Sustainable Use of Plastic E-Waste with Added Value

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Abstract The suitability of using plastic from Waste Electrical and Electronic Equipment (WEEE) for the manufacturing of new products, closing the loop of circular economy will be analyzed in this chapter. In this way, two business models were identified for market opportunities, gross margin-low-turnover and low-margin high-turnover products. High Impact Polystyrene (HIPS) WEEE, Acrylonitrile–Butadiene–Styrene (ABS) WEEE, and an equitable blend of these materials (H50/A50 blend) were considered for the study. From the initial characterization of HIPS WEEE and ABS WEEE, it was found the presence of different kinds of mineral fillers and additives that give them UV resistance, flame retardance, and specific mechanical properties to each material, that favored certain characteristics depending on the final application. From the study, it is possible to claim that plastics from WEEE are suitable for the manufacturing of different kinds of products, since they can be easily processed, achieving a good overall performance, including UV and flame retardance. These results are very promising for the recycling of this complex plastic waste stream with profit, promoting sustainable methodologies and, consequently, closing the loop of circular economy.

1 Introduction

Recycling of plastic from Waste Electrical and Electronic Equipment (WEEE) has become a challenge during the last years. It is estimated that 13 million tons of plastic WEEE were generated worldwide in 2018 and it is expected to increase up to 14 million tons by 2021 (Baldé et al. 2017). This particular plastic waste stream

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M. Jawaid and A. Khan (eds.), *Conversion of Electronic Waste in to Sustainable Products*, Sustainable Materials and Technology,
https://doi.org/10.1007/978-981-19-6541-8_11

is composed of several kinds of thermoplastic resins like Acrylonitrile–Butadiene–Styrene (ABS), High Impact Polystyrene (HIPS), and Polycarbonate (PC), among others (Tansel 2017). The composition of plastics WEEE depends on the source of origin (television, cellphones, computers, fridges, air conditioners, etc.) although in general ABS and HIPS represent the major fractions. Moreover, these two plastics are styrenic copolymers usually black colored (Lepawsky 2020; Turner 2018). These facts became a problem during the sorting step by using different characterization methods and techniques because their precision strongly depends on the composition. Most popular technique is Near-Infrared Spectroscopy (NIR) and also density separation and impact milling are used too (Öztürk 2015; WRAP 2009). Classification by NIR is not precise since materials are mainly dark-colored which makes detection difficult by the equipment. Additionally, as it was aforementioned, they are mainly styrenics resins and, consequently, their chemical similarities also contribute to complicate the detection (Da Silva and Wiebeck 2020; Arends et al. 2015). In this way, sorting is commonly performed manually which also is not accurate and increases labor costs. Moreover, this kind of methodology implies unsafe and unhealthy conditions for workers since plastics can contain contaminants and hazardous substances (Wannomai et al. 2020; Sutawon et al. 2020). In this regard, a more sustainable and safer alternative is recycling the major fractions of plastic WEEE (ABS and HIPS), and also more complicated to separate, together as a blend. Several studies of ABS and HIPS blends have been carried out indicating that blends with similar properties to single ABS or HIPS can be obtained (Vazquez and Barbosa 2018, 2016; Tostar 2016).

Plastics WEEE can be considered as an innocuous waste stream. However, since they contain hazardous additives like brominated substances as flame retardant, they also can be treated as special waste. In this way, they must be analyzed in order to determine the concentration of hazardous components. Then, if it is necessary, they should be treated to reduce or eliminate those additives in order to be able for recycling (Haarman and Gasser 2016; Peeters et al. 2014; European Union 2011). Besides these particular additives, it is well known that plastics from WEEE contain several kinds of mineral fillers such as calcium carbonate, talc, silica, aluminum silicates, titanium dioxide, and carbon black, among others (Rothon DeArmitt 2017; Wagner et al. 2019). In the case of ABS and HIPS, it is known that the total amount of fillers is around 10 wt% and 5 wt%, respectively (Vazquez and Barbosa 2016; Tostar 2016). This fact indicates that they actually are composite materials with a complex polymer matrix. It is important to note that these fillers are aggregated onto the polymer matrix in order to achieve specific properties for different requirements (e.g., impact resistance, tensile and flexural strength, ductility, etc.). For example, besides the use of carbon black to give dark colors, it could also be incorporated in plastic products or devices parts for outdoors uses (e.g., housing for electrical and electronic devices, automobile components, piping, etc.), providing UV and thermal stability (Turner 2018). Moreover, in the case of white plastic, the color is given by the addition of titanium dioxide. However, this additive also provides UV resistance since it absorbs UV radiation protecting outdoor plastic devices/products from these rays (Buxbaum 2008).

