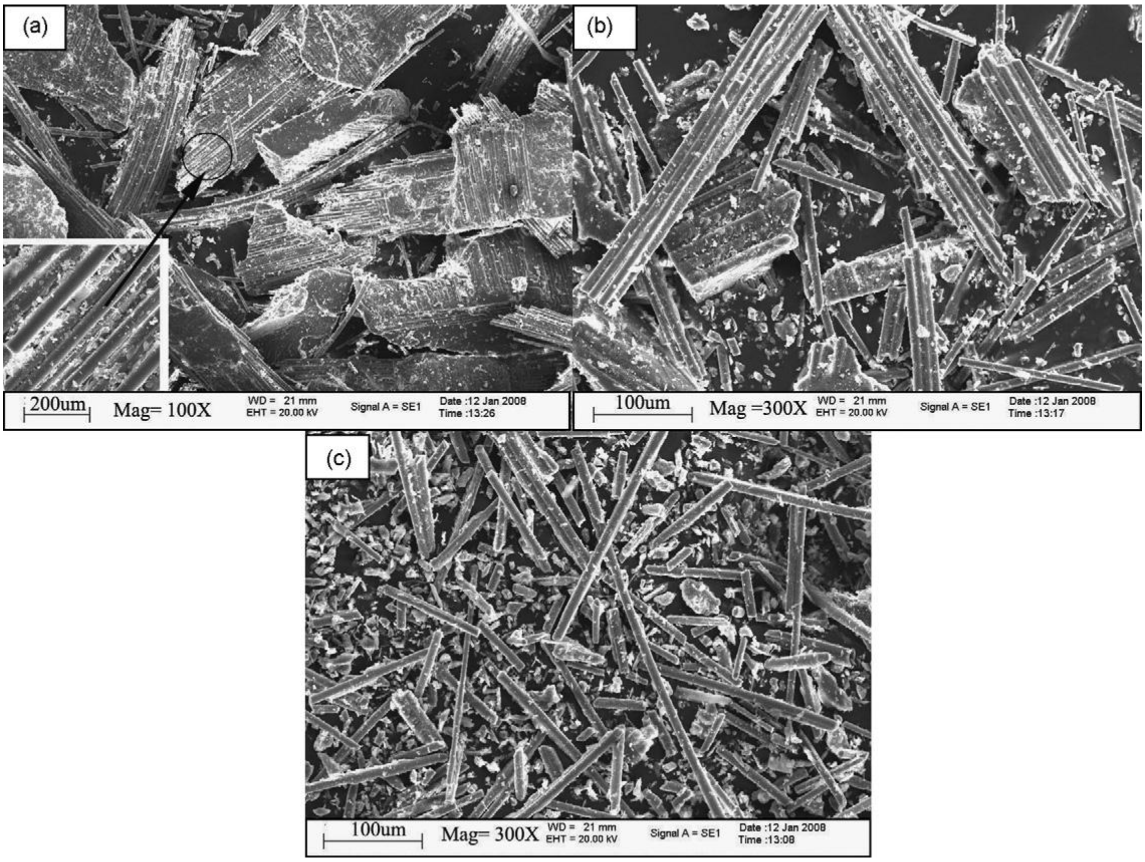

Figure 2.4: SEM image of the nonmetallic PCBs with several particle size (a) Coarse, (b) Medium and (c) Fine (Zheng et al., 2009)

In another study by Guo et al. (2009) revealed that nonmetallic PCB with particle size from 0.3 to 0.09mm contained predominantly sheet nonmetallic PCB. It was also found that the majority of fibers were being encapsulated in resin. It was the same with the previous study conducted by Zheng et al. (2009). The nonmetallic PCB from 0.09 to 0.07mm consisted of fiber bundles and resin sheet. From this study they found that after liberated from epoxy resin, the surfaces of fiber bundles were clean. For the nonmetallic PCB shorter than 0.07mm, it consisted of single fiber resin powder. From all of these studies they concluded that nonmetallic PCBs consist of different shapes and compositions. The differences of shape and compositions among of nonmetallic PCBs are due to the intrinsic structure of PCBs and the crushing technic during separation process (Wang et al., 2010).

2.7 Separation Process of Printed Circuit Board

Currently, PCBs wastes are processed by physical methods (Musson et al., 2000). Physical recycling involves a preliminary step where size reduction of the waste is performed followed by separation of waste into metallic and non-metallic fractions and collection of separated wastes for further management (Li et al., 2007). A size reduction and separation stage is necessary for an easier further easier management of PCBs waste.

Many methods have been developed to recycle waste PCBs, such as physical methods, chemical methods and biological methods (Wen et al., 2005). In practice, physical processes such as wet shredding, water table separation, dry shredding and air table separation were used for small and middle scale enterprises. It is because, all of these processes have great potential and give advantages in terms of lower investment, operation cost and environmental friendly. Hydrometallurgical and pyrometallurgical methods are preferred for middle and large scale enterprises because they can refine high value products such as noble metals and rare metals (Wen et al., 2005). In Malaysia there are two techniques that are used to crush and separate the PCBs waste into metallic and nonmetallic fraction. These techniques are wet chemical process and dry process (Awang, 2012).

2.7.1 Wet Chemical Process

In wet chemical process, the wet impact crusher is used to crush PCBs waste. Crushing process is done in water medium. In this technique the wet crushing equipment such as hammer mill and water medium were used. During the crushing and separation process, hammer is connected to the rotating arms to enable the hammer to swing freely. When PCBs waste are inserted into the drum, hammer will hit the PCBs waste with high speed. The effect of this impact resulted PCBs waste to be broken and formed into small pieces. Then the water will be diverted to bring particles selected through a sieve plate. Here the PCBs waste will be separated into metal and non-metal. Metal will sink while the nonmetal will be channeled through the water medium into special bins. According to Zheng et al. (2009) the main functions of water in the wet process is to absorb dust, prevent an increase in temperature on the machine during the crushing process, avoiding gas production by pyrolysis during crushing and speeding up discharge of crushed material and controlling over-crushing in the process.

Compared to dry crushing techniques, wet crushing impact has the advantages of higher crushing efficiency, less over crushing and no secondary pollution (Xiu and Zhang, 2009; Tan et al., 2011). In this technique the slurry of ground PCBs is pumped to a separator. The water can be recycled and only a small amount of fresh water need be supplied. This will prevent water and air pollution discharge into the environment. In terms of effectiveness, impact crushing wet techniques only result in loss of precious metals by 10% during the separation process compared to 35% for dry techniques (Duan et al., 2009).

2.7.2 Dry Process

In dry process, metals and nonmetals from PCBs waste are separated by using Air Table Separation Systems (Hall and Williams, 2007). Air Table Separation Systems have been researched with a view to effecting separation of metallic and nonmetallic components from shredded scrap PCBs. In this process, PCBs waste will be fed and crushed in the surface of the rotating roll. Air is used and is continuously injected through the porous bed of the table. PCBs wastes that have been crushed will go through the table separation. Table separation is comprised of a rectangular shape deck, covered with riffles (raised bars running perpendicular to the feed side of the table), and mounted in a flat position. Then PCBs waste moved along the table and then back to the starting position between 200 and 300 times per minute. According to Darren (2009), this shaking movement helps transport the concentrates or heavy material to the concentrate end of the table. Normally, the feed side is lower, and the concentrate end is higher on an air table, which creates an upward slope where the heavy material will ascend, while the light density material will not, and, consequently, will flow over the riffles. The tailing (low density) side is near level to lower than the feed side. At this point, separation process occured. This technique is suitable use for fine particles in the size range 0.1-0.5mm. Based on Veit et al. (2006), the advantages of dry crushing technique are less noise, great output and high innovation.

2.8 Reuse of Recovered Nonmetallic PCBs

The recovered nonmetallic PCBs material has been used long time ago in several ways. It is used based on the physical characteristics of the nonmetallic PCBs powder. Based on the research conducted by Wang et al. (2010), they have studied the feasibility of using recycled nonmetallic PCBs as additives for polyvinyl chloride (PVC) substrate. From this study, they found that recycled nonmetallic PCBs powder, when added below a threshold, it can encourage in increasing the tensile strength and bending strength of PVC. When 20 wt% nonmetallic PCBs powders with diameter of 0.08 mm were added, the composite tensile strength and bending strength were achieved to 22.6 MPa and 39.8 MPa, respectively. This result shows about 107% and 123% improvement of tensile strength and bending strength over pure PVC. Only the addition of nonmetallic PCBs particles with small size slightly increases the thermal stability of PVC, while the larger sized nonmetallic PCBs particles tend to worsen the thermal stability of the composite material.

Another study conducted by Mou et al. (2007) they have produced composite boards from nonmetallic PCBs waste. From this study, they revealed that, the most important and useful characteristic of the recovered nonmetallic PCBs material is their compatibility with the epoxy resin adhesive used to bind the filler and the fibers, so the nonmetallic PCBs has better compatibility with the resin adhesive which suggests better moulding properties and mechanical strength (Mou et al., 2007). In this research, they used different proportions of nonmetallic PCBs. The results obtained from this research were compared with the two typical materials used for making composite boards which are talc and silica powder. They revealed that the flexural strength of composite board with nonmetallic PCBs waste was improved by more than 50% compared with talc and silica powder. Therefore, it could be concluded that the characteristic of nonmetallic PCBs waste is good to produce products that mainly bear flexural strength.

If we make comparison of nonmetallic PCBs with talc and silica powder, nonmetallic PCBs have its own advantages of coarser granularity, containing glass fiber. Coarser granularity and glass fiber may enhance the intensity. It also has better compatibility with the binding agent used in making composite board. From analysis of the mechanical properties conducted by Mou et al. (2007) indicates that the nonmetallic PCBs have excellent flexural strength, so it can best be used to make products which resulted in greater bending stresses. In construction industry the nonmetallic PCBs could be used in many ways. Nonmetallic PCBs may potentially used to make the other construction materials including walls, frames and sewer grates. The main advantages of products made of nonmetallic PCBs are lower in cost, because nonmetallic PCBs are waste materials and considered low material cost. Besides that products made of nonmetallic PCBs have better mechanical strength, especially the flexural strength. The reuse of nonmetallic PCBs materials is a better alternative rather than be sent to landfills.

In another study by Guo et al. (2009) found that, the glass fiber and resins powder contained in the nonmetallic PCBs can also be used to strengthen the asphalt by composition effect. Besides that, the reuse of nonmetallic PCBs to make modified asphalt can also reduce the cost of asphalt whose usage amount is very large in construction industry. Same as Mou et al. (2007), the reuse of nonmetallic PCBs are more economic since the cost of the nonmetallic PCBs waste can be considered as zero because they are unwanted waste otherwise would be expensive if sent to disposal or treatment.

2.8.1 Nonmetallic PCBs Material as Filler

In accordance with the rapid development of the construction industry, most of the structures around the world have been strengthened with fiber reinforced materials (Arya et al., 2002). The used of fiber as filler or additive have two functions, one is to reduce the cost of the products, and the other one is to enhance the performance of the products. In general, the performance of reinforcing strongly depends on the few factors that effecting properties of composite. The first factors effecting the properties of composite is modulus of elasticity of matrix. The modulus of elasticity of matrix must be much lower than that of fiber for efficient stress transfer. The examples of high modulus fibers are such as steel, glass and carbon. All of this fiber will impart strength and stiffness to the composite. Besides that, interfacial bond between the matrix and the fiber also determine the effectiveness of stress transfer, from the matrix to the fiber.

Guo et al. (2008) studied the application of glass nonmetals of PCBs to produce phenolic moulding compound. From the observation conducted on flexural fractured surface of phenolic moulding compound glass nonmetals, they reported that, there was filler or matrix filled in the gap of glass fibers, which showed very strong interfacial bonding between glass fibers and the phenolic resin. Based on this research, they concluded that, good adhesion between glass fibers and matrix can strengthen the flexural properties to some extent.

Another factor that affects the properties of composite is the volume of fibers used in composite. This is because the strength of the composite largely depends on the quantity of fibers used in it. The tensile strength and toughness of the composite will be increase with the increase in the volume of fibers. But the use of higher percentage of fiber will cause segregation and harshness of composite. This statement is in line with research conducted by Guo et al. (2008), they found that the performances of phenolic moulding compound glass nonmetals (PMCGN) varied with different contents of nonmetallic PCBs. Considering the general properties of PMCGN, they concluded that the adding content of nonmetallic PCBs can reach 40 wt% without negatively affecting the properties of PMCGN.

In another study conducted by Guo et al. (2009) on the plate produced by nonmetallic PCBs materials showed that when nonmetallic materials content was 20wt% in plate, the flexural fractured surface of plate was flat and compact as show in Figure 2.5 (a), which showed strong interfacial bonding between resin and fillers. When the content of nonmetallic materials was increased to 30 wt%, the deep voids can be seen in the flexural fracture surface of plate. As shown in Figure 2.5 (b), this condition can cause lack of sufficient particle bonding. The higher the content of nonmetallic materials in the plate, the worse the surface quality was. When the content of nonmetallic material was 40%, burn marks were clearly seen on the surface of plate, especially in the center.

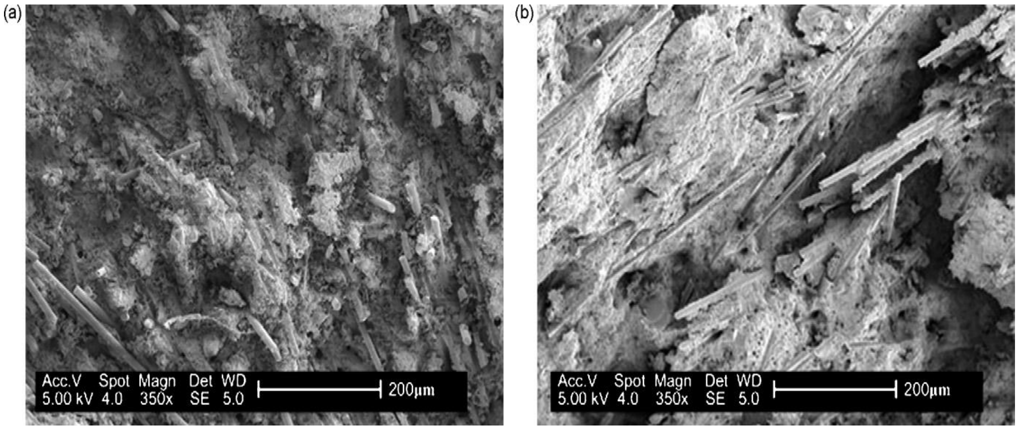

Figure 2.5: SEM photographs of specimens filled with nonmetallic materials after flexural fracture: (a) 20 wt% and (b) 30 wt%. (Guo et al. 2009)

The size of the fibers also can influence the properties and behavior of the composite. In the application of fibers as reinforcement in concrete, fibers act as aggregate. The inter-particle friction between fibers and between fibers and aggregates controls the orientation and distribution of the fibers, and consequently the properties of the composite. Besides that, fibers diameter is an important factor here. The smaller diameter fibers providing higher fiber surface areas. Most recently, Zheng et al. (2009) investigated the reuse of nonmetals PCBs as filler in the polypropylene composites. From this study, they showed that the size of nonmetals also can affect the tensile properties of the composites. The flexural properties of the polypropylene composites increase with increasing of filler contents. This is occurring in the case where the filler is fine or medium in size. The optimum content for the best flexural properties of the polypropylene composite for these nonmetals size can increase until 30 wt% with the maximum increment of flexural strength and modulus of the composites were 87.8% and 133.0% respectively. Maximum flexural strength and modulus reach a maximum value of 56.5% and 83.1% respectively when coarse nonmetals filler is reach up to 20%. The flexural strength and modulus gradually decrease when the content of filler added into composites increase to 30 wt%. It can be concluded that the size and amount of the nonmetals are important factors in affecting the tensile strengths of the polypropylene composites. Decreasing particle size results in dramatic increases in the specific surface area of particles, which leads to an increase in interfacial contact area between the filler and matrix. The increase in interfacial contact area would be beneficial to transfer the stress from the matrix to particles, therefore resulting in higher tensile strength of the composite.

Lately, Guo et al. (2009) also investigated the use of nonmetallic materials of waste PCBs to produced plate. They found similar result with Zheng et al. (2008) where only the nonmetallic plate (NMP) with nonmetallic materials less than 0.07 mm has excellent mechanical properties, with flexural strength of 68.8 MPa and impact strength of 6.4kJ/m^2. From this condition, the researcher revealed mechanical properties are intimately related to the inner structure of the NMP. During the mixing process, the liquid polyester resin was able to coat the nonmetallic fraction (NMFs) and flow into the pores between the fillers. The fine nonmetallic materials with bigger surface areas were found to enhance the adhesion between the filler and resin. They revealed that the presence of voids can affect the performances of the NMP severely. When the size of nonmetallic material is large, the resin only coated on the surface of large nonmetallic materials and voids existed. However, when nonmetallic material size decreased, the resin can encapsulate nonmetallic materials entirely and voids were not easily generated. Therefore, mechanical properties of the NMP with fine nonmetallic materials are better than those of the NMP with large nonmetallic materials.

2.9 Scheduled Wastes Treatment

The definition of treatment is any activity after waste has been handed over to a facility for disassembly, shredding, recovery, or preparation for disposal carried out for the recovery and the disposal of waste (Rakesh, 2008: Kellner, 2009). Indiana Department of Environmental Management (IDEM, 2000) defines waste treatment as any method, technique, or process, designed to change the physical, chemical, or biological characteristic or composition of any hazardous waste. It also is including neutralization process. The purpose of treating hazardous waste is to convert it into nonhazardous substances or to stabilize and encapsulate the waste so that it will not present a hazard when released into the environment. Besides that, the treatment process is to neutralize such waste, to recover energy or material resources from the waste, to render such waste non-hazardous, or less hazardous, safer to transport, store, dispose and reduced in volume.

Several studies have been conducted to treat hazardous waste, particularly scheduled wastes. Based on Finnveden et al (1995), the treatment processes can be divided into six different classes as the followings:

i. Physical treatment
ii. Chemical treatment
iii. Biological treatment
iv. Recovery and recycling
v. Thermal treatment
vi. Solidification and stabilization

2.9.1 Physical Treatment

Physical method is the process to immobilize the hazardous component of waste or to prepare waste for further treatment, recycling or to disposed of in landfill. In this process, wastes are changed into substances that are easier to further treatment or to dispose. This method involves physically separating phases which contain hazardous substances from other non-hazardous constituents which form part of the waste stream. For examples separation of oils from ship bilge waters (Brian et al., 1989).

Niu and Li (2007) also reported that, physical methods include filtration, carbon adsorption, flocculation, reverse osmosis, ion exchange and distillation. Physical methods also consist of mechanical breaking, shredding, and ripping (Finnveden et al., 1995). These methods are used to physically break up the waste to either prepare it for further treatment or recycling. It also used to reduce the physical hazard and the volume of waste.

2.9.2 Chemical Treatment

Chemical treatment method is a process to alter the hazardous elements of waste using the different properties of a chemical (Darren, 2009). In this process, the chemicals, and hazardous elements alter by chemical reaction to destroying the hazardous elements or producing new compounds that are easier to treat or dispose of. Brian et al. (1989) stated that, chemical reaction can transform the waste from hazardous become non-hazardous or less hazardous. The examples of chemical reaction were such as chemically neutralize, oxidize, reduce, hydrolyze, precipitate, dechlorinate and catalytically detoxify the component that caused the waste hazardous.

In neutralization reaction, a substance or solution with a high acidity or high alkalinity is treated to become more neutral or closer to a pH of 7. Waste acid is reacted with an alkali and waste alkali with an acid. While in oxidation reaction, a common oxidizing substance such as hydrogen peroxide or calcium hypochlorite is used to oxidize a hazardous compound. For examples, Cyanide waste reacted with calcium hypochlorite (Swagat et al., 2012).

2.9.3 Biological Treatment

Biological treatment is more commonly referred to as bioremediation. It is a process whereby waste materials are biologically degraded under controlled conditions. In this method the bacteria is use under optimized conditions to mineralize hazardous organic substances. Bacteria are applied naturally or their growth conditions enhanced to break down specific chemicals or chemical mixtures (Brian et al., 1989; Rajeshwari, 2008). Through this process, the hazardous component of the waste is thereby converted to nonhazardous condition or to levels below concentration limits establish by the authorities. Bacteria may be applied directly on contaminated soil, placed in ponds, lagoons or added to groundwater. Some examples of bioremediation technologies are bioventing, land farming, bioreactors, composting, bioaugmentation and biostimulation (Rajeshwari, 2008).

