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Eddy current evaluation of recovered conductive waste purity

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ABSTRACT

The main goal of this paper is to present a new approach to evaluate the recovered conductive granular waste purity. For this purpose, the eddy current approach which is commonly applied in nondestructive evaluation has been used. The experimental tests consist of several samples composed of copper particles mixed with sand inserted in a cylindrical container with solenoidal coil. The impedance of the coil is measured, using precision LRC-meter, for several frequencies per sample and used according to the Experiment Design Methodology (EDM) to determinate the relationship between input and output of experiments, to have a quadratic model that will be used for inversion. The input and output are successively impedance and percentage of copper particles contained in the container. The results show the capability of the proposed approach to evaluate the conductive recovered waste purity.

1. Introduction

Due to the technologic evolution and the widespread use of electronic devices the amount of electric and electronic equipment wastes (WEEE) has been increased during the last decades, in a way never seen before which gave waste management a great importance on the environmental, economic and social level (Torretta et al., 2013; Miloudi et al., 2015). The continuous accumulation of this wastes leads to the pollution of the environment (Asokan et al., 2007). For this reason, Recycling becomes a very important operation. Moreover, the recycling of WEEE is cheaper than the extraction of raw materials (Dalmijn and De Jong, 2007).

Wastes sorting are an essential step in the recycling process; it consists of separating and recovering the wastes according to their nature. The main two steps of recycling WEEE are sorting and processing. In the sorting step, wastes go through several stages, primarily the shredding and separation (Menad et al., 2012; Fabrizi et al., 2003). At the end of the sorting procedure, the materials are in granular form. But the presence of impurities such as insulating particles mixed with conductors reduces the quality of the recycled products.

In the field of electrostatic separation of conductive and non-conductive materials the process is affected by various parameters (voltage levels, material flow, speed of drum, granules size and shape, etc.), which are reflected to the middling product (Fig. 1) and therefore on the efficiency of separation (Lai et al., 2015; Dascalescu et al., 2014). That is why there is a great need to know the percentage of impurities in the given volume of recycled conducting materials (Jujun et al., 2014; Zeghloul et al., 2016).

Eddy current (EC) evaluation is a technique used in electromagnetic and geometric characterization of conducting materials.

In this work, the EC technique has been implemented to evaluate the percentage of purities after separation of conductive waste. The recovered waste is introduced in a cylindrical container immersed in a solenoidal coil.

To demonstrate the capability of eddy current technique to evaluate the purity of conductive waste after separation, several samples of recovered conductive waste are formed using pure copper mixed with insulating particles, the samples occupy the same volume but they are different in the proportions of copper and insulator that it formed.

The Experiment Design Methodology (EDM) is then used to get the mathematical relation (prediction model) between the parameters of eddy current evaluation and the purity of the recovered conductive waste.

The experimental setup (Fig. 1) is performed with a solenoidal coil surrounding a cylindrical container that is dedicated to the proposed tests. This container is filled each time with one of the samples then, the impedance of the probe is measured using a precision LCR-meter for several frequencies. The used platform of the EDM is MODDE 5.0 software (Dascalescu et al., 2004; Eriksson et al., 2000). The inputs parameters of EDM are percentage and length of the conductive particles, and the output one is electrical impedance of the coil. To get the percentage of conductive particles

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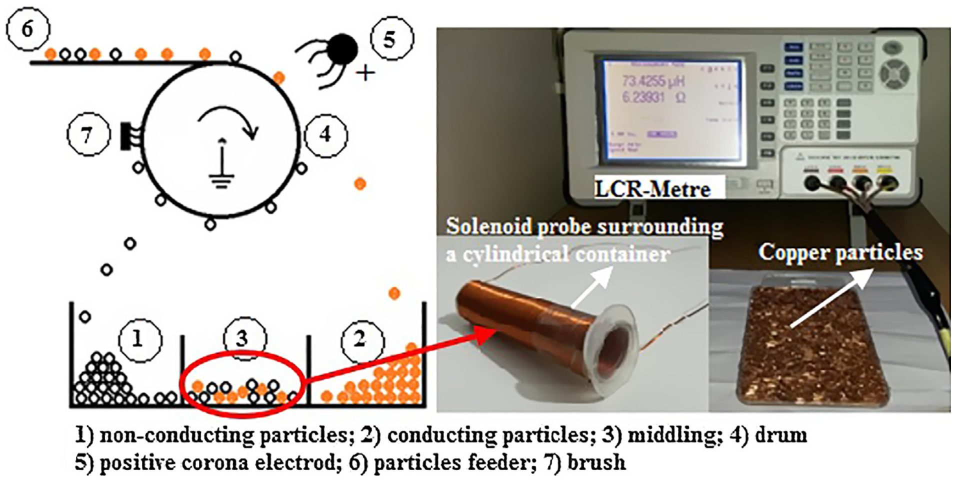

Fig. 1. Experimental setup.

contained in the recovered waste, the obtained mathematical model must be inversed.