From the aforementioned characteristics, it is possible to appreciate that these materials could be suitable for the manufacture of new different kinds of products. In this way, two business models are identified for market opportunities, high-margin low-turnover and low-margin high-turnover products (Sahajwalla and Gaikvad 2018; Besley and Brigham 2014). The first one, high-margin low-turnover products, involves a business model in which products are sold for higher costs than those associated with the acquisition, and the expenses related to the product usually are covered with low sales volumes. Regarding the type of products involved in this category, one clear example are the design objects such as trays or boxes for cosmetics. On the other hand, low-margin high-turnover products represent the opposite scenario. Within this business model, products are sold at prices close to the production ones and the benefit is obtained by high volume sales in a short period of time with low costs. Taking into account the source of the materials analyzed in this chapter, an example of this product are housings for new electrical and electronic equipment (EEE), like outdoor luminaries. These alternatives indicate that, if recycled materials could be introduced into the market like new EEE or other types of products, the loop of the circular economy would be closed. In this way, the aim of this chapter is to analyze the suitability of using plastic WEEE in the fabrication of different kinds of products. Two case studies will be considered as examples: housings for public luminary as low-margin high-turnover products, and design objects for high-margin low-turnover products. Since they constitute the major fraction of plastic WEEE, HIPS and ABS are the materials considered for the study. Moreover, taking into account that, within plastic WEEE, the amounts of ABS and HIPS are similar (29% and 26%, respectively) and their separation by type is difficult (Cardamone et al. 2021), equitable ABS WEEE/HIPS WEEE blends are included in the study. This blend is considered in order to analyze the feasibility of avoiding sorting these plastics and recycling them together.

Plastic from WEEE—Sustainable Alternatives of Use

Plastic materials considered in this work came from WEEE and not only from a single source. According to the supplier, plastic came mainly from computer screens and keyboards but also, may come from refrigerators, air conditioners, and televisions, among others. Consequently, each plastic WEEE material is actually a mix of different types of ABS or HIPS, respectively. It is important to mention that these materials were manually sorted by type and ground into flakes. In this way, and in order to obtain a representative sample of each plastic WEEE and analyze their homogeneity, materials were arranged separately in rafts to perform a quartering. For each material, eight samples of 5 g were taken from different sectors of the draft. They were processed and injected one by one in a mini mixer, at 10 rpm and 180 ºC for 5 min. Then, in order to analyze the relative copolymer content of ABS WEEE and HIPS WEEE, modulated high-resolution thermogravimetric analysis (HiRes^{TM}-MTGA) was carried out for each obtained specimen of both materials. Tests were performed at a heating rate of 5 ºC/min from room temperature to 650 ºC, with a sensitivity of 1.00 and a resolution of 6.00. Regarding the modulation parameters, an amplitude of 5 ºC with a period of 200 s was used. This technique allows to separate different degradation events which occur within a degradation process (TA Instruments 1992). As a result, a semiquantitative composition of each material was obtained. In this way, approximate percentages of each block within ABS and HIPS are presented in Table 1 meanwhile the corresponding thermograms can be observed in Fig. 1. It is important to mention that only one curve of each material is presented in a representative way. From this information, it can be seen that both plastic WEEE can be considered as homogeneous materials, since the obtained errors are less than 5%. In the case of ABS, it contains approximately 20 wt% acrylonitrile (AN), 56 wt% of styrene (St), and approximately 13 wt% of butadiene (Bu). Moreover, a 9 wt% of mineral fillers was observed as was expected. On the other hand, in the case of HIPS, the composition was 52 wt% of St and 34 wt% of Bu, approximately. Also, 5 wt% of mineral fillers were detected. Additionally, the presence of 6 wt% of AN was found in HIPS. This result evidenced that separation by type is not accurate, as was expected. The presence of mineral fillers in both materials corroborates that WEEE plastics are actually composite materials with a very complex polymer matrix. These results agree with the literature regarding other case studies (Tostar 2016; Vazquez and Barbosa 2016).

