Proceedings of the International Seminar on Mineral Processing Technology - 2006, Chennai, India. pp. 14 - 19.

Recycling of Consumer Electronic Scrap

Jirang Cui and **Eric Forssberg**

Luleå University of Technology, Luleå, Sweden

Abstract

In the context, characterization of TV scrap was carried out by using chemical analysis and particle shape analysis. The result of particle shape analysis indicates that the non-ferrous metals particles in TV scrap formed as a variety of shapes, it is much more heterogeneous than that of plastics and printed circuit boards. Furthermore, separability of TV scrap was evaluated by sink-float test, air table, and optical sorting process.

INTRODUCTION

The amount of electronic scrap in the world is growing rapidly. Due to their hazardous material contents, electronic scrap may cause environmental problems during the waste management phase if not properly pre-treated [1].

Consumer electronic equipment (brown goods), such as television sets, radio sets, and video recorders, are most common. However, recent work on recycling of waste electric and electronic equipment primarily focused on personal computer and printed circuit boards scraps [2].

The European Directive (2002/96/EC) on waste electric and electronic equipment (WEEE) has to be implemented into national legislation by 13 August 2004 [3]. According to the WEEE directive, member states shall ensure that, by 31 December 2006, producers meet the following targets:

- The rate of recovery for consumer electronic equipment shall be increased to a minimum of 75% by an average weight per appliance;
- Component, material and substance reuse and recycling for consumer electronic equipment shall be increased to a minimum of 65% by an average weight per appliance.

In order to meet the above targets, disassembly and mechanical recycling of consumer electronic scraps are of concern in European member states due to the fact that they are oriented to towards full materials recovery including plastics [4].

MATERIALS AND METHODS

Materials

Television scrap sample was provided by Stena Technoworld AB, Bräkne-Hoby, an electronic recycling corporation in Sweden. End-of-life TVs of any model and brand with plastic houses that were collected primarily from Sweden were pre-dismantling to remove the cathode ray tubes, CRTs. Then the scraps were shredded into -12 mm particles. An approximately 30 kg of the TV scrap sample was procured and packed for the laboratory study. The test sample was subsequently riffled by a rotary sampler with each sample up to 1.5 kg for further analyses.

Methods

Chemical Analysis

Chemical analyses were carried out in the laboratory of OVAKO Steel AB, Hofors, Sweden. Samples were ground to powder and treated with aqua regia for dissolution of the metal. The plastic was then

filtrated and the remaining solution analyzed with ICP/AES (inductively coupled plasma/ atomic emission spectroscopy) and ICP/MS (inductively coupled plasma/mass spectroscopy).

Particle Shape Analysis

An image process system, produced by Kronton Elektronik GmbH, Germany, was utilized for particle shape analysis. The quantitative criterion is expressed in terms of *FCIRCLE* defined as follows [5]:

$$FCIRCLE=4\pi \cdot AREA/PERIM^2 \quad (1)$$

$$PERIM=PERIMX+PERIMY+PERIMXY \cdot \sqrt{2} \quad (2)$$

where *AREA*, is defined as the number of pixels multiplied by the scaled pixel area, *PERIM* is the perimeter of the object, *PERIMX*, *PERIMY* is the length of perimeter in x and y direction, respectively, *PERIMXY* is the length of perimeter having direction of 45 and 135 degrees to x-axis. In this case, holes in the object will contribute to the perimeter.

Separation Test

Air table separation was carried out by using a DGS-Sort 300D in MinPro AB, Stråssa, Sweden. The separator was developed by Fren Erschliessungs-und Bergbau GesmbH, Austria. The optical sorting process was performed by a Clara All-metal Separator (Scan & Sort GmbH, Wedel, Germany).

Hand picking method was used in the evaluation of separation for qualitative and quantitative analysis of products. Approximately 1 kg of each product sample was separated by a chute riffling for hand picking. Subsequently, metals, printed circuit boards and cables (PCBs), and plastics were separated from each other by hand.

RESULTS AND DISCUSSION

Chemical Analysis

A comparison of TV scrap, personal computer scrap [6], and printed circuit boards scrap [4] is given in Table 1. It is apparent that the content of non-ferrous metals and precious metals in TV scrap is much lower than that of in personal computer or printed circuit boards scrap. From the point of view of recycling industry, the major economic drive force to process those scraps is recovery of non-ferrous metals and precious metals. Therefore, it is expected that recycling of TV scrap will not be economically viable by using conventional manual dismantling. Mechanical processing techniques may provide an alternative to separate copper and different plastics.

