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Disassembly properties and material characterisation of household small waste electric and electronic equipment

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ABSTRACT

This paper is focused on characterising small waste electric and electronic equipment, specifically small household appliances, from two different points of views: disassembly properties and material identification. The sample for this characterisation was obtained from a selective collection campaign organised in Castellón de la Plana (Spain). A total amount of 833.7 kg (749 units) of small waste electric and electronic equipment was collected, of which 23.3% by weight and 22.4% by units belonged to the subcategory household equipment. This subcategory, composed of appliances such as vacuum cleaners, toasters, sandwich makers, hand blenders, juicers, coffee makers, hairdryers, scales, irons and heaters, was first disassembled in order to analyse different aspects of the disassembly process for each equipment type: type of joints, ease of identification of materials, ease of access to joints for extracting components, ease of separation of components from the whole, uniformity of tools needed for the disassembly process and possibility of reassembly after disassembly. Results show that the most common joints used in these equipment types are snap-fits and screws, although some permanent joints have also been identified. Next, the material composition of each component of each appliance belonging to each equipment type was identified visually and with additional mechanical trials and testing. It can be observed that plastic and electric/electronic components are present in all the equipment types analysed and are also the material fractions that appear with higher percentages in the material composition: 41.1 wt% and 39.1 wt% for the plastic fraction and electric/electronic components, respectively. The most common plastics are: polypropylene (PP), acrylonitrile butadiene styrene (ABS) and polycarbonate (PC), while the most common electric/electronic components are: cable, plug and printed circuit boards. Results also show that disassembly properties and material characterisation vary widely from one equipment type to another.

1. Introduction

Waste Electrical and Electronic Equipment (WEEE) is a term used to cover all items of electrical and electronic equipment (EEE) or its parts that have been discarded by their owner as waste without the intention of re-use (Step Initiative, 2014). According to Widmer et al. (2005), this waste stream has been found to be one of the fastest growing waste streams in our society today. The European regulatory framework applicable to WEEE is regulated by Directive 2012/19/EU, which aims to contribute to sustainable production and consumption through the prevention of WEEE generation and by re-use, recycling or other forms of recovery.

This paper is especially focused on small WEEE (sWEEE), which will be included within category 5 from 15 August 2018 onwards and which, according to Annex III of the Directive 2012/19/EU, includes equipment with no external dimension more than 50 cm, e.g. household appliances, consumer equipment, luminaires, equipment reproducing sound or images, musical equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices, monitoring and control instruments, automatic dispensers, etc. And, more specifically, it is also focused on analysing waste of small household electrical and electronic equipment (household sWEEE), (e.g. hand blenders, irons, toasters, kettles, etc.), since due to its small size and low weight are generally disposed in the general household refuse container (Dimitrakakis et al., 2009a).

Directive 2012/19/EU states that, as of 2016, the minimum collection rate shall be 45% and from 2019 the minimum collection rate to be achieved annually shall be 65% of the average weight of electrical and electronic equipment placed on the market in the three preceding years or, alternatively, 85% of the WEEE generated.

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In addition, selective collection is a priority that should be ensured for sWEEE, among other categories.

Recovery rates are also established for sWEEE and from 15 August 2018, 75% of them will have to be recovered, being 55% prepared for re-use and material recycling.

In Spain, there are mechanisms that promote and facilitate the separate collection of large WEEE and these are well known and regularly used by consumers. However, for sWEEE this is still a task pending. The transposition of Directive 2012/19/EU to the Spanish legal framework has tried to address this problem by imposing the obligation on large distributors with a sales area for EEA of more than 400 m^2, to collect sWEEE, free of charge and without the condition that the user must purchase an equivalent appliance.

In addition to the targets for selective collection and recovery or preparing for re-use/recycling proposed by Directive 2012/19/EU, this legal framework also encourages the promotion of the design and production of electrical and electronic equipment that facilitate re-use, disassembly and recovery of WEEE, including both components and materials. This requirement is in line with those promoted by Directive 2009/125/EC.

A review of the literature yields some previous research related to these aspects. Among others, Kim et al. (2013), Guimarães et al. (2012) and Wäger et al. (2011), analysed the rate of generation of WEEE in different countries. As a general remark, they concluded that knowing the collected rates helps to determine the future perspectives of WEEE management systems, while also being helpful to make strategic decisions in planning for appropriate recycling schemes and infrastructure. However, these studies are focused on WEEE in general (Khan et al., 2014; Orzturk, 2014) or certain products such as computer equipment (Steubing et al., 2010; Yu et al., 2010), or mobile phones (Rahmani et al., 2014). WRAP (2012) analyses electrical product material composition for different WEEE categories, including some household appliances.