As it was aforementioned, the presence of considerable amounts of fillers was determined by HiRes™-MTGA. In this regard, it is important to know which kind of minerals they are in order to analyze their influence on the final properties of the processed materials. Figure 2 shows Wide-Angle X-ray Scattering (WAXS) spectra for ABS WEEE and HIPS WEEE, with the corresponding diffraction peaks of mineral fillers, and the carbon black halo. From this study, it was possible to detect the presence of talc, antimony trioxide (Sb_2O_3), titanium dioxide (TiO_2), calcium carbonate

Table 1 Relative mass content of volatiles, acrylonitrile, styrene, butadiene, and fillers in ABS and HIPS from WEEE determined by HiRes™—MTGA

Material	Volatiles (wt%)	AN (wt%)	St (wt%)	Bu (wt%)	Filler (wt%)
ABS WEEE	0,7 ± 0,1	20.3 ± 1.7	56.4 ± 3.1	13.7 ± 0.5	8.9 ± 0.5
HIPS WEEE	1,4 ± 0,2	6.7 ± 1.3	52.9 ± 3.2	34.4 ± 3.2	4.6 ± 0.4

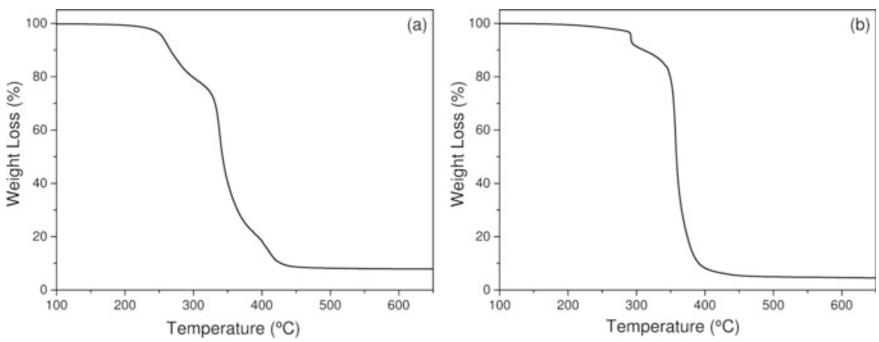


Fig. 1 HiRes TGA thermograms for **a** ABS and **b** HIPS

($CaCO_3$), and carbon black. These types of mineral fillers correspond to the typical additives used in this kind of material (Al-Malaika et al. 2017; Maris et al. 2015). In thermoplastics, different fillers are incorporated in order to achieve specific characteristics, such as enhanced processing, improved mechanical properties, flame retardancy, and UV resistance, among the most important. TiO_2 is often used as a colorant in light-colored plastics, but it also acts as a thermal and UV stabilizer (Turner 2018). Moreover, the use of carbon black has similar features to TiO_2, since it is used as black colorant and additionally confers UV resistance properties (Buxbaum 2008). Regarding talc and $CaCO_3$, they are the most common fillers used to improve impact resistance, hardness, and stiffness of thermoplastics like ABS and HIPS (Rothon and Dearmitt 2017). On the other hand, the detection of Sb_2O_3 also indicates the presence of brominated flame retardants since antimony is widely used as a synergistic additive for this kind of flame retardant additive (Arduin et al. 2020; Hahladakis et al. 2018). It is important to note that the presence of antimony and consequently brominated compounds can be used as an opportunity considering the final application of recycled plastic from WEEE, as long as they are within the allowed limits. In this way, X-ray Fluorescence (XRF) analysis was performed in order to corroborate the presence of bromine and its amount. Results indicate that ABS WEEE bromine content is 1750 mg/kg, while HIPS WEEE contains less than 1000 mg/kg, both under the maximum amount allowed of 2000 mg/kg (Hennebert and Fillela 2018; CLC/TS 50,625-3-1 2015).

From the characterization results, it can be concluded that plastic WEEE considered in the study are actually composite materials with several types of mineral fillers

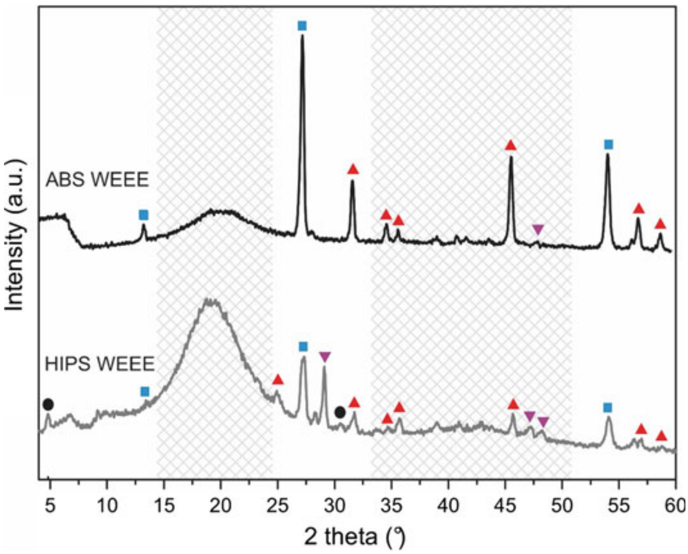


Fig. 2 WAXS spectra for ABS and HIPS with the corresponding identified peaks and the carbon black halo. Ref: Talc (●), Sb_2O_3 (■), TiO_2 (▲), $CaCO_3$ (▼), and carbon black (crosshatch)

