



Recycling of mixed plastic waste from electrical and electronic equipment. Added value by compatibilization



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ABSTRACT

Plastic waste from electrical and electronic equipment (WEEE) grows up exponentially fast in the last two decades. Either consumption increase of technological products, like cellphones or computers, or the short lifetime of this products contributes to this rise generating an accumulation of specific plastic materials such ABS (Acrylonitrile-Butadiene-Styrene), HIPS (High impact Polystyrene), PC (Polycarbonate), among others. All of them can be recycled by themselves. However, to separate them by type is neither easy nor economically viable, then an alternative is recycling them together as a blend. Taking into account that could be a deterioration in final properties, to enhance phase adhesion and add value to a new plastic WEEE blend a compatibilization is needed. In this work, a systematical study of different compatibilizers for blends of HIPS and ABS from WEEE was performed. A screening analysis was carried out by adding two different compatibilizer concentration (2 wt% and 20 wt%) on a HIPS/ABS physical blend 80/20 proportion from plastic e-waste. Three copolymers were selected as possible compatibilizers by their possible affinity with initial plastic WEEE. A complete characterization of each WEEE was performed and compatibilization efficiency was evaluated by comparing either mechanical or morphological blends aspects. Considering blends analyzed in this work, the best performance was achieved by using 2% of styrene-acrylonitrile rubber, obtaining a compatibilized blend with double ultimate strength and modulus respect to the physical blend, and also improve mechanical properties of initial WEEE plastics. The proposed way is a promise route to improve benefit of e-scrap with sustainable, low costs and easy handling process. Consequently, social recycling interest will be encouraged by both ecological and economical points of view.

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1. Introduction

In the last two decades, it has been noticed that waste from electrical and electronic equipment (WEEE) grows up exponentially mainly by the increase in technological products consumption (European Commission, 2003a; Namias, 2013). It is expected that by 2016 the number of cellphones users reached 2.08 billion (Statista, 2016b). The new generation of mobile phones are replaced in a period of time of no more than two years, meaning that an equivalent amount will be discarded and turned into e-scrap. From all of cells used in the worldwide, 49% is reused as phone, 48% is discarded or is kept aside and only a 3% is recycled (Statista, 2016a). This information evidence a continue and constant increase in mobile phones contribution to WEEE and cell phones are just a part of the total electrical and electronic devices used. Electronic scrap or junk technology is a set of wastes consid-

ered hazardous, from computers, cell phones, televisions and appliances in general, which has been consumed or discarded. It is composed of valuable elements that justify the recycling of many of its components. Within electronic waste, plastics are neither the main residue nor the most contaminant, but they occupy much space because of their low density and parts shapes. They constitute approximately 17% of WEEE stream (Baxter et al., 2014). On the other hand, usually they are thermoplastics and can be recycled by reprocessing.

Final disposal of plastic from WEEE is reaching similar levels to those plastics from urban solid waste, about 2 tons per year and it is estimated that the problem will grow even more in terms of the detailed reasons (Namias, 2013; Plan Nacional de Valorización de Residuos, 2001). In order to reduce the amount of plastic WEEE in landfills or in other kind of final disposal, US states authorities have adopted regulations that force manufacturing companies of electronic and electrical housings to use at least 25% post-consumer recycled and certified material (IEEE Standard 1608 Section 4). The main manufacturer of computers in the world are

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located in east countries and regions, like China, Taiwan and Vietnam. In this sense, these countries import certified plastic WEEE from other countries to satisfy US regulations. Particularly, Argentina exports this kind of scrap mainly to China, conditioning, washed and separated by resin type and involves an income of approximately \$ 2.5 million per year (CAIP, 2010; Ongondo et al., 2011; Protomastro, 2009). The kind of plastics including in WEEE are very difficult to separate by type using automatic methods. There are some sorting methods by using spectroscopic techniques. However, these devices are expensive and not easy to handle for recycling industries (Beigbeder et al., 2013). Because of that, in this kind of industries, usually, trained persons separate plastics WEEE manually. This procedure highly increases labor costs, thus added value of recycling resins and consequently recycler profit decreases.

An alternative to reduce labor costs is to recycle mixed resins in order to avoid manual separation step. However, resins are complex polymers immiscible between them, then direct reprocessing of mixed plastic WEEE results in a blend with poor final mechanical properties because resins segregate in different phases. To enhance it, plastic compatibilization is needed. This process needs to achieve the optimization of interfacial tension, stabilize the morphology against high stress during forming and improve adhesion between the phases in the solid state. Compatibilization can be in two different ways, by reactive processing or by the addition of a compatibilizer. Generally, because of their easy processability, the most popular method has been the addition of a third component, a block or graft copolymer is added like an additive. As the major factor is miscibility, it is not necessary that the copolymer has identical chain segments as those of the main polymers. It is enough that the copolymer has segments with specific interactions with the main polymeric components (Utracki, 2002).

