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Procedia CIRP 26 (2015) 746 – 751
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12th Global Conference on Sustainable Manufacturing

Design of a Proper Recycling Process for Small-Sized E-waste

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Abstract

Recently, small-sized home appliances have been included in the recycling legislations of Japan. However, since small-sized home appliances have many varieties and individual products are small, it won't be economically feasible to disassemble each e-waste manually. Thus, combinations of pulverization and physical separation technologies are being discussed. This paper applies pulverization plus physical separation for the basic recycling process of used mobile phones. By applying XRF analysis to classified particles, the paper clarifies that valuable material such as copper, silver, etc are more concentrated in printed circuit board (PCB) and relatively larger particles. Based on the result, the paper shows that separation of PCB-origin particles after rough pulverization can be a good strategy for low-cost and high-quality material recycling. Plus, the paper proposes a basic concept of a totally new recycling process so-called "remote separation," for the future studies.

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Peer-review under responsibility of Assembly Technology and Factory Management/Technische Universität Berlin.

Keywords: e-waste; material recycling; pulverization; remote separation; XRF.

1. Introduction

Electrical and electronic equipment (EEE) are popular in recent world and have large impacts on environment. Recently in Japan, non-recycled products so-called "urban mine [1]" are the targets of discussion. Since the urban mine contains electronic products such as PCs, mobile phones, etc., it is said that considerable amounts of critical metals are being abandoned. Especially for small and medium-sized e-waste, no legislations to promote recycling and circular economy had existed. Because of the smallness, these products are often hibernated or dumped as municipal wastes, after the product life. As a countermeasure to this situation, a new recycling legislation to cover used small and medium sized e-waste has been discussed [2] and started from April, 2013. In the new legislation, recycling fee is not collected from consumers, unlike the large-sized e-waste such as air conditioner, refrigerator, etc. Thus, new social system for recycling should be economically profitable without any subsidy or recycling fee from consumers. Although small-sized e-wastes contain relatively higher concentrations of valuable metals, manual disassembly of such products is very time consuming and will be a cost driver. Therefore, a more automated recycling process than the recycling process of large-sized e-waste will be necessary to promote recycling of small-sized e-waste. The purpose of this paper is to propose a totally new concept for recycling operations which can reduce the cost for recycling of small-sized e-waste drastically, and to collect some fundamental data to discuss the feasibility of the new method.

2. Target product

Since there are too many variations of small-sized e-waste, this paper focuses on used mobile phones. Used mobile phones contain valuable metals compared to other small-sized e-waste. (Table 1, Original data from [2].) As shown in the table, most of Nd which can be potentially recovered from small-sized e-waste is contained in used mobile phones. About Pd, W, La and Au, nearly or more than half of the metals contained in small-sized e-waste are contained in used mobile phones. In addition, mobile phones are one of the most common electronic products in Japan and its ownership rate is over 80%. It means that huge amount of used products are currently hibernated in personal homes, and will be emitted from now. Thus, the paper focuses on a process design to enhance recycling efficiency from used mobile phones.

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doi:10.1016/j.procir.2014.07.088

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Table 1. Ratio of valuable metals contained in small-sized e-wastecomparing to total consumption in Japan(%). [2]

Product	Pd	Ta	W	Nd	Dy	La
Mobile phone	**0.55**	**4.12**	**3.44**	**3.93**	**0.08**	**1.22**
Portable game player	0.05	0.94	0.14	0.73	0.02	0.44
Non-portable game player	0.03	0.24	0.13	0.12	0.01	0.05
Portable CD/MD player	0.01	0.18	0	0.01	0	0
Portable digital audio player	0	0	0	-	0	0
Digital camera	0.07	2.85	0.24	0.12	0.02	0.05
Driving navigation system	0.09	0.99	0.14	0.28	0.07	0.07
Video camera	0.21	2.19	0.15	0.21	0.02	0.11
DVD player	0.09	2.51	0.47	0.44	0.11	0.26
Others	0.08	3.20	1.31	0.08	0.14	0.35

