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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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

LIST OF APPENDICES

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.

REFERENCES

Abu, Z. (1990). The Pozzolanicity of Some Agricultural Fly Ash and Their Use in Cement Mortar and Concrete. *Universiti Teknologi Malaysia: Thesis Sarjana*.

Ahmed, M. A. B. (2008). Study on Durability of High Strength Palm Oil Fuel Ash (POFA) Concrete. *Universiti Teknologi Malaysia: Thesis Degree of Master of Engineering (Civil Structure and Material).*

ASTM. Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes. American Society for Testing and Materials. ASTM C267-01.

ASTM. Standard Specification for Mortar Cement. American Society for Testing and Materials. ASTM C1329-05.

ASTM. Standard Specification for Mortar for Unit Masonry. American Society for Testing and Materials. ASTM C270-12a.

ASTM. Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. American Society for Testing and Materials. ASTM C348-08.

ASTM. Standard Specification for Concrete Building Brick. American Society for Testing and Materials. ASTM C55-11.

ASTM. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). American Society for Testing and Materials. ASTM C109/C109M−12.

ASTM. Standard Specification for Aggregate for Masonry Mortar. American Society for Testing and Materials. ASTM C144-11.

ASTM. Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. American Society for Testing and Materials. ASTM C140-12.

Anderson, G. K. (1993). Collection and Treatment of Hazardous Waste. Short Course on Solid and Hazardous Waste Management. *Department of Environmental Engineering, Faculty of Civil Engineering, Johor Bahru: University Technology Malaysia*.

Arya, C., Clarke, J. L., Kay E. A. and O'Regan, P. D. (2002). Design Guidance for Strengthening Concrete Structures Using Fibre Composite Materials: A Review. *Engineering Structures*. 24, 889-900

Ashour, S. A., Wafa, F. F. and Kamal, M. I. (2000). Effect of the Concrete Compressive Strength and Tensile Reinforcement Ratio on the Flexural Behavior of Fibrous Concrete Beams. *Engineering Structures*. 22, 1145-1158.

Ban, B. C., Song, J.Y., Lim, J.Y., Wang, Kwang, G. A. and Dong, S. K. (2005). Studies on the Reuse of Waste Printed Circuit Board as an Additive for Cement Mortar. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering.* 40:645-656.

Benson, R. E., Chandler, H. W. and Chacey, K. A. (1986). Hazardous Waste Disposal as Concrete Admixture. *Journal of Environmental Engineering*. 111(4), 441-7.

Bishop, P. L. (1988). Leaching of Inorganic Hazrdous Constituents From Stabilized/Solidified Hazardous Wastes. *Hazardous Wastes Materials*. 5, 129-143.

Bonen. (1994). The Present State of the Art of Immobilization of Hazardous Heavy Metal in Cement-Based Material. *Advance in Cement and Concrete.*

Boyle, W. C., Ham, R. K., Pastene, J. and Stanforth, F. (1983). Leach Testing of Foundry Process Waste. In: Conway RA, Gulledge WP, editors. Proceedings Hazardous and Industrial Solid Waste Testing: Second Symposium, ASTM STP 805. Philadelphia: American Society for Testing and Materials. 67.

Brian, W. B., Eric, I. P. and Aarne, P. V. (1989). Planning Hazardous Waste Reduction and Treatment Strategies: An Optimization Approach. *Waste Management and Research*. 7, 153-163.

Brigden, K., Labunska, I., Santillo, D. and Allsopp, M. (2005). Recycling of Electronic Waste in China and India: Workplace and Environmental Contamination. *Greenpeace International*. 1-12.

British Standard Institution. (1985). BS 3921: Specification for Clay Bricks. *London: British Standard Institution.*

British Standard Institution. (1981). BS 6073 : Part 1 : Specification for Precast Concrete Masonry Units. *London: British Standard Institution.*

Castro, J., Bentz, D. and Weiss, J. (2011). Effect of Sample Conditioning on the Water Absorption of Concrete. *Cement and Concrete Composite*. 33, 805-813.