2.9.4 Recovery and Recycling

According to Hageluken, (2008); Deng et al., (2008) and Finnveden et al., (1995), recycling means the reprocessing of the waste materials for the original purpose or for other purposes. While, based on DOE, recycling means removing or using the material from the manufactured equipment as part of raw materials for new products or components. Recovery is defined as any operation for the purpose of retrieval of valuable material or product from waste (Hageluken, 2008).

As stated by (Rajeshwari, 2008; Wei and Liu, 2012), waste recycling process usually consist of three stages, pretreatment, separation or concentration, and mechanical or chemical refining. Waste recycling basically starts from the pretreatment stage. This stage are includes an optional composition analysis and disassembly of the reusable and toxic parts. The reusable parts are shipped back to the market for reuse while hazardous parts are separately treated. After that, through shredding and separation, wastes are reduced into small-sized particles. In the end of recycling process, the materials are finally recovered after mechanical or chemical refining process.

Based on Poonam and Arvind (2008), wastes type that have good potential in undergoing recovery and recycling are solvents (halogenated and non-halogenated) resin and glue, rags, paper and plastic and sludges with heavy metals. To an extent, paint, and sludges too can undergo this treatment. The advantages of this technique are including could eliminate waste disposal costs, reduce raw material costs and provide income from a salable waste (Song et al., 2012).

2.9.5 Thermal Treatment

Based on (Havlik et al., 2011 and Darren, 2009) thermal treatment is defined as treatment processes which involve the application of heat to convert the waste into less hazardous forms. The purpose of thermal treatment is to convert the hazardous waste into less hazardous forms, reduces the volume of waste and allows opportunities for the recovery of energy from the waste.

In this treatment, thermal destruction methods with high temperatures (416°C to 1648°C) were used. The purpose of this method is to break down organic chemicals into less toxic forms. Darren (2009) stated that, there are two systems usually used in this treatment, systems with oxygen (incineration) or without oxygen (pyrolysis). During pyrolysis wastes are typically combusted in two stages. The first stage occurs in the main chamber and the next stage occurs in the secondary chamber. At the first stage, gases formed in the main chamber are burned at 976 °C - 1648 °C. Carbon monoxide and organic vapours generated in the first chamber were burnt off in the second chamber.

Thermal incineration is defined as a process that uses high-temperature thermal oxidation (Kellner, 2009). The purpose of thermal incineration is to convert a waste to a less bulky, less toxic or less noxious material. As stated by Holmes (2009), thermal incineration also can be considered as a volume-reduction process where the component elements of organic materials, are converted wholly or partially to gaseous form. In this process, wastes are incinerated by heating to a high temperature of between 880-12000 °C, whereby the contaminants are either destroyed or detoxified (Kellner, 2009).

2.9.6 Solidification and Stabilization

Solidification or stabilization is a process that physically encapsulates the contaminant. It is similar with technique to locking the contaminants in the soil. Solidification or stabilization technique can be used alone or it can combine with other treatment and disposal methods. Solidification or stabilization techniques is a chemical process in which it may naturally change waste such as reduce or eliminate the basic properties of waste, so that it can reduce the harmful effects of waste on the environment (Bonen, 1994). As mentioned by EPA, solidification or stabilization is the most suitable and frequently selected treatment technology for controlling the sources of environmental contamination.

The treatment of industrial waste has successfully implemented using solidification or stabilization (Zaidi, 1996). The use of industrial waste such as fly ash, slag, furnace granular powder, silica fume and sludge as a partial fiber (aggregate or binder) in concrete has been successfully implemented (Abu, 1990; Ishira, 1999). The most general form of solidification or stabilization treatment is in cement process. In cement process, it only involves the addition of cement or a cement-based mixture to the contaminant.

There are various types of Solidifying or stabilizing agents. They include cement, gypsum, modified sulfur cement, consisting of elemental sulfur and hydrocarbon polymers, and grout, consisting of cement and other dry materials, such as acceptable fly ash or blast furnace slag. Cement is a generic material that basically used in concrete for construction. Solidification or stabilization binding reagents have the ability to both solidify and stabilize a wide variety of wastes.

Based on Conner (1990), cement-based mix designs have been the popular solidification or stabilization treatment and have been applied to a greater variety of wastes than any other solidification or stabilization binding reagent. The waste gains physical integrity or become more solid by mixing them into cement and water. Based on the chemical properties of hydrating cement, it is used to lower the solubility of toxic contaminants in the waste. Besides that, it also used to lower the toxicity of hazardous constituents. This condition can achieve by changing the physical characteristic and chemical properties of hazardous wastes. Cement is frequently used because of their reagent’s ability to chemically bind free liquids, and reduce the permeability of the waste form. Cement provides permeable conditions to encapsulate waste particles. This condition is important to make sure the stability of waste particles. Inorganic and organic hazardous constituents can be treated using cement-based solidification and stabilization application.

The goal of the solidification or stabilization is to limit the spread of contaminants through leaching process. Leaching test is one of the methods to measure the concentration of contaminant in leachate. It is because leachability testing is typically performed to measure the immobilization of contaminants. Rabitah (2000), has performed a study on the copper slag as a partial fiber cement material in the mortar. Leaching tests were conducted to determine the pollution of this waste to the environment. From the study, it was found that the process of solidification or stabilization has been successful in reducing the concentration of pollutants that leach into the environment. In addition, the compressive strength of mortar also increased based on the percentage of material replacement.

In recent research, Yin et al, (2007) studied the strength and leachability aspects of metal-contaminated soil treated with Ordinary Portland Cement (OPC). In this study, the effectiveness of the treatment was evaluated by performing compressive strength as well as crushed and whole block leaching tests on the treated soil. From this research, they found that chemical stabilization of metal-contaminated soils using OPC was effective for prevention of metal leaching into the environment. Based on the results the high compressive strength values obtained indicated that solidified contaminated soils had tremendous potential in construction material applications such as engineering fills, pavement blocks and bricks amongst others.

In another study, Zain et al, (2004) developed concrete with the blasted copper slag played a role as cement replacement in concrete. For this research, two types of samples were prepared which are normal concrete and concrete added blasted copper slags as solidified samples. From this research, they found that the strength of the mortar added with copper slag was lower than the control mortar. For optimum strength the amount of ground copper slag to replace cement was about 5%. Based on Benson et al, (1986) the lower strength could be attributed to the retardation of cement hydration due to the presence of heavy metals in copper slag. Besides that the lower strength could also be due to the fact that the very fine particles of the slag supplied a large amount of surface area per unit volume to be coated with cement. This might have effectively reduced the amount of cement available for binding the fine and coarse aggregates required to provide adequate strength. From all of the results obtained they concluded that the cement was sufficiently effective in reducing the leaching of heavy metals. This is due to the low permeability of the concrete and the mineralization and absorption of metals by the cement can prevent metals from leaching out. The cement solidification was found to be an effective way to convert the hazardous wastes into strong monoliths with high compressive strengths.

Solidification or stabilization is flexible and economical process to be used in a large amount of waste, especially organic wastes and also more profitable for waste containing heavy metals (Mashitah et al., 2000). Product from solidified process has potential for commercialization. For example, products such as concrete solidified have potential to be used in the condition where the high compressive strength of concrete is not critical. In terms of cost for solidification treatment, it is considered appropriate because solidified product provide long-term advantages and give more benefit to the environment. At the same time, this product can solve the problems of hazardous waste disposal cost. Solidification or stabilization treatment technology has contributed a lot of sustainable development and environmental conservation. Although originally this technology using hazardous materials, but after the treatment it can produce the treated materials, that is can be reuse in construction industries.

2.10 Leaching

If the soil or surface runoff contact or through a material, some elements will be dissolved in a certain rate. Therefore, when a waste is processed or not and is exposed to water, it will cause leaching process (Connor, 1990). Water is agent for leaching process. Water pollution through waste is called as leachate. The ability of a substance to be leach is called as leachability. Leachate is defined as the pollutants release when they was exposed to aqueous media (Anderson, 1993; Gilliam and Wiles, 1992). Leaching can also be defined as the transfer of mechanical or chemical components into the liquid from the solid matrix, through solvent (water) (Bishop, 1988). Leaching is a point where unwanted constituents was removed from the waste and transferred to the environment through leaching agent. This level is usually determined and expressed as a concentration of elements in leaching agent. This is because the concentration is important in water quality standards, and leaching standards.

In landfills, waste would be exposed and leach of through the rainwater action (Yan et al., 1998). Rainwater will cause the absorption of water into the soil and leachate will be produced after soil and water saturated. Water is the main element that causing leaching. This is because, water will be absorbed into material when subjected to high pressure forces, although that material are impervious material such as glass, concrete and metal. Leaching process occurs when pollutants dissolved in the matrix and transported through the matrix pores to the environment.

The main environmental aspect from leaching is the quality of surface runoff and ground water if the leachate release. Effect of leachate on the surface runoff, for example, river and groundwater has long been known (Christensen et al., 1992). Leaching tests was designed to measure the ability of a stabilized waste to release contaminants into the environment (Tossavainen and Forssberd, 1999). The types of leachate are depending on site conditions and duration of the leaching process. Pollution from leachate depends on various factors, including physical factors, chemical, engineering and environmental properties.

2.11 Toxicity Characteristic Leaching Procedure

Leaching tests are often applied in assessing worst case environmental scenario where components of the samples become soluble and mobile. There is various leaching methods to remove soluble components from solid matrix such as acid digestion, Toxicity Characteristics Leaching Procedure (TCLP), Equilibrium leach test (ELT), and Multiple Extraction Procedure (MEP) (Esakku et al., 2006). Based on Christensen et al (1994) these methods are different depending upon the amount and particle size of leached samples, the type and volume of leachant solutions and the leachant delivery time. MEP is basically designed to simulate the leaching condition from repetitive precipitation of acid rain where the sanitary landfill is improperly designed. While ELT is designed for the measure of the maximum leachate concentration under mild conditions (Esakku et al., 1996). TCLP developed by the United States of Environmental Protection Agency (USEPA) is generally used to classify hazardous solid wastes and evaluate the worst leaching conditions in a landfill environment (USEPA, 1986).

As state by (USEPA, 1999), Toxicity Characteristic Leaching Procedure (TCLP) is mainly used to classify whether or not a waste material is hazardous according to its toxicity characteristic. Besides that, TCLP is also used to evaluate the effectiveness of stabilization of hazardous wastes in term of toxicity. TCLP is the U.S. Environmental Protection Agency (USEPA) method used to determine the leaching of heavy metals and solid wastes status as a hazardous waste due to the toxicity characteristic. Based on (Tossavainen and Forssberg, 1999) the properties or leaching characteristics were used to evaluate the waste material and to determine the heavy metal elements in waste. Besides that, leaching tests were used to determine the presence of elements that can disrupt and pollute the groundwater (Fallman and Hartlen, 1996).

Table 2.1 shows the limits of leachability that are imposed and used for the national standards in the United States, Malaysia, and Japan and for the draft standard in France.

Table 2.1: Leachability limits for various heavy metals

	Leachate Concentration (mg/L)			
Heavy Metals	**United States**	**Japan**	**Malaysia**	**France**
Ag	5	-	5	-
As	5	1.5	5	100
Ba	100	-	100	1000
Cd	1	0.3	1	100
Cr	5	-	5	1000
Cr^{6+}	-	1.5	-	100
Hg	0.2	0.005	0.2	100
Pb	5	3	5	1000
Se	1	-	1	100
Zn	-	-	-	5000

Most of the elements listed in the table are found in electrical and electronic device. They are presented along with their appropriate concentrations limits as show in the Table. If the leachate concentration exceeds the concentration limits the waste is classified as a hazardous waste (Townsend et al., 2004). If these elements are present in an electronic device, the device could potentially be classified as a hazardous waste when discarded. The TCLP was designed to be a rapid test and simulate the conditions that might occur in landfill as the waste decomposes for determining whether a solid waste should be a hazardous waste because of the presence of certain toxic elements. Leaching tests is divided into crushed block leaching (CBL) and whole block leaching (WBL).

2.11.1 Crushed Block Leachability

As stated by USEPA, the Crushed Block Leachability (CBL) test was similar to the TCLP test. Based on Yin et al. (2007) the CBL test was designed to simulate worst case leaching condition in landfill for extreme leaching conditions where leachate was produced due to prolonged aging effect. According to Townsend, (1998) even if the waste is stored or disposed in non-landfill conditions TCLP test is still the suitable method to determine the concentration of leachate. In this test, waste must be crushed so that the waste material is capable of passing through a 9.5-mm standard sieve (Connor, 1990).

Several studies have been conducted on the leachate of heavy metals from electronic waste components using the U.S. Environmental Protection Agency (EPA) standard toxicity characteristic leaching procedure (TCLP). Firstly Li et al. (2006) conducted CBL test on the leachate of the heavy metals from the personal computers (PC) components. In this study, the total contents of eight heavy metals including As, Ba, Cd, Cr, Pb, Hg, Se, and Ag in the printed wire boards (PWBs) and their leaching from the PWBs were examined. From this research, they found that, the concentrations of Pb in the CBL extracts of (PWBs) in all the (PC) components ranged from 150 to 500 mg/L. This result significantly exceeds the standard imposed by United States. While the contents of Ba and Ag were found to be high in some components, but this condition were not leachable under the TCLP test conditions. While the contents of barium and silver were found to be high in some components, but this condition still passing the standard. Besides that, the contents of other five elements in all the PC components were hardly detectable. So they make the conclusion these five elements would not have the potential to cause toxicity characteristic leaching concern.

In another research by Townsend, (2004) and coworkers tested a variety of electronic devices including cathode ray tubes (CRTs), desktop PCs, laptop PCs, cell phones, printers, keyboards, and some toys using TCLP. They reported that, every device that were tested produced TCLP extracts with the concentration of Pb being below the standard.

2.11.2 Whole Block Leaching

The leachability of metals from monolitic solidified cubes such as concrete can be determined using WBL test. WBL are frequently used to characterize the release of pollutants from stabilized waste materials. WBL is also known as semi-dynamic leaching test. WBL test is designed to simulate short-term leaching conditions of intact monolithic products. Based on Kameswari et al. (2001) the term semi-dynamic means that the leachant is replaced periodically after intervals of static leaching. In this WBL test, acetic acid was added into the leaching system as every solution renewal period. This condition enabled the rate of acid penetration to remain at a comparatively constant speed (Zain et al., 2004). It is contrast to the CBL test where the acidity of the leachant decreased with time due to leaching of alkalinity from the treated waste. The leaching solution used in CBL is the same as used in the WBL test.

Generally the leachability results from CBL test is higher than WBL test. It is because the surface area of crushed sample in CBL test is higher than that of the sample in WBL test. But, from the research conducted by Zain et al. (2004) the results show all concentrations of leachate on sample in CBL test were below the stipulated limits. The important thing that they found in this research is the leaching concentrations in the WBL test is higher than those in CBL test. This result contradicts with the general theory that CBL test should produce higher leachability than that of the sample in WBL test. In CBL test on mortar cubes, the areas of contact of the specimen with extraction fluid are higher than that WBL test. It is due to sample used crushed and as a result, the calcium hydroxide from the mortar dissolved rapidly into the extraction fluid and neutralized it. Thus the extraction condition was less severe than the WBL test and hence the low leachability. However, this is certainly not the case in natural environment, as fresh leachant will continuously wash away the leachate.

2.12 Mortar

Mortar is generally a construction material that consists of cement, sand, and water (ASTM C270). Mortar is defined as a compound of cementitious materials and sand with sufficient water to reduce the mixture to a workable consistency (Elsen, 2006). The cementitious materials are cement, and hydrated lime (ASTM C1329). Mortar is used as a bonding agent that integrates brick. Mortar must be strong, durable, and capable of keeping the wall intact. It should help to create a water resistant barrier, and it must accommodate dimensional variations and physical properties of the brick when laid. These requirements are influenced by the composition, proportion, and properties of the mortar.

2.12.1 Types of Mortar

As stated by Zaid et al. (2011), mortars are classified into three general types on the basis of the composition of the cementitious materials. They are namely cement lime mortars, mortar cements, and masonry cement mortars. Cement lime mortars consist of lime as cementitious material, sand, and water. Whereas masonry cement mortars consist of masonry cement as cementitious material, sand, and water. Mortar cements are mixture of Ordinary Portland Cement as cementitious material, sand and water (ASTM C270). Mortar cement must be mixed according to the property requirements of ASTM C270. The proportion of cementitious materials to sand as aggregate usually measured by volume or weight. The commonly used proportion of cementitious material to sand for mortar cements is one part of cementitious material to three part of sand (ASTM C109). These proportions may be varied within certain limits. Most specifications required that the proportion of sand shall not be less than two times or more than three times of the volume or weight of cementitious materials. Too much sand in the mortar mixed will produces a harsh mortar in which it is difficult to bed the bricks properly and leaky masonry is likely to be the result (Wongkeo et al. 2012).

2.12.2 Mortar Strength

Mortar cements are identified by ASTM C270 as type M, S, and N mortars. As shown in Table 2.2 type M mortar is very good for general use such as foundation, retaining wall, and walkways. It is recommended with the structure that contact with earth. While for type S mortar is very suitable for general purpose. This type of mortar used in extreme weather and below grade. It also being used in interiors and all load bearing structures. Type M or S mortar may be required where the wall is load bearing masonry. Type N mortar usually used in bearing wall that are above grade if stresses are not too great such as partitions and some exterior walls where climate conditions are negligible. The mortar type specification under the property specification is dependent solely on their strength characteristic and is determined using standard laboratory test. Mortar cement must be conform to the physical properties listed in Table 2.3 (ASTM C1329). These property requirements assure consistent performance of the product with respect to bond strength, compressive strength, and workability. In the construction industry, mortars having moderate or lower strength are preferred because this type of mortar is able to deform under load and has the ability to control small movements with minimal cracking (Islam and Bindiganavile, 2011).

Table 2.2: Recommended guide for selection of mortar type

Building Segment	**Type of Mortar**
Exterior, above grade:	
• Load bearing	N or S
• Non load bearing	N
Parapet wall	N or S
Exterior, at or below grade	S or M
Interior:	
• Load bearing	N or S
• Non load bearing	N

Table 2.3: Physical requirements of mortar (ASTM C1329)

Mortar Cement Type	**N**	**S**	**M**
Fineness, residue on a 45-µm (No. 325) sieve, max, %	24	24	24
Autoclave expansion, max, %	1.0	1.0	1.0
Time of setting, Gillmore method:			
Initial set, minutes, not less than	120	90	90
Initial set, minutes, not more than	1000	1000	1000
Compressive strength (average of three cubes): The compressive strength of mortar cubes, composed of 1 part cement and 3 parts blended sand (half graded standard sand and half standard 20–30 sand) by volume, prepared and tested in accordance with this specification, shall be equal to or higher than the values specified for the ages indicated below:			
7 days, MPa	3.5	9.0	12.4
28 days, MPa	6.2	14.5	20.0
Flexural bond strength:			
28 days, min, MPa (psi)	0.5	0.7	0.8
Air content of mortar:			
	8	8	8
Min, volume %	17	15	15
Max, volume %	70	70	70
Water retention value, min, %, of original flow			

2.13 Compressive Strength

The most important criteria in defining whether the mortar is good or bad quality is by conducting the compressive strength test (Halimah, 2009). Compressive strength of concrete is defined as the ability of concrete to resist the compressive stress without any damage or crack (ASTM C109). Acoording to Ashour (2000), the results from compressive strength are important to identify the early age and continued strength development of mortar. It is because the strength of concrete can be used as an indicator of other physical properties. At the same time it reflects the degree of hydration which also influences other performance characteristics. To achieve this criterion, the materials used in making mortar or concrete must be ensured in good quality and the method of mixing must be done carefully and according to procedure. The formula usually used for compressive test is load of failure divided by surface area of the sample (ASTM C109).

2.14 Flexural Strength

Flexural strength is one of the tests conducted to determine the strength of mortar. Based on ASTM C348-08, flexural strength, also known as modulus of rupture, bend strength, or fracture strength, is measured in terms of stress, and thus is expressed in units of pressure or stress, the two being equivalent. As stated by Shannag and Al-Ateek (2006), the value of flexural strength represents the highest stress experienced within the material at its moment of rupture.

2.15 Durability

According to Mullick (2007) durability of concrete means the resistance of concrete from deterioration characteristics caused by exposure to certain conditions during its service life. Some aspects such as results in loss of weight, cracking of concrete and the consequent deterioration of concrete should be most important aspect when doing investigation on durability of concrete (Prasad et al., 2006).

