© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.594-595.990

Feasibility Study of Waste Motor Recycling Through Manual Dismantling and Hydrometallurgical Process

Nik Hisyamudin Muhd Nor[1,a], Thirumoorthy Nathan[1,b], Shafizan Jaibee[1,c], Mohd Hafiz Burhan[1,d], Fariza Mohamad[1,e], Al Emran Ismail[1,f], Sia Chee Kiong[1,g], Zulkifli Ahmad[1,h], Seiji Yokoyama[2,i]

[1]Engineering Design Research Group (EDRG), Department of Materials and Design Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, Malaysia.

[2]Faculty of Mechanical Engineering, Toyohashi University of Technology, 1-1 Hibarigaoka Tempaku Toyohashi Aichi Japan.

[a]nhisyam@uthm.edu.my, [b]ru_thiru@outlook.com, [c]cd100012@siswa.uthm.edu.my, [d]hafiz_unearth@yahoo.com, [e]farizamd@uthm.edu.my, [f]emran@uthm.edu.my, [g]sia@uthm.edu.my, [h]zul@uthm.edu.my, [i]yokoyama@me.tut.ac.jp

Keywords: E-waste, waste motor, recycling, hydrometallurgical, dissolution, leaching

Abstract. Huge amount of waste electrical and electronic equipments (WEEE) or electronic waste (E-waste) has been produced every year in the world. It consists of valuable and hazardous metals that can be reused or extracted to minimize the environmental impact. This study is focusing on the investigation of recycling potential of e-waste through manual dismantling process and leaching test. The leaching test was conducted by changing the initial pH with constant stirring speed, constant water-sample ratio and in open air. The morphological structures of the solid samples were observed by SEM and the liquid residue was analyzed by Atomic Absorption Spectroscopy (AAS). It was found that total time required to dismantle all parts in the waste motor is about 10 minutes and the part that required longest dismantling time was armature windings. The metal elements that were observed are Fe, Mg, Pb and Cr. It was found that the pH of the solution increased with the increasing leaching time. The dissolution of Fe and Pb was high in the early stage of leaching but gradually decreased afterward. The dissolution for Mg and Cr was low throughout the leaching process. It was revealed that the metal elements in e-waste can be dissolved using this method and further investigation to increase the dissolution rate is required to ensure that the method proposed is applicable in industry. However, dissolved concentration of Pb must be controlled to ensure that it follows the permissible amount set under environmental standard.

Introduction

Our world is undergoing a rapid growth in the production of electrical and electronic equipments (EEE). It is undeniable that without the EEE, there is no high technology can be created or designed. However, along with the fast growth of EEE production, tremendous amount of E-waste has also been produced every year. It is estimated that by 2020, the cumulative total of E-waste from seven categories of E-waste (television sets, personal computers, mobile phones, refrigerators, air conditioners, washing machines and rechargeable batteries) that will be discarded in Malaysia is about 1,165 billion units (21.379 million metric tons) [1].

In Malaysia, E-waste is generally defined as ‘used’ electrical and electronic assemblies categorized as scheduled wastes in the First Schedule of the Environmental Quality (Scheduled Wastes) Regulations 2005, administered by the Department of Environment (DOE) [2]. E-waste management is taken seriously nowadays not only because of the tremendous amount of production volume but also because it has grown in increasing complexity. It is chemically and physically distinct from other forms of municipal or industrial waste; it contains both valuable and hazardous materials that require special handling and recycling methods to avoid environmental contamination and detrimental effects on human health [3]. There are many health and environmental problems occurred from e-waste such as the toxic pollution from materials such as cadmium, chromium, lead, mercury, beryllium and many more. For instances, sampling of heavy metals and toxic organics sediments in e-waste recycling sites such as Guiyu (China) and Bangalore (India) showed that heavy contamination from backyard recycling brings severe damage to the local environment and leads to human health risks [4, 5]. Air pollution around the e-waste processing area was also found in China [6]. Thus, technology on the E-waste handling, managing as well as recovering and recycling is very much essential in order to reduce the environmental impact brought by the E-waste.

