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Intelligent Liberation and classification of electronic scrap

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Abstract

Mechanical recycling of electronic scrap oriented towards overall materials recovery from obsolete electronics is being implemented worldwide. The main reason is that the amount of electronic scrap is increasing and that the content of the precious metals present is decreasing. In this context, an effective liberation of various materials like metals and plastics is a crucial step towards mechanical separation. In addition, classification of electronic scrap is also important to be able to provide an appropriate feed material for the subsequent separation process. In the present study, liberation and its impact on the separation of personal computer (PC) scrap and printed circuit board (PCB) scrap has been investigated in detail. A special equipment functioning as a shape separator and an aspirator was used for the classification of electronic scrap. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: Liberation; Classification; Electronic scrap; Recycling

1. Introduction

Recycle and reuse of end-of-life electronics is ever-increasingly recognized as one major challenge. It is reported that, 75% of all used electric and electronic equipment in the US is stored, 15% is landfilled, 7% is resold and 3% is recovered. In 1991, a Carnegie-Mellon University study estimated that if the current rate at which the US discards scrap computers 10 millions per year continues, around 150 million old personal computers (PCs) and workstations will have been sent to landfills by the year 2005 [1,2]. However, this represents only a small portion of the electronic equipment that will require disposal in the US. A recent survey for the consumption of electric and electronic equipment in Western Europe shows that in 1992, approximately 7 million tons of electric and electronic items were consumed. The total waste approached 4 million tons, and accounted for 2–3% of the entire European waste stream. It can be expected that over the next decade the amount of consumption (by weight) will increase by 3% annually.

On October 15, 1992, the Electronic Scrap Ordinance was enacted in Germany, which stipulates that it is the responsibility of manufacturers and retailers to take back electronic waste. It is estimated that, by virtue of this ordinance, around 1.2 to 1.5 million tons of electronic scrap was generated in Germany in 1993. In addition, it is expected that the quantity of electronic scrap is increasing by 5% to 10% annually such that in the year 2000 approximately 2.0–2.5 million tons can be anticipated [3]. In Scandinavia, it is estimated that Sweden generates about 120 000 tons of electric and electronic scrap per annum.

According to Zhang and Forssberg [4], electronic scrap is proven to be recycling-worthy on the basis of materials composition. Usually, electronic scrap contains precious metals like Au, Ag, Pd, base metals like Cu, Al, Fe, and non-metals like plastics, glass and ceramics. In addition, the reusable components like computer chips are of great value. The current treatment of electronic scrap is directed primarily towards energy and metals (Cu and precious metals like Au and Ag) recovery. By hydrometallurgical methods, only partial extraction of the precious metals can usually be made because of the significant heterogeneity and complexity of the materials present in electronic scrap. For that reason, physical separation of electronic scrap will be indispensable. At this point, an effective and efficient liberation is a crucial step.

In the present paper, the characteristics of liberation of electronic scrap are analyzed by means of a grain-counting approach and with the microprobe analysis. Shape variations of metal particles resulting from the shredding (com-

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minution) process and their relations to the separation processes have been investigated.

2. Experimental

2.1. Materials

PC and printed circuit board (PCB) scrap samples were provided by the sampling plant at the Ronnskar smelter, Boliden Mineral, Skelleftehamn, Sweden. Initially, approximately 400–500 kg samples were extracted, blended and divided to procure approximately 45 kg samples for laboratory work. Obsolete PCs of any model and brand available which were manufactured a decade ago were collected primarily from the Scandinavian countries. End-of-life PCBs used in this study are heterogeneous and came from PCs, telecommunications, and other electronic devices. The as-received samples were reshredded by a laboratory hammermill to homogenize the samples and were subsequently riffled. Size analyses of the materials from the laboratory hammermill were made on a 1.5 kg sample, by screening with a ASTM Retsch testing sieve series in a RO-TAP testing sieve shaker. The size distribution of both PC and PCB scrap after shredding is shown in Fig. 1.