Chandramouli, K., Srinivasa, R. P., Pannirselvam, N., Seshadri, S. T. and Sravana, P. (2010). Strength Properties of Glass Fiber Concrete. *Journal of Engineering and Applied Sciences*. 5 (4), 1819-6608.

Christensen, T. H., Cossu, R. and Stegmann, R. (1992). Landfill Leachate: An Introduction in Landfilling of Waste: Leachate. *Elsevier Applied Science*. 3-14.

Christensen, T. H., Kjeldsen, P., Albrechtsen, Hans-Jorgen, Heron, Gorms, Neilson, Bjerg, P. H., Holm, P. L., and Peter, E. (1994). Attention of Landfill Leachate Pollutants inAquifers-Critical Review. Environmental Science and Technology, 24 (2), 119-202.

Conner, J. R. (1990). Chemical Fixation and Solidification of Hazardous Wastes. New York: Van Nostrand Reinhold. *Chemical Waste Management Inc.*

Cote, P. L., Bridle, T. R. and Andrew, B. (1986). An Approach for Evaluating Long Term Leachability From Measurement of Intrinsic Waste Properties. Hazardous and Industrial Solid Waste Testing and Disposal: Sixth Volume, ASTM STP 993, Lorenzen, D. R., Conway, R. A., Jackson, L. P., Ahmed, H., Perket, C. L., and Lacy, W. J., Eds. *American Society for Testing and Materials*, *Philadelphia*. 63-78

Cui, J. and Forssberg, E. (2003). Mechanical Recycling of Waste Electric and Electronic Equipment: A Review. *Journal of Hazardous Materials*. 99, 243-263.

Dalrymple, I., Wright, N., Kellner, R., Bains, N., Geraghty, K., Goosey, M. and Lightfoot, L. (2007). An Integrated Approach to Electronic Waste (WEEE) Recycling. *Circuit World*. *Emerald Group Publishing Limited.* 33(2), 52-58.

Darren, K. (2009). Recycling and Recovery. Issues in Environmental Science and Technology. *Electronic Waste Management*. 27, 91-110.

DOE. (2012). Department of Environment Malaysia. List of Contractor.

DOE. (2010). Percentage of Scheduled Waste Generated by Category. Department of Environment Malaysia.

DOE. (2005). Guidelines for the Classification of Used Electrical and Electronic Equipment in Malaysia, Department of Environment Malaysia. Second Edition, DOE. (2010). Guidelines for the Classification of used Electrical and Electronic Equipment in Malaysia. Department of Environment Malaysia

DOE. (2007). Scheduled W*astes.* Department of Environment Malaysia. *Edisi 2007.*

Deng, J.J., Wen, X. F. and Zhao, Y. M. (2008). Evaluating the Treatment of E-waste- A Case Study of Discarded Refrigerators. *Journal of China University of Mining and Technology*. 18, 454–458.

Duan, C., Wen, X., Shi, C., Zhao, Y., Wen, B. and He, Y. (2009). Recovery of Metals From Waste Printed Circuit Boards by a Mechanical Method Using a Water Medium. *Journal of Hazardous Materials*. 166 (1), 478-482.

Eeydzah, A. (2010). Engineering Properties of POFA Cement Brick. *Universiti Teknologi Malaysia: Tesis Sarjana Muda.*

Elsen, J. (2006). Microscopy of Historic Mortars- A Review. *Cement and Concrete Research.* 36, 1416-1424.

Esakku, S., Selvam, A., Palanivelu, K., Nagendran, R. and Joseph, K. (2006). Leachate Quality of Municipal Solid Waste Dumpsites at Chennai. *Asian Journal of Water, Environment and Pollution.* 3 (1), 69-76.

Fallman, A. M. and Hartlen, J. (1996). Utilization of EAF Slag in Road Construction. *Enviromental Geotechnics. Rotterdam: Balkena*. 703-708

Fathollah, S. (2012). Effect of Curing Regime and Temperature on the Compressive Strength of Cement-Slag Mortars. *Construction and Building Materials*. 36, 549-556.