Table 1: Comparison of TV Scrap, Personal Computer (PC) Srap, and Printed Circuit Boards (PCBs) Scrap

		Al	Cu	Pb	Zn	Ni	Ag	Au
				%			ppm	
Assay	TV scrap	1.2	3.4	0.2	0.3	0.038	20	<10
	PC scrap[6]	2.8	14.3	2.2	0.4	1.1	639	566
	PCBs scrap[4]	7.0	10.0	1.2	1.6	0.85	280	110

Particle Shapes of Materials in TV Scrap

Fig. 1 shows images of non-ferrous metals (a), plastics (b), and printed circuit boards (PCBs) (c) separated from TV scrap sample. It is evident that non-ferrous metals are extremely heterogeneous, formed as wide variety of particle shapes such as, straight and bent bars, bent plates, cable and wire bundles. Furthermore, it can be seen that almost all of the plastics in TV scrap is black in color (Fig. 1 (b)). Therefore, with the fast development of CCD (Charge-Coupled Device) sensor technology, optical sorting process may provide a good choice to separate black plastics.

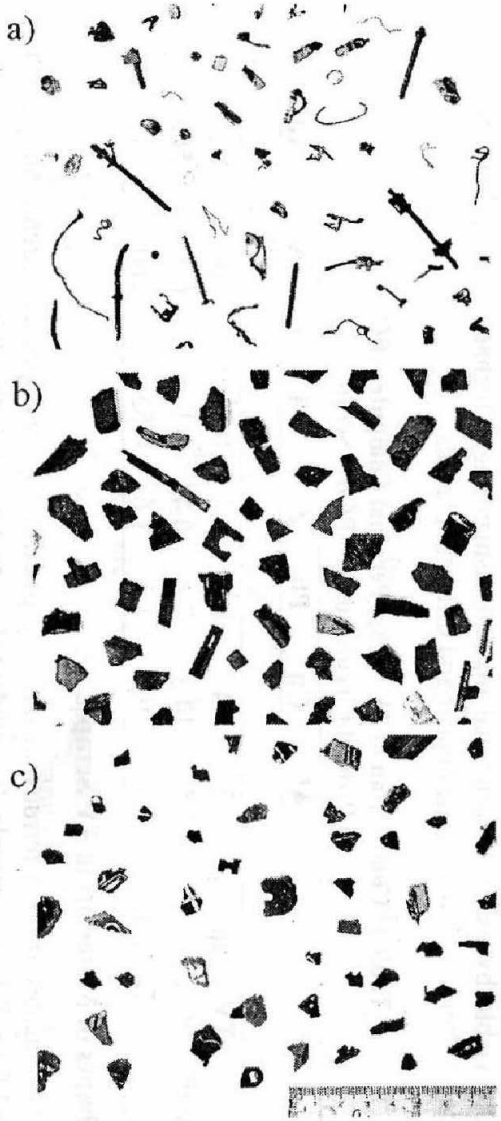


Fig. 1: Images of Non-Ferrous Metals (A), Plastics (B), and Printed Circuit Boards (C) Separated From TV Scrap Sample (+2.36mm)