2.2. Methods

2.2.1. Liberation degree determination by grain-counting

Electronic scrap from obsolete electronic equipment has lower interfacial bonds when compared with natural ores. For this reason, the liberation size is comparatively large. A proven and simple method that is capable of determining the liberation degree is grain counting, which can be expressed as:

$$\mathrm{LD} = \sum_{i=1}^{n} \frac{N_{\mathrm{f}i}}{N_{\mathrm{f}i} + N_{\mathrm{l}i}} \bigg/ n \tag{1}$$

in which LD denotes mean liberation degree, n is the number of samples to be counted, $N_{\mathrm{f}i}$ indicates the free particles of the desired material in the ith sample, and $N_{\mathrm{l}i}$ represents the locked particles of the same material in the ith sample. In the present study, two samples, with each being up to 1.5 kg, were analyzed and the liberation degree was calculated with this formula.

2.2.2. Microprobe analysis

Representative composites encountered in each fraction, which were not yet liberated, were investigated by the CamScan scanning electron microscope, coupled with the Link analytical program for microprobe analyses. The photographs shown in Figs. 3–6 were taken by one laboratory Zeiss stereomicroscope (No. 475052), together with a camera.

2.2.3. Eddy current separation experiment

The eddy current separation experiment was conducted with a newly developed High-force® eddy current separator (HFECS) shown in Fig. 2. The objective was to investigate the effect of particle shape variations resulting from the comminution process on the separation results. Pure metal particles with certain shapes were obtained by cutting the corresponding pure metal pieces. A sample of the aluminum alloy particles was obtained by shredding obsolete PC scrap with a ring shredder. The materials distribution after the HFECS was calculated by positioning eight collecting boxes in front of the external shell of the HFECS.

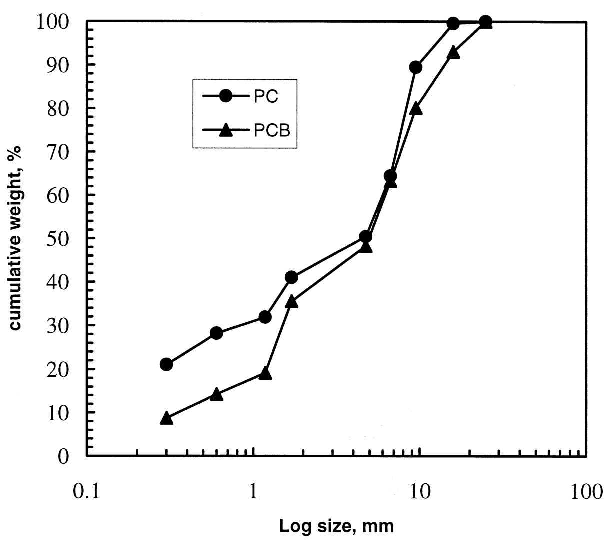


Fig. 1. Size analysis of PC and PCB scrap after the hammermill.

3. Results and discussion

3.1. Liberation characteristics of electronic scrap

It is easy to obtain liberation of the composites present in electronic scrap, due to lower interfacial bonds of the materials used in electronic equipment. Basically, the materials are attached by fastening, inserting, welding, binding, wrapping and so forth. Therefore, it is not energy intensive to unlock the associated materials like ceramics, glass, and metals having distinctive mechanical properties [5]. After the secondary shredding by a laboratory scale hammermill with the opening grates up to 10 mm, the liberation degree of both PC and PCB scrap was analyzed and calculated. The results obtained are presented in Tables 1 and 2, respectively. It can be seen that in fractions (< 3 mm), the metals achieve approximately complete liberation. In coarser fractions, copper has poorer liberation due to the presence of copper pins associated with