In construction, durability of mortar is also a main property that should be considered. Based on Gambhir, (2002), durability of mortar defined as the ability of the mortar to resist any aggressive conditions during its design life. Some elements have been identified as the cause of mortar damage. These elements are water, soluble salts, chemical and temperature change (Mullick, 2007). Basically the durability of the mortar will increase, when the cement content in the mortar increased. According to Gambhir, (2002), mortar that did not have good durability did not mean it cannot be used. This type of mortar can still be applied for the internal use. Generally Ordinary Portland Cement (OPC) concrete usually does not have good resistance to acid attack. So it is important to investigate the durability of mortar cement in acid condition.

2.15.1 Durability in Acid Attack

Cement based materials are subjected to acidic environment in a variety of ways although concrete in most structures is not likely to be exposed to acid very often or severely. Acidic waters may be found in or adjacent to, landfilled areas and in places where mining operations and stock piling of mine tailings have occurred (Ahmed, 2008). Based on Vanchai et al. (2012), highly acidic conditions sometimes exist in agricultural and industrial wastes, particularly from food and animal processing industries. A list of commonly found acids with likely occurs is shown in Table 2.4 (Mindess and Young, 1981)

Table 2.4: Common acids with likely occur (Mindess and Young, 1981)

Acid	**Likely Occurrence**
Hydrochloric and Sulfuric acid	Chemical industry
Nitric acid	Fertilizer manufacture
Acetic acid	Fermentation process
Formic acid	Food processing and dyeing
Lactic acid	Dairy industry
Tannic acid	Tanning industry, peat waters
Phosphoric acid	Fertilizer manufacture
Tartaric acid	Winemaking

2.16 Cement Brick

Brick is one of the important materials that has been used for a very long time ago. Brick has own characteristic which is more resistant and generally used as a building material in construction of wall (Oti et al., 2009). One of the brick type is cement brick. This type of brick is made from a mixture of cement and sand. The types of sand used in making cement brick is fine grain sand, and a cementitious material such as Ordinary Portland Cement. The aggregate materials used in cement brick are much finer compared to concrete brick (ASTM C55-11). Typically brick are prepared in various sizes. As referred to the British Standard (1985), it is specified that the size of brick should not exceed 337.5mm in length, 225mm in width or 112.5mm in height. For normal brick, the standard dimensions are 225mm x 112.5mm x 75mm.

2.16.1 Brick Strength

Brick are available in a wide range of compressive strengths. Unless a higher strength is agreed in accordance with Malaysian standard M.S.7.6:1972, the compressive strength of clay bricks for load bearing internal walls when tested shall not be less than 5.2 N/mm^2. This minimum strength is accepted provided the bricks are satisfactory in their aspect. The highest practical strength can be obtained for loadbearing brick in Malaysia is 103.0 N/mm^2. However, the most common range would be 6.9 to 7.0N/mm^2. The current specifications for the strength of bricks of the Malaysian Standard recognized 10 classes of bricks as stated in Table 2.5. The classes are given in accordance to the strength of the bricks.

Table 2.5: Strength of clay bricks in accordance with M.S. 7.6:1972

Designation	**Class**	**Average compressive strength (N/mm^2) not less than**
Engineering Brick	A	69.0
	B	48.5
Load Bearing Brick	15	103.0
	10	69.0
	7	48.5
	5	34.5
	4	27.5
	3	20.5
	2	14.0
	1	7.0

2.16.2 Water Absorption

Most building materials are porous and absorb water to some extent. As stated by Castro et al. (2011), water absorption of brick depends upon their porosity and a good brick does not absorb water greater than one-seventh of its weight. Bricks of most types have a relatively high porosity and it has in the past often been deemed desirable that some limit should be placed upon the porosity values for particular types of bricks. Rate of absorption and permeability test are used to determine the rate of water absorbed by brick. It has been commonly assumed that the total absorption of a brick gives some measure of the ability of a wall to withstand driving rain (Kolias and Georgiou, 2005).

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This chapter will explain in detail about how the research has been conducted. It includes research planning, explanation about materials used, method for TCLP test and also the methods to determine the engineering properties of mortar cement and cement brick added with nonmetallic PCBs. The materials used in this research are nonmetallic PCBs, cement, and fine aggregate. Scanning Electron Microscope test (SEM), X-ray Fluorescence Spectrometry (XRF), Toxicity Characteristic Leaching Procedure test (TCLP), Compressive Strength test, Flexural Strength test, Durability test and Water Adsorption test were conducted in this research in order to achieve the objectives of the study. The actual research methodology conducted is shown in Figure 3.1.

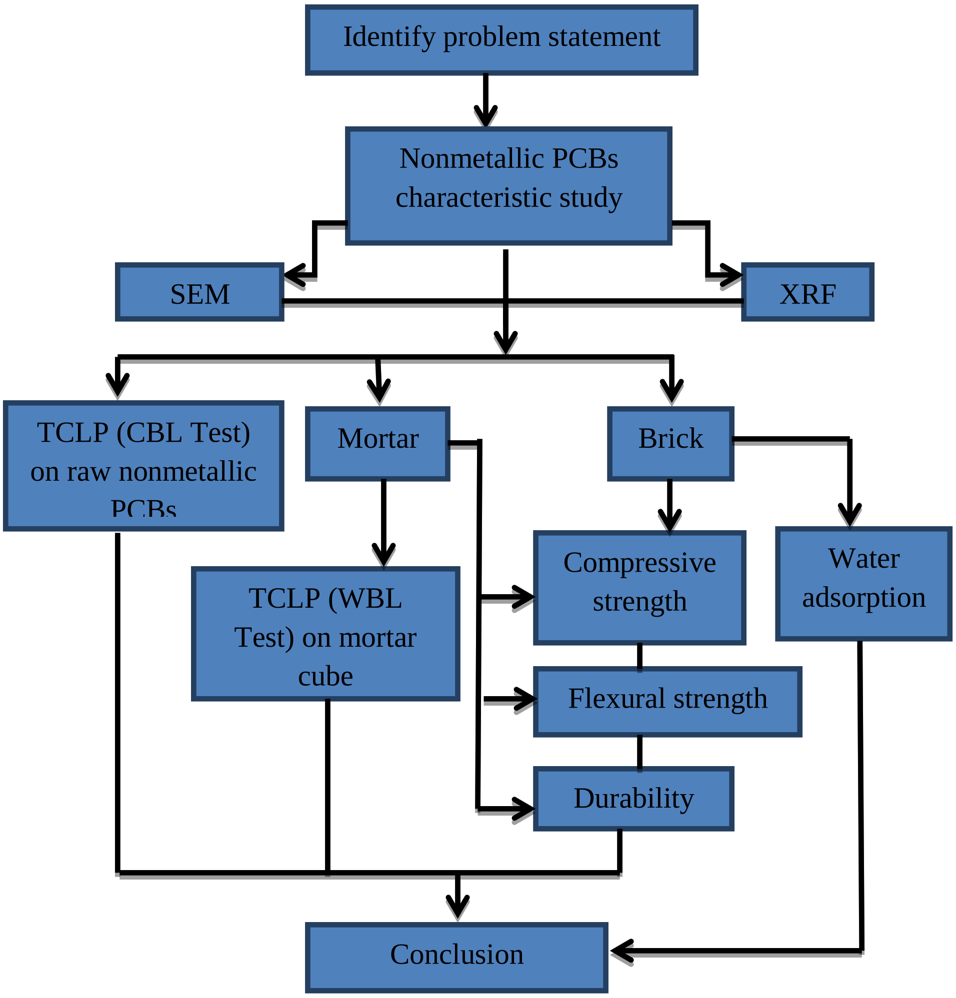

Figure 3.1: Research methodology flow chart

3.2 Samples

For sample preparation, nonmetallic PCBs (Figure 3.2) were taken from two electronic waste recycling plants. Samples were taken from two recycling factory because each factory using different method during the separation process of PCBs. Samples are in powder form. Samples were also divided into two types which are PCBs made of glass fiber reinforced epoxy resin (Sample A1 and A2) and cellulose paper reinforced phenolic resin (Sample B1 and B2). Two different types of nonmetallic PCBs were used in this study because each type is made of different materials and has different chemical compositions. The samples description is shown in Table 3.1. These samples then were sieved according to the (ASTM C144-11). The size distribution of nonmetallic PCB materials is shown in Table 3.2. The details of the chemical composition of the nonmetallic PCBs are given in chapter 4.

Figure 3.2: Nonmetallic PCBs powder

Table 3.1: Samples description

Sample	**Factory**	**Type of Material**	**Separation Process**
A1	X	Glass fiber reinforced epoxy resin	Wet process
B1	X	Cellulose paper reinforced phenolic resin	Wet process
A2	Y	Glass fiber reinforced epoxy resin	Dry process
B2	Y	Cellulose paper reinforced phenolic resin	Dry process

Table 3.2: Size distribution of nonmetallic PCBs materials

Sieve Size (mm)	Weight Retained (g)	% Retained	Cum. % Passing
4.75	0	0	100
2.36	0	0	100
1.18	0	0	100
0.60	1,195	6.45	93.55
0.30	9,627	51.96	41.59
0.15	5,517	29.79	10.8
Pan	2,188	11.80	0
Total Weight of Aggregate	**18,529**	**100.00**	

3.3 Experimental Method

Several tests have been conducted in this research. The tests involved in this research are as follows:

i. Scanning Electron Microscope test on raw nonmetallic PCBs and mortar cubes.

ii. X-ray fluorescence spectrometry on raw nonmetallic PCBs and cement.

iii. Toxicity characteristic leaching procedure test (TCLP) on raw nonmetallic PCBs.

iv. Compressive Strength, Flexural strength, and Durability test on mortar cubes.

v. Toxicity characteristic leaching procedure test (TCLP) on mortar cubes with the use of nonmetallic PCBs as sand replacement.

vi. Compressive Strength and Water Absorption test on cement brick.

3.4 Scanning Electron Microscope

The instrument used for this test is a Philips XL 40 Scanning Electron Microscopy and SEM EDAX AMRAY model as shown in Figure 3.3. In this experiment, the 1.0 cm x 1.0 cm samples were prepared and made into sheets with a flat and smooth surface. To get a smooth surface, the samples were coated with gold. Samples were coated with gold for 105 seconds in Automatic Coating Machine to improve conductivity and protect the sample from dust. The prepared samples were then stacked on a clean stud with tape conductor. The studs were then inserted into the machine that is maintained in vacuum condition. The structure of samples were detected and analyzed by SEM-EDAX. The analysis was done by selecting the appropriate focus, magnification range, working distance, and other suitable parameters for the required results.

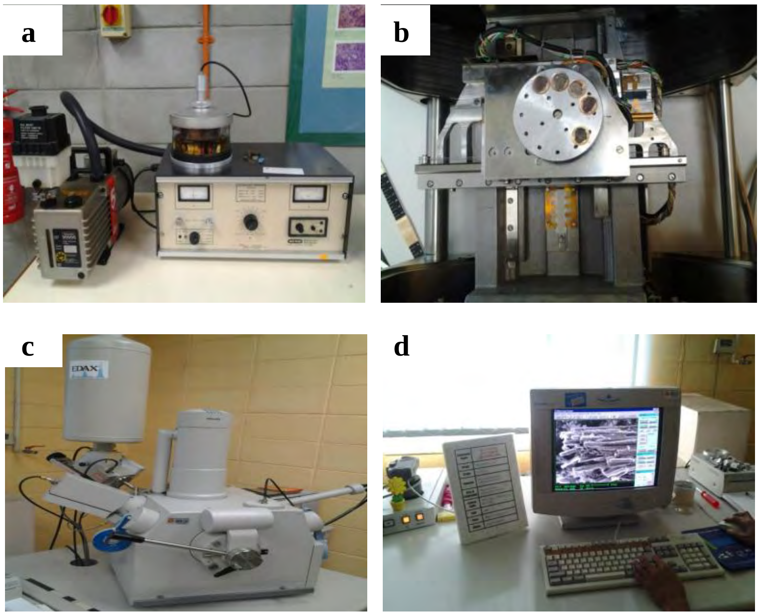

Figure 3.3: Sequences of SEM Test procedure

3.5 X-ray Fluorescence Spectrometry

The nonmetallic PCBs powder and cement were quantitatively analyzed for chemical composition using X-ray Fluorescence Spectrometry (XRF). XRF is a non-destructive analytical technique used to identify and determine the chemical composition of samples.

XRF is used in a wide range of applications, including cement production, and environmental studies. Before the samples were analyzed using XRF method, the samples must be well prepared. Nonmetallic PCBs were sieved through a sieve of 60µm size until no grains larger than 60µm was left. Samples were then pressed into pellet and boric acid was added in the mixture as a binder in a proportion of 1:10 by weight. The XRF tests were then performed on the samples to determine the percent of oxide in the samples. In this test, the metals that have been analyzed were Cr_2O_3, Al_2O_3, SiO_2, Fe_2O_3, BaO, Na_2O, SrO, CuO, MgO, Br, SnO_2, CaO, and others.

3.6 Toxicity Characteristic Leaching Procedure

Toxicity Characteristic Leaching Procedure (TCLP) test was carried out to evaluate and determine the heavy metals leached from the raw nonmetallic PCBs and mortar added with nonmetallic PCBs. The EPA standard TCLP method 1311 EPA 1992a was employed to test and measure all the heavy metals contained in nonmetallic PCBs and mortar added nonmetallic PCBs. The TCLP tests were done in three replicates and the average value was reported. This test was conducted for four samples from two different factories. Leaching tests of waste material and the amount of pollutants in leachates were measured and compared with existing standard, which is the Maximum Concentration of Contaminants for the Toxicity Characteristic Leaching Procedure (TCLP) specified under the guideline of Environmental Quality (Scheduled Wastes) Regulations 2005.

3.6.1 Extraction Fluid

In this study, acetic acid that was diluted with distilled water was used as an extraction fluid. Distilled water has a high ability to ionize materials and increase the rate of the material to dissolve (Means et al., 1995). Distilled water was prepared by passing distilled water through a device called as Elgastal UHQ. Acetic acid is used as diluents that provide aggressive condition to sample compare than rain water or groundwater (Connor, 1990). The function of Extraction fluid is to move the metal. Extraction fluid should be prepared on the day it is to be used, and were prepared as follows:

a. Extraction fluid 1:

5.7 mL glacial CH_{32} CHOOH was diluted with reagent water to a volume of 500 ml. 64.3 ml of 1N NaOH was diluted to a volume of 1 liter and added to reagent water. The pH of the TCLP extraction fluid 1 was 4.93 ± 0.05.

b. Extraction fluid 2:

5.7 mL glacial CH_{32} CHOOH was diluted with reagent water to a volume of 1 liter. The pH of this fluid was 2.88 ± 0.05.

Extraction fluid used in this study depends on the alkalinity of the waste to be tested (Means et al., 1995). In leaching test, only one of these two types of extraction fluid is to be used. Determination of appropriate extraction fluid is as follows:

i. A small subsample of the solid phase of the nonmetallic PCBs waste was weighed. 5.0 grams of the solid phase of the waste was transferred to a 500 mL beaker or Erlenmeyer flask.

ii. 96.5 mL of reagent water was added into the beaker, covered with a watchglass, and stirred vigorously for 5 minutes using a magnetic stirrer. The pH was measured and recorded. If the pH is <5.0, the extraction fluid 1 was used.

iii. If the pH is >5.0, 3.5 mL 1N HCl was added and then covered with a watchglass, heat to 50 ^{o}C, and hold at 50 ^{o}C for 10 minutes.

iv. After that the pH was recorded. If the pH is <5.0, the extraction fluid 1 was used. But if the pH is >5.0, then the extraction fluid 2 was used.

There are two methods used in the leaching tests, which is:

i. Crushed Block Leachability Test (CBL)

ii. Whole Block Leachability Test (WBL)

3.7 Crushed Block Leachability Test

This method used in the leaching test on raw nonmetallic PCBs powder. To conduct Crushed Block Leachability Test (CBL) test, the pulverized nonmetallic PCBs were sieved. Only nonmetallic PCBs that passing through sieve 9.5 mm were taken (USEPA, 1996). As much as 2 liters of extraction fluid were then prepared. Extraction fluid was placed in a High Density Polyethylene (HDPE) bottle. A total of 100 gram Nonmetallic PCBs were then placed in the bottle. Sample was prepared with mixing ratio of extraction fluid to nonmetallic PCBs is 20:1. The bottle was spinned for 18 hours with a rotation rate of 30 to 32 revolutions per minute (30 ± 2) rpm. After completion of the leaching process, the sample was filtered with borosilicate glass fiber filter size 0.6 to 0.8 micrometers with 50 psi pressure. This process must be done immediately after the sample was collected. The heavy metals in the leachate sample were then analyzed using the Inductively Coupled Plasma Mass Spectrometry (ICP MS). In this test, the metals checked were Cu, Zn, Cr, Cd, Pb, As, Ba, Se, Silver, Sn, B, Hg, and Ni. The Sequences of CBL test procedure was shown in Figure 3.4.

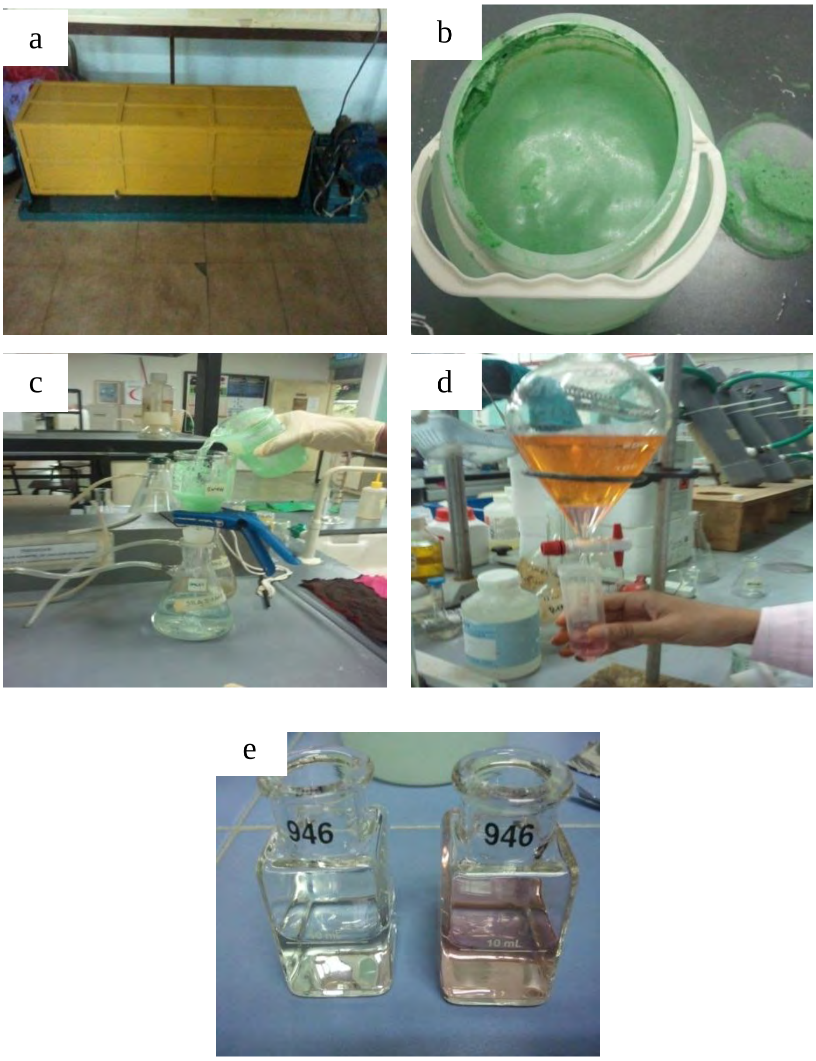

Figure 3.4: Sequences of CBL Test procedure

3.8 Whole Block Leachability Test

Whole Block Leachability (WBL) test was conducted to determine the leachability of metals from the monolithic solidified cubes after 28 days of air drying. WBL was conducted based on procedure developed by Montgomery et al. (1988). The advantage of this test compared with CBL is, sample only tested on the surface without pulverized the samples. For the WBL test, 25 mm mortar cubes were suspended to extraction fluid. The sample to extraction fluid ratio is 1:10 by weight. The same leaching solutions used in TCLP were used in the WBL test. Acetic acid was added into the leaching system as every solution renewal period which enabled the rate of acid penetration to remain at a comparatively constant speed (Yin et al., 2007). The leachates were then filtered through 0.6 μm borosilicate glass-fiber filter. Leachates were collected after 3, 7, and 28 curing days. The heavy metals in the leachate sample were then analyzed using the ICP MS. In this experiment, the parameters tested were Cr, Ni, Zn, Cu, Pb, and Cd.