Product	Au	Ag	Cu	Zn	Pb
Mobile phone	**2.1**	**12.2**	**486**	**9.6**	**18.9**
Portable game player	0.4	1.3	265	15.1	20.0
Non-portable game player	0.1	2.1	67	2.9	10.1
Portable CD/MD player	0	0.1	9	0.5	0.4
Portable digital audio player	0	0	0	0	0
Digital camera	0.3	2.4	87	3.3	5.7
Driving navigation system	0.1	1.4	109	9.4	5.5
Video camera	0.1	2.2	49	3.5	6.8
DVD player	0.4	5.4	507	55.0	39.2
Others	2.5	24.9	2262	213	135

3. Proposal on a remote process for e-waste recycling

3.1. The original concept

Reducing disassembly cost is one of the keys to improve cost-profit balance of e-waste recycling. Simply, operating manual disassembly processes at locations where labor costs are more inexpensive, will be effective in reducing the recycling cost. However, exporting used products which contain considerable critical metals and rare earths is not welcomed, in the aspect of Japanese resource securing policy. At the same time, outflow of "waste" is restricted by Basel Convention. In the existing paper [3], a basic concept of remote recycling system utilizing tele-operation technologies was proposed as a countermeasure of this problem. The concept was named tele-inverse manufacturing. The feature of the model is that the operations for recycling are carried out via tele-operation. Fig.1 illustrates the basic concept. Suppose that e-waste is located at location B and it is processed at the location. However, in tele-inverse manufacturing, the operators do not stay at the same location. They can stay at a different location and carry out recycling processes by tele-operation.

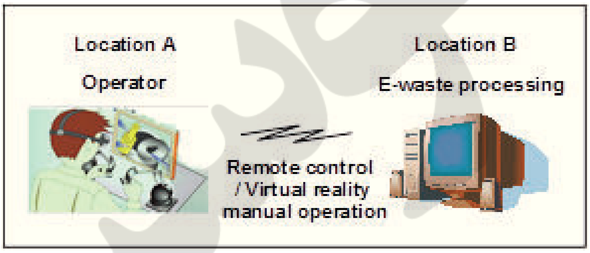

Fig.1. The basic concept of remote recycling process

3.2. Modifying the idea for small-sized e-waste

The original concept of remote recycling was proposed in order to apply to the recycling process of large-sized e-waste which contains many manual disassembly processes. However, we thought the concept is more suitable for small-sized e-waste recycling, since the cost issue is more critical than large-sized e-waste. An existing survey [4] estimated the labor cost of a used mobile phone reaches about 145JPY per unit, while the total price of recoverable materials will be only 112JPY [5]. As an analogy to remote recycling of medium-sized e-waste, it is estimated that labor cost can be reduced to 30% by implementing manual disassembly operation in countries where labor cost is relatively inexpensive. This estimation roughly suggests that labor cost of used mobile phone recycling can be reduced to less than 50JPY. So, there is a possibility that we can design the profitable total process of mobile phone recycling by applying remote recycling. So-called "hand-picking" which means manual separation is sometimes observed in recycling facilities. The feasibility of the manual separation is assured by the fact that the workers can recognize valuable parts from other parts. This visibility of the valuable parts suggests that remote separation using visual data is possible.

4. Primary pulverization and classification

4.1. Classification characteristics of particles

Since this paper focuses on an efficient recycling process of valuable materials, the paper first carried out conventional recycling process shown in an existing study [6]. Since the authors supposed that the combination of pulverization and classification based on particle sizes will be effective in increasing metal concentration, the primary experiments were carried out. The pulverization was carried out using a cutting mill. Table 2 shows the conditions of the process. Plus, in advance to pulverize the used product to small particles, rough crushing larger up to 2mm was tested. Using 2mm size particles, it could tell which particles are from ICs, or from PCB.