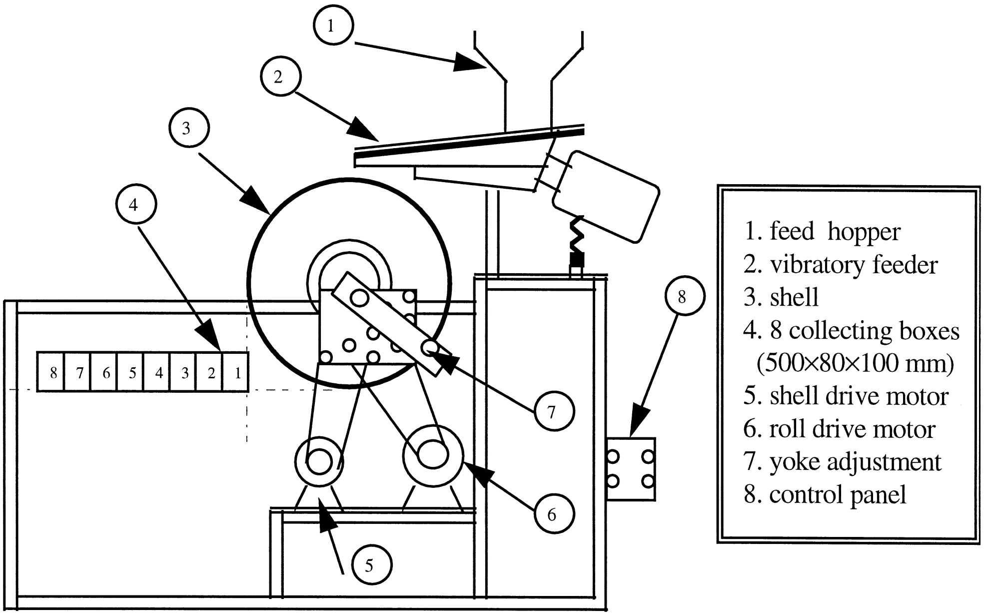


Fig. 2. Illustration of eddy current separation experiments.

plastics (see Figs. 3 and 4) and copper wire segments encapsulated with plastics (see Fig. 5). Also, the ferromagnetics obtain a good liberation, except for the +16 mm fraction in which a substantial portion of ferromagnetics is locked with plastics through the inserting pattern (see Fig. 6). Further, it has been shown that aluminum in the +7 mm fraction of both PC and PCB scrap accomplishes an excellent liberation. Consequently, a granulator or a cutter using cutting stresses will be more effective for liberating copper from plastics than a hammermill based on impact stresses.

Further, a substantial portion of bromine (Br) was detected in the finer fraction (−0.6 mm), as shown in Fig. 7. The presence of Br in electronic scrap comes from a variety of plastics that are treated with flame retardants. Those chemical compounds usually contain Br. Since they are potentially hazardous, care must be taken when shredding electronic scrap.

3.2. Effect of particle shape on separation processes — ''Intelligent Liberation''

The characterization and quantification of the particle shapes in PC and PCB scrap has been described in detail by Zhang and Forssberg [5]. An influence of the particle shapes on the subsequent separation is significant, especially, on eddy current separation. Fig. 8 shows that the aluminum distribution by weight in the collection boxes is considerably dependent on the aluminum particle shapes. It appears that the deflections of aluminum particles with different shapes follow:

$$D_{ss} > D_{rs} > D_{cd} > D_{sp} \quad (2)$$

where D_{ss} denotes the deflection of a square sheet, D_{rs} the deflection of a rectangular strip, D_{cd} the deflection of a cylindrical particle, and D_{sp} the deflection of a spheric particle. Since metal sheets or plates obtain the largest

Table 1
Liberation degree of major metals (alloys) in PC scrap (hammermill with grates 10 mm)