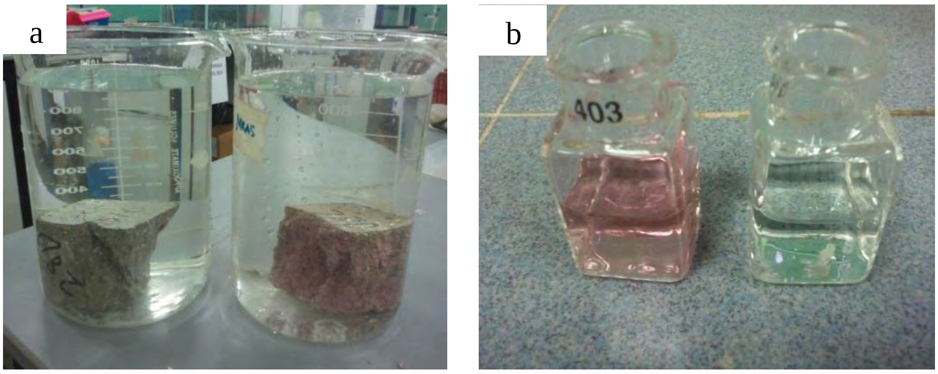

Figure 3.5: Whole Block Leachability Test procedure

3.9 Mortar Samples

The cubes with size of 50 mm x 50 mm x 50 mm were used for compressive strength test and durability test. While for flexural strength test, the size of beams was 40 mm x 40 mm x 160 mm. The samples are different in terms of the proportion of nonmetallic PCBs added into mortar cements. The water cement ratio of the mortar was at 0.50 and the sand cement ratio was at 2.75 (ASTM C109/109M-12). Mortars with no nonmetallic PCBs were used as the control mortar. Total of samples used were 60 cubes for compressive test, 30 cubes for durability test and 60 beams for flexural test. Table 3.4 below shows the proportions of each sample.

Table 3.3: Mixture proportioning of mortar sample

Sand substitution by nonmetallic PCBs (%)	**0%**	**10%**	**20%**	**30%**	**40%**
Cement (g)	1.00	1.00	1.00	1.00	1.00
Water (g)	0.50	0.50	0.50	0.50	0.50
Sand (g)	2.75	2.475	2.20	1.925	1.65
Nonmetallic PCBs (g)	0.00	0.275	0.55	0.825	1.10
Sand size	Passing through sieve 5mm				
Nonmetallic PCBs size	Passing through sieve 5mm				

3.9.1 Raw Materials for Making Mortar and Cement Brick

a) Cement

The cement that was used is Ordinary Portland Cement (OPC). OPC was stored in a humidity-controlled chamber in order to maintain the quality of cement. The details of the chemical composition of the cement are given in chapter 4.

b) Water

Water used to produce mortar that is perfect due to the process of hydration between cement and water. Therefore, the bond between the mixes becomes stronger and more stable (Halimah, 2009). Supplied tap water was used throughout the study in mixing, curing and other purpose.

c) Fine Aggregate

Fine aggregate or sand was dried in oven before it is being used. Sand was oven dried at 105ºC for 24 hours to remove its moisture content. The dried sand then sieved to remove litter or rubbish from the sand. Sieved analysis was performed according to standard (ASTM C144-11). Percentages of sand passing the sieve were compared to the size limits of its distribution in accordance with standard. The size distribution of the sand is shown in Table 3.4.

Table 3.4: Sieve analysis for sand

Sieve Size (mm)	**Weight Retained (g)**	**% Retained**	**Cum.% Passing**	**Spec.Limits**
4.75	0	0	100.00	100
2.36	2,961	6.38	93.62	95-100
1.18	3,713	8.00	85.62	70-100
0.60	11,359	24.46	61.16	40-75
0.30	17,668	38.04	23.12	10-35
0.15	9,251	19.92	3.20	2-15
Pan	1,488	3.20	0	
Total weight of Aggregate	**46,440**	**100.00**		

Figure 3.6: Fine aggregate

3.9.2 Manufacture of Mortar and Brick

Cement, sand, water and nonmetallic PCBs waste were mixed together in the concrete pan mixer for about 3 minutes. The mixture of mortar and brick were left for 5 minutes before poured into the mould. The mortar and brick mixture were cast into the mould, in two layers for cube sample. For compaction of the sample, each layer was given 25 to 30 manual strokes using a rodding bar, before vibrated on vibrating table for 12 to 15 second. The top surface of the mortar and brick were leveled. The top surface of the mould was covered by gunny for 24 hours.

3.9.3 Method of Curing

In order to obtain good quality, mortar must be cured in a suitable environment during the early stage of hardening (Neville, 2005). According to Fathollah (2012), curing is the procedures use for promoting the hydration of cement and consists of a control of temperature and of the moisture movement from and into the mortar. In this research, water curing (Figure 3.7) was used based on (ASTM C109/109M-12). The mortar cubes were placed in the water tank until the age where the test for compressive and flexural strength should be done.

Figure 3.7: Curing of mortar in the water

3.10 Testing on Mortar

Mortar samples were tested according to standard method. The tests were including compressive strength, flexural strength and acid resistant test.

3.10.1 Compressive Strength

The main purpose of this test is to determine the compressive strength of mortar at the age of 3, 7, and 28 curing days. The procedure to determine the compressive strength of mortar is based on ASTM C109/C109M-12. 60 samples were tested for the compressive strength. Loading rate was maintained at 0.9kN/s.

In order to obtained the compressive strength of the tested mortar, the Equation 3.1 is used:

$$Fc = P / A \tag{3.1}$$

Where: P = Load when sample failed; and A = Area of mortar

Figure 3.8: Compressive Strength Test

3.10.2 Flexural Strength

The main purpose of flexural strength test is to determine the flexural strength of mortar at the age of 7, and 28 curing days. The procedure to determine the flexural strength of mortar is based on ASTM C348-08. 60 Samples were tested for the flexural strength. Loading rate was maintained at 2.64kN. In this test, sample was tested until a failure under a load in a three point bending system.

In order to get the flexural strength of the tested mortar, the Equation 3.2 is used:

$$Sf = 0.0028P \quad (3.2)$$

Where: P = Total maximum load (N); and Sf = Flexural Strength (MPa)

Figure 3.9: Flexural Strength Test

3.10.3 Durability

In order to examine the durability of mortar, mortar added with 10 wt% nonmetallic PCBs and control mortar were compared based on the weight change and loss in compressive strength after acid exposure. The choice of acids solution and their concentration are based on practical utilization of concrete as a construction material in various applications such as sewage pipes, mining and food processing industries. The sulfuric acid resistances of mortars were tested by modified test method B in accordance with ASTM C 267. In order to examine chemical resistance under acidic conditions, 30 mortar samples were soaked in 5% H_2SO_4 solution for specified periods which is 0, 10, 20, 40, 60 days. Samples for weight change measurements were initially primed in water for 3 days and its saturated surface dry weight was taken as initial weight. The solution should be stirred every week and replaced with fresh solution after the immersions of 10, 20, 40, and 60 days to maintain the pH value of the acid solutions throughout the study.

a. Weight Change

It should be noted that change in weight is commonly used to evaluate the deterioration of concrete under acid attack. Samples for change in weight test were removed from the acid solution containers and wiped clean prior to the measurement. The samples were returned back into the solution containers after the weight measurement. The changes in weight were measured from time to time. The percentage of change in weight is calculated according to standard method of ASTM C 267. In order to obtained the change in weight, the Equation 3.3 is used:

$$\text{Change in weight} = \frac{W - C}{C} \times 100\ \% \tag{3.3}$$

Where: C is the initial weight of the sample; and W is the sample's weight after immersion.

b. Change in Compressive Strength

On the day of test, the samples were removed from the acid solution container and wiped clean. Compressive strength test was performed at 0, 10, 20, 40 and 60 days of acid solution immersion. Three identical samples from each mixture were tested at each date and the average value was calculated. The change in compressive strength of the corroded samples was calculated according to standard method of ASTM C267.

The calculation is according to Equation 3.4.

$$\text{Change in compressive strength} = \frac{(S2_{\text{after curing}} - S1_{\text{initial curing}})}{S1_{\text{initial curing}}} \times 100\,\% \qquad (3.4)$$

Where $S1_{initial\ curing}$ is compressive strength at initial curing; and $S2_{after\ curing}$ is compressive strength after immersion in acid solution.

3.11 Brick Samples

The size of brick used for compressive strength test is 215 mm x 103 mm x 65 mm which work size stated in British Standard (BS 3921:1985). The samples are different in terms of the proportion of nonmetallic PCBs added in cement brick. The water cement ratio of the cements brick is at 0.50 and the ratio cement to sand is 1:6 (BS 3921:1985). Samples with no nonmetallic PCBs were used as the control samples. Total of samples were 63 cubes. Table 3.5 below shows the proportions of each sample.

Table 3.5: Mixture proportioning of brick samples

Cement: sand ratio	1:6
Nonmetallic PCBs	10%, 15%, 25%, 40%, 45%, 50% of sand replacement
Water/cement ratio	0.50
Sand size	Passing through sieve 5mm
Nonmetallic PCBs (g)	Passing through sieve 5mm
Number of sample	63

3.12 Tests on Brick

Brick samples were tested according to standard method. The tests were including compressive strength, and water absorption test.

3.12.1 Compressive Strength Test on Brick

Compressive strength test for brick was carried out according to BS 6073:1981. The compressive strength of brick was determined at the age of 7 and 28 curing days. The samples were tested using ELE International ADR 2000 hydraulic press with capacity of 2000 kN. The loading rate of 14.8 kN/s was used. To ensure a uniform bearing is applied, thin plywood sheets were placed between the brick during testing. The maximum load can be carried by the samples were then recorded.

3.12.2 Water Absorption Test

Water absorption test was conducted according to ASTM C140-12 using the immersion method. The test was carried out to determine the percentage of water absorbed by cement brick. Water absorption test was conducted after 28 days of curing ages. The samples were weighed while suspended by a metal plate and completely submerged in water. Water were then removed from the samples by damp cloth and allowed to drain for 1 minute. The saturated weight was recorded. The samples were then dried in oven at 105 ^{0}C until two successive weights at intervals of 2 hours show an increment of loss not greater than 0.2 % of the last previously determined weight of the samples. The oven-dry weight was recorded. Water absorption was determined by Equation 3.5.

$$\text{Absorption} = [(Ws - Wd) / Wd\,] \times 100\ \% \qquad (3.5)$$

Where: Ws = saturated weight of samples (kg); Wi = immersed weight of samples (kg); and Wd = oven-dry weight of samples (kg).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Microstructural Analysis

Samples were analyzed using Scanning Electron Microscope test (SEM) to determine the pattern of microstructure surface, size and particles arrangement of raw nonmetallic PCBs powder and mortar added with nonmetallic PCBs waste. Four types of nonmetallic PCBs powders were taken from two different factories and recorded as sample A1, A2, B1, and B2. Nonmetallic PCBs can be divided into two different types of material which are glass fiber reinforced epoxy resin (sample A1 and A2) and cellulose paper reinforced phenolic resin (sample B1 and B2).

From Figure 4.1, and 4.2, nonmetallic PCBs consist of different design, composition and particle size. Samples A1 and B1 have elongated shape and sharp structure, while samples A2 and B2 are square in shape, perforated, porous and have small pores on their surface.

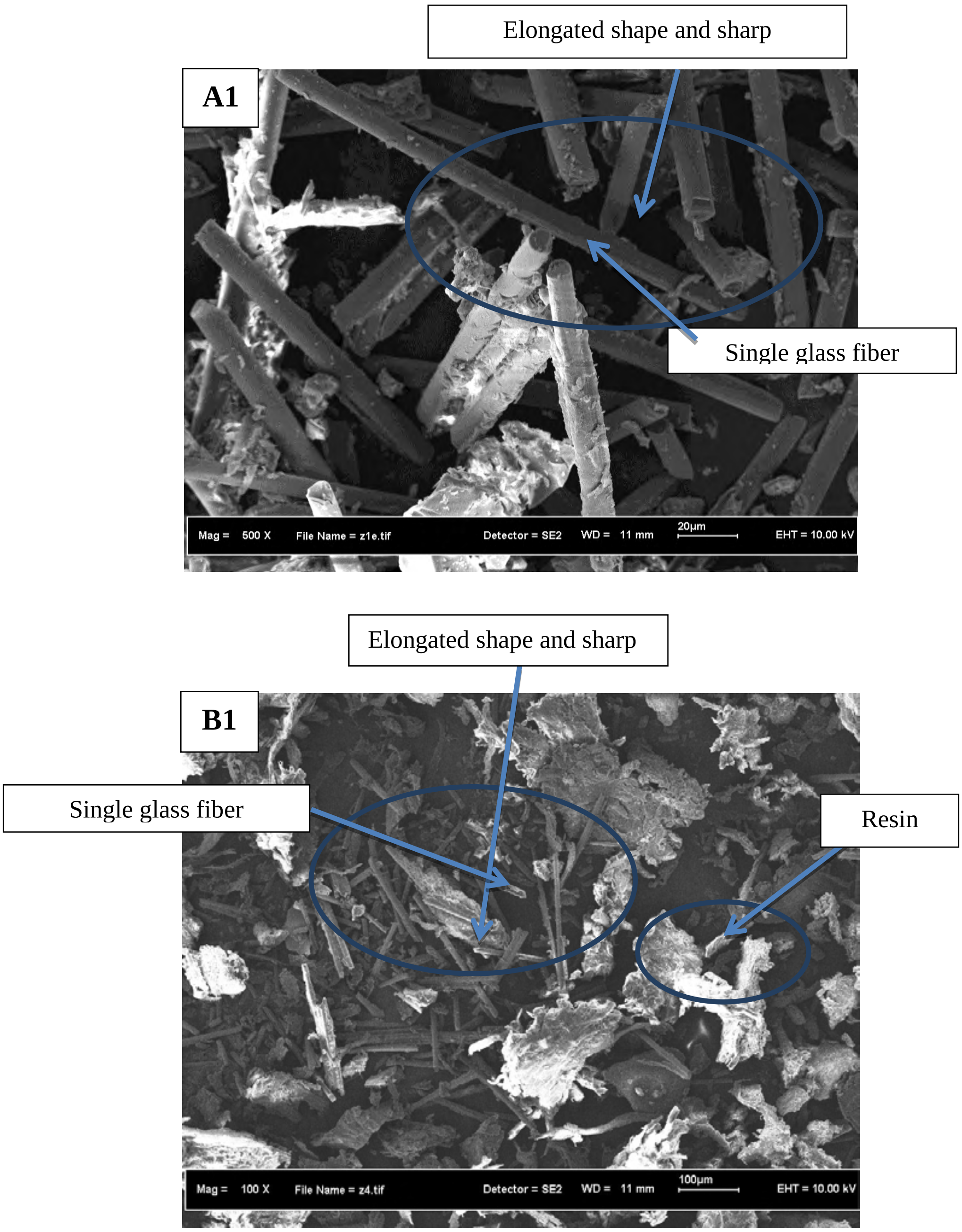

Figure 4.1: SEM micrograph of sample A1 and B1 contain single glass fiber of nonmetallic PCBs waste, separated using wet process

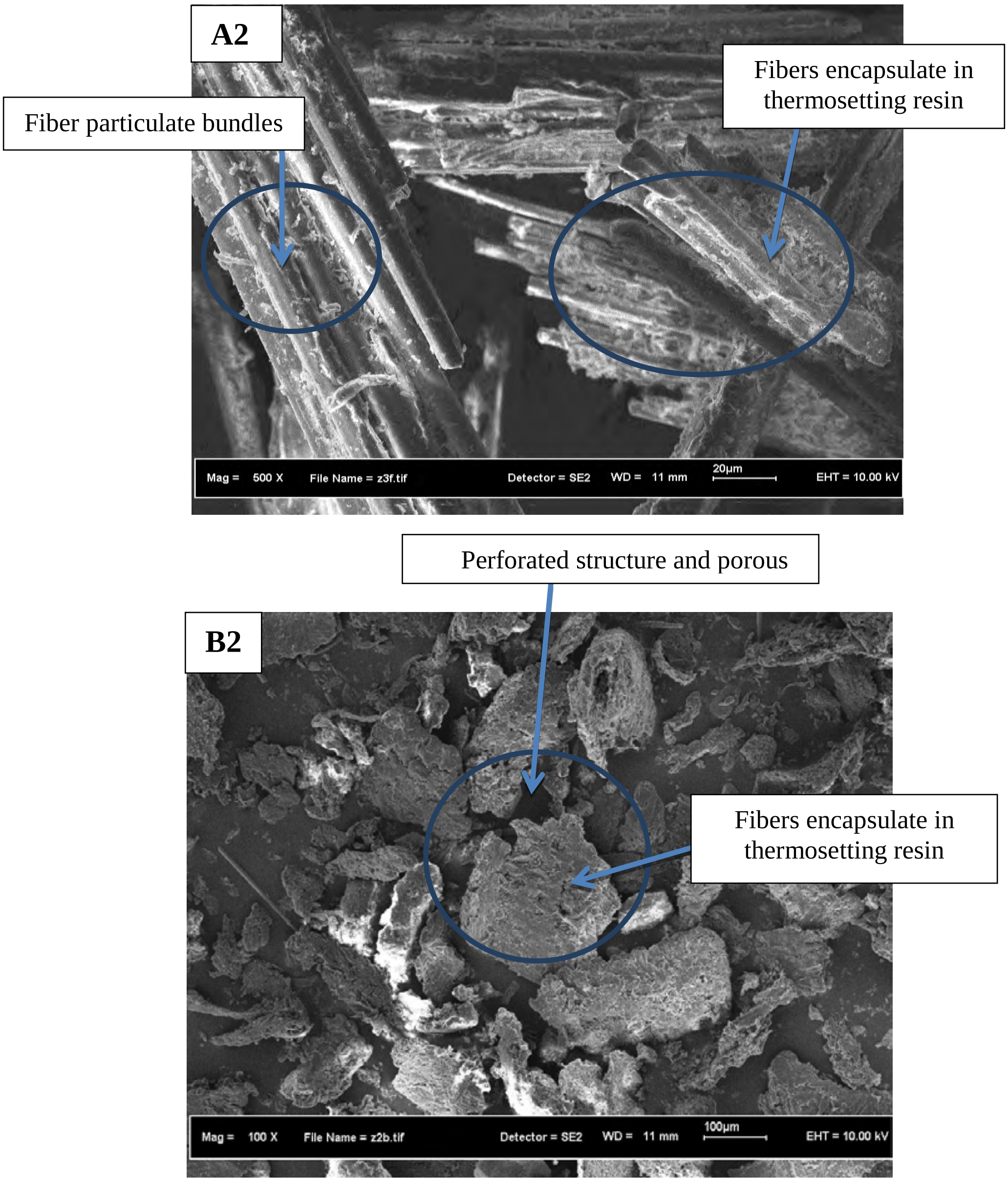

Figure 4.2: SEM micrograph of sample A2 and B2 contain coarse nonmetallic PCBs waste, separated using dry process

The differences of shapes and compositions among nonmetals with different particle sizes are determined by intrinsic structure of waste PCBs and the physical recycling processes (Zheng et al., 2009). Nonmetallic PCBs also do not have a smooth surface. Figures 4.1, and 4.2, show that nonmetallic PCBs have a rough surface structure and jagged. Based on Francis and Brown (1994) aggregate that have a rough texture and jagged give good interlocking properties, provide anti-skid and suitable structure for high shear impact. These characteristic makes the nonmetallic PCBs suitable to be used as sand replacement.

Microscopic observation reveals that for sample A2 and B2, the coarse nonmetallic PCBs contain predominantly fiber-particulate bundles, with the majority of fibers being encapsulated in thermosetting resin as shown in Figure 4.2. The single glass fibers and thermosetting resin powders are not seen in these samples. Thermosetting resin is stuck inside the glass fibers, forming a large fiber-particulate bundle of loosely entangled fibers. While for samples A1 and B1, the nonmetallic PCBs contain predominantly single glass fibers and only a small content of resin stuck on the surface of the glass fiber. It shows that the samples were properly separated during separation process. Wet crushing techniques were used in separation process of samples A1 and B1. While dry impact crushing techniques were used in separation process of samples A2 and B2. Compared to dry crushing techniques, wet impact crushing has the advantages of higher crushing efficiency, and less over crushing (Duan et al., 2009). Therefore, the samples A1 and B1 are more properly separated compared with samples A2 and B2.