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Table 2. Basic conditions of the pulverization

Process	Make	Type	Major parameters
Pulverization	Retsch	SM100	Disk rotation: 2500rpm, Screen size: 2.0mm

After eliminating batteries which can be hazardous, and liquid crystal display which can be reusable, the rest of the parts were crushed by using the device. Then, a sieve shaker (Fig.2) was used to classify the particles. The particles were classified into 5 categories; over 1.18mm, 1.18mm-600μm, 600μm-300μm, 300μm-150μm and under 150μm. Since the classification efficiency should be higher than 80%, throughout the primary experiment (Fig.3), 10 min. was thought to be enough to classify the particles. Fig.4-6 show the classified particles.

Fig. 2. Sieve shaker

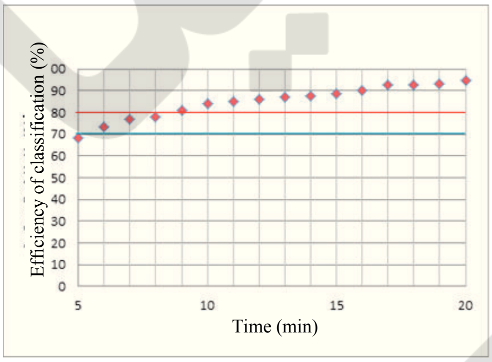

Fig. 3. Efficiency of classification and shaking time

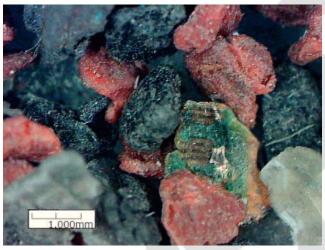

Fig. 4. Particles larger than 1.18mm

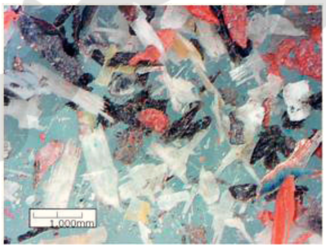

Fig. 5. Particles of 600μm-300μm

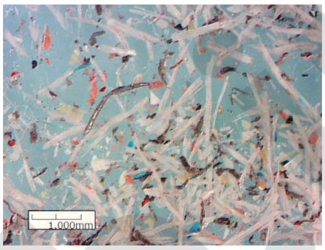

Fig. 6. Particles smaller than 150μm

The existing study [6] says that metals will be concentrated in relatively larger particles, while plastics will be concentrated in smaller particles. Basically, valuable materials which can be potentially extracted from used mobile phones are metals. Mixed plastics usually have little value. Thus, from the cost aspect, it might be better to separate plastics, and put into thermal combustion process. So, one of the purposes of designing recycling process is to separate metals and plastics efficiently. From the above photos, it can be estimated valuable materials which should be recovered will be concentrated in larger particles. To know the actual material compositions of the particles, X-ray Fluorescence Analysis [7] was carried out. Fig.7 shows the compositions of materials of the particles larger than 1.18mm and smaller than 150μm.

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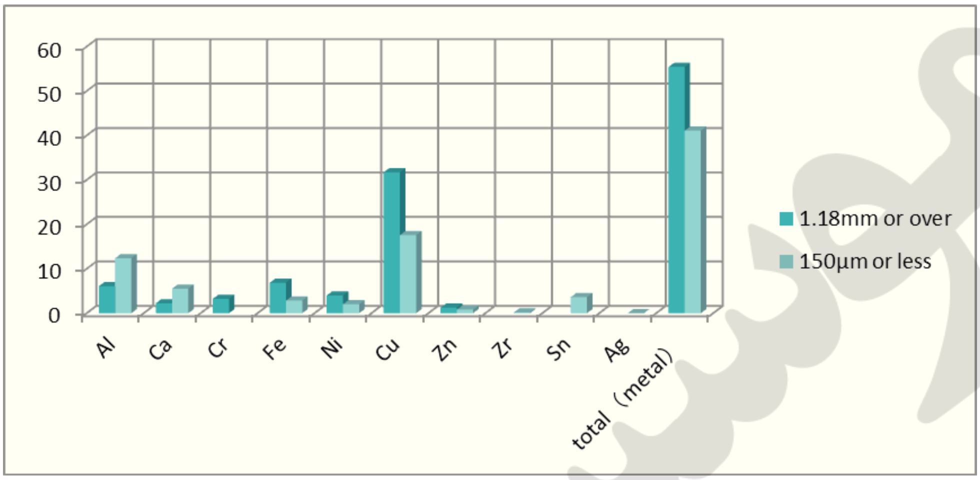