Finnveden, G., Albertsson, A. C., Berendson, J., Eriksson, E., Hoglund, L. O., Karlsson, S. and Sundqvist, J.O. (1995). Solid Waste Treatment Within the Framework of Life-Cycle Assessment. *Journal of Cleaner Product*. 3,189-199.

Francis, C. and Brown, D. (1994). Steel Slag Asphalt- A Trial in Newcastle. *9th AAPA International Asphalt Conference Proceeding, Queenland, Australia*. 13-17.

Gambhir, M. L. (2002). Concrete Technology Third Edition. Tata McGraw-Hill Publishing.

Gao, Z., Li, J. and Zhang, H. C. (2002). Printed Circuit Board Recycling: A State-of-Art Survey. *IEEE International Symposium on Electronics and the Environment*. 234-241.

Gary, C., Stevens. and Martin, G. (2009). Materials Used in Manufacturing Electrical and Electronic Products: Issues in Environmental Science and Technology. *Electronic Waste Management.* 27, 40-73.

Gilliam, T. M. and Wiles, C. C. (1992). Stabilization and Solidification of Hazardous Radioactive and Mixed Wastes. *ASTM. Philadelphia, United State*. 2, 250.

Goosey, M. and Kellne, R. (2003). Recycling Technologies for the Treatment of End of Life Printed Circuit Boards (PCB). *Circuit World*. 29, 33-37.

Guo, J., Rao, Q. and Xu, Z. (2008). Application of Glass Non-metals of Waste Printed Circuit Boards To Produce Phenolic Moulding Compound. *Journal of Hazardous Materials*. 153, 728-734.

Guo, J., Jie, G. and Zhenming, X. (2009). Recycling of Non-Metallic Fractions From Waste Printed Circuit Boards: A Review. *Journal of Hazardous Materials.* 168, 567-590.

Hageluken, I. C. (2008). Recycling of E-scrap in a Global Environment Opportunities and Challenges: E-waste, Implications, Regulations, and Management in India and Current Global Best Practices. The Energy and Resources Institute. 217-231.

Halimah, A. (2009). Engineering Properties of Polymer and Natural Fibre Reinforced Mortar. *Universiti Teknologi Malaysia: Tesis Sarjana Muda*.

Hall, W. J. and Williams, P. T. (2007). Separation and Recovery of Materials From Scrap Printed Circuit Board. *Resources, Conservation and Recycling.* 51, 691-709.

Hanna, R. A., Cheeseman, C. R., Hill, C. D., Sollars, C. J., Buchler, P. M. and Perry, R. (1995). Calcium Hydroxide Formation in Cement-Solidified Industrial Waste. *Environment Technology*. 15, 1001-1008.

Havlik, T., Orac, D., Petranikova, M. and Miskufova, A. (2011). Hydrometallurgical Treatment of Used Printed Circuit Boards After Thermal Treatment. *Waste Management*. 31, 1542-1546.

He, W., Li, G., Ma, X., Wang, H., Huang, J., Xu, M. and Huang, C. (2006). WEEE Recovery Strategies and The WEEE Treatment Status in China. *Journal of Hazardous Materials*. 136, 502-512.

Hino, T., Agawa, R., Moriya, Y., Nishida, N., Tsugita, Y. and Araki, T. (2009). Techniques to Separate Metal From Waste Printed Circuit Boards From Discarded Personal Computers. *Journal of Materials Cycles and Waste Management*. 11, 42-54.

Holmes, I. (2009). Dumping, Burning and Landfill. : Issues in Environmental Science and Technology. *Electronic Waste Management*. 27, 75-89.

Huang, K., Guo, J. and Xu, Z. (2008). Recycling of Printed Circuit Board: A Review of Current Technologies and Treatment Status in China. *Journal of Hazardous Materials*. 164(2–3), 399-408.

IDEM. (2000). Treatment of Hazardous Waste On-Site by Generators. Indiana Department of Environmental Management. *Office of Land Quality*. 1-5.