The composition of WEEE is a topic that has been broadly analysed in the literature (Pérez-Belis et al., 2015). This information can be obtained through analysing of samples from municipal solid waste (Chancerel and Rotter, 2009; Dimitrakakis et al., 2009a) or from household waste recycling centres (Martinho et al., 2012; Oguchi et al., 2012). Regarding the materials analysed, Bigum et al. (2012), Tuncuk et al. (2012) and Delfini et al. (2011) focused on the metal composition, Maris et al. (2015), Menad et al. (2013), Nnorom and Osibanjo (2009), Schlummer et al. (2007) and Taurino et al. (2010) on the plastic composition, while Kang and Schoenung (2005) and Mohabuth and Miles (2005) focused on systems for the recovery of recyclable materials. As regards the electronic components, other studies mainly focused on methods to measure the amount of metals present in printed circuit boards (PCB) (Ernst et al., 2003; Legarth et al., 1995). Regarding the WEEE category, most of them focused on categories related to large WEEE (fridges, freezers, etc.) (Matsuto et al., 2004), mobile phones (Lincoln et al., 2007; Moltó et al., 2011), TVs (Cui and Forssberg, 2007) and laptops/computers (Alsheyab, 2015; Li et al., 2006). However, the number of studies focused on the composition of sWEEE is small (Chancerel and Rotter, 2009; Dimitrakakis et al., 2009a; Morf et al., 2007) and none of them are specifically focused on analysing the disassembly properties of household sWEEE.

Although the number of studies related to WEEE has increased over the last years (Pérez-Belis et al., 2015), there is still limited information regarding the assessment of the disassembly properties for repairing or the refurbishment of WEEE and specifically of sWEEE (Li et al., 2013; Kuo, 2013; Ardente et al., 2014). Information about the disassembly properties of WEEE is crucial to be able to analyse the potential repairability of these appliances (iFixit, 2015). According to Darby and Obara (2005), the sWEEE category is physically difficult to disassemble.

So, in this context, this article focusses on analysing the current situation of household sWEEE in terms of their disassembly properties and material characterisation. Results provide quantitative information per type of small household equipment. As no regular selective collection system for sWEEE has yet been implemented in Spain, a local campaign was designed and carried out to obtain a representative sample. With this approach, this paper provides up-to-date information on the characteristics of small household equipment. In addition, these objectives are directly related to the EU action plan for the circular economy (COM 614, 2015).

2. Methodology

From March to June 2015, a campaign to collect a sample of small household electrical and electronic equipment was designed and implemented in Castellón de la Plana, a Spanish town with approximately 180000 inhabitants (INE, 2015). The campaign was carried out in collaboration with a social enterprise which is authorised for the management of WEEE.

The main aims of the campaign were:

- To raise the population's awareness about the need for a management process, in agreement with the current legal framework, for the sWEEE generated in households.
- To collect a sample of household sWEEE in order to analyse its characteristics:
  – disassembly properties, and
  – material characterisation.

The methodology followed during the selective collection campaign and the posterior analysis of the disassembly properties and the material identification is shown in Fig. 1.

Educational centres were selected as suitable places to locate the selective collection points. Thus, the awareness campaign was carried out from the education centres to the households through awareness material distributed to children. The content of this awareness material in brochure format explained the need to manage properly sWEEE, how to do it and the period during which they could carry their household sWEEE to the containers temporary placed in the school.

In order to calculate the representative sample size needed for this study, the method proposed by Bartlett et al. (2001) was applied, according to the following equation:

$$n = \frac{(t)^2 * (p)(1-p)}{(d)^2} \quad (1)$$

where n is the sample size, t is the value for an specific confidence level, p is the proportion of respondents who selected a specific choice and d is the confidence interval or margin of error. Taking a confidence level of 99% ($t = 2.576$), the maximum possible proportion of 50% ($p = 0.5$) which gives the largest sample size and a margin of error of 2% ($d = 0.02$), a sample size of 4148 is obtained.

For each centre participating in the campaign, a container (240 l) and awareness-raising material (poster with the image of the campaign and leaflets for children and parents) were distributed. A container was located for 15 days at each collection point. After that time, it was collected and the sample transported to the Waste Lab, where its characterisation took place.

Once the sample arrived at the lab, the characterisation process was organised at three different levels:

- First, the collected sample was classified into household sWEEE, other sWEEE and non-WEEE categories. Equipment belonging to each category was then classified, according to its function, into the subcategories and equipment types reported in Table 1,

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