Fig. 7. Material compositions of the classified particles.

4.2. Difference in material composition

Unlike the existing study, Fig.7 shows percentage of metals in particles larger than 1.18mm and that of particles smaller than 150μm are not very different. This means that only by the classification based on the particle size, efficiency of recycling cannot be enhanced. Thus, another concept for separation will be necessary. This paper proposes a procedure to separate roughly crushed particles based on its origin. In other words, separation of PCB-origin particles from other particles can be a good strategy. Corresponding to this idea, Figure 8 shows the material composition of PCB-origin particles and other particles. The figure shows that concentration of metals is apparently higher in PCB than the whole product. Actually, it is reported [8] that most of the material value which can be recovered from used mobile phones exists on PCBs. Therefore, if it is possible to separate PCB efficiently by low cost, it will be helpful to enhance the total efficiency of the recycling process.

5. Basic concept of the remote separation system

As it was mentioned in the former section, it will be meaningful to separate PCB and some other metal concentrated parts, from plastic parts. Of course, manual disassembly [9] is the best way to do that. However, manual disassembly process will be the cost driver of the total process. In order to avoid the increase of the cost, aforementioned idea tele-inverse manufacturing can be applied. In this paper, since we focused on separation of metal-rich particles by tele-operation process, we named it “remote separation.” Fig.9 shows the basic concept of the remote separation. Roughly crushed particles come along on a conveyor and metal-rich particles are separated by a sorting device. The sorting device is remotely controlled from locations where labor cost is relatively inexpensive. Or, it can be also controlled from unspecified persons via internet. Then, Fig.10 shows the basic process diagram using remote separation. Since metal concentration will be insufficient only by “remote separation,” other separation process such as magnetic separation and electrostatic separation are combined.

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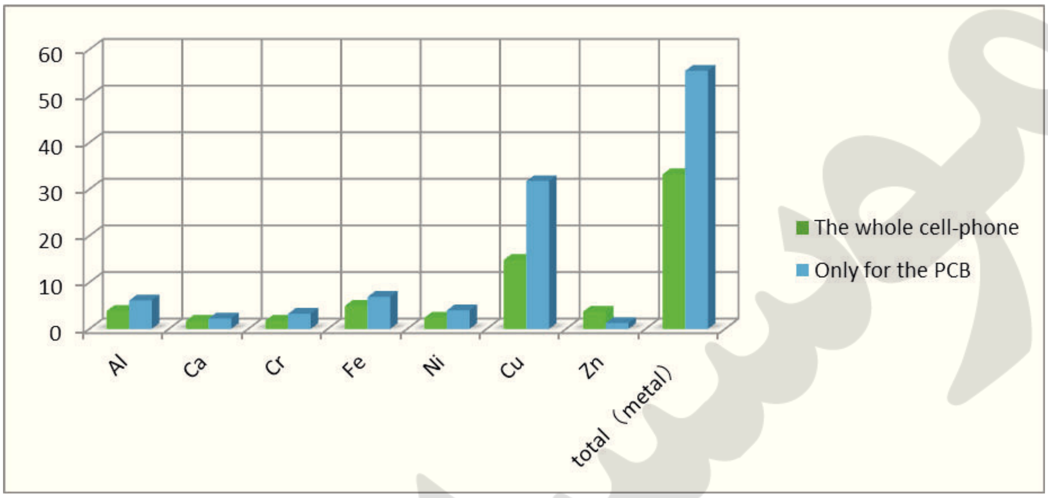