There are several methods for the metal recovery from waste materials or by-product. Oishi et al. conducted research on recovery of copper from printed circuit board (PCB) by hydrometallurgical techniques [7]. Frey and Park performed research for recovery of high purity precious metals from PCBs using aqua regia as leachant [8]. According to DOE Malaysia, the main technology employed to recover e-wastes in terms of precious metals in Malaysia is still limited to wet chemical processes and electrolysis. There are still very limited literatures on the e-waste management, handling and recovery process of hazardous materials in Malaysian e-waste industry. In our previous study, the re-utilization of industrial waste had been investigated [9-11]. Thus, the current study is to investigate the recycling process of E-waste through the manual dismantling process and hydrometallurgical process. The E-waste that been used is waste dc motor due to the massive amount of it in the E-waste industry in Malaysia.

Experimental Procedures

Fig. 1 shows the waste motor used in the study. It is a common motor that can be easily found at the e-waste disposal area or second hand electronic shops. The motor was manually dismantled and the time required to dismantle all parts was measured. The dismantled parts were then categorized into ferrous, non-ferrous and plastic parts, and composition of each types of part was measured. Then, in order to investigate the leaching behavior of ferrous parts, the ferrous parts were collected from several numbers of motor and the leaching test of the ferrous parts was conducted. The leaching test of the ferrous parts was carried out according to Fig. 2. The parameters of the leaching test are shown in Table 1. The ratio between samples and leachant is 1:10. 100g samples were inserted into glass beaker and then the leachant which is purified water with the pH adjusted to be 6.0 by HCl was softly poured into the beaker. After that, the water in the vessel was mixed at rotational speed of 100 rpm. The test was conducted in ambient air and temperature. 50 ml liquid samples were collected every 1, 3, 6, 12, 24 and 48 hours by syringe and filtered by filter paper. The liquid residue was then analyzed by Atomic Absorption Spectroscopy (AAS). The samples before the leaching test were characterized by Scanning Electron Microscope (SEM) and the chemical composition was measured by Energy Dispersive X-Ray Spectroscopy (EDX) that equipped in the SEM.

Fig. 1 Waste motor used

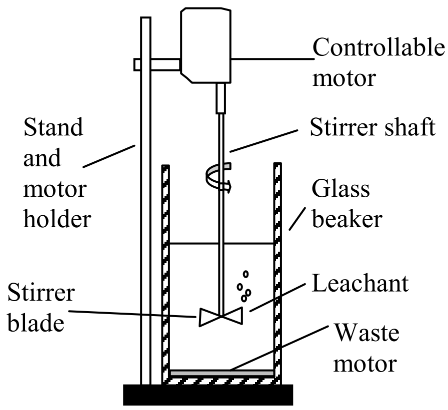


Fig. 2 Schematic of the leaching test

Table 1 Parameters of Leaching Test

Leaching Time [H]	1, 3, 6, 12, 24 and 48
pH	2, 4, 6, 8

Results and Discussion

Dismantling Process of Waste Motor Fig. 3 shows the dismantling process of waste motor. The dismantling process was conducted manually using hammer and screw driver. The sequences of dismantling processes are as follows: (a) Housing and stator → (b) End cap → (c) Armature → (d) Main sleeve bearing → (e) Magnet → (f) Armature windings and laminate armature → (g) Shaft and nylon core former. Time required for each processes is shown in Table 2. The total time required to dismantle all components is about 605 seconds or 10 minutes. The process that required longest time is the process to separate the armature windings from the armature body. If this process can be simplified, the overall dismantling time can be reduced and it can ease the recycling process of waste motor. There are three types of parts consisted in the motor; ferrous, non-ferrous and plastic parts, as shown in Fig. 4. The weight contributions of each type of parts are 61.2%, 34.7% and 4.1% respectively.