Plastic WEEE stream is composed mainly of thermoplastics copolymers like ABS: Acrylonitrile-Butadiene-Styrene, HIPS: High Impact Polystyrene, PC: Polycarbonate, among others. Particularly, mechanical properties of ABS and HIPS, especially impact properties, are highly dependent on the PB phase, particle size and volume fraction (Bucknall et al., 1986). It is important to note that ABS and HIPS are themselves “mixtures” of several components resulting in complex morphologies, which depend on the relative composition and phase separation (Bisio and Xanthos, 1995; Hoyle and Karsa, 1997).

Both, HIPS and ABS have styrene and butadiene phase, so it is possible to assume that their blends could be “self-compatibilized”. However, the results obtained when they are mechanically blended show that there is a deterioration in the final mechanical properties because blends contain phase segregation and many bubbles (Brandrup et al., 1998; Datta and Lohse, 1996; Hoyle and Karsa, 1997). Some preliminary studies in the literature validate this claim (Brennan et al., 2002). Particularly Arnold et al., working with HIPS and ABS blends, postulates that the phase separation depends on the relative concentration of the constituents of each copolymer among of the relative HIPS and ABS concentration (Arnold et al., 2010). Then, it is clear that for obtaining good mixed recycled WEEE plastic is necessary to work on the compatibilization of its phases in order to increase their miscibility and adhesion, making effective load transfer, avoiding phase separation and consequently increasing final properties (Hoyle and Karsa, 1997; Brandrup et al., 1998; Datta and Lohse, 1996).

As it was discussed above, compatibilization by addition is the most convenient method to use in this case. Several copolymers were selected as compatibilizers. In the literature, there are only few studies of the compatibilization of HIPS/ABS blends. Particularly, Parres et al. consider SEBS (Styrene-Ethylene-Butylene-Styrene) as a possible compatibilizer of virgin ABS and HIPS for having very similar structures to them (Parres et al., 2011). The obtained

results with the addition of SEBS (Styrene-Ethylene-Butylene-Styrene) show an improvement of ductile properties with some loss of tensile strength (Peydro Rasero et al., 2013).

Other commercial copolymers which contain similar structures to HIPS and ABS could be considered as compatibilizers. Taking into account, ABS is obtained by mixing Styrene-Acrylonitrile copolymer (SAN) with a Polybutadiene (PB) rubber phase SAN could be considered as compatibilizer because it contains styrene and acrylonitrile phase. Note that PB particles in ABS are generally grafted with acrylonitrile and/or styrene to improve the adhesion with SAN matrix (Xu et al., 2005). Other copolymers that could be used as compatibilizers because of the same reasons are SBS: Styrene-Butadiene-Styrene and SBR: Styrene-Butadiene-Rubber.

The aim of this paper is to make a comparative analysis of the performance and effectiveness of SAN, SBS and SBR as compatibilizer of HIPS and ABS blends from WEEE with an 80/20 proportion. The major content of HIPS was selected according to a previous study, which shows that small quantities of ABS in HIPS does not affect the global final performance as in the opposite case of small quantities of HIPS in ABS (Brennan et al., 2002). Initially, a complete characterization of HIPS and ABS from WEEE was carried out. Compatibilization was studied through a comparative study of the effect of each copolymer used on morphology and mechanical properties improvement of a specific HIPS/ABS blend. In addition, the influence of the amount of copolymers was analyzed in order to select the best copolymer and concentration.

2. Experimental

2.1. Materials

HIPS and ABS from e-scrap were used as initial materials of blends. They were kindly provided in powder form by Ecotécnica del Pilar S.R.L. SBS KIBITON® Q-Resin PB-5903 from CHI MEI CORPORATION; SAN Luran 348Q from BASF and SBR ARPOL 1502 from Petrobras were used as compatibilizers of WEEE blends.

2.2. Blending

HIPS(80 wt%)/ABS(20 wt%) physical blend was prepared under nitrogen atmosphere, in a batch mixer (Brabender Plastograph W50) at 180 °C and 30 rpm for 10 min. Compatibilized Blends were prepared in the same batch mixer under the same condition as physical one. In order to make a screening test, two different concentrations of each compatibilizer were chosen, one very low (2 wt%) and other bigger enough (20 wt%). In this way, 2 wt% and 20 wt% of SAN, SBS and SBR were added to HIPS(80 wt%)/ABS(20 wt%) physical blend. Table 1 summarizes the characteristics of all blends prepared.

Table 1
Name and composition of all blends prepared.