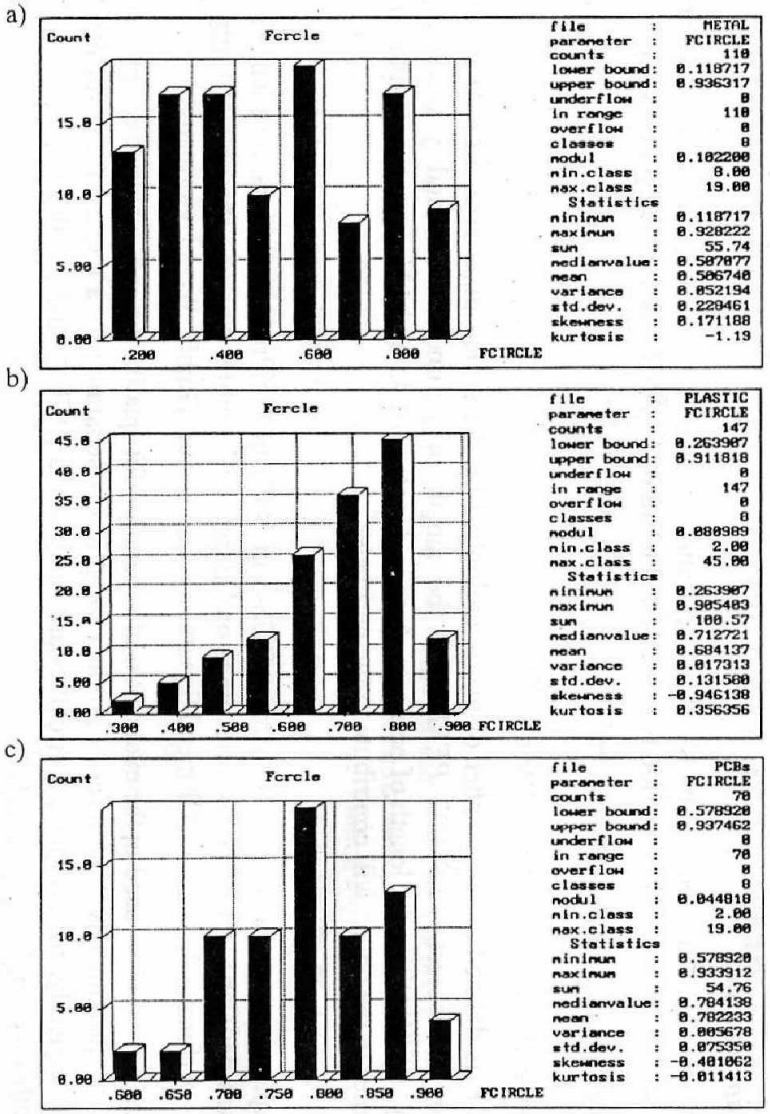


Fig. 2: FCIRCLE Analysis of Non-Ferrous Metals (A), Plastics (B), and Printed Circuit Boards (C) Separated From TV Scrap Sample (+2.36mm)

An image process system introduced by Kronton Elektronik was used to quantify particle shape factor, *FCIRCLE* (as shown in Fig. 2). It is obvious from Fig. 2 that the frequency distribution of *FCIRCLE* for non-ferrous particles varies to a large range (0.1-0.9); the frequency distributions of *FCIRCLE* for plastics and PCBs are mainly in the range of 0.6 to 0.9. This result indicates that non-ferrous metals particles in TV scrap sample form in a variety of shapes, much more different than that of plastics and printed circuit boards. The separation processes will be significantly influenced by the particle shape for recovery of non-ferrous metals.

Sink-Float Test

The result of the sink-float test is given in Fig. 3. It is obvious that a high recovery of copper is obtained by using a sink-float process. For +1.4 g/cm^3 fraction, the recovery of Cu is up to 88.4% with an assay of 42.4%. In addition, it must be pointed out that approximately 18% of the copper is distributed in –2.0+1.23 g/cm^3 fraction with an assay of only 7%. As discussed in the liberation degree section, this is because copper in printed circuit boards is not liberated from plastics and ceramic materials.