Islam, M. T. and Bindiganavile, V. (2011). The Impact Resistance of Masonry Units Bound with Fibre Reinforced Mortars. *Construction and Building Materials*. 25, 2851-2859.

Ishira, T. (1990). Creep and Shrinkage of Concrete Containing Palm Oil Fly Ash. *Universiti Teknologi Malaysia: Tesis Sarjana*.

Jang, Y. and Townsend, T. (2003). Leaching of Lead From Computer Printed Wire Boards and Cathode Ray Tubes by Municipal Solid Waste Landfill Leachate. *Environmental Science and Technology.* 37, 4718-4784.

Johan, S., Shantha, K. M. and Siti, S. M. (2012). A Review on Printed Circuit Boards Waste Recycling Technologies and Reuse of Recovered Nonmetallic Materials. *International Journal of Scientific & Engineering Research.* 3, 1-7.

Joseph, L. (2006). Printed Circuit Board Industry. *International Journal of Hygiene and Environmental Health.* 209, 211-219.

Kamarudin, M. Y. (1995). Pengenalan Kekuatan dan Ketahanlasakan Konkrit. *Kuala Lumpur: Dewan Bahasa dan Pustaka*. 93-123.

Kameswari, K. S. B., Bhole, A. G. and Paramasivam, R. (2001). Evaluation of Solidification/Stabilization (S/S) Process For the Disposal of Arsenic Bearing Sludges in Landfill Sites. *Environmental Engineering Science.* 18(3), 167-76.

Kellner, R. (2009). Integrated Approach to E-waste Recycling: Issues in Environmental Science and Technology. *Electronic Waste Management*. 27, 111-160.

Kolias, S. and Georgiou, C. (2005). The Effect of Paste Volume and of Water Content on the Strength and Water Absorption of Concrete. *Cement and Concrete Composites*. 27, 211-216.

Li, J., Lu, H., Guo, J., Xu, Z. and Zhou, Y. (2007). Recycle Technology for Recovering Resources and Products from Waste Printed Circuit Boards. *Environmental Science and Technology*. 41(6): 1995-2000.

Li, L., Richardson, J., Walker, A. and Yuan, P. (2006). TCLP Heavy Metal Leaching of Personal Computer Components. *Journal of Environmental Engineering*. 132, 497-504.

Li. J., Xu. Z. and Zhou. Y. (2007). Application of Corona Discharge and Electrostatic Force to Separate Metals and Nonmetals From Crushed Particles of Waste. Journal of Electrostatics 65(4), 233-238.

Lee, C. H., Chang, C. T., Fan, K. S. and Chang, T. C. (2004). An Overview of Recycling and Treatment of Scrap Computers. *Journal of Hazardous Materials***.** 114(1-3), 93-100

Malaysian Standard. (1972). Specification For Brick And Blocks of Fired Brickearth, Clay or Shale. Part 2: Metric Units. MS 76: 1972. ICS: 91.100.15. *Standards & Industrial Research Institute of Malaysia.*

Mashitah, M.D., Vel, M.V. and Bakar, A.M.D. (2000). Stabilization of Industrial Hazardous Wastes by Oil Palm Mill Incinerator Ash. *Prosiding Seminar Persekitaran 2000. Perak: Universiti Sains Malaysia*. 195-200.

Martin, G. and Rod, K. (2002). A Scoping Study End-of-Life Printed Circuit Boards. Department of Trade and Industry. 1-3.

Martin, W. J. (1997). Printed Circuit Board Materials Handbook. McGraw-Hill, Chatsworth California.

Means, J. L., Smith, L. A., Nehring, K. W., Brauning, S. E., Gavaskar, A. R., Sass, B. M., Wiles, .C. C and Mashni, C. I. (1995). The Application of Solidification / Stabilization to Waste Materials. Florida: Lewis Publishers.

Menad, N., Bjorkman, B. and Allain, E. G. (1998). Combustion of Plastics Contained in Electric and Electronic Scrap. *Resource, Conservation and Recycling.* 24, 65-85.

Mehta, P. K. (1983). Mechanism of Sulfate Attack on Portland Cement Concrete: Another look. *Cement Concrete Research*. 13(3), 401-406.