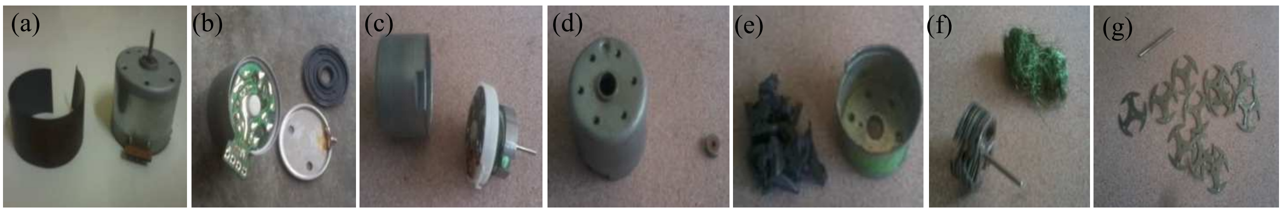


Fig. 3 Dismantling process of waste motor.

Table 2 Time required for the dismantling process

Process	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Total
Time (s)	20	35.7	10	20	80	410	30	605.7

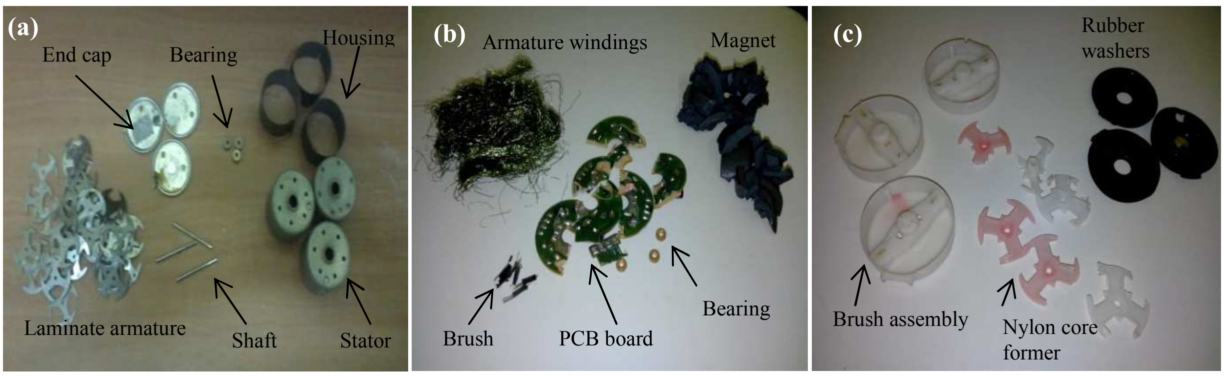


Fig. 4 Dismantled parts by type; (a) Ferrous parts, (b) Non-ferrous parts, (c) Plastic parts

Characterization of Waste Motor Fig. 5 shows the morphological structures of several ferrous parts in the waste motor. There were numerous scratch marks observed on the housing, stator and end cap. Thus, these parts must be re-processed to be re-used again. Three different points were used to characterize the chemical composition of each part and the average value of the three points was then calculated to identify the chemical composition of metal elements inside the parts. Table 3 shows the chemical composition of each main part. Part A which is the housing is composes of mainly Fe and Cr with low quantity of Si. The shaft is mainly consists of Fe and Na, while the laminate armature is mainly consists of Si and Al with low detection of Mg, Fe and Na. The Cr, Fe and Mg were highly consisted in the stator, and finally, the main composition of end cap was Fe.