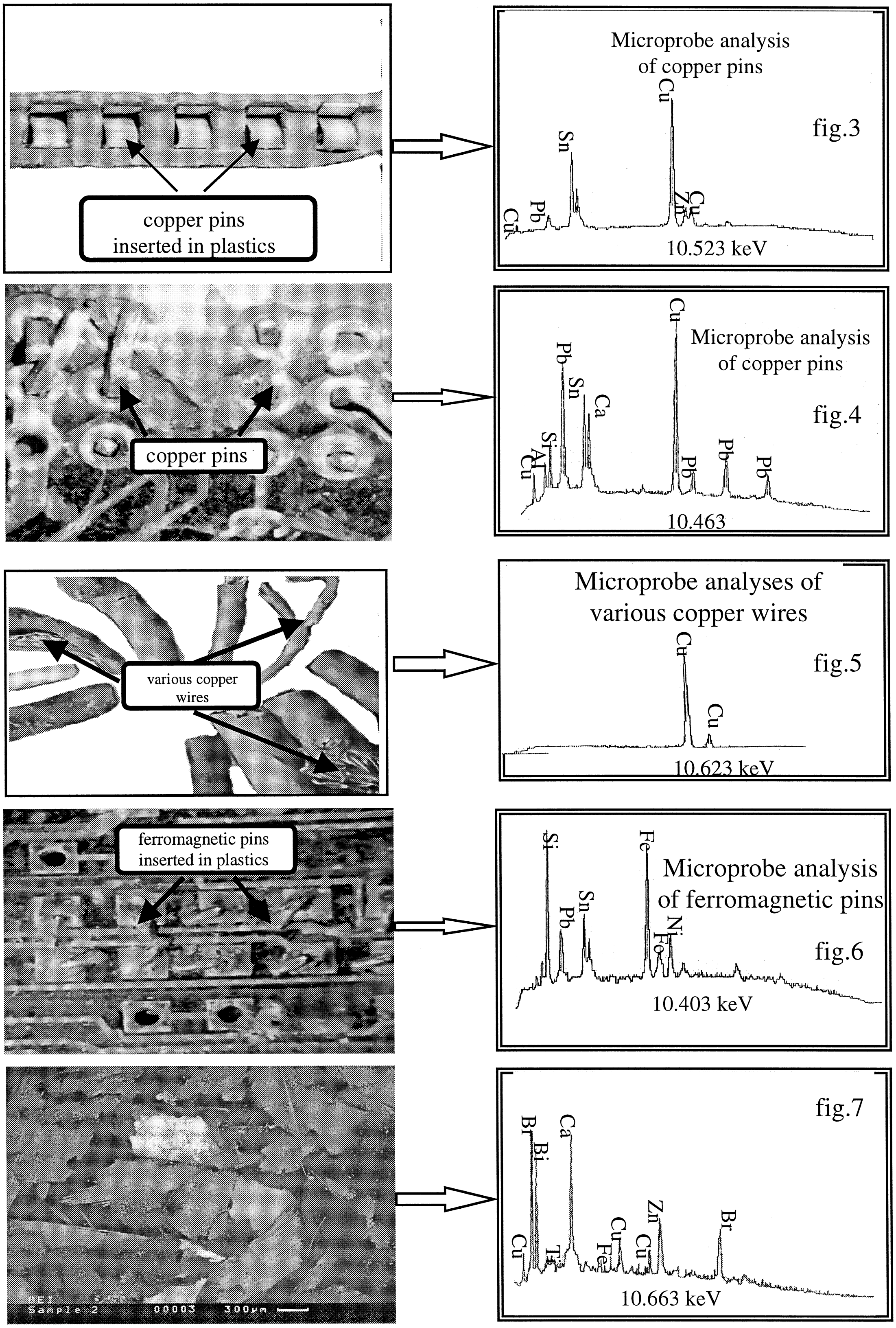
Size range (mm)	Weight (% retained)	Degree of liberation (%)		
		Ferromagnetics	Al	Cu
+16	10.48	62.5	100.0	0.0
−16+9.5	25.07	94.6	100.0	50.0
−9.5+6.7	13.98	94.9	100.0	85.3
−6.7+4.75	9.44	87.0	n.d.[a]	93.2
−4.75+1.7	9.13	98.5	n.d.	98.6
−1.7+0.6	10.85	100.0	n.d.	99.0
−0.6+0.3	8.37	100.0	n.d.	100.0
−0.3	12.68	100.0	n.d.	100.0
Total	100.00	92.6		74.1

[a] n.d. denotes ''not determined''.