4.2 Chemical Composition Analysis of Nonmetallic PCBs and OPC

Analysis of data obtained from X-ray Fluorescence Spectrometry (XRF) test can be used to find out the chemical elements in nonmetallic PCBs. Results for chemical composition analysis from XRF test is shown in Table 4.1. Nonmetallic PCBs mainly consist of epoxy resin, glass fibers and a small concentration of metals. The nonmetallic PCBs glass fiber reinforced epoxy resin (sample A1, and A2) mainly contained 72.8% of glass fibers materials such as SiO_2, Al_2O_3, CaO, MgO, BaO, Na_2O, and SrO, 9.4% of metallic materials such as CuO, SnO_2, and Fe_2O_3, and 9.2% of organic resin materials containing elements such as C, O and Br. For glass fiber materials, SiO_2 was found at the highest content of mass which is 43.2%, followed by CaO 18.98%, Al_2O_3 9.2%, MgO 0.5%, and BaO 0.59%. In terms of the metal composition, CuO was found at 8.3%, followed by Fe_2O_3 with 1.1% of mass. In terms of the nonmetallic composition, Br was found at 9.2%.

Other elements found in nonmetallic PCBs were TiO_2, SO_3, K_2O, Na_2O, SrO, Cl, P_2O_5, SnO_2, ZrO_2, ZnO, As_2O_3, NiO, and PbO. This element exists only in small amounts which are in the range of 0.44% to 5 ppm. The results obtained above is accordance with the results of studies have been reported by Hino et al. (2009), which stated that C, O, Al_2O_3, SiO_2, CaO, Cu and Br are the main content in glass fiber reinforced PCB nonmetallic epoxy resin.

Table 4.1 shows the results of XRF tests on nonmetallic PCBs cellulose paper reinforced phenolic resin (sample B1 and B2). The nonmetallic PCBs generally contained 26.6% of organic resin materials containing elements of C, O, Sb_2O_3 and Br, 17.9% of glass fibers materials such as SiO_2, MgO, BaO, Na_2O, SrO, and CaO, and 6.4% of metallic materials such as CuO, SnO_2, Fe_2O_3, and Cr_2O_3. The main elements detected in these raw nonmetallic PCBs were Br. Br was found at a content of mass 26.4%. In terms of the glass fiber materials, SiO_2, had the highest content at mass 10.2%, followed by CaO 7.2% and MgO 0.18%. For metallic materials, SnO_2

were found at a content of mass 2.14%, followed by CuO 3.05%, Fe_2O_3 1.10% and Cr_2O_3 0.07%.

Other elements found in nonmetallic PCBs cellulose paper reinforced phenolic resin were K_2O, TiO_2, Cl, Sb_2O_3, BaO, SO_3, SrO, Na_2O, ZnO, and MnO. These elements exist in small amount which is K_2O was found at mass 0.62%, followed by TiO_2 0.40%, Cl 0.31%, Sb_2O_3 0.25%, BaO and SO_3 0.51%, and SrO 0.07%. While other elements such as Na_2O, ZnO, and MnO were found at mass 0.05%, 0.04% and 0.02% respectively.

The elements that cannot be detected in raw nonmetallic PCBs glass reinforced epoxy resin and cellulose paper reinforced phenolic resins are carbon (C) and oxygen (O). It is because of carbon and oxygen elements exist in gaseous form. These caused carbon and oxygen elements cannot be detected even if it is present in the samples.

From the comparison on chemical composition of the nonmetallic PCBs, sand and cement it can be revealed that the silica content in nonmetallic PCBs is higher than cement but lower than sand. The presence of the higher amount of silica would assists towards pozzolanic reaction. However, the calcium oxide content is lower than cement.

Table 4.1: Chemical composition of nonmetallic PCBs samples A1, A2, B1, and B2, sand and cement

Elements	Nonmetallic PCBs glass fiber reinforced epoxy resin		Nonmetallic PCBs cellulose paper reinforced phenolic resin		Sand	Cement
	A1	**A2**	**B1**	**B2**		
CaO	18.98	18.62	5.67	7.21	-	60.85
SiO_2	43.24	41.39	10.16	10.02	84.15	18.45
Al_2O_3	9.17	7.86	-	-	0.75	4.07
SO_3	0.33	0.77	0.23	0.51	-	4.04
Br	6.53	9.22	26.36	22.49	-	-
CuO	5.83	8.27	1.42	3.05	-	-
BaO	0.50	0.59	0.23	0.51	-	-
Fe_2O_3	0.77	1.06	1.04	1.10	0.39	3.19
Na_2O	0.14	0.11	0.05	0.02	-	-
Cl	0.06	0.04	0.28	0.31	-	-
SnO_2	0.05	0.02	2.14	1.69	-	-
MgO	0.52	0.50	0.18	0.15	-	2.85
K_2O	0.16	0.25	0.47	0.62	-	0.22
MnO	-	-	0.02	0.02	-	0.12
TiO_2	0.44	0.17	0.40	0.37	-	0.12
P_2O_5	0.06	0.09	3.08	3.00	-	0.06
Sb_2O_3	-	-	0.25	0.22	-	-
SrO	0.14	0.06	0.07	0.04	-	0.02
ZrO_2	0.02	0.08	-	-	-	75ppm
ZnO	0.02	0.02	0.04	0.02	-	54ppm
As_2O_3	0.01	0.03	-	-	-	48ppm
Cr_2O_3	-	-	0.02	0.07	-	-
MoO_3	-	-	-	-	-	29ppm
Rb_2O	-	-	-	-	-	21ppm
NiO	77ppm	62ppm	-	-	-	-
pbO	5ppm	-	-	-	-	-

4.3 Leaching Tests for Heavy Metals

Since the waste nonmetallic PCBs used in this study also included heavy metals such as Cu, Pb and Cr, Crushed Block Leachability (CBL) tests for heavy metals were conducted in order to examine possible noxious effects of heavy metals to the environment. Thirteen elements were detected in this study. All elements studied are listed as heavy metal based on Environmental Quality (Scheduled Wastes) Regulation 2005. The EPA standard TCLP method EPA 1992a was employed to test and measure all the heavy metals contained in nonmetallic PCBs waste. The CBL tests were done in three replicates samples and the average value was reported. Table 4.2 lists the concentration of metals leached from nonmetallic PCBs and compared with existing standard, which is the Maximum Concentration of Contaminants for the Toxicity Characteristic Leaching Procedure (TCLP) specified under the guideline of Environmental Quality (Scheduled Wastes) Regulations 2005. Based on leaching tests conducted on nonmetallic PCBs, the concentrations of Cu, Zn, Cr, Cd, Pb, As, Ba, Se, Ag, Sn, B, Hg and Ni do not exceed the limits that was established by DOE.

Analysis of the samples showed that all parameters from four different types of samples did not exceed the prescribed limit stated in the guideline of DOE. Results showed that nonmetallic PCBs passed the DOE standard and considered not harmful to human or the environment if it is used as replacement in construction or other uses. The results of these analyses can be used because the nonmetallic PCBs were in critical condition where the chemical content was force to get released during testing. These conditions occur due to the concentration of extraction fluid used for laboratory leaching tests is higher compared on site, where they are generally prepared by the addition of chemicals with a high concentration (U.S. EPA, 1986). Distilled water does not contain chemical elements that are commonly found in soil and in turn will force the rest of the waste material dissolution rate become larger (Cote et al., 1986). Another advantage of distilled water is to reduce the influence of interference between extraction fluid and solid. Based on Reis and Brookes, (1999) distilled water is the best solution used for TCLP test.

Besides that, according to (Zain et al., 2004; Boyle et al., 1983), the use of acetic acid as an extractant provides an extreme condition for the samples and is expected to predict the metal released over many years in landfill conditions. In addition, during the leaching test, the sample was shaken. This procedure causes the extraction capability of the solution increases, because agitation provides aggressive conditions to extract a mixture (Salmiati, 2002). It means that, if the leaching tests were performed at site, the expected results will be less than the results obtained from this study. The TCLP was designed to be a rapid test for determining whether a solid waste should be a hazardous waste because of the presence of certain toxic elements. It was designed to simulate plausible worst-case leaching conditions that might be encountered in a landfill (Townsend et al., 2008). Based on research conducted by (Jang and Townsend, 2003), they had found that lead leachability is less in typical landfill leachate relative to the TCLP. Even though the nonmetallic PCBs still contains some metals, after separation process, their concentration are much lower compared to the DOE guideline. Therefore, as a conclusion, the results of these analyses are reliable and the use of waste nonmetallic PCBs is not expected to pollute environments.

Table 4.2: Result for leaching tests for heavy metals

Method	**Parameter**	**Content of Metals (mg/L) Sample A1**	**Content of Metals (mg/L) Sample B1**	**Content of Metals (mg/L) Sample A2**	**Content of Metals (mg/L) Sample B2**	**Guideline of Environmental Quality (Scheduled Wastes) Regulations 2005**
JSEPA 6010 B	Copper	59.09	62.380	54.72	60.11	100
JSEPA 6010 B	Zinc	0.436	0.130	0.642	0.194	100
JSEPA 6010 B	Chromium	0.004	0.155	0.004	0.083	5.00
JSEPA 6010 B	Cadmium	0.01	0.021	0.03	0.035	1.00
JSEPA 6010 B	Lead	0.074	0.026	0.051	0.020	5.00
JSEPA 6010 B	Arsenic	0.005	0.011	0.009	0.017	5.00
JSEPA 6010 B	Nickel	0.046	0.029	0.041	0.033	100
JSEPA 6010 B	Barium	2.462	2.773	2.572	2.531	100
JSEPA 6010 B	Selenium	< 0.004	< 0.004	< 0.004	< 0.004	1.0
JSEPA 6010 B	Silver	< 0.001	< 0.001	< 0.001	< 0.001	5.0
JSEPA 6010 B	Tin	< 0.01	< 0.01	< 0.01	< 0.01	100
JSEPA 6010 B	Boron	0.12	0.19	0.07	0.15	400
JSEPA 7470 A	Mercury	0.001	0.004	0.001	0.001	0.2

4.4 Mechanical Testing of Mortar

The purpose of this test was to identify the performance of mortar added with nonmetallic PCBs compared to the control mortar in term of compressive strength, flexural strength, and durability in acid condition.

4.4.1 Compressive Strength with Different Nonmetallic PCBs Content

The main purpose of compressive strength test is to determine the compressive strength of mortar at the age of 3, 7, and 28 curing days. Figure 4.3 and Table A1 (APPENDIX A) shows the change in compressive strength of mortars with different amounts of nonmetallic PCBs waste which are 0%, 10%, 20%, 30% and 40% by weight, for sample A1. Cement and sand were mixed at the ratio of 1 to 2.75. After three days, the compressive strength of mortar was 7.375 N/mm^2 for control mortar specimen, and for other mortars, the compressive strengths were 6.653 N/mm^2, 5.957 N/mm^2, 4.258 N/mm^2, and 2.490 N/mm^2 respectively. While for seven days, the compressive strength of control mortar specimen was 24.327 N/mm^2, and those of mortars with 10 wt%, 20 wt%, 30%, and 40 wt% nonmetallic PCBs were 22.589 N/mm^2, 19.383 N/mm^2, 12.541 N/mm^2, and 6.492 N/mm^2 respectively. Lastly, after twenty-eight days, the compressive strength of control mortar specimen was 33.562 N/mm^2, and the compressive strength for other mortars were 31.943 N/mm^2, 26.950 N/mm^2, 16.434 N/mm^2 and 10.145 N/mm^2 respectively.

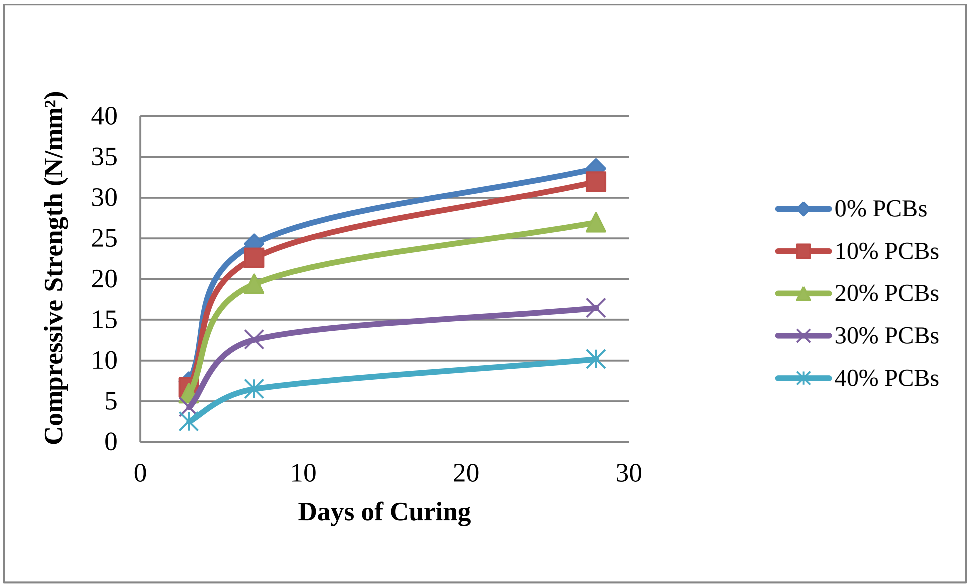

Figure 4.3: Result for compressive strength of mortar at the age of 3, 7, and 28 days of glass fiber reinforced epoxy resin sample A1, from wet separation process

Figure 4.4 and Table A2 (APPENDIX A) shows the change in compressive strength of mortars for PCBs made of cellulose paper reinforced phenolic resin. After three days, the compressive strength of mortar for sample B1 with 10 wt% nonmetallic PCBs was 6.173 N/mm^2, and for other mortars, the compressive strength were 4.741 N/mm^2, 1.960 N/mm^2, and 0.828 N/mm^2 respectively. While for seven days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 18.945 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 16.875 N/mm^2, 6.352 N/mm^2, and 1.549 N/mm^2 respectively. Lastly, after twenty-eight days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 27.726 N/mm^2, and the compressive strength for other mortars were 20.618 N/mm^2, 10.751 N/mm^2, and 3.437 N/mm^2 respectively.

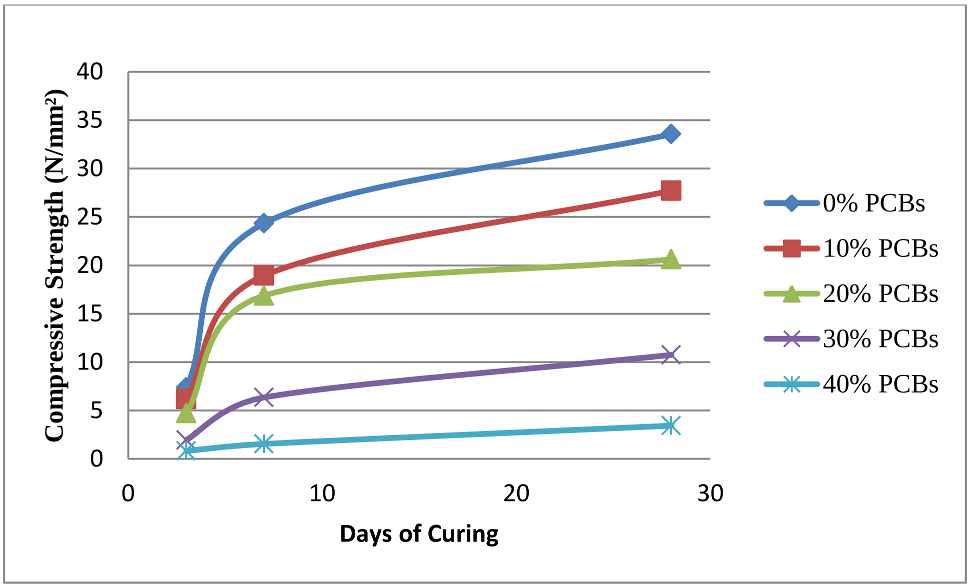

Figure 4.4: Result for compressive strength of mortars at the age of 3, 7, and 28 days for cellulose paper reinforced phenolic resin sample B1, from wet separation process

Figure 4.5 and Table A3 (APPENDIX A) shows the change in compressive strength of mortars for sample A2. After three days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 6.413 N/mm^2, and for other mortars, the compressive strength were 5.074 N/mm^2, 4.025 N/mm^2, and 2.360 N/mm^2 respectively. While for seven days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 20.350 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 17.622 N/mm^2, 10.629 N/mm^2, and 6.083 N/mm^2 respectively. Lastly, after twenty-eight days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 29.471 N/mm^2, and the compressive strength for other mortars were 21.882 N/mm^2, 16.073 N/mm^2, and 8.753 N/mm^2 respectively.

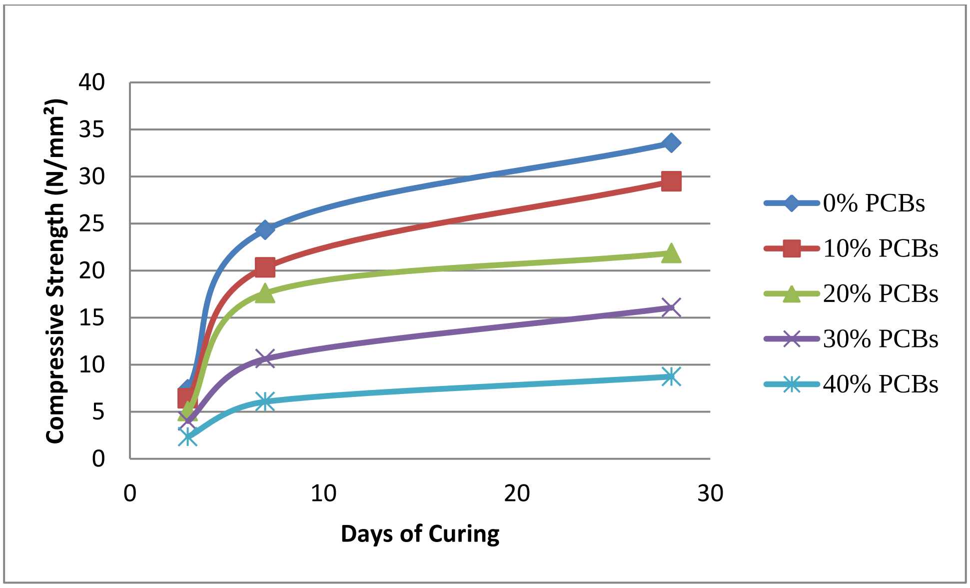

Figure 4.5: Result for compressive strength of mortar at the age of 3, 7, and 28 days for glass fiber reinforced epoxy resin sample A2, from dry separation process

Figure 4.6 and Table A4 (APPENDIX A) shows the change in compressive strength of mortars for sample B2. After three days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 5.778 N/mm^2, and for other mortars, the compressive strength were 5.232 N/mm^2, and 1.846 N/mm^2 respectively. While for seven days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 15.574 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 8.875 N/mm^2, 3.099 N/mm^2, and 0.64 N/mm^2 respectively. Lastly, after twenty-eight days, the compressive strength of mortar with 10 wt% nonmetallic PCBs was 23.322 N/mm^2, and the compressive strength for other mortars were 13.097 N/mm^2, 5.551 N/mm^2, and 1.22 N/mm^2 respectively.

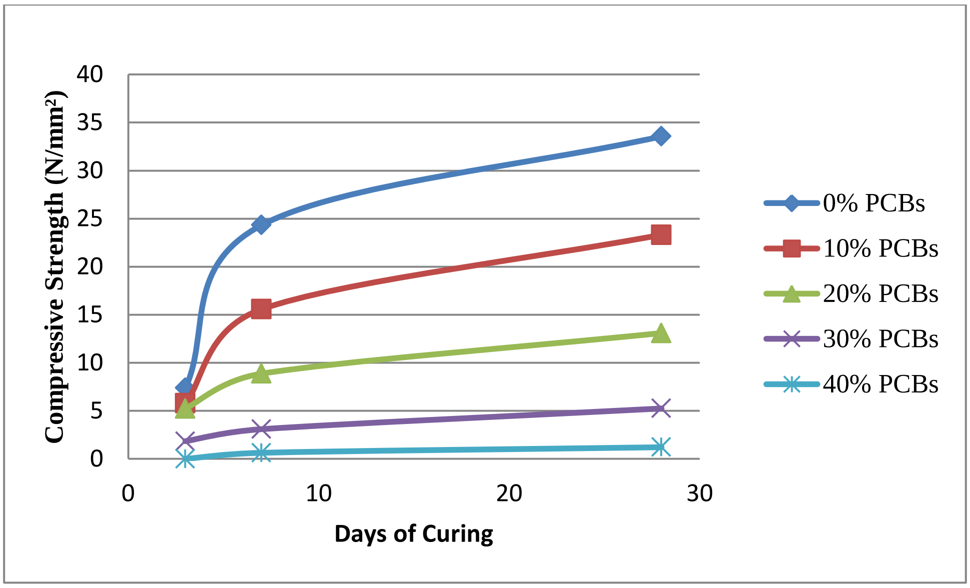

Figure 4.6: Result for compressive strength of mortar at the age of 3, 7, and 28 days for cellulose paper reinforced phenolic resin sample B2, from dry separation process

Based on overall results obtained from samples A1, A2, B1, and B2, it was found that the compressive strength for control mortar is higher compared with the others mortars added with nonmetallic PCBs waste. The compressive strength of mortars increase by days, but the strength reduces when the nonmetallic PCBs waste added in mortar increased. This might be due to the percentage of aggregate in control mortar is higher compared with the mortars added with nonmetallic PCBs. Generally aggregate will react with the cement during the hydration process and producing C-H-S gel mainly will produce calcium hydroxide. The calcium hydroxide then will react with silica and immediately the new C-S-H gel will be created and keep the bond between aggregate and cement (Eeydzah, 2010).