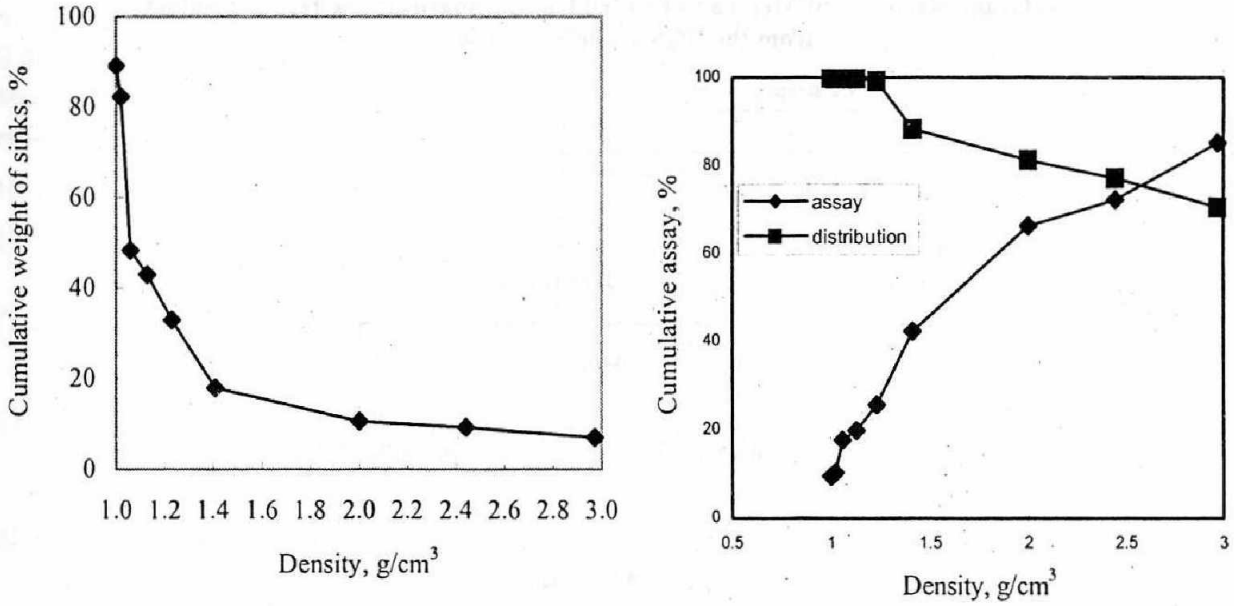


Fig. 3: Cumulative Data of Sinks Versus Specific Density for TV Scrap (-9.5+1.65mm)

DGS Table Separation

Fig. 4 gives the separation results of DGS table separation. It can be seen that 70% to 90% of metals are recovered in the heavy product with metal content between 40% and 60%. In addition, printed circuit boards and cables in the sample are difficult to separate from plastics by the DGS table. The result indicates that DGS table separation is effective and efficient for recovery of metals from consumer electronic scraps. Printed circuit boards and cables should be dismantled before further mechanical separation.

Optical Sorting

The optical (metal) sorting experiments by using color and/or metal sensors were carried out in Scan & Sort GmbH, Wedel, Germany. Two samples with particle size of +9.5 mm and -9.5+4.6 mm, were processed respectively (as shown in Fig 5). Table 2 and 3 give the results of optical (metal) sorting of TV scrap. It is evident that 90% of metals can be recovered in metallic product by utilizing optical sorting system.

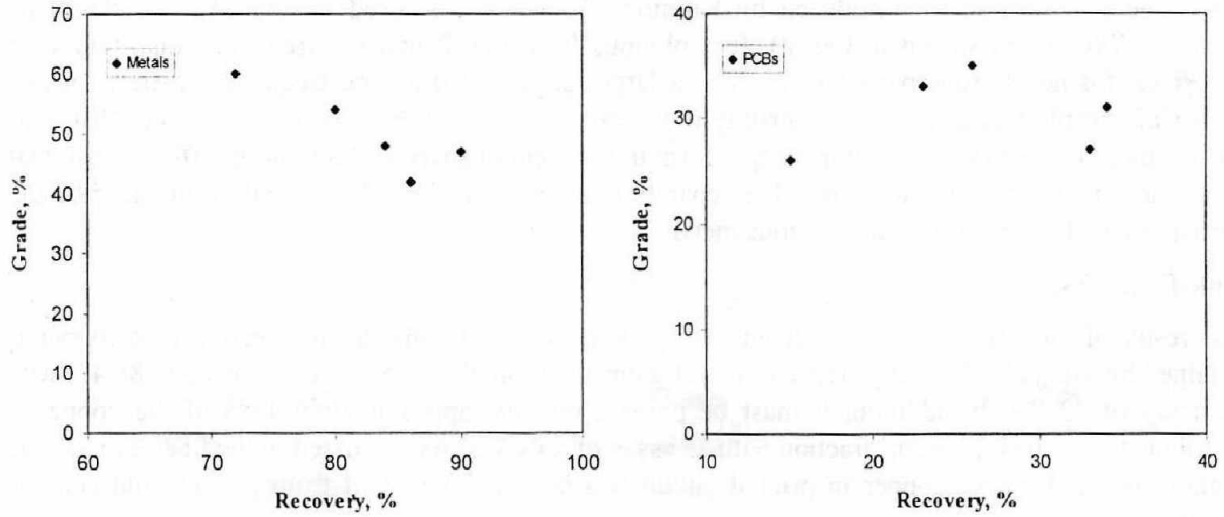
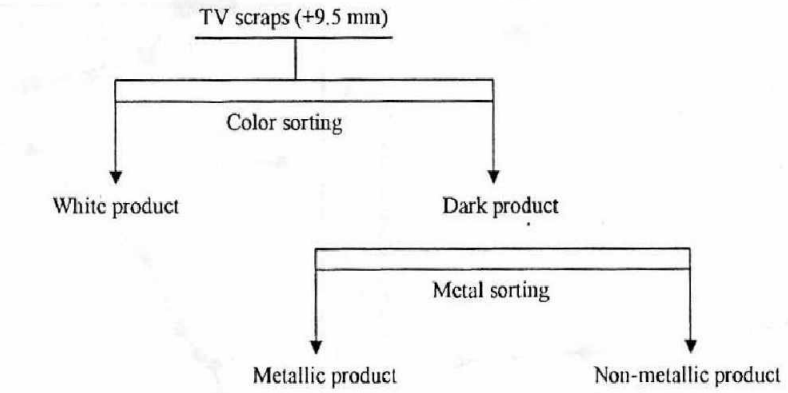