and additives. Amount and types of these components indicate that recycled plastics would have certain properties that, depending on the final application, can be taken advantage of. In this way, the proposal of this chapter is to analyze the use of recycled ABS and HIPS from WEEE in the development of housings for outdoor luminaires and design objects, as opportunities for low- and high-margin products, respectively. In this way, considering the final application of each product, recycled plastic will need different characteristics. In the following sections, they will be analyzed according to the requirements of each product.

2 Case Study of Low-Margin High-Turnover Products: Outdoor Luminaries

Main requirements of housings for outdoors luminaries include flame retardant properties, UV and thermal resistance, and good mechanical properties, since they are electrical articles exposed to environmental factors and mechanical and thermal conditions from the electrical parts of the equipment (Wang et al. 2020; Turner 2018). In this way, as it was aforementioned, the presence of additives to achieve flame retardant, UV and thermal resistance could be useful and it is expected that would not be necessary to add new additives, which is also an economic advantage. In order to analyze the suitability of using HIPS WEEE and ABS WEEE in the manufacturing of housings for outdoor luminaries, tensile mechanical performance will be analyzed along with material morphology and environmental conditions' influence will be assessed.

Mechanical Behavior

Tensile mechanical performance of HIPS WEEE, ABS WEEE, and the corresponding 50/50 blend (from this point named H50/A50 WEEE) was first performed, in order to analyze their behavior and also, equitable blend compatibilization effectiveness. Initial HIPS WEEE and ABS WEEE were processed in a single-screw extruder with a flat nozzle at 180ºC and an extrusion rate of 1.5 kg/h. H50/A50 WEEE blend was also processed at the same conditions in order to perform an accurate comparison with the initial materials. The extruded materials were ground into flakes. Specimens for tensile tests were cut from plates prepared by compression molding at 180ºC with the flakes. Test conditions and specimen dimensions were determined according to the ASTM D638 standard for thermoplastics and were performed at room temperature (ASTM D638 2010). Modulus, ultimate strength, and elongation at break were comparatively assessed from the stress–strain curves. In this way, mechanical properties which depend on phase adhesion would indicate if compatibilization was achieved. Young Modulus (E), a low strain property, is related with the internal structure of the species and relative concentration of the components in blends. However, variations in high strain properties like ultimate strength (σ_u)

Table 2 Tensile mechanical properties (E, ε_b, and σ_u) of HIPS WEEE, H50/A50 WEEE blends, and ABS WEEE

Sample	E (Mpa)	ε_b (%)	σ_u (Mpa)
HIPS WEEE	1256 ± 34	11.0 ± 2.1	17.3 ± 0.4
H50/A50 WEEE	1430 ± 31	2.5 ± 0.3	23.1 ± 0.6
ABS WEEE	1390 ± 44	2.6 ± 0.3	26.0 ± 2.0

and elongation at break (ε_b) are the best evidence of compatibilization effectiveness. Then, blend compatibility is assessed through the analysis of changes in σu and εb of H50/A50 WEEE blend with respect to ABS WEEE and HIPS WEEE. Tensile mechanical properties (E, σ_u, and ε_b) for HIPS WEEE, H50/A50 WEEE, and ABS WEEE are shown in Table 2, while the representative stress–strain curves are presented in Fig. 3. It is evident that ABS WEEE is more rigid and resistant than HIPS WEEE since its E and σ_u are greater, which is expected due to the presence of more rigid chains from the acrylonitrile phase in ABS WEEE. Moreover, in both cases, it is possible to observe that ABS WEEE has lower ε_b than HIPS WEEE which indicates a less ductile behavior. The difference in ductility between ABS WEEE and HIPS WEEE is related to the presence of higher amounts of mineral fillers in ABS WEEE. This fact is also associated with higher content of butadiene in HIPS WEEE (twice the corresponding in ABS), the rubber component in these materials, which gives more ductility.