Besides that, the lower strength could be attributed to the fact that the very fine particles of the nonmetallic PCBs supplied a large amount of surface area per unit volume to be coated with cement. This might have effectively reduced the amount of cement available for binding the fine and coarse aggregates required to provide adequate strength (Benson et al., 1986). In previous studies conducted by Yusof et al. (2000) on the use of steel slag as aggregate, it indicated that slag has angular and rough surface. This attribute provides a good resistivity and interlocking in the concrete, and resulted in a higher compressive strength of concrete. In another study conducted by Guo et al. (2009), they found that when the content of nonmetallic PCBs increased the interlocking reaction and interfacial bonding between resin and nonmetallic PCBs does not occur. It is shows in Figure 2.5. The interlocking of cement and sand (Figure 4.7) occurs in reaction of one molecule with another molecule. These molecules are inter-related knitting. However the interlocking reaction does not occur in mortar added nonmetallic PCBs. This can clearly be seen from Figure 4.9 to 4.15. There is existence of pores caused by non-interlocking reaction between the molecules in mortar.

The lower strength also could be attributed to the retardation of cement hydration due to the presence of heavy metals in nonmetallic PCBs waste. From the previous studies conducted by Zain et al. (2004), they found that the strength of the copper slag mortar is generally lower than that of the control mortar.

Based on the ANOVA test, the result showed that (APPENDIX B), there is significant difference between the compressive strength of control mortar and mortar added with nonmetallic PCBs Sample B2, where the value of $P < 0.05$, which is 95% confidence level.

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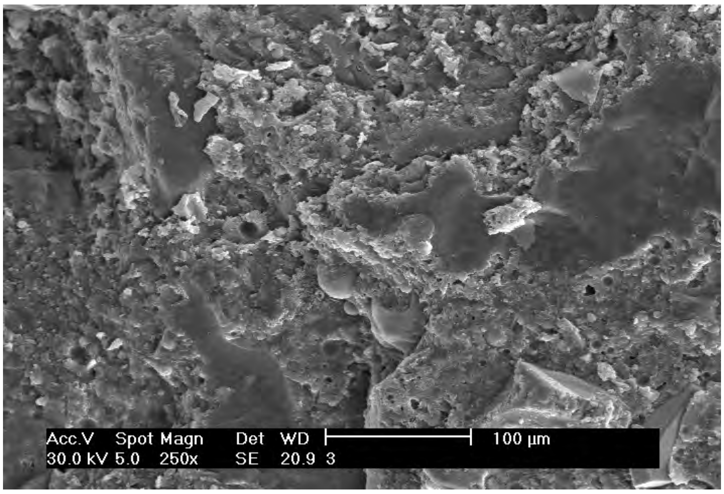


Figure 4.7: SEM micrograph of control mortar

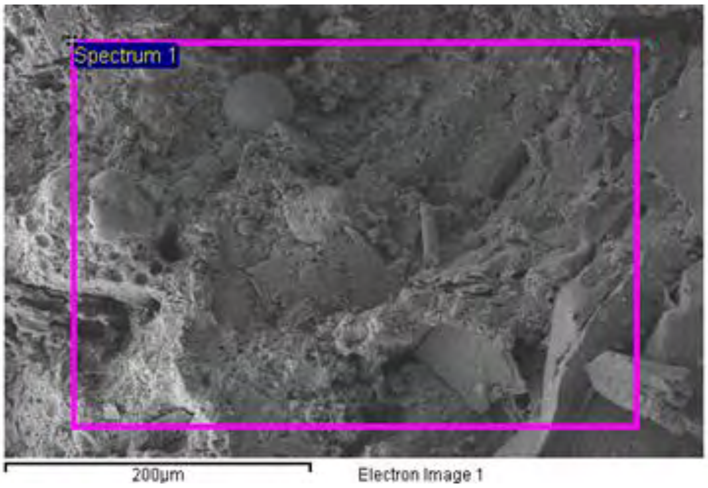
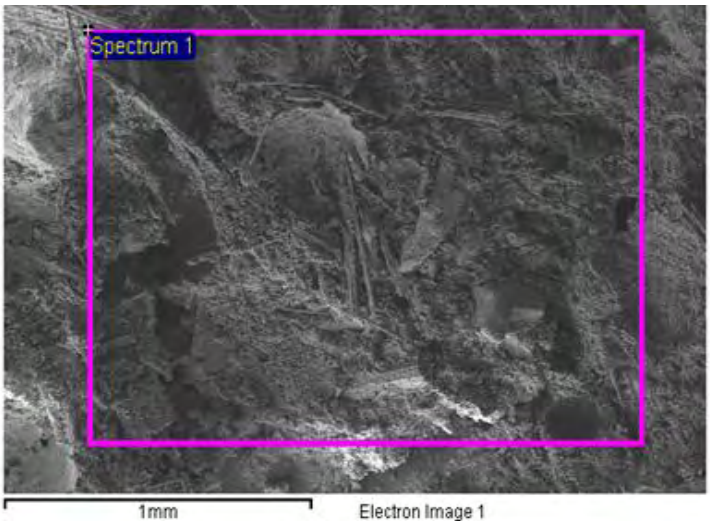


Figure 4.8: SEM micrograph of mortar added 10% nonmetallic PCBs sample A1



e 4.9: SEM micrograph of mortar added 40% nonmetallic PCBs sample A1

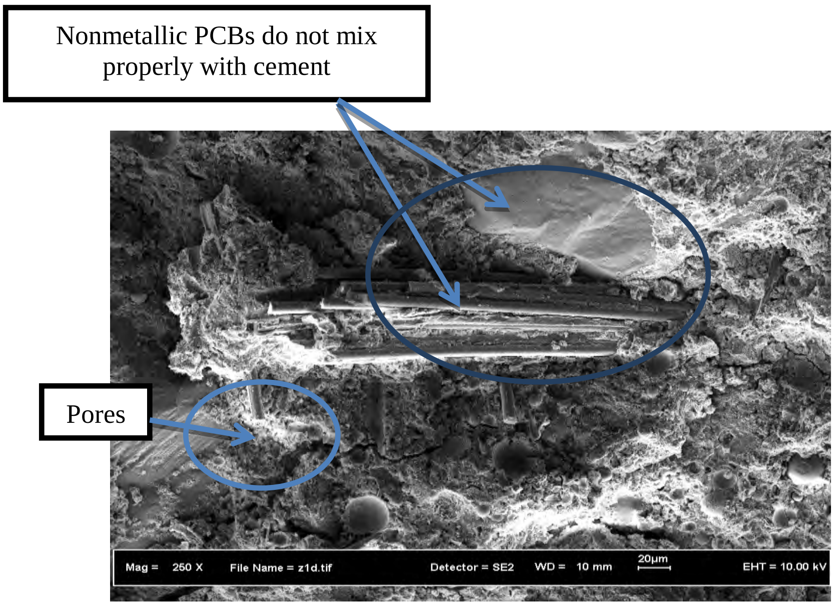


Figure 4.10: SEM micrograph of mortar added 10% nonmetallic PCBs sample B1

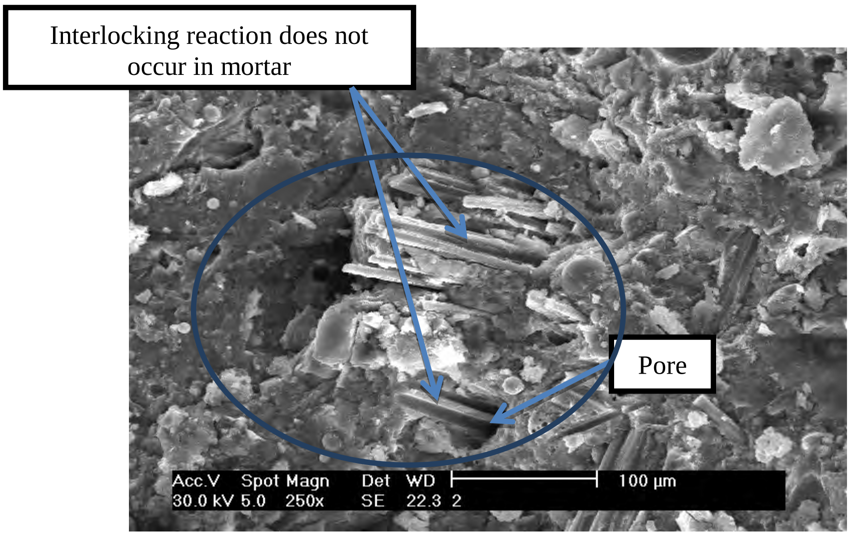


Figure 4.11: SEM micrograph of mortar added 40% nonmetallic PCBs

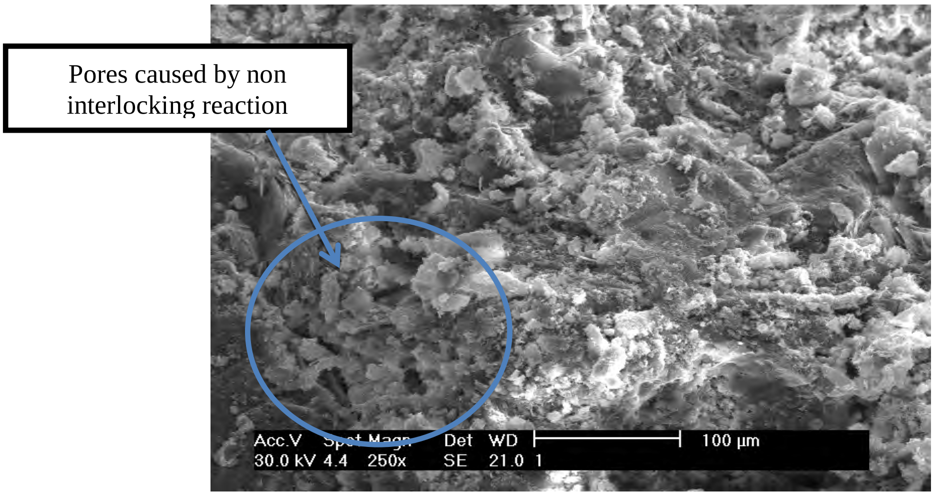


Figure 4.12: SEM micrograph of mortar added 10% nonmetallic PCBs sample A2

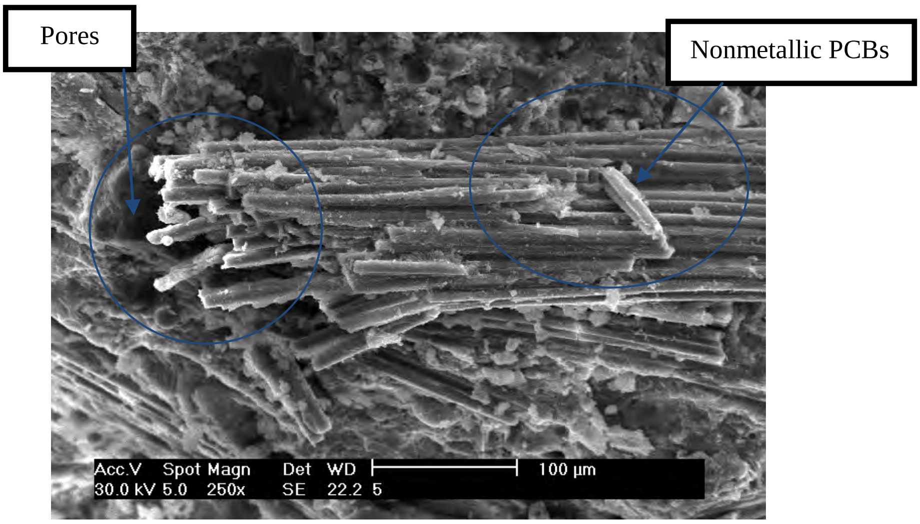


Figure 4.13: SEM micrograph of mortar added 40% nonmetallic PCBs sample A2

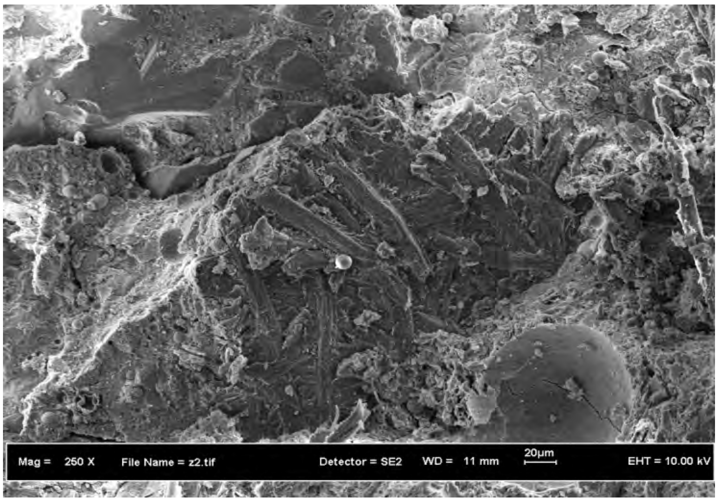


Figure 4.14: SEM micrograph of mortar added 10% nonmetallic PCBs sample B2

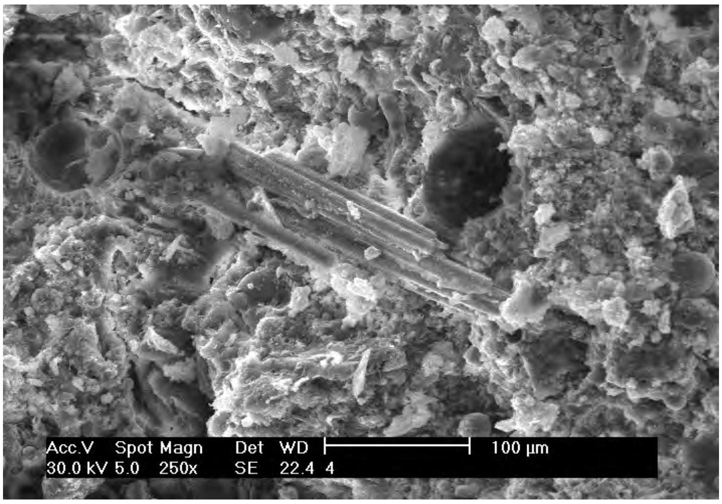


Figure 4.15: SEM micrograph of mortar added 40% nonmetallic PCBs sample B2

As the curing time prolonged, the compressive strengths of both control mortar specimens and mortar added with nonmetallic PCBs increased. After 28 days of curing time, considerably high compressive strengths were measured. According to Kamarudin (1995), almost the entire strength of the mortar was achieved within 28 days from the date of mixture and ultimate strength is between 70%-80% after 28 days. The increasing strength of mortar after this period is slow even decline. Therefore, most of the mix design is based on the compressive strength of mortar at 28 days.

The value of compressive strengths of mortars sample A1 is higher than sample A2 and sample B1 is higher than sample B2. Meanwhile, the value of compressive strength for mortar sample of nonmetallic PCBs made from epoxy resin reinforced glass fiber (sample A1 and A2) is higher than mortar sample of nonmetallic PCBs that made from cellulose paper reinforced phenolic resin (sample B1 and B2). Higher the amount of waste nonmetallic PCBs added into mortar, lower compressive strength is achieved. It was speculated that, considerable amount of resin contained in mortar added with nonmetallic PCBs waste might have an influence on the compressive strength of mortar (Ban et al., 2005). From the analysis of chemical composition, it was found that sample A1 contains the smallest element of resin compared with others samples. This affects the increase of compressive strength of mortar. In addition, the content of glass fiber also affects the strength of concrete. The higher compressive strength of sample A1 might because of the higher content of glass fiber compared with others samples. Based on Chandramouli et al. (2010), fibers like glass, carbon, polypropylene and aramid fiber provide improvements in tensile strength, fatigue characteristics, durability, shrinkage characteristics, impact, cavitation, erosion resistance and serviceability of concrete.

From the overall analysis conducted, it was found that the final value of compressive strength for sample A1 gave the highest value compared with other samples. All analysis was based on ASTM C1329/C1329M - 12, where the standard compressive strength of cement mortar at 28 days is 20.0 N/mm^2. From analysis of compressive strength with different proportions of nonmetallic PCBs waste (Figure 4.16), it was found that the optimum compressive strength of 20 N/mm^2 was achieved when 28% of nonmetallic PCBs are used to replace sand.

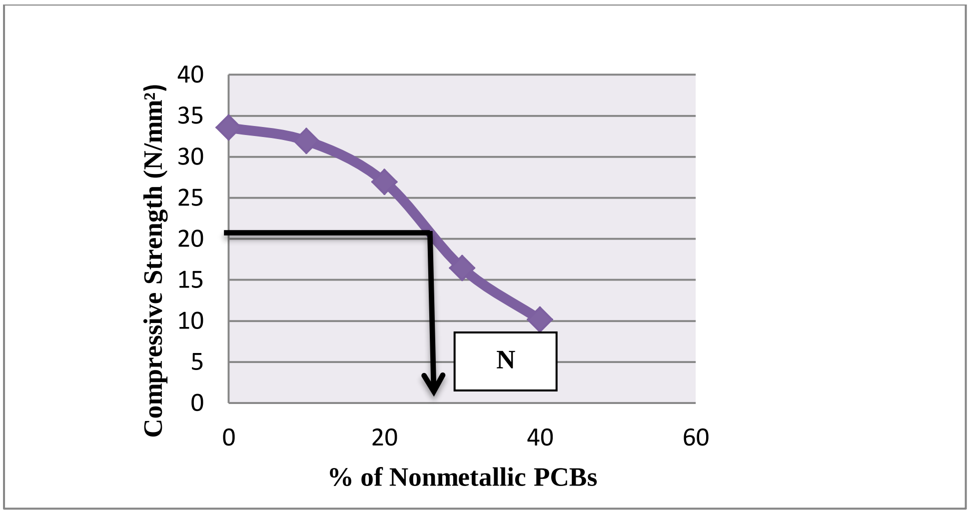


Figure 4.16: Compressive strength of certain proportion mixture of nonmetallic PCBs. The compressive strength of 20 N/mm^2 is achieved with 28% of nonmetallic PCBs.

4.4.2 Durability in Acid Atmosphere

The change in weight and compressive strength of mortar added with 10 % by wt of nonmetallic PCBs waste and control mortar in the acid atmosphere were examined in order to investigate the durability of the mortars. Based on Figure 4.17, the change in weight after 40 days soaking in 5% H_2SO_4 solution is 1.06% for mortar with nonmetallic PCBs and 0.85% for control mortar. It was considered, during the soaking period, its weight is increased due to the adsorption of acid solution into the mortar. After 60 days, the weight gradually decreased and the total weight change is about 1.11% for mortar added PCBs waste and 0.94% for control mortar. Based on Ban et al. (2005), all of this condition occurs due to the dryness of cement and the creation of hydrates inside the mortar. Besides that, according to Ahmed (2008) the weight of mortar decreased during soaking time might be due to the immersing reaction of H_2SO_4 solution to cement. The reaction between calcium hydroxide $Ca(OH)_2$ presented in the specimens and H_2SO_4, could induce tensile stress, resulting in cracking and scaling of mortar.

Figure 4.18 shows the changes in compressive strength of mortar added with 10 % by wt of nonmetallic PCBs and control mortar after soaking in 5% H_2SO_4 solution. From analysis, it was found that the change in compressive strength after 60 days soaking in 5% H_2SO_4 solution is 11.11% for mortar with nonmetallic PCBs and 13.29% for control mortar. Compared to original strength prior to soaking, the compressive strength of mortar added with nonmetallic PCBs gradually decreased during the soaking period. The control mortar also showed a similar behavior.