Table 2
Liberation degree of major metals (alloys) in PCB scrap (hammermill with grates 10 mm)

Size range (mm)	Weight (% retained)	Degree of liberation (%)		
		Ferromagnetics	Al	Cu
+16	19.85	8.7		2.8
−16+9.5	16.91	80.0	100.0	15.4
−9.5+6.7	15.00	95.0	100.0	48.6
−6.7+4.75	12.71	95.4	n.d.[a]	62.5
−4.75+1.7	16.32	99.2	n.d.	99.0
−1.7+0.6	10.46	100.0	n.d.	99.0
−0.6+0.3	3.54	100.0	n.d.	100.0
−0.3	5.21	100.0	n.d.	100.0
Total	100.00	77.0		53.7

[a] n.d. denotes ''not determined''.



Figs. 3–7. Microprobe analyses of the composites in the +1.7 mm fractions and Br in the −0.6 mm fraction.

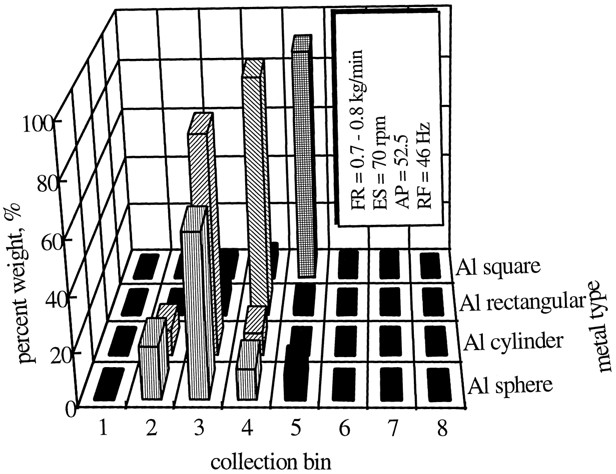


Fig. 8. Al distribution in the collection box at RF = 46 Hz (FR = feed rate, ES = rotational speed of external shell, AP = angular position of magnetic roll assembly, RF = rotational frequency of the magnetic field).

deflections compared to other shapes, a liberation technique aimed at generating sheet/plate-shaped particles in favor of ECS is essential.

It is well-known that a hammermill shredder, making use of the impact stress, can bundle up (encase) the liberated metal particles, particularly aluminum, into ball-shaped particles. Therefore, the hammermills are not recommended for the first stage liberation of electronic scrap. Instead, shear-type, or cutting-type or a combination of both shredders can be used for this purpose. Here, a ring shredder developed by the Scandinavian Recycling, Malmö, Sweden, has been used. Fig. 9 shows that a series of crushing rings, capable of being turning around, are connected with a rotor. When electronic scrap to be shredded is introduced into the crushing chamber, the crushing rings can shear, or even cut, the feed against the wall of the shredder. This depends on the configuration and shape of the crushing rings. The rotor has asymmetric distance to the wall, with the left distance being larger than the right one, as shown in Fig. 9. Components that failed to be shredded at the left side can be crushed at the right side. By adjusting the discharge screen, a desirable product from the ring shredder can be obtained. One of the salient advantages is that the encasing of liberated aluminum sheets into balls can be minimized to maximize aluminum recovery by eddy current separation. Fast running hammers in a hammermill can easily twist, bend, and crack metallic particles. This can result in a substantial number of irregularly shaped particles. It is of vital importance that ''Intelligent Liberation'', which is oriented towards obtaining material particles suitable for subsequent separation, is developed.