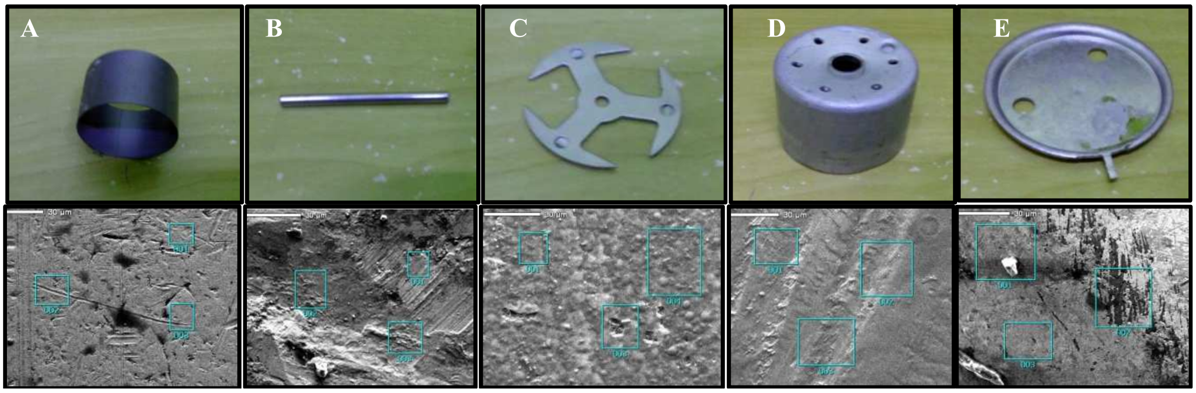
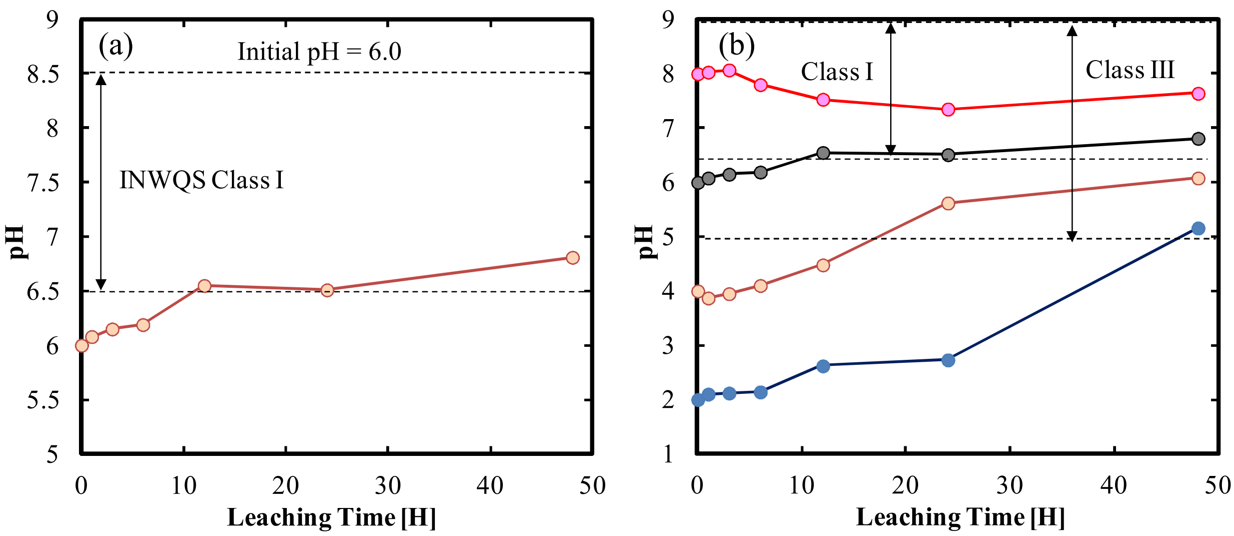


Fig. 5 Morphological structures of each parts in the waste motor.

Table 3 The chemical composition of part E in motor [mass %]

Sample	Mg	Al	Cr	Si	S	Fe	Na	O
A	-	-	16.78	1.42	-	81.79	-	-
B	-	-	-	-	-	16.58	71.65	11.77
C	4.02	5.05	0.00	19.79	-	2.33	1.83	66.97
D	8.49	-	21.65	-	-	20.69	-	49.17
E	-	-	-	-	1.58	91.28	-	7.14

Leaching Behavior of Waste Motor Fig. 6(a) shows the change in pH during the leaching test. The initial pH was 6 and it increased as the leaching started and continuously increased up to 6.8 at the end of the leaching test. The standard of pH for river that was based on Interim National Water Quality Standards (INWQS) is also shown in the figure [12]. The final pH was within the permissible range of pH set in INWQS Class 1. Class 1 is considered as the “best” with no requirement of treatment and suitable for the conservation of natural environment. However, in the case of initial pH were 4 and 2, the final pH were not in range of class I, but in class III which is requires extensive treatment as shown in Fig. 6(b). Looking on the trends of pH changes for both cases, it is expected that by prolonging the leaching time, the final pH would be in the range of class I. Since this work is more on the fundamental study of the dissolution behavior of each main elements in the waste motor, more study is required to validate this expectation in the coming works.