Regarding the equitable blend, H50/A50 WEEE, it is possible to note that its mechanical behavior is similar to the ABS WEEE one (Table 2 and Fig. 3). Values of ε_b and E are close to the corresponding ABS WEEE meanwhile, mechanical resistance is lower than the ABS WEEE. However, considering standard deviations

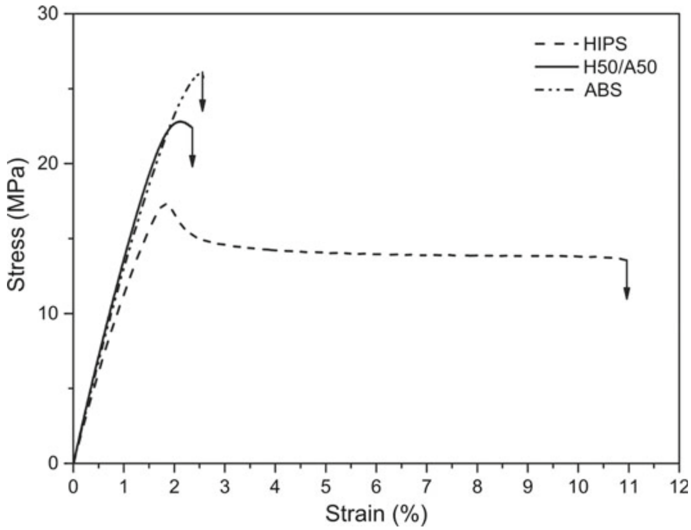


Fig. 3 Tensile stress–strain curves for HIPS WEEE, H50/A50 WEEE blends, and ABS WEEE

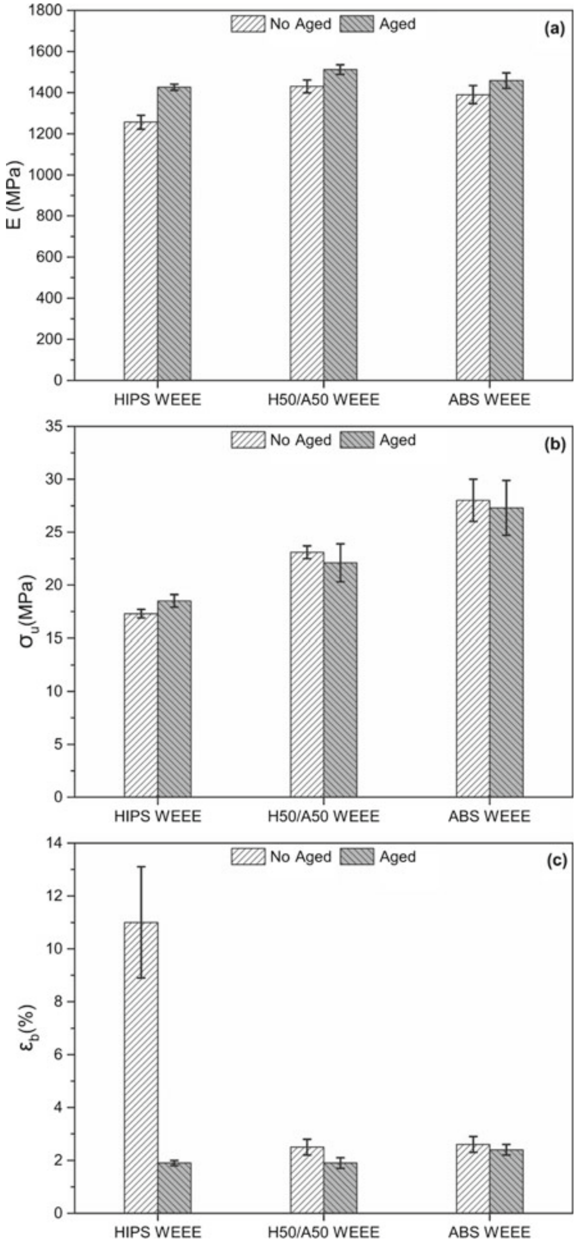
this change is less than 10%. On the other hand, H50/A50 WEEE σ_u is higher than the HIPS WEEE one. This indicates that mechanical resistance is between those values of both initial materials, which is expected to be seen in compatibilized blends (Subramanian 2017; Utracki and Wilckie 2014). It is important to note that equitable blends generally present phase segregation and very complex morphology which results in poor mechanical properties. However, from this mechanical analysis, it is possible to say that H50/A50 WEEE blend was compatibilized indicating that sorting of these plastics, ABS WEEE and HIPS WEEE, can be avoided in order to reduce the cost of workforce and improve workers' labor conditions. Sorting is not accurate, as it was demonstrated previously with the presence of AN in HIPS WEEE. Even using specific techniques and equipment these difficulties persist since ABS and HIPS are very similar resins from the compositional point of view and they are generally dark-colored, which difficult their differentiation (Da Silva and Wiebeck 2020; Arends et al. 2015). Because of these reasons, obtained results are very promising for the recycling industry.