Mindess, S. and Young, J. P. (1981). Concrete, Prentice-Hall Inc. 670.

Montgomery, D. M., Sollars, C. J., Sheriff, T. S. and Perry, R. (1988). Organophilic Clays for the Successful Stabilization/Solidification of Problematic Industrial Wastes. *Environmental Technology Letters*. 9, 1403-1412.

Mou, P., Dong, X. and Guanghong, D. (2007). Products Made From Nonmetallic Materials. Reclaimed From Waste Printed Circuit Boards. *Tsinghua Science and Technology*. 12, 276-283.

Mullick, A. K. (2007). Performance of Concrete with Binary and Ternary Cement Blends. *The Indian Concrete Journal*. 15-22.

Musson, S., Jang, Y., Townsend, T. and Chung, I. (2000). Characterization of Lead Leachability From Cathode Ray Tubes Using the Toxicity Characteristic Leaching Procedure, *Environmental Science and Technology*. 34, 4376-4381.

Neville, A. M. (1995). Properties of Concrete. Edisi Kelima dan Terakhir. Essex: Addison Wesley Longman Limited.

Niu, X. and Li, Y. (2007). Treatment of Waste Printed Wire Boards in Electronic Waste for Safe Disposal. *Journal of Hazardous Materials*. 145, 410-416.

Norazlina, A. H. (2010). E-waste Management In Malaysia. Country Presentation: Department of Environment Malaysia.

Oner, M. (2000). A Study of Intergrinding and Separate Grinding of Blast Furnace Slag Cement. *Cement and Concrete Research*. 30, 473-480.

Oti, J. E., Kinuthia, J. M. and Bai, J. (2009). Compressive Strength and Microstructural Analysis of Unfired Clay Masonry Bricks. *Engineering Geology*. 109, 230-240.

Perrin, D., Clerc, L., Leroy, E., Lopez, C. M. and Bergeret, A. (2008). Optimizing a Recycle Process of SMC Composite Waste. *Waste Management.* 28, 541-548.

Poonam, K. and Arvind, K. N. (2008). Optimal Planning for Computer Waste: E-waste, Implications, Regulations, and Management in India and Current Global Best Practices. The Energy and Resources Institute. 203-215.

Prasad, J., Jain, D. K., and Ahuja, A. K. (2006). Factors Influencing the Sulphate Resistance of Cement Concrete and Mortar. *Asian Journal of Civil Engineering and Housing*. 3, 259-68.

Rabitah, H. (2000). Portland Cement-Based Solidification/Stabilization for the Treatment of Industrial Waste. *Universiti Teknologi Malaysia: Tesis Sarjana.*

Rajeshwari, K. V. (2008). Technologies for Recovery of Resources From Electronic Waste: E-waste, Implications, Regulations, and Management in India and Current Global Best Practices. The Energy and Resources Institute. 233-252.

Rakesh, J. (2008). E-waste: Implications, Regulations and Management in India and Current Global Best Practices. The Energy and Resources Institute, New Delhi India.

Reid, J.M. and Brookes, A. H. (1999). Investigation of Lime Stabilized Contaminated Material. *Engineering Geology*. 52, 217-231.

Salmiati, M. Y. (2002). Analisis Kimia dan Penggunaan Jermang Keluli Relau Arka Elektrik (EAF) Sebagai Agregat Dalam Mortar. *Universiti Teknologi Malaysia: Thesis Degree of Master of Engineering (Environmental).*

Scarlett, J. A. (1984). An Introduction to Printed Circuit Board Technology. Electrochemical Publications Limited, 8 Barns Street, Ayr, Scotland.

Shannag, M. J. and Al-Ateek, S. A. (2006). Flexural Behavior of Strengthened Concrete Beams with Corroding Reinforcement. *Construction and Building Materials.* 20, 834-840.

Song,Q., Wang, Z., Li, J. and Duan, H. (2012). Sustainability Evaluation of an E-waste Treatment Enterprise Based on Emergy Analysis in China. *Ecological Engineering*. 42, 223-231.