The decrease in compressive strength of mortar might be due to the cement erosion that was glued to mortar. Based on Mehta et al. (1983) H_2SO_4 solution is known to play a role in decreasing adhesive between cement pastes and aggregate. This condition typically occurs where H_2SO_4 solution penetrates the surface of mortar. The reactions occurred between calcium hydroxide $Ca(OH)_2$ and H_2SO_4 in mortar can cause the change of microstructure of mortar (Vanchai et al., 2012). It is because some of cement paste compounds are unstable in the presence of acid, might decompose causing the concrete to expand losses of bond between the cement paste and aggregate, losses its compactness and strength, and ultimately decrease its service life. The effect of these changes causes an overall loss of mortar strength. However it should be marked that the erosion resistance of mortar added nonmetallic PCBs was stronger than control mortar. This condition is due to the acid resistance of resin included in waste PCB (Ban et al., 2005).

Based on the ANOVA test, the result showed that (APPENDIX B), there is no significant difference between the change in weight of control mortar and mortar added with 10% Nonmetallic PCBs, where the value of $P > 0.05$, which is 0.806 (95% confidence level). While, there is significant difference between the change in compressive strength of control mortar and mortar added with 10% Nonmetallic PCBs, where the value of $P < 0.05$, which is 0.011.

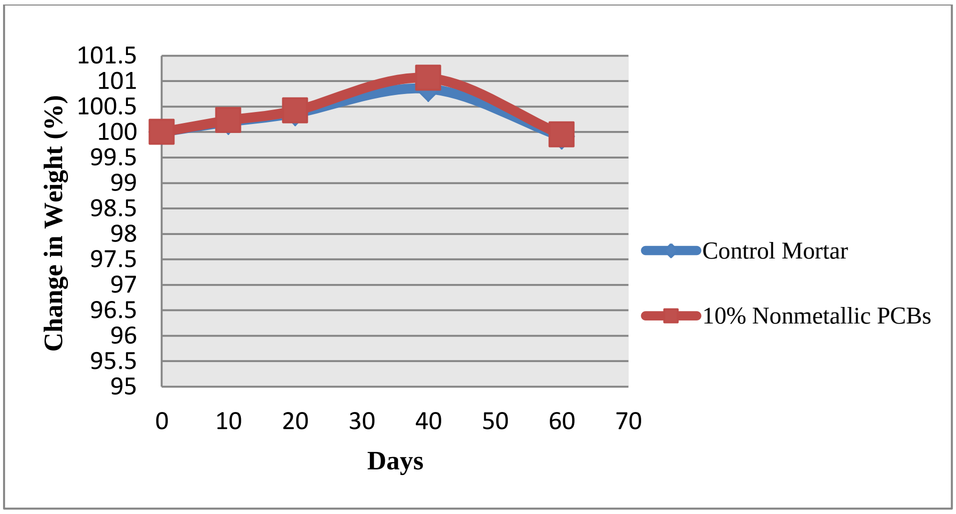


Figure 4.17: Change in weight of control mortar and mortar added with 10% nonmetallic PCBs in (5% H_2SO_4) acid conditions.

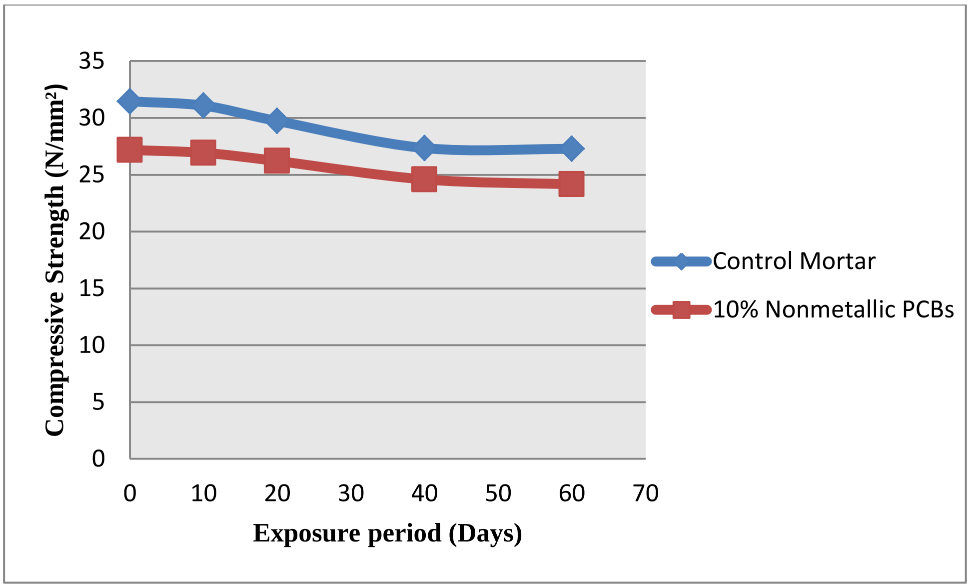


Figure 4.18: Changes in compressive strength of control mortar and mortar added with 10% Nonmetallic PCBs in (5% H_2SO_4) acid conditions

4.4.3 Flexural Strength on Mortar

The main purpose of flexural strength test is to determine the flexural strength of mortar at the age of 7, and 28 curing days. Figure 4.19 and Table A8 (APPENDIX A) shows the results for flexural strength test of control mortar, and mortar added with nonmetallic PCBs sample A1. Based on the results, the flexural strength at seven days curing age for control mortar was 5.26 N/mm^2 and those of mortars with 10 wt%, 20 wt%, 30%, and 40 wt% nonmetallic PCBs were 4.98 N/mm^2, 3.93 N/mm^2, 3.59 N/mm^2, and 2.31 N/mm^2 respectively. Figure 4.20 and Table A8 (APPENDIX A) shows the result for flexural strength after twenty-eight days curing age. The flexural strength of control mortar was 8.03 N/mm^2 and the flexural strength for other mortars were 7.74 N/mm^2, 6.25 N/mm^2, 4.71 N/mm^2 and 3.50 N/mm^2 respectively.

While Figure 4.19 and Table A9 (APPENDIX A) shows the flexural strength of sample B1. For seven days curing age, the flexural strength of mortar added with 10 wt% nonmetallic PCBs was 4.05 N/mm^2, and for other mortars, the flexural strength were 3.79 N/mm^2, 3.38 N/mm^2, and 2.71 N/mm^2 respectively. While for twenty-eight days (Figure 4.20), the flexural strength of mortar added with 10 wt% nonmetallic PCBs was 7.21 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 6.19 N/mm^2, 4.58 N/mm^2, and 3.92 N/mm^2 respectively.

Based on analysis of sample A2 (Figure 4.19 and 4.20) and Table A10 (APPENDIX A), it was found that the Flexural strength of mortar added with 10% nonmetallic PCBs for seven days curing age was 3.88 N/mm^2, and for other mortars, the flexural strength were 3.20 N/mm^2, 2.62 N/mm^2, and 1.83 N/mm^2 respectively. For twenty-eight days curing ages, the flexural strength of mortar added with 10 wt% nonmetallic PCBs was 6.25 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 4.90 N/mm^2, 3.27 N/mm^2, and 2.65 N/mm^2 respectively.

The results of sample B2 are shown in Figure 4.19 and and Table A11 (APPENDIX A). At seven days curing ages, the Flexural strength of mortar added with 10 wt% nonmetallic PCBs was 3.73 N/mm^2, and for other mortars, the flexural strength were 3.11 N/mm^2, 2.45 N/mm^2, and 1.59 N/mm^2 respectively. While Figure 4.20 shows the result for flexural strength after twenty-eight days curing age. The flexural strength of mortar added with 10 wt% nonmetallic PCBs was 5.81 N/mm^2, and those of mortars with 20 wt%, 30 wt%, and 40 wt% nonmetallic PCBs were 4.76 N/mm^2, 4.05 N/mm^2, and 2.71 N/mm^2 respectively.

From the results, it can be concluded that the flexural strength of control mortar is higher than mortar added with nonmetallic PCBs waste. The lower flexural strength of mortar added with nonmetallic PCBs might be due to balling effect of fiber during the mixing process. In this study, result from SEM test shows the particle of nonmetallic PCBs did not mix evenly with cement particles. When the fiber is not randomly distributed in samples, the fibers do not fully act as reinforcement and not much assists in flexural strength (Halimah, 2009).

Compared between the two types of nonmetallic PCBs used, the result showed that mortar added with nonmetallic PCBs glass fiber reinforced epoxy resin samples A1 and A2 showed higher flexural strengths than that of mortar added with nonmetallic PCBs cellulose paper reinforced phenolic resin samples B1 and B2. This may be due to the higher in the length and diameter of nonmetallic PCBs glass fiber reinforced epoxy resin compared with nonmetallic PCBs cellulose paper reinforced phenolic resin. The higher in the length and diameter ratio of the fiber usually enhances the flexural strength and toughness of the concrete (Zheng et al. 2009). From this study, the length of fibers applied in mixes is not same for both samples. Based on SEM test, it was found that nonmetallic PCBs glass fiber reinforced epoxy resin is long in size and sharp compared with nonmetallic PCBs cellulose paper reinforced phenolic resin that is short and round.

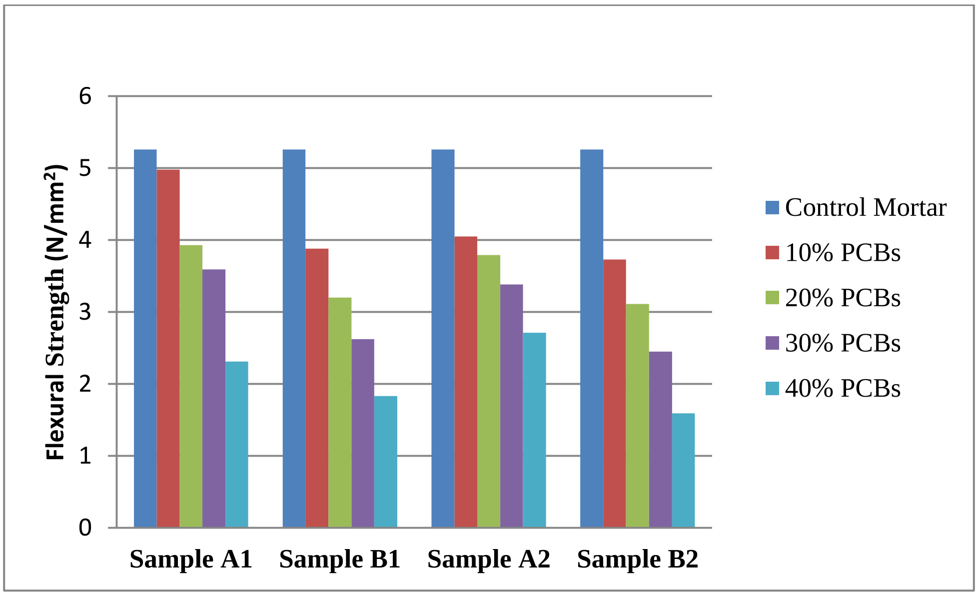


Figure 4.19: Flexural strength of mortars at 7 Days

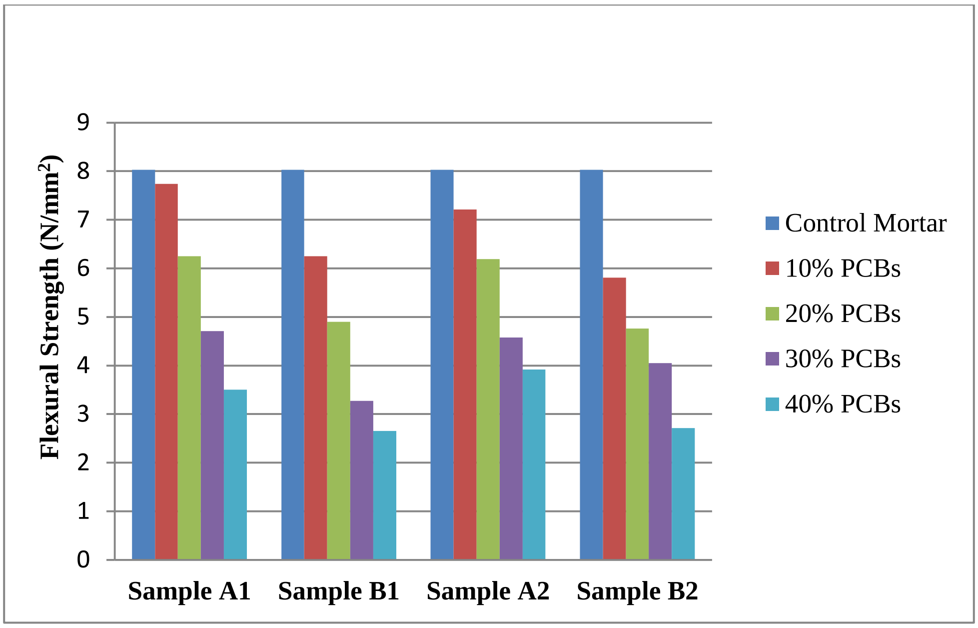


Figure 4.20: Flexural strength of mortars at 28 Days

4.5 Whole Block Leachability Test

Whole Block Leaching (WBL) test was conducted to determine the leachability of metals from the solidified cubes such as mortar. It is important to determine the concentration of metals from treated waste. In this study, wastes were treated using solidification and stabilization processes by adding the nonmetallic PCBs waste into cement mortar as sand replacement. In this experiment, the parameters tested were Cu, Ni, Cr, Zn, Pb and Cd. It is because these metals are considered hazardous by DOE compared with other metals. From the analysis carried out on the control mortar, it was found that, the metal concentrations of Cu, Ni, Cr, Zn, Pb and Cd achieved DOE standard which is Environmental Quality (Scheduled Wastes) Regulations 2005 at all curing ages. Although the concentrations of metals are not stable with the increasing in curing ages of mortars, but it still achieved the standard.

Table 4.3 shows the result of metal concentrations from leaching test for sample A1. From the analysis, the concentration of Cr, Pb, Cd, Zn, Cu and Ni achieved the standards at all curing ages of mortar and nonmetallic PCBs added mortar at all proportions. Concentration of all the ions declined with the increasing in curing ages of mortar. Although the concentration of Cr, Ni, and Cd increased and sometimes unstable, but it still achieved the standards.

Based on Table 4.4 and analysis conducted on sample B1, it was found that concentration of all the ions achieved the standards. The concentrations of Ni and Zn decreased with the increasing of curing ages. While the concentrations of Cr, Cd, and Cu were unstable but they still passed the standards. Although the concentration of Pb increased, but it still achieved the standard.

Based on the analysis on sample A2, Table 4.5, it was found that the concentrations of Cu, Zn, Cr, Ni, Pb, and Cd passed the standards. The concentrations of Cu and Cd increased while for Pb decreased when the mortar curing ages increase. The changes in concentration of Ni, Cr and Zn for this sample were unstable.

From the analysis on sample B2, Table 4.6, it can be noted that the concentration of all the metals such as Cr, Ni, Zn, Cu, Pb and Cd met the standards. It also found that the concentration of Ni, Cd and Zn decreased, while the concentrations of Cr and Pb were unstable. But the concentration of Cu increased.

The patterns of the metal concentrations leached from mortar samples A1, A2, B1, and B2, were varied which are increase, decrease or unstable. It was found that the concentration of Zn and Ni were decreased with the increasing of curing ages. While, the concentration of Cu increased. The concentration of Cr was unstable but still achieved the standard. The concentrations of all metals were below the DOE standards. Generally the longer curing ages of the mortars, the lower concentrations of metal in leachate. It means that the ability of metal ions to be bound with other materials is higher after 28 days curing ages. According to Hanna et al. (1995), in a solid such as concrete, insoluble particles containing hazardous components of waste can be effectively confined in the matrix of the hydrated cement. All of chemicals was trapped and does not move, caused the concentration of metal ions release out decreased. This is also suitable with study conducted by Mashitah et al. (2000) and Rabitah (2000) which states that waste material containing metal ions was successfully solidified into cement matrix. This caused the concentrations of ion leached achieved the standard.

Besides that, study conducted by Tashiro et al. (1977) stated that even if heavy metal compounds have high solubility, but metal ions were fixed in a solid through solidification of cement. This is a principal feature of solidification of cement. This mechanism is considered to be due to absorption by cement hydrates, substitution and solid solution in hydrate structure, or formation of compounds.

Table 4.3: Result for Whole Block Leachability test on mortar sample A1

Parameter	**Curing days for different proportions of nonmetallic PCBs waste**														
	3 Days					**7 Days**					**28 Days**				
	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Copper	1.37	2.56	2.45	3.47	4.77	0.019	3.30	2.10	3.13	4.52	0.005	2.31	0.30	1.60	1.29
Zinc	1.51	1.78	2.08	2.44	2.51	0.042	1.61	1.86	1.01	2.19	0.026	1.53	1.77	2.10	1.93
Chromium	0.01	0.014	0.017	0.038	0.000	0.000	0.057	0.016	0.012	0.094	0.000	0.000	0.013	0.038	0.071
Nickel	0.021	0.016	0.041	0.044	1.02	0.005	0.05	0.018	0.027	0.14	0.002	0.01	0.013	0.021	0.05
Cadmium	0.000	0.005	0.018	0.018	0.016	0.000	0.000	0.009	0.010	0.012	0.000	0.008	0.010	0.017	0.015
Lead	0.012	0.038	0.021	0.029	0.032	0.000	0.095	0.071	0.078	0.064	0.000	0.011	0.023	0.018	0.024

Table 4.4: Result for Whole Block Leachability test on mortar sample B1

Parameter	**Curing days for different proportions of nonmetallic PCBs waste**														
	3 Days					**7 Days**					**28 Days**				
	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Copper	1.37	0.03	1.64	0.98	2.56	0.019	1.09	0.25	1.33	2.57	0.005	0.50	3.84	2.41	2.79
Zinc	1.51	1.85	2.11	2.13	2.20	0.042	1.69	2.06	1.41	1.49	0.026	1.17	1.62	1.38	1.41
Chromium	0.01	0.017	0.025	0.083	0.044	0.000	0.005	0.087	0.006	0.019	0.000	0.148	0.046	0.001	0.035
Nickel	0.021	0.025	0.041	0.042	0.046	0.005	0.018	0.025	0.024	0.029	0.002	0.013	0.027	0.019	0.020
Cadmium	0.000	0.004	0.009	0.007	0.004	0.000	0.001	0.014	0.011	0.006	0.000	0.007	0.013	0.008	0.002
Lead	0.012	0.027	0.010	0.029	0.012	0.000	0.018	0.023	0.028	0.021	0.000	0.037	0.039	0.042	0.031

Table 4.5: Result for Whole Block Leachability test on mortar sample A2

Parameter	Curing days for different proportions of nonmetallic PCBs waste														
	3 Days					7 Days					28 Days				
	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Copper	1.37	2.39	2.75	2.97	4.31	0.019	2.82	2.80	3.16	4.51	0.005	2.15	2.89	3.21	4.55
Zinc	1.51	2.06	2.41	2.69	2.82	0.042	2.22	2.49	2.31	2.90	0.026	2.27	2.38	2.66	2.97
Chromium	0.01	0.013	0.025	0.066	0.061	0.000	0.009	0.016	0.082	0.048	0.000	0.007	0.011	0.035	0.018
Nickel	0.021	0.021	0.055	0.072	0.079	0.005	0.019	0.038	0.060	0.047	0.002	0.013	0.026	0.055	0.04
Cadmium	0.000	0 007	0.004	0.010	0.009	0.000	0.010	0.007	0.015	0.012	0.000	0.016	0.011	0.019	0.023
Lead	0.012	0.014	0.019	0.012	0.011	0.000	0.017	0.012	0.010	0.010	0.000	0.013	0.015	0.008	0.002

Table 4.6: Result for Whole Block Leachability test on mortar sample B2

Parameter	Curing days for different proportions of nonmetallic PCBs waste														
	3 Days					7 Days					28 Days				
	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Copper	1.37	0.09	0.91	1.59	1.33	0.019	0.18	0.94	2.01	2.42	0.005	0.57	1.73	2.49	2.71
Zinc	1.51	1.83	2.12	2.05	2.66	0.042	1.46	1.79	1.77	2.30	0.026	1.08	1.35	1.42	1.99
Chromium	0.01	0.007	0.035	0.006	0.086	0.000	0.064	0.082	0.075	0.091	0.000	0.053	0.085	0.077	0.032
Nickel	0.021	0.017	0.022	0.028	0.022	0.005	0.012	0.017	0.023	0.019	0.002	0.012	0.015	0.025	0.013
Cadmium	0.000	0.018	0.025	0.020	0.023	0.000	0.013	0.019	0.018	0.020	0.000	0.011	0.016	0.020	0.017
Lead	0.012	0.47	0.52	0.71	0.78	0.000	0.55	0.59	0.74	0.71	0.000	0.53	0.69	0.65	0.77

4.6 Comparison Results of Crushed Block Leachability Test and Whole Block Leachability (WBL) Test

In this study, Crushed Block Leachability (CBL) test is categorized as a testing on samples without treatment, where 100 gram raw nonmetallic PCBs powder was used in this test to get the metal concentrations in leachate. While Whole Block Leachability (WBL) test is categorized as nonmetallic PCBs that has been treated using solidification and stabilization processes where 100 gram nonmetallic PCBs was used as fine aggregate in mortar to replace sand. Table 4.7 showed that almost all of concentrations of metals detected in the CBL test (without treatment) were higher than the concentration of metals in WBL test (with treatment).