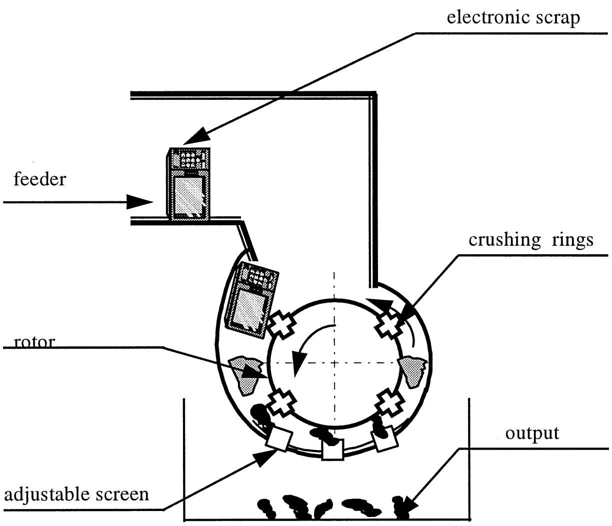


Fig. 9. Illustration of cross-section of a ring shredder.

3.3. Classification of electronic scrap

A detailed sink-float analysis of PC and PCB scrap has been made. The results obtained show that density-based separation techniques are capable of producing a high quality copper concentrate. In view of the advantages of the dry process, air tables are employed for that purpose. The materials to be separated according to their densities must have similar sizes. After the granulation (−3 mm), the materials can be liberated, but they remain heterogeneous in terms of shape. A substantial portion of copper wires with an elongated shape are present. Plastics and glass particles are either cubic-like or ball-like. The classification of the materials shall also take advantage of the shape differences. As can be seen in Fig. 7, a substantial portion of Br-containing chemical compounds can be present in the granulated fraction. Because they are potentially

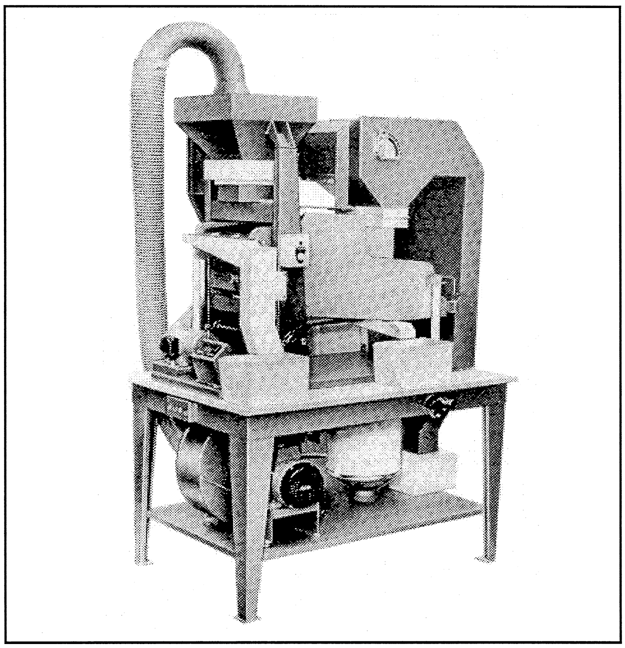


Fig. 10. Illustration of the shape separator.