Abbreviation	HIPS/ABS (H/A) (wt%/wt%)	SBS (wt%)	SAN (wt%)	SBR (wt%)
<i>Physical Blend (PB)</i>				
H80/A20WEEE	80/20	0	0	0
<i>Compatibilized blends</i>				
H80/A20-2SBS	78.4/19.6 (80/20)	2	0	0
H80/A20-20SBS	64/16 (80/20)	20	0	0
H80/A20-2SAN	78.4/19.6 (80/20)	0	2	0
H80/A20-20SAN	64/16 (80/20)	0	20	0
H80/A20-2SBR	78.4/19.6 (80/20)	0	0	2
H80/A20-20SBR	64/16 (80/20)	0	0	20

2.3. Characterization

2.3.1. WEEE characterization

As the main materials are residues, *Fourier Transform Infrared Spectroscopy (FTIR)* analysis were performed on plastic e-scrap in order to assess their actual composition. The experiment was made in transmittance mode on a Nicolet Nexus FTIR 520. As minerals was detected by FTIR, this initial analysis was completed by a qualitative and quantitative study of WEEE plastics in order to determine the type and concentration of minerals. This analysis was performed using three complementary techniques. Initially, plastic WEEE elemental composition was assessed by using *X-ray Fluorescence (XRF)* in a MagiX spectrometer with rhodium anode using the IQ+ standardless PANalytical program. The kind of mineral was determined by the identification of crystal patterns using *Wide Angle X-ray Scattering, WAXS* on a Philips PW 1710 diffractometer with copper anode and curved graphite monochromator. With the combination of this X-ray techniques, the qualitative analysis was achieved, meanwhile plastic WEEE mineral filler concentration was assessed by a thermogravimetric analysis on a Discovery TGA-TA Instruments using a speed rate of 10 °C/min up to 700 °C.

2.3.2. Blends morphology

Blends morphology analysis were performed by *Scanning Electron Microscopy (SEM)* in a LEO EVO 40 XVP electron microscope, operated at 10 kV. 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 (sputter coater PELCO 91000).

2.3.3. Mechanical properties

Flexural tests were performed at room temperature in the *Universal Testing Machine Instron 3369*. Flexural specimens were cut from plates prepared by compression molding at 180 °C. Test conditions and specimen dimensions were determined according to *ASTM D790-03* standard for plastic. Eight specimens for each sample were measured. Modulus, ultimate strength and elongation at break were comparatively assessed from stress–strain curves.

3. Results and discussion

3.1. Plastic WEEE characterization

Since initial materials proceed from WEEE an accurate characterization is needed. In order to analyze the composition of WEEE plastic used, FTIR was performed on each e-scrap sample. Fig. 1 includes FTIR spectra from ABSWEEE and HIPSWEEE. Typical peaks of base polymers, ABS and HIPS, and some of minerals appear. The FTIR spectrum of ABSWEEE (Fig. 1a) evidence the presence of acrylonitrile (AN) at a wavelength of 2237 cm⁻¹, as it was expected. However, a small AN peak appears in HIPSWEEE spectrum (Fig. 1b) evidencing that this sample contains traces of ABS. For determining the relative amount of AN impurities in HIPSWEEE, a ratio between the intensities of AN peak and C=C from aromatic double bond (at 1602 cm⁻¹) was calculated. This method was previously applied by Bai et al. to see what happened with the absorption of the AN related with C=C after reprocessing the ABS, showing no significant change in that relation (Bai et al., 2007). AN/C=C peak ratio for ABSWEEE is 0.360 and 0.085 for HIPSWEEE allowing to demonstrate the claim that AN is only a trace in HIPSWEEE. Also, in both spectra appears some peaks at 1016 cm⁻¹ and 426 cm⁻¹ that could be assigned to calcium carbonate, silica and talc, typical mineral fillers used as additives in EEE (Electrical and Electronic Equipment) plastics.