Fig. 4: Grade-Recovery of Metal and Printed Circuit Boards in the Heavy Product from the DGS Table Separation



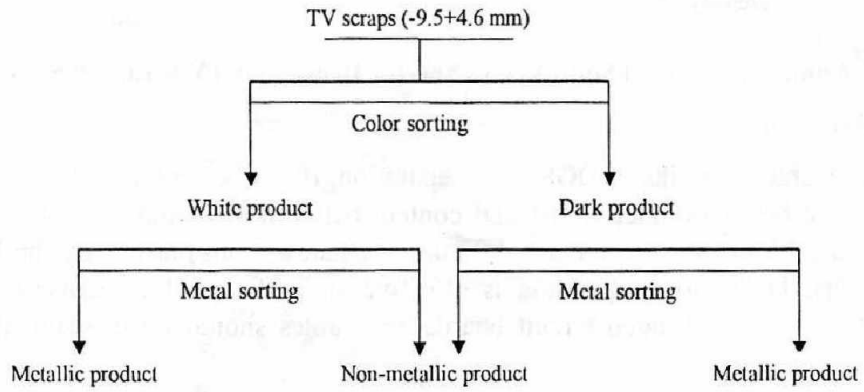


Fig. 5: Flowsheet of Optical (Metal) Sorting Process of TV Scraps

Table 2: Optical Sorting Result of TV Scrap (+9.5mm)

	Weight, %	Metal content, %	Recovery, %
White fraction	37	75	60
Metallic product from dark fraction	32	40	32
Non-metallic product from dark fraction	31	1	8
Total	100	41	100

Table 3: Optical Sorting Result of TV Scrap (-9.5+4.6 Mm)

	Weight, %	Metal content, %	Recovery, %
Metallic product	55	47	90
Non-metallic product	45	6	10
Total	100	29	100

CONCLUSIONS

1). The comparison of TV scrap, personal computer scrap, and printed circuit boards scrap shows that non-ferrous metals and precious metals content in TV scrap is much lower than that of in personal computer scrap or printed circuit boards scrap. From the point of view of recycling industry, it is expected that recycling of TV scrap will not be economically viable by using conventional manual disassembly. Mechanical recycling provides an alternative to separate copper and different plastics. In addition, the result of *FCIRCLE* indicates that non-ferrous metals particles in TV scrap sample form as a variety of shapes that is much more different than that of plastics and printed circuit boards.

2). A high recovery of copper is produced by utilizing an effective gravity separation technique. For +1.4 g/cm^3 density fraction in sink-float test, the recovery of Cu is up to 88.4% with an assay of 42.4%. The separation results of DGS table show that approximately 70% to 90% of non-ferrous metals are recovered in the heavy product with purity 40% to 60%. The results of optical sorting process show that 90% of metals can be recovered in metallic product.

REFERENCES

[1] Cui, J. and E. Forssberg: Mechanical recycling of waste electric and electronic equipment: a review, Journal of Hazardous Materials B99 (2003) 243-263

[2] Zhang, S., E. Forssberg, J. van Houwelingen, P. Rem, and L. Wei: End-of-life electric and electronic equipment management towards the 21st century, Waste Management & Research. 18, (2000) 73-85.

[3] The European Parliament and the Council of the European Union: Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE), Official Journal of the European Union, (2003) L37/24-L37/38

[4] Zhang, S. and E. Forssberg: Electronic scrap characterization for materials recycling. Journal of Waste Management & Resource Recovery. 3, (1997) 157-167.

[5] Kronton Elektronik GmbH: VIDAS User's Manual Volume 1, Germany, (1991) 6.7-6.10.

[6] Legarth, J.B., L. Alting, B. Danzer, D. Tartler, K. Brodersen, H. Scheller, K. Feldmann: A New strategy in the recycling of printed circuit boards, Circuit World. 21, (1995) 10-15.