2. Experiment setup

In our experimental setup the recovered waste samples are created by mixing the conductive and insulating particles. The conductive particles are from copper wire. Fine sand is used as insulating particles. Each sample is inserted in a PVC cylindrical container with a known volume.

The impedance of the coil, surrounding the cylindrical container, is measured using a precision LCR meter.

To obtain the purity percentage of recovered waste samples, the weight of copper is taken by using a precision balance.

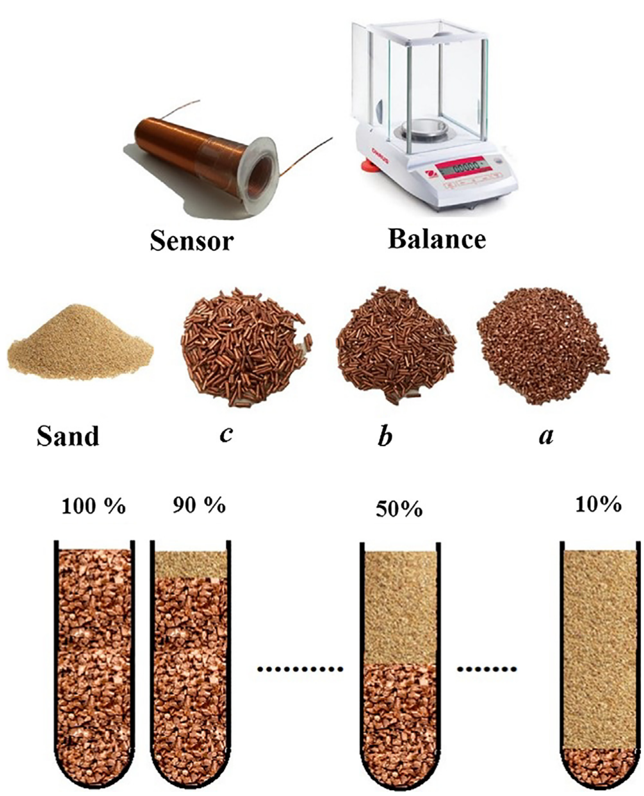

Fig. 2. Materials and equipment used to prepare samples.

Fig. 2 shows all materials and equipment used in the experimental setup.

Table 1 gives the geometric parameters of the problem.

3. Sample preparation steps

Samples preparation is a crucial step in the characterization process, in which all samples have the same volume.

To obtain the cylindrical conductive particles, a copper wire with a circular section is manually cut into three groups (a, b and c) whose lengths are successively 1 mm, 3 mm and 5 mm.

For the first sample, the entire volume of the container is filled with copper particles of identical length. This sample represents the case of perfect purity of recovered waste with 100% of copper and 0% of sand (insulator).

The other samples with different percentages of copper are obtained by extracting, step by step, an amount of copper (multiple of 10%), replaced by another amount of sand in order to maintain the same volume of the samples. The percentage of copper (Co) in the sample is computed as follow:

$$\text{Sample}_{\text{Co\%}} = \frac{\text{Weight of Co in sample}}{\text{Weight of Co in first sample}} \times 100 \tag{1}$$

The weight of copper particles is obtained using a precision balance.

Finally, the impedance of coil is measured according to the frequency (4–100 kHz) for all samples by filling the container each time with a sample (Fig. 3).

Table 1
Dimensions of Experimental setup constituents.

Dimensions	Values
Cylindrical container	
Inner diameter (mm)	13
Height (mm)	6.1
Solenoid coil	
Height (mm)	5.84
Inner diameter (mm)	14.5
Number of turns	101
Copper cylindrical particles	
Average particle lengths (mm) groups A, B, C	1, 3, 5
Diameter (mm)	0.5