Environmental Degradation Analysis

As it was previously explained, recycled materials used in the manufacturing of housings for outdoor luminaries will be exposed to environmental conditions which could affect their performance. In this way, accelerated aging tests were performed on HIPS WEEE, H50/A50 WEEE blends, and ABS WEEE. Experiments consisted of alternating cycles of 4 h of light at 60ºC with 1.23 W/m^2 of irradiance and 4 h without light at 50ºC with 100% relative humidity, according to the ASTM G53-96 standard (ASTM G53 1996). The total duration of the test was 25 days (600 h), rotating the samples every 4 days to ensure that all of them received the same irradiation and humidity. These tests allow the analysis of materials deterioration when they are exposed to the environment for a period of approximately 11 years (Perez et al. 2010). One of the best evidence of material degradation is mechanical performance deterioration. In this way, after aging all samples were subjected to mechanical tensile tests in order to analyze changes in their mechanical properties through a comparison with no-aged specimens. Moreover, mechanical behavior after and before aging was comparatively analyzed with morphology.

Mechanical properties of aged HIPS WEEE, H50/A50 WEEE, and ABS WEEE compared with no aged tensile properties (from Table 2) are presented in Fig. 4 for HIPS WEEE, H50/A50 WEEE, and ABS WEEE. It is possible to appreciate that aged HIPS WEEE became more rigid and resistant, increasing approximately 13% of its elastic modulus (Fig. 4a) and mechanical resistance (Fig. 4b). Also, its ductility (Fig. 4c) was reduced by around 80%. Regarding ABS WEEE, it can be observed an increment of approximately 10% in mechanical resistance value and a decrement of 5% in the elongation at break, evidencing that material is more resistant but less ductile after aging. In the case of the H50/A50 WEEE blend, mechanical resistance and rigidity did not suffer notable changes. However, this sample presents a reduction of 25% in ductility. All these results agreed with polymer crosslinking, resulting in harder and less ductile materials, as a consequence of UV exposure (Lagern 2020; Signoret et al. 2020).

Fig. 4 Mechanical properties comparison between No-Aged and Aged samples: **a** Elastic Modulus (E), **b** Mechanical Resistance (σ_u), and **c** Ductility (ε_b)



Mechanical performance after and before aging, as well as structural characterization of materials, is complemented through materials morphology analysis. In this way, morphology analyses were performed by Scanning Electron Microscopy (SEM) in an electron microscope, operated at 10 kV. Same type of specimens used for mechanical tests were prepared for this study. These samples were cryo-fractured by immersion in liquid nitrogen, mounted on bronze stubs, and then coated with a gold layer (30 Å), using an argon plasma metallizer. In Fig. 5, SEM micrographs (1000x) of cryo-fracture surfaces for HIPS WEEE, H50/A50 WEEE, and ABS WEEE after and before aging are presented. For no-aged samples, it can be appreciated that HIPS presents bigger and less homogeneous domains than ABS; meanwhile, ABS evidence has sharper edges than HIPS. This fact corroborates that HIPS is a more ductile and less resistant material than ABS. Moreover, H50/A50 blend present sharpened fracture edges and also there are unmasked fillers. These facts corroborate mechanical performance, where it was observed a similar behavior to the ABS one but slightly less ductile and resistance.

On the other hand, if no-aged micrographs are now compared with aged ones, for HIPS WEEE it can be appreciated that soft fracture edges of no-aged HIPS WEEE became sharp after aging, which corroborates the reduction in elongation at break and the increment of mechanical resistance of this material. Regarding ABS WEEE, sharpen edges in the aged sample are more evident than in the corresponding no-aged one, agreeing mechanical resistance increment as a consequence of aging. For H50/A50 WEEE samples, slight differences in edges and the presence of mineral fillers along the fracture surface can be appreciated, consistent with the reduction in ductility after aging. In all cases, morphology agrees with mechanical behavior and also verifies the presence of mineral fillers. Additionally, it is evident that ABS WEEE and H50/A50 WEEE present similarities which is a notable result, since it is possible to claim that separation can be avoided.