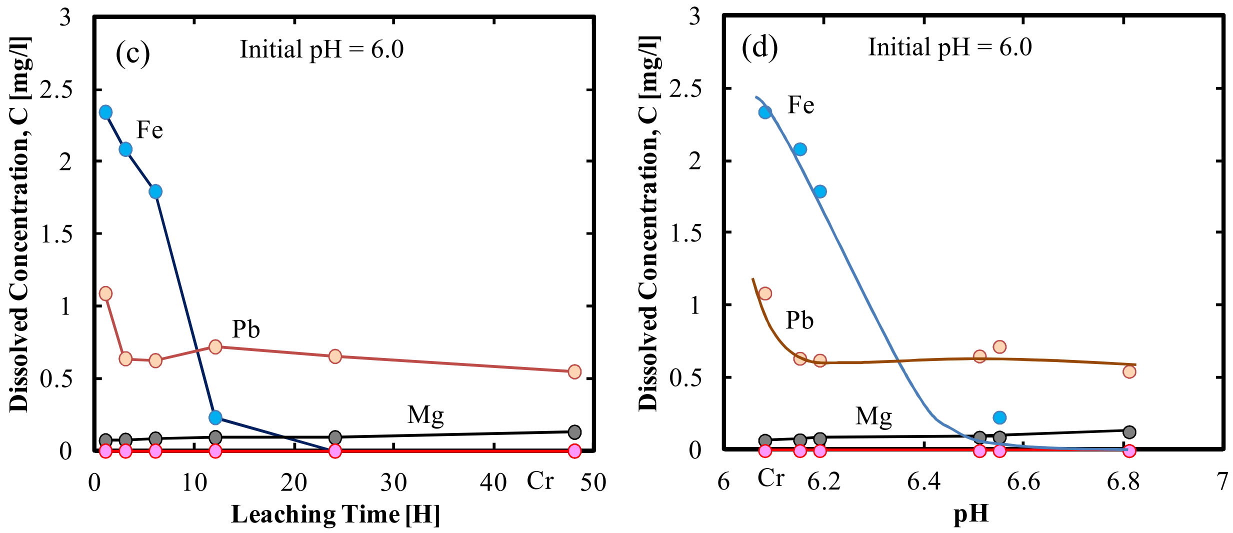


Fig. 6 pH changes and dissolution behavior of main elements during the leaching test.

Fig. 6(c) shows the dissolved concentration of main elements inside waste motor during the leaching test. Fe shows the highest dissolved concentration during the initial stage of leaching. However, it gradually decreased afterward and almost no dissolution of Fe was observed after 12 hours leaching. Even though the Pb was not observed by EDX on the main parts as stated above, but the dissolution of Pb was also observed during the leaching test. It might be existed in a small amount that hardly detected by the EDX and furthermore it is mainly composed in the solders, cathode ray tubes (CRT) and batteries [13]. The dissolution of Pb was little bit high in the early stage of leaching before decreased and almost unchanged afterward. The dissolved concentration was higher than permissible level class IIA of INWQS and all pollutions of EQS as shown in Table 4. The concentrations for Mg and Cr were very low throughout overall leaching test.

Fig. 6(d) shows the behavior of dissolved concentration of each element with changes in pH of the leachant. Fe concentration decreased as the pH increased and almost not dissolved after pH exceeded 6.6. Pb also decreased and almost unchanged after pH more than 6.2. On the other hand, concentration of Mg and Cr almost unchanged with the increasing pH. It can be concluded that there is a high potential of recycling of waste motor by utilizing the leaching test and hydrometallurgical method. However, more effort has to be putted on reducing the dismantling time of the waste motor and on managing the dissolved Pb during the recycling process.

Table 4 Malaysian interim national water quality standard (INWQS) and Japanese environmental quality standard (EQS).