Swagat, S. R., Pradeep, N., Mukherjee, P.S., Chaudhury, G. R. and Mishra, B. K. (2012). Treatment of Electronic Waste to Recover Metal Values Using Thermal Plasma Coupled with Acid Leaching- A Response Surface Modeling Approach. *Waste Management.* 32, 575-583.

Tan, Z., He, Y., Xie, W., Duan, C., Zhou, E. and Yu, Y. (2011). Size Distribution of Wet Crushed Waste Printed Circuit Boards. *Mining Science and Technology*. 21, 359-363.

Tashiro, H. C., Takahashi, M., Kanaya, I., Hirakida. and Yoshida, R. (1977). Hardening Property of Cement Mortar Adding Heavy Metal Compound and Solubility of Heavy Metal From Hardened Mortar. *Cement and Concrete Research*. 7, 283-290.

Theng, L. C. (2008). E-waste Management. *Impact Issues*. 1, 12-13.

Tossavainen, M. and Forssberg, E. (1999). The Potential Leachability from Natural Road Construction Materials. *The Science of the Total Environment*. 239, 33-47.

Townsend, T., Musson, S., Dubey, B. and Pearson, B. (2008). Leachability of Printed Wire Boards Containing Leaded and Lead-Free Solder. *Journal of Environmental Management*. 88: 926-931.

Townsend, T.G. (1998). Leaching Characteristics of Asphalt Road Waste: Technical Report. *Florida Center for Solid and Hazardous Waste Management.* 352, 392-0846.

Townsend, T. G., Kevin, V., Sarvesh, M., Brian, P., Yong, C.J., Stephen, M. and Aaron, J. (2004). RCRA Toxicity Characterization of Computer CPUs and Other Discarded Electronic Devices. *Department of Environmental Engineering Sciences University of Florida Gainesville, Florida.*

UNEP. (2007). E-waste Volume 1: Inventory Assessment Manual. United Nations Environment Programme.

USEPA. (1996). SW-846 Test Methods for Evaluating Solid Wastes, EPA Test Method 1311: Toxicity Characteristic Leaching Procedure (TCLP). United State Environmental Protection Agency .*Office of Solid Waste and Emergency Response, Washington, DC.*

USEPA. (1996). Characterisation of Municipal Solid Waste in the United State. United State Environmental Protection Agency. *U.S. Environmental Protection Agency Municipal and Industrial Solid Waste Division Office of Solid Waste Report No. EPA530.*

USEPA. (1999). Identification and Listing of Hazardous Waste. The Code of Federal Regulations. United State Environmental Protection Agency. Washington, DC.

USEPA. (1986). Multiple Extraction Procedure (MEP) Test Method and Structural Test Methods for Evaluation of Solid Waste. United State Environmental Protection Agency. *U.S. EPA publication SW- 846, 1320.*

USEPA. (1986). Handbook for Stabilization /Solidification of Hazardous Waste. United State Environmental Protection Agency. EPA/ 540/ 2-86/ 001. Hazardous Waste Engineering Research Laboratory, Cincinati, Ohio.

Veit, H. M., Bernardes, A. M., Ferreira, J. Z., Tenorio, J. A. S. and Malfatti, C. D. F. (2006). Recovery of Copper From Printed Circuit Boards Scraps by Mechanical Processing and Electrometallurgy. *Journal of Hazardous Materials*. 137, 1704-1709.

Veit, H.M., Diehl, T.R., Salami, A.P., Rodrigues, J.S., Bernardes, A.M., and Tenorio, J.A.S. (2005). Utilization of magnetic and electrostatic separation in the recycling of printed circuit boards scrap. *Waste Management.* 25: 67–74.

Vanchai, S., Apha, S. and Prinya, C. (2012). Resistance of Lignite Bottom Ash Geopolymer Mortar to Sulfate and Sulfuric Acid Attack. *Cement and Concrete Composites.* 34, 700-708

Vincenzo. T., Marco. R., Irina. A. I. and Elena. C. R. (2013). Review Management of Waste Electrical and Electronic Equipment in Two EU Countries: A Comparison. *Waste Management*. 33, 117-122.