Flame Retardance

Since housings for outdoor luminaries will be exposed to heat from electric/electronic components, it is necessary to analyze material performance under combustion. In this way, burning time of the materials involved was assessed. The criteria proposed by Underwriters Laboratories according to the UL 94 Standard (UL 94 1996) and the ASTM D 635 98 Standard (ASTM D 635 1998) were considered for this analysis. Specimens were cut from plates obtained by compression molding at 180 ºC. According to this criteria, two marks were included in HIPS WEEE, H50/A50 WEEE, and ABS WEEE specimens. Flame resistance will be classified depending on flame behavior during test and if ignition reaches or not the second mark. Results showed that in all cases ignition did not reach the second mark of the specimen. Regarding ABS WEEE, it did not hold the flame when the ignition source was removed. In the case of HIPS WEEE, it maintained the flame alive when the source was removed, but the combustion did not spread to the second mark. The H50/A50 WEEE blend showed a similar behavior to ABS WEEE but it maintained a slight flame when the ignition source was taken out. Based on these results, both standards indicate that all materials can be classified as Horizontal Burning (HB). This means that they

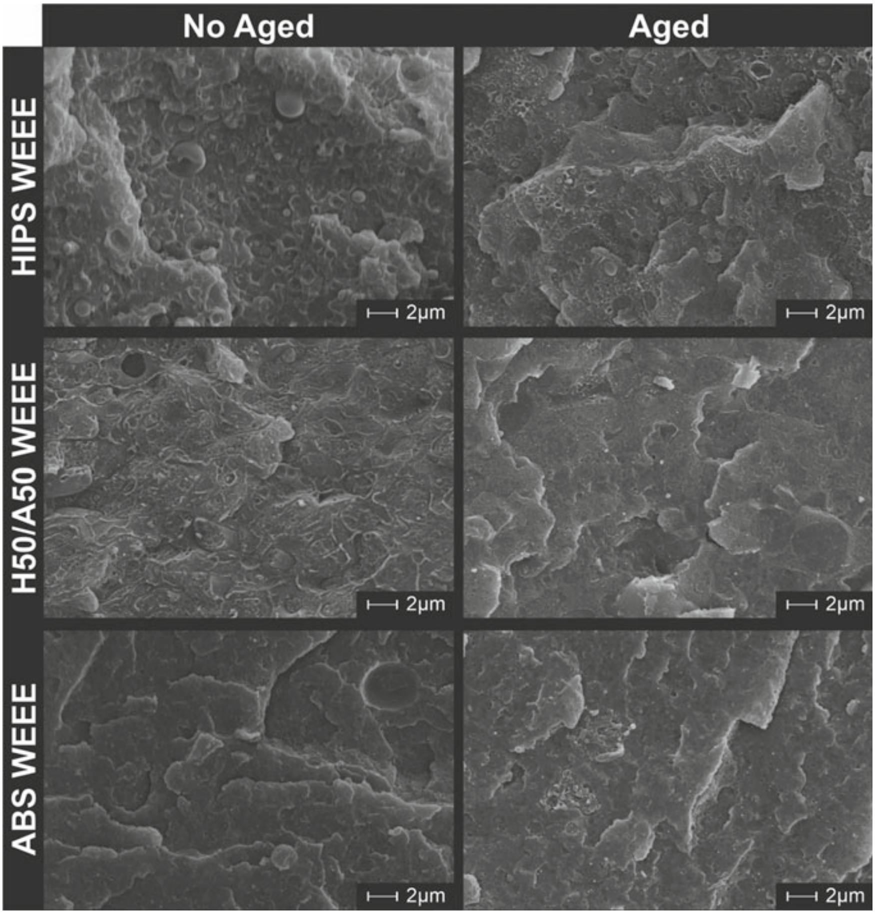


Fig. 5 Cryo-fracture surface SEM micrographs for HIPS WEEE, H50/A50 WEEE, and ABS WEEE, before and after aging

present a slow flame spread. This result was expected considering the presence of Br and Sb (from flame retardant additives) that WEEE plastics contain presenting low flammability and slow combustion (Mao 2020; Buezas Sierra 2010). Also, it is possible to claim that low quantities of these substances can confer flame retardancy without the addition of extra additives.

3 Case Study of High-Margin Low-Turnover Products: Design Objects

Requirements for this final application are different in comparison with the public luminaries' ones. In this case, considering that objects will not be exposed to environmental conditions and also, will not be subjected to high temperatures, UV resistance, and flame retardance are not priority requirements. Design and image are the most important characteristics of these products, along with a good mechanical performance. In this way, design objects, such as trays to put cosmetics or toiletries products, guest trays, holders, and external containers, among others, are considered.

Taking advantage of the gray color scale of HIPS WEEE and ABS WEEE flakes, samples were prepared by compression molding and injection molding, without previous mixing. Compression molding was carried out at 180 ºC for 3 min and injection molding was performed on a mini-injector at 180 ºC for 5 min for stabilization. Photographs of square plates obtained by compression molding, and rectangular sticks from injection molding, for HIPS WEEE, H50/A50 WEEE, and ABS WEEE are shown in Fig. 6. As it is possible to observe, this kind of processing without mixing gives the final piece a texture and a distribution of colors similar to marble (injection molding) or granite (compression molding). Moreover, it can be appreciated that HIPS WEEE contains more black-colored flakes and, on the contrary, ABS WEEE more white-colored ones. These differences allow the obtention of different color combinations to get lighter or darker textures.