Fig. 8. Material compositions of the particles having different origins

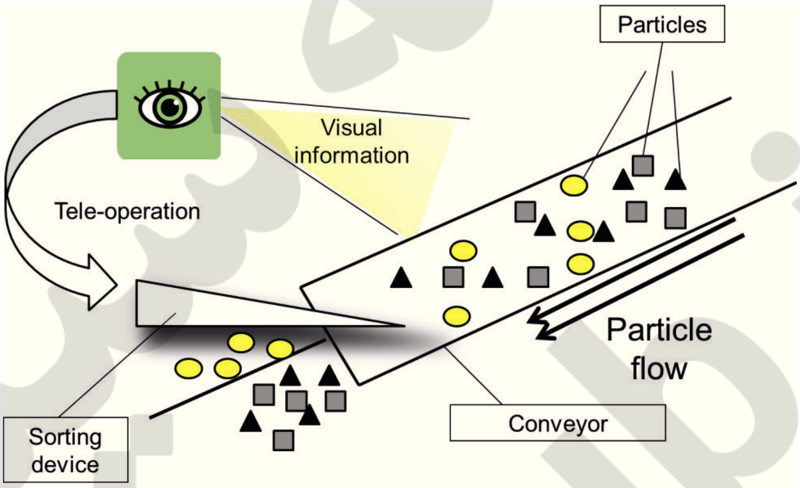

Fig. 9. Schematic image of the remote separation

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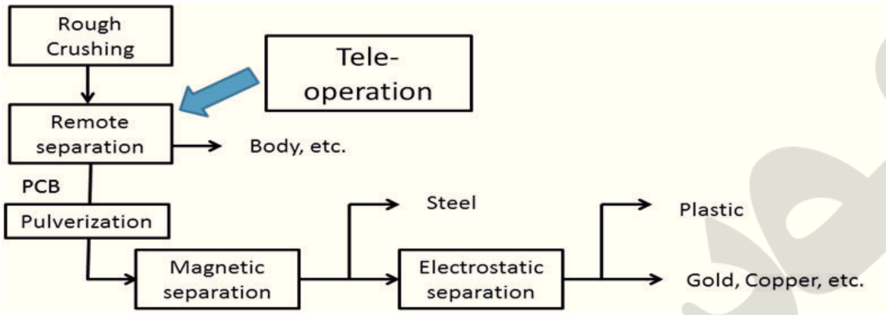

Fig. 10. Basic block diagram of a recycling process including remote separation

6. Conclusions

In this paper, a new concept of recycling "remote separation" has been proposed. The concept aims to replace some of the time consuming and cost consuming process by tele-operation. Since rather big percentage of the recycling cost due to the labor cost, the new concept focused on reducing the labor cost by implementing separation of valuable parts remotely operating from countries where labor cost is relatively inexpensive.

Furthermore, the paper also proposed voluntary and distributed operation as an online game. If this concept is realized, the labor cost of manual separation and sorting will be zero.

To know the feasibility of the proposal, the paper tried to identify what kind of pre/post process is suitable. At first, classification of pulverized particles was tried. However, only by sorting the particles by size, the efficiency of separating valuable parts (mainly metals) and non-valuable parts (mainly plastic) was not enough.

Then the paper tried to know the difference of composition of materials between particles from Printed Circuit Board and particles from other parts including body. The result suggested that separating the particles from PCB and particles from other parts of the used products, can be efficient in enhancing the quality of recycling.

Finally, what we have to solve from now, is to clarify what kind of pre/post treatment is suitable to be combined with the remote separation. Then, of course it is necessary to design the prototype system and examine the new method is really feasible.

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