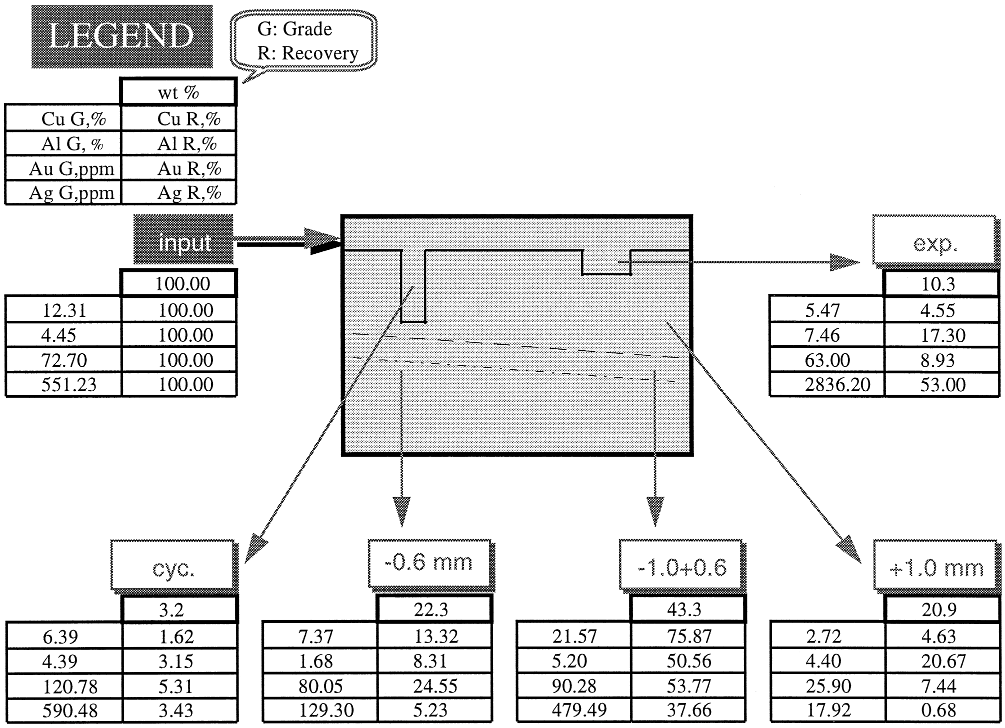


Fig. 11. Results of the shape separation.

toxic, the equipment to be used must be able to remove the dust present in the material.

The unique separator used in this study is shown in Fig. 10. This equipment consists essentially of a screening system and aspiration system. By changing the screen decks with specially designed apertures, the equipment can function as a shape separator. Further, this equipment incorporates pre-aspiration and post-aspiration with a primary cyclone collector and a secondary bag filter for a dust-free operation so that it also works as an aspirator. The upper screen deck used in this experiment is the one with elongated apertures (slot-like), each having 1×10 mm^2 dimension. The lower deck is the one with round apertures, each having a 0.6-mm diameter. In the present study, a Model LA-LS shape separator was employed. This equipment is particularly applicable for electronic scrap since electronic scrap contains a large amount of aluminum foils which are used in the capacitor fabrication. Liberated aluminum foils which are a nuisance for processing the material can be sucked up into the cyclone and the expansion chamber.

The results obtained by the shape separator are shown in Fig. 11. It has been shown that copper and gold is primarily concentrated in the $-1.0+0.6$ and -0.6 mm fractions. Both of them can further be processed using air tables. In the present study, only one fraction, i.e., the $-1.0+0.6$ mm fraction, was used for the air table separation by the authors [6]. Apparently, aluminum foils report in the expansion chamber and other aluminum particles are beneficiated in the $-3.0+1.0$ and $-1.0+0.6$ mm fractions. It seems that, to a large degree, silver is distributed in the light fraction collected in the expansion chamber and the $-1.0+0.6$ mm fraction. The reason why a substantial portion of the silver reports into the light fraction is that a very fine pure silver film is plated on the Fe–Ni alloys used as leadframes in integrated circuits fabrication, and is coated on the ceramics or other carrier materials [7]. The fine film can be liberated from the matrix materials by the granulator. Liberated silver films are so fine that they can easily be sucked up into the expansion chamber.

4. Conclusions

It has been shown that the materials present in electronic scrap are easy to liberate, due to their weak interfacial bonds. The focal point, in this context, is how to develop an ‘‘Intelligent Liberation’’ technique, which is capable of selectively producing particles with a favorable shape and size for eddy current separation. Further, the shape separator used in this study can effectively provide an appropriate feed material for air table separation.

Acknowledgements

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