On the other hand, despite the fact that appearance is very important in this kind of product, appropriate mechanical performance needs to be achieved. These objects will not be subjected to great mechanical stresses, however, they must resist falls and bending stresses produced by their handling. In this way, drop tests were performed from an average height of 1 m. This value was chosen taking into account the average height of people and the position of hands during handling the piece at the center of the upper part of the body. All samples, compression molding and injection molding, were dropped 20 times each and no damage was observed. These results indicate a good impact on mechanical performance for both kinds of processing.

Moreover, manual bending experiments were carried out. In this way, female and male volunteers between 30 and 34 years old, manually bend plates and sticks in order to analyze their resistance to this kind of manipulation. Results indicate that both types of samples are resistant to manual bending since no one was broken with the application of an average effort. When the applied force is considerably increased, according to volunteers, samples could be intentionally broken. In this way, from this study, it is possible to claim that obtained pieces resist an average force of 37 kgf, considering estimated force values for females and males between 30 and 34 years old (Wang et al. 2018).

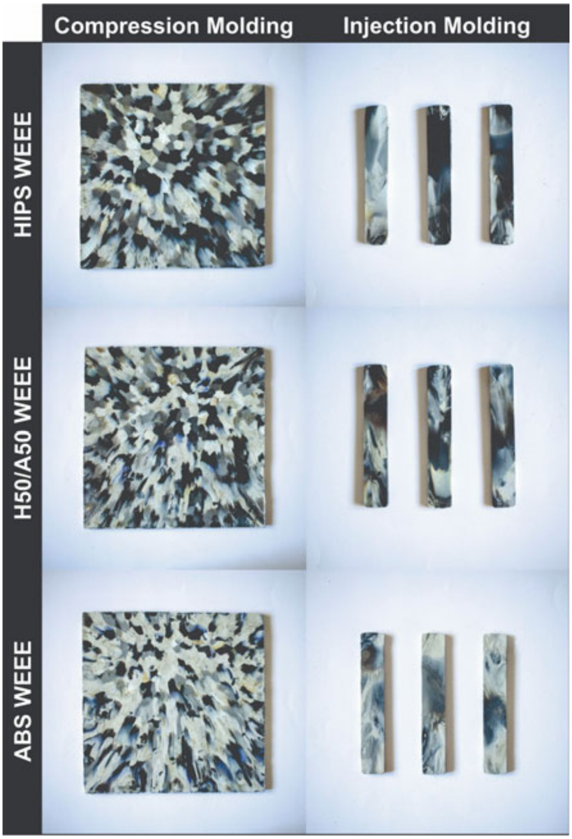


Fig. 6 Samples of HIPS WEEE, H50/A50 WEEE, and ABS WEEE obtained by compression

4 Concluding Remarks

The aim of this work was to analyze the suitability of using plastic from WEEE for the manufacturing of new products. Two business models were identified for market opportunities, high-margin low-turnover and low-margin high-turnover products. HIPS WEEE, ABS WEEE, and an equitable blend of these materials (H50/A50 WEEE blend) were considered for the study. From the initial characterization of HIPS WEEE and ABS WEEE, it was found the presence of different kinds of mineral fillers and additives that give them UV resistance, flame retardance, and specific mechanical properties to each material. Regarding low-margin high-turnover products, housings for outdoor luminaries were taken into account as an example. Main materials requirements for this product can be fulfilled using recycled plastic from WEEE. All considered materials, HIPS WEEE, H50/A50 blend, and ABS WEEE, showed good processability, mechanical performance, and stability under UV and flame exposure. Additionally, it was demonstrated that H50/A50 WEEE blend presents similar behavior to ABS WEEE, which indicates that sorting can be avoided and, consequently, workers' conditions can be improved.

In the case of high-margin low-turnover products, design objects such as trays for toiletries were considered as an example. In this case, image, texture, and certain manipulation resistance are the main requirements to achieve. It was demonstrated that these materials can be easily processed through compression and injection molding, without previous blending. This kind of process allows to obtain textures and color distribution very similar to marble and granite. Also, samples present an adequate resistance to drop and bending.

From this analysis, it is possible to claim that plastics from WEEE are suitable for the manufacturing of different kinds of products, since they can be easily processed, achieving a good overall performance, including UV and flame retardance. These results are very promising for recycling this plastic waste stream with profit, promoting sustainable methodologies and, consequently, closing the loop of circular economy.

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