Wang, X., Yuwen, G., Jingyang, L., Qi, Q. and Jijun, L. (2010). PVC-Based Composite Material Containing Recycled Non-Metallic Printed Circuit Board (PCB) Powders. *Journal of Environmental Management.* 91, 2505-2510.

Wei, L. and Liu, Y. (2012). Present Status of E-waste Disposal and Recycling in China. *The Seventh International Conference on Waste Management and Technology*. *Procedia Environmental Sciences*. 16, 506-514.

Wen, X. F., Zhao, Y. M. and Duan, C. L. (2005). Study on Metals Recovery From Discarded Printed Circuit Boards by Physical Methods. *Proceedings of the 2005 IEEE International Symposium on Electronics & the Environment.* 121-128.

Wongkeo, W., Thongsanitgarn, P. and Chaipanich, A. (2012). Compressive Strength and Drying Shrinkage of Fly Ash-Bottom Ash-Silica Fume Multi-Blended Cement Mortars. *Materials and Design*. 36, 655-662.

Xiu**,** F. R. and Zhang, F. S. (2009). Recovery of Copper and Lead From Waste Printed Circuit Boards by Supercritical Water Oxidation Combined with Electrokinetic Process**.** *Journal of Hazardous Materials*. 165, 1002-1007.

Yan, J., Baverman, C., Moreno, L. and Neretnieks, I. (1998). Evaluation of the Time Dependent Neutralising Behaviours of MSWI Bottom Ash and Steel Slag. *The Science of the Total Environment*. 216, 41-54.

Yap, S. G. (1998). Engineering Properties and Characteristic of Cement-Based Solidified/Stabilized Autoblast Copper Slag. *Universiti Teknologi Malaysia: Tesis Sarjana*.

Yin, C. Y., Shaaban, M. G. and Mahmud, H. (2007). Chemical Stabilization of Scrap Metal Yard Contaminated Soil Using Ordinary Portland Cement: Strength and Leachability Aspects. *Building and Environment*. 42, 794-802.

Yusof. A., Ahmad, M. M. dan Salmiati, M. Y. (2000). Kajian Penggunaan Jermang Keluli dari Kilang Penghasilan Keluli Tempatan untuk Batu Baur Kasar. *Prosiding Seminar Persekitaran 2000. Perak: Universiti Sains Malaysia*. 187-194.

Zaidi, Z. (1996). Cement-based Solidification/Stabilization for the Treatment of Hazardous Waste. *Universiti Teknologi Malaysia: Tesis Sarjana*.

Zain, M. F. M., Islam, M. N., Radin, S. S. and Yap, S. G. (2004). Cement-Based Solidification for The Safe Disposal of Blasted Copper Slag. *Cement & Concrete Composites*. 26, 845-851.

Zheng, Y., Shen, Z., Cai, C., Ma, S. and Xing, Y. (2009). The Reuse of Nonmetals Recycled From Waste Printed Circuit Boards as Reinforcing Fillers in the Polypropylene Composites. *Journal of Hazardous Materials*. 163, 600-606.

Zheng, Y., Shen, Z., Ma, S., Cai, C., Zhao, X. and Xing, Y. (2009). A Novel Approach to Recycling of Glass Fibers From Nonmetal Materials of Waste Printed Circuit Boards. *Journal of Hazardous Materials.* 170, 978-982.

Ziad, A. S. and Mohamed, A. H. A. H. (2011). Laboratory Evaluation of Various Types of Mortars for the Conservation of Qasr Al-Bint Monument, Petra-Jordan. *Engineering Structures.* 23, 926-933.

Zulkifli, A. R., Azil, B. A., Ayub, M. S., Mohd, J. A. and Mahmud, H. N. M. E. (2010). Laporan Akhir Projek Penyelidikan: Development of Generic Decision Support System for Scheduled Waste Management in Malaysia. *Institut Pengurusan Penyelidikan Universiti Teknologi Mara.*