The high concentrations of metals leached from CBL test are probably due to the physical properties of the sample, where the surface area of the waste used in this study have influenced the concentration of metals. The smaller size of wastes the more surface area available per unit weight. This phenomenon has been reported in various studies, including Yap (1998) and Conner (1990).

The concentration rates of contaminants are lower in treated nonmetallic PCBs. This is due to the stabilization from matrix bonding of solidified contaminants in cement and the whole integration undisturbed cube that used in this test. The cube has a limited surface area for contaminants to be discharged out by leachate (Rabitah, 2000).

Table 4.7: Results of Crushed Block Leachability Test and Whole Block Leachability (WBL) Test

Method	Parameter	Content of Metals (mg/L) CBL	Content of Metals (mg/L) WBL	DOE Guideline
USEPA 6010 B	Copper	62.380	4.590	100
USEPA 6010 B	Zinc	0.130	0.004	100
USEPA 6010 B	Chromium	0.155	0.011	5.00
USEPA 6010 B	Cadmium	0.021	0.004	1.00
USEPA 6010 B	Lead	0.026	0.007	5.00
USEPA 6010 B	Arsenic	0.011	0.004	5.00
USEPA 6010 B	Nickel	0.029	0.005	100
USEPA 6010 B	Barium	2.773	0.062	100
USEPA 6010 B	Selenium	< 0.004	<0.004	1.0
USEPA 6010 B	Silver	< 0.001	<0.001	5.0
USEPA 6010 B	Tin	< 0.01	<0.01	100
USEPA 6010 B	Boron	0.19	0.003	400
USEPA 7470 A	Mercury	0.004	0.000	0.2

4.7 Mechanical Testing of Cement Brick

The purpose of this test was to identify the performance of cement brick added with nonmetallic PCBs compared to the control cement brick in term of water absorption and compressive strength.

4.7.1 Water Absorption

Water absorption for brick is important in order to get the rate of water absorbed to the brick. Figure 4.21 indicates the result of water absorption on cement bricks at 28 curing days. The result shows, the percentage of water absorption is

3.18% for control cement bricks. While for 10%, 15%, 25%, 40%, 45% and 50% cement brick added with nonmetallic PCBs the percentage of water absorption were 3.55%, 5.72%, 9.32%, 13.18, 13.47, and 13.6% respectively. From the figure, we found that after 28 days of curing age the control cement brick has a lesser absorption capability compared to cement brick added with nonmetallic PCBs. The absorption capability is increased with the increasing of proportions of nonmetallic PCBs waste added into the cement bricks. This might happen because of the capillary effect on the cement brick with the nonmetallic PCBs is higher compared with control cement brick. Capillary effect is depends on the structure of the surface area exposed to water. The more compact of surface structure, the smaller the capillary effect (Ahmed, 2008). From SEM analysis, it was found that the surface structure of control brick (Figure 4.22a) is more compact than brick added with nonmetallic PCBs (Figure 4.22b). There are existences of pores on the surface structure of the brick added with nonmetallic PCBs. This resulted the higher capillary effect on brick added with nonmetallic PCBs.

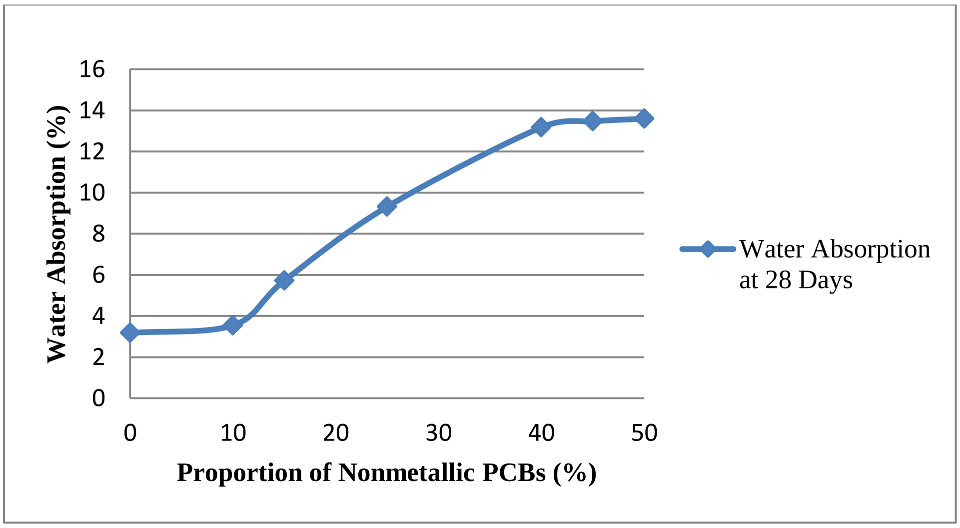


Figure 4.21: Water absorption of cement brick at 28 day

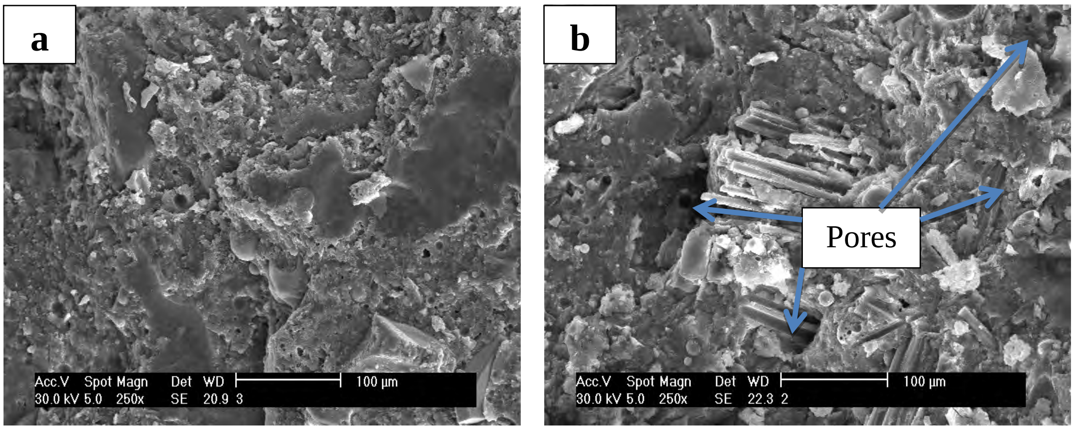


Figure 4.22: SEM micrograph of sample control cement brick (a) and brick added with nonmetallic PCBs (b).

4.7.2 Compressive Strength of Cement Brick

Table 4.8 shows the compressive strength of cement brick and cement brick added with nonmetallic PCBs as sand replacement. The compressive strength of control cement bricks at seven days was 18.21 N/mm^2. While the compressive strength for 10%, 15%, 25%, 40%, 45%, and 50% cement bricks added with nonmetallic PCBs were 9.06 N/mm^2, 8.71 N/mm^2, 3.81 N/mm^2, 3.73 N/mm^2, 3.04 N/mm^2, and 2.82 N/mm^2 respectively. The compressive strength of control brick at 28 days was 23.36 N/mm2, while the strength for different percentages of nonmetallic PCBs added into cement bricks were 13.419 N/mm^2, 12.504 N/mm^2, 7.578 N/mm^2, 5.803 N/mm^2, 5.56 N/mm^2, and 5.253 N/mm^2 respectively.

All analysis was based on M.S. 7.6:1972, where the standard compressive strength of cement bricks is 7.0 N/mm^2. From the graph of compressive strength of brick versus proportion of nonmetallic PCBs as sand replacement (Figure 4.23), it was found that the optimum compressive strength of 7 N/mm^2 was achieved when 30% of nonmetallic PCB was used to replace sand. This showed that, the nonmetallic PCBs that are able to be used in cement bricks is not more than 30%.

This is to ensure that the value of compressive strength of bricks is still within the standard. This result also shows, if the generation of nonmetallic PCBs waste are 40 tons per year per factory, it is estimated that a total of 40,040 bricks can be produced using nonmetallic PCBs as sand replacement. The calculation for this estimation is shown in APPENDIX E.

Table 4.8: Compressive strength of cement brick

Proportion of Nonmetallic PCBs	**Compressive Strength (N/mm^2) at Different Curing Days**	
	7 Days	**28 Days**
0%	18.214	23.36
10%	9.061	13.419
15%	8.71	12.504
25%	3.814	7.578
40%	3.730	5.803
45%	3.046	5.56
50%	2.821	5.253

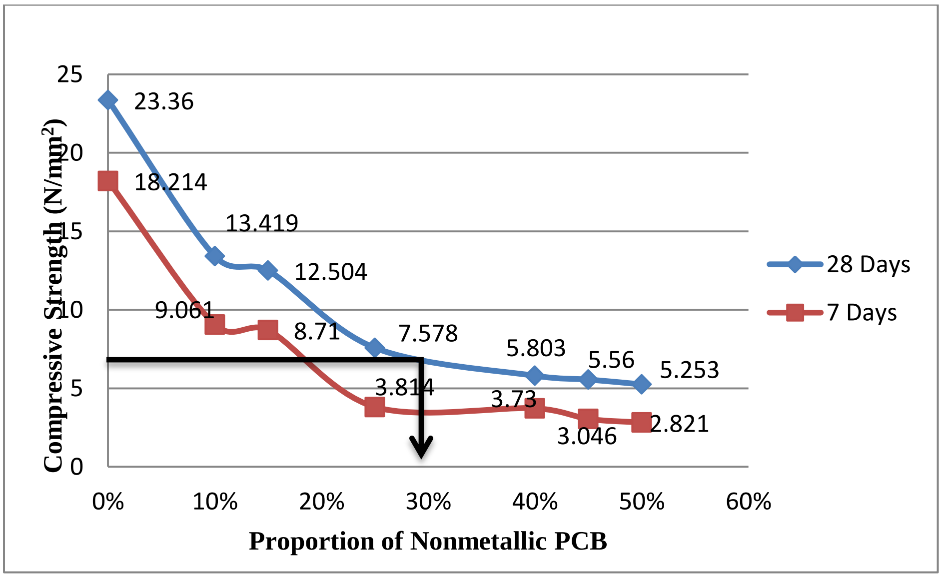


Figure 4.23: Compressive strength of cement brick versus proportion of nonmetallic PCBs.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This research aimed to study the suitability of nonmetallic PCBs as a nontoxic material in terms of environmental quality and the effectiveness of waste treatment processes on nonmetallic PCBs in term of leachability, and mechanical properties of mortar and cement brick.

5.2 Conclusion

Based on this research, the following conclusions can be drawn. Firstly we found that the concentration of all metals from four different types of raw nonmetallic PCBs did not exceed the prescribed limit. So nonmetallic PCBs is considered not harmful to human or the environment if it is used as an additive in construction or others uses.

Although the compressive and flexural strength of mortar added with nonmetallic PCBs is lower than control mortar, but the strength still achieved the standard if the nonmetallic PCBs used to replace sand is not more than 28%. For potential application, nonmetallic PCBs made from epoxy resin reinforced glass fiber can be reuse as materials in making cement brick. It is because the proportion of cement to sand for brick is higher compared with mortar, thus making more nonmetallic PCBs can be used as sand replacement. The reuse of nonmetallic PCBs are more economic since the cost of the nonmetallic PCBs waste can be considered as zero because they are unwanted waste otherwise would be expensive if sent to disposal or treatment.

The concentrations of all metals of control mortar and mortar added with nonmetallic PCBs were below the DOE standards. The longer curing ages of the mortars, the lower concentrations of metal in leachate. Almost all of concentrations of metals detected in the raw nonmetallic PCBs (without treatment) were higher than the concentration of metals in mortar added with nonmetallic PCBs (with treatment). Waste treatment of nonmetallic PCBs using cement was effective for prevention of metal leaching from mortar cubes. As a conclusion this study has achieved the objectives to proved that nonmetallic PCBs is safe to environmental and have potential to be reuse as sand replacement in construction materials.

5.3 Recommendations for Future Works

There are many aspects in reuse of nonmetallic PCBs which could be investigated further in the future. Some suggestion and recommendations in future study are as follows:

i. Study the mechanical properties of composite materials made from nonmetallic PCBs waste.

ii. Leachability test should be done in a longer period to study the leaching characteristics of mortar added with nonmetallic PCBs waste.

iii. Further study on the strength and durability aspects of mortar added with nonmetallic PCBs cooperating with any other replacement or admixtures materials.

iv. Also can be recommended to carry on the investigation of mortar added nonmetallic PCBs for the rest of durability aspects of high strength concrete that not yet investigated such as alkali resistance.

Since it has been proven that none of the parameters tested in TCLP test exceeded the limits specified by the DOE, so it is recommended that the DOE review the nonmetallic PCBs waste are no longer classified as scheduled waste in Malaysia. So it is hoped that nonmetallic PCBs can be used in making value added products, and also can solve the problem of waste generated by electronic industry in Malaysia. Only by this way, the nonmetallic PCBs waste can be reused just like in other countries in the world.

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APPENDICES

APPENDIX A: Mechanical Properties of Mortar

Table A1: Result for compressive strength of mortar at the Age of 3, 7, and 28 days of glass fiber reinforced epoxy resin sample A1, from wet separation process

	Compressive Strength (N/mm²) Based on Sand Substitution by Nonmetallic PCBs (%)				
Days of Curing	0%	10%	20%	30%	40%
3	7.375	6.653	5.957	4.258	2.49
7	24.327	22.589	19.383	12.541	6.492
28	33.562	31.943	26.95	16.434	10.145

Table A2: Result for compressive strength of mortar at the age of 3, 7, and 28 days of cellulose paper reinforced phenolic resin sample B1, from wet separation process

	Compressive Strength (N/mm²) Based on Sand Substitution by Nonmetallic PCBs (%)				
Days of Curing	0%	10%	20%	30%	40%
3	7.375	6.173	4.741	1.960	0.828
7	24.327	18.945	16.875	6.352	1.549
28	33.562	27.726	20.618	10.751	3.437

Table A3: Result for compressive strength of mortar at the age of 3, 7, and 28 days of glass fiber reinforced epoxy resin sample A2, from dry separation process

	Compressive Strength (N/mm²) Based on Sand Substitution by Nonmetallic PCBs (%)				
Days of Curing	0%	10%	20%	30%	40%
3	7.375	6.413	5.074	4.025	2.360
7	24.327	20.350	17.622	10.629	6.083
28	33.562	29.471	21.882	16.073	8.753

Table A4: Result for compressive strength of mortar at the age of 3, 7, and 28 days of cellulose paper reinforced phenolic resin sample B2, from dry separation process

	Compressive Strength (N/mm²) Based on Sand Substitution by Nonmetallic PCBs (%)				
Days of Curing	0%	10%	20%	30%	40%
3	7.375	5.778	5.232	1.846	0.000
7	24.327	15.574	8.875	3.099	0.64
28	33.562	23.322	13.097	5.251	1.22

Table A5: Compressive strength of mortar with different proportion of Nonmetallic PCBs waste

Proportion (%) of Nonmetallic PCBs to Replace Sand	0%	10%	20%	30%	40%
Compressive Strength (N/mm²)	33.562	31.943	26.950	16.434	10.145

Table A6: Change in weight of control mortar and mortar added with 10% nonmetallic PCBs in (5% H_2SO_4) acid conditions

Change in Weight		
Days	**Control Mortar**	**10% Nonmetallic PCBs**
0	100.00	100.00
10	100.20	100.23
20	100.37	100.42
40	100.85	101.06
60	99.91	99.95

Table A7: Changes in compressive strength of control mortar and mortar added with 10% Nonmetallic PCBs in (5% H_2SO_4) acid conditions

Compressive strength (N/mm^2)		
Days	**Control Mortar**	**10% Nonmetallic PCBs**
0	31.46	27.18
10	31.08	26.93
20	29.73	26.21
40	27.35	24.59
60	27.28	24.16

Table A8: Flexural strength of sample A1

Samples of Mortar	7 Days	28 Days
Control mortar	5.26	8.03
10% nonmetallic PCBs	4.98	7.74
20% nonmetallic PCBs	3.93	6.25
30% nonmetallic PCBs	3.59	4.71
40% nonmetallic PCBs	2.31	3.50

Table A9: Flexural strength of sample B1

Samples of Mortar	7 Days	28 Days
Control mortar	5.26	8.03
10% nonmetallic PCBs	3.88	6.25
20% nonmetallic PCBs	3.20	4.90
30% nonmetallic PCBs	2.62	3.27
40% nonmetallic PCBs	1.83	2.65

Table A10: Flexural strength of sample A2

Samples of Mortar	7 Days	28 Days
Control mortar	5.26	8.03
10% nonmetallic PCBs	4.05	7.21
20% nonmetallic PCBs	3.79	6.19
30% nonmetallic PCBs	3.38	4.58
40% nonmetallic PCBs	2.71	3.92

Table A11: Flexural strength of sample B2

Samples of Mortar	**7 Days**	**28 Days**
Control mortar	5.26	8.03
10% nonmetallic PCBs	3.73	5.81
20% nonmetallic PCBs	3.11	4.76
30% nonmetallic PCBs	2.45	4.05
40% nonmetallic PCBs	1.59	2.71

APPENDIX B: Anova Analysis

Table B1: Compressive strength sample B2 by group

ANOVA

strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	670.011	1	670.011	7.580	.051
Within Groups	353.550	4	88.387		
Total	1023.561	5			

Table B2: Change in weight by group

ANOVA

Weight

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.011	1	.011	.064	.806
Within Groups	1.358	8	.170		
Total	1.369	9			

Table B3: Compressive strength in acid by group

ANOVA

Strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	31.791	1	31.791	10.882	.011
Within Groups	23.372	8	2.921		
Total	55.163	9			

APPENDIX C: Mix Design of Mortar

Calculation for mix design of mortar

Size of sample = 50mm x 50mm x 50mm

Ratio of cement:sand = 2.75

Water cement ratio = 0.55

Mix design of mortar:

Saiz of mold = 50mm x 50mm x 50mm

= 0.05m x 0.05m x 0.05m

=1.25×10^{-4} m^3

Total number of samples = 60 cubes

Total volume = $60 \times 1.25 \times 10^{-4}$ m^3

= 7.5×10^{-3} m^3

Density of mortar = 2400 kg/m^3

Mass of mortar = 2400 kg/m^3 x 7.5×10^{-3} m^3

= 18 kg

+ 20% wastage = 18 kg + 3.6 kg

Total mass = 21.6 kg

Ratio of cement = 1

Ratio of sand = 2.75

Ratio of water = 0.5

Total ratio = 4.25

Total mass of cement = (1 / 4.25) x 21.6 kg x 1

= 5.08 kg

Total mass of sand = (1 / 4.25) x 21.6 kg x 2.75

= 13.98 kg

Total mass of water = (1 / 4.25) x 21.6 kg x 0.5

= 2.54 kg

APPENDIX D: Mix Design of Cement Brick

Calculation for mix design of cement brick
Size of sample = 215mm x 103mm x 65mm
Ratio of cement:sand = 6
Water cement ratio = 0.5

Mix design of mortar:
Saiz of mold = 215mm x 103mm x 65mm
= 0.215m x 0.103m x 0.065m
=1.44×10^{-3} m^3
Total number of samples = 63 cubes
Total volume = $63 \times 1.44 \times 10^{-3}$ m^3
= 0.091 m^3
Density of mortar = 2400 kg/m^3
Mass of mortar = 2400 kg/m^3 x 0.091 m^3
= 218.4 kg
+ 20% wastage = 218.4 kg + 43.68 kg
Total mass = 262.08 kg
Ratio of cement = 1
Ratio of sand = 6
Ratio of water = 0.5
Total ratio = 7.5
Total mass of cement = (1 / 7.5) x 262.08 kg x 1
= 34.9 kg
Total mass of sand = (1 / 7.5) x 262.08 kg x 6

= 209.66 kg

Total mass of water = (1 / 7.5) x 262.08 kg x 0.5

= 17.47 kg

APPENDIX E: Calculation of Bricks That Can Be Produced by Using Nonmetallic PCBs Wastes Per Year

Total mass of nonmetallic PCBs produced / year = 40, 000 kg / year

Total mass of sand = 3.33 kg / brick

30 % of nonmetallic PCBs = (30 / 100) x 3.33 kg

= 0.999 kg / brick

Total briks that can be produced by using nonmetallic PCBs wastes per year = 40,040