Parameters	Malaysian INWQS [14] Classes						Japanese EQS [10]		
	I	IIA	IIB	III	IV	V	Soil pollution	Marine pollution	Water pollution
CrIII [mg/l]	-	-	-	0.01	-	-	-	2	-
Pb [mg/l]	NL*1	0.05	-	-	5	-	0.01	0.1	0.01
Fe [mg/l]	NL	-	-	-	-	-	-	-	-
Mg [mg/l]	NL	-	-	-	-	-	-	-	-

*1: Natural level

Conclusion

Fundamental study of waste motor recycling was carried out to investigate the dismantling processes and dissolution behavior of the waste. It was found that the longest dismantling time was contributed by the dismantling of armature windings. More efficient recycling technique can be achieved by reducing the dismantling time especially when it involved huge amount of waste motor. Dissolution of each main element in the waste motor was observed and it has affected to the increase of pH. The increase of pH has then led to the reduction of Fe and Pb concentration. Dissolved concentration of Pb must be controlled to ensure that it does not exceed the permissible amount set under INWQS.

Acknowledgements

This work is financially supported by the Research Acculturation Grant Scheme (RAGS) under the Ministry of Higher Education Malaysia.

References

[1] Information on Department of Environment Malaysia, E-waste inventory project in Malaysia, http://www.env.go.jp/en/recycle/asian_net/Project_N_Research/E-wasteProject/06.pdf

[2] T.L. Chong: E-waste Management, Impak 1 (2008) p. 12-13.

[3] A. Terazono et. Al, Current status and research on E-waste issues in Asia, J Mater Cycles Waste Management 8 (2006) p. 1-12.

[4] X. Huo, L. Peng, X.J. Xu, L.K. Zheng, B. Qiu, Z.L. Qi, et al.: Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. Environ Health Perspect 115 (2007) p. 1113-1117.

[5] N.N. Ha, T. Agusa, K. Ramu, N.P.C. Tu, S. Murata, et al.: Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere 76 (2009) p. 9-15.

[6] H. Li, L. Yu, G. Sheng, J. Fu and P. Peng: Severe PCDD/F and PBDD/F pollution in air around an electronic waste dismantling area in China, Environ. Sci. Technol. 41 (2007) p. 5641-5646.

[7] T. Oishi, K. Koyama, S. Alam, M. Tanaka and J. C. Lee: Recovery of high purity copper cathode from printed circuit boards using ammoniacal sulphate or chloride solutions, Hydrometallurgy 89(1-2) (2007) p. 82-88.

[8] Y. J. Park and D. Fray: Recovery of high purity precious metals from printed circuit boards, Journal of Hazardous Materials 164(2-3) (2009) p. 1152-1158.

[9] M.N.N Hisyamudin, S Yokoyama, M Kawakami and M Umemoto: Reaction Between CO_2 and CaO Under Wet Grinding, Powder Technology 196(2) (2009) p. 156-162.

[10] S. Yokoyama, A. Suzuki, M.N.N. Hisyamudin, H. Kanematsu, A. Ogawa, T. Takahashi, M. Izaki and M. Umemoto: Serial Batch Elution of Electric Arc Furnace Oxidizing Slag Discharged from Normal Steelmaking Process into Fresh Water, ISIJ International 50(4) (2010) p. 630-638.

[11] S. Yokoyama, A. Suzuki, M.N.N. Hisyamudin, H. Kanematsu, A. Ogawa, T. Takahashi, M. Izaki and M. Umemoto: Serial batch elution of electric arc furnace oxidizing slag discharged from normal steelmaking process into fresh water, Tetsu-To-Hagane/Journal of the Iron and Steel Institute of Japan 96(12) (2010) p. 698-705.

[12] Z. Zainudin: Benchmarking River Water Quality in Malaysia, Jurutera February (2010) p. 12-15.

[13] B. H. Robinson: E-waste: An assessment of global production and environmental impacts, Science of the Total Environment 408 (2009) p. 183-191.

[14] A.K. Ahmad, I. Mushrifah and M.S. Othman: Water Quality and Heavy Metal Concentrations in Sediment of Sungai Kelantan, Kelantan, Malaysia: A Baseline Study, Sains Malaysiana 38(4) (2009) p. 435-442.