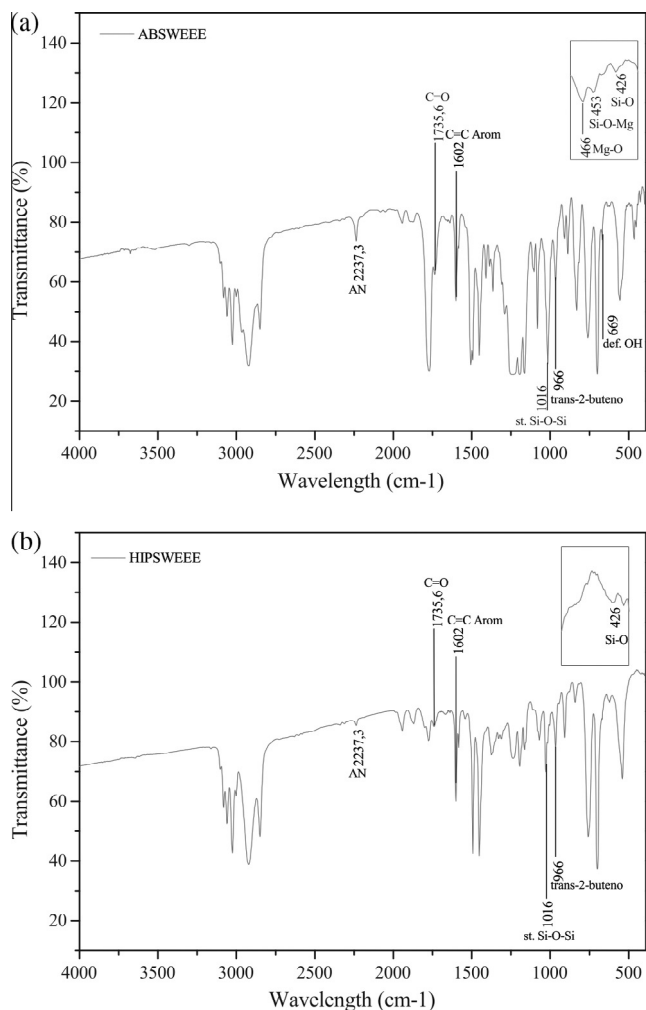


Fig. 1. FTIR spectra, of: (a) ABSWEEE and (b) HIPSWEEE. Specific peaks with their wavelength are signed.

In order to corroborate the above results regarding the type of mineral filler in each WEEE plastic sample, a combined fluorescence and X-ray diffraction analysis was carried out. Table 2 shows chemical elements detected by XRF and its relative percentage. Carbon, Titanium, Calcium, Silicon and Magnesium are the main components detected. WAXS spectra included in Fig. 2, allow to assessing the presence of talc, silica, calcium carbonate, carbon black (Ungár et al., 2002) and titanium oxide as mineral, agreed with the elements detected by XRF and bonds by FTIR and correspond to fillers used as common additives of WEEE (Goodship and Stevels, 2012). Overall filler concentration in ABSWEEE and HIPSWEEE, determined by TGA, are 8.84 wt% and 4.58 wt% respectively.

Table 2
Major components founded in X-ray fluorescence analysis.

Element	% (element mass/sample mass)	
	ABS	HIPS
Carbon	24.96	26.05
Titanium	1.40	0.97
Calcium	0.57	0.86
Silicon	1.10	0.27
Magnesium	0.43	0.07
Bromine	0.34	0.13

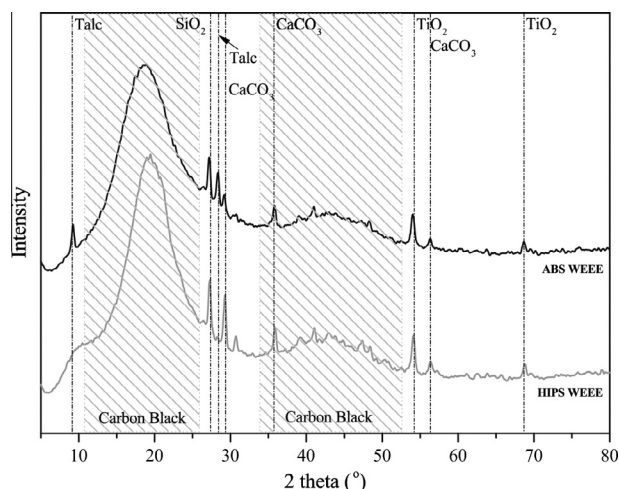


Fig. 2. WAXS spectra of for ABSWEEE and HIPSWEEE with peaks identified.

WAXS analyses also evidences the presence of Bromine (Br) from flame-retardants considered hazardous substances. The amount of Br presents in WEEE samples are 0.34 wt% in ABSWEEE and 0.13 wt% HIPSWEEE. The EU Directive 2002/95/EC (European Commission, 2003b) gives a maximum allowed level of each brominated substance present in WEEE to not be consider hazardous. This values are 1 wt% for PBDEs (polybrominated diphenyl ethers) and 0.1 wt% for PBBs (polybrominated biphenyls). However, the amount of each compound is neither direct nor easy to assess. Then, an alternative is to determine overall bromine concentration by an element analytical method like XRF. In this way, Aldrian et al. analyze the effectiveness of use XRF to determine Br content, the incidence of experimental error and propose a level based on this content. Using empirical factors, they determine the maximum level of Br amount (0.82 wt%), which corresponds overall content of brominated compounds admitted in EU Directive 2002/95/EC. According to this criterion, WEEE samples used in this work are not hazardous (Aldrian et al., 2015).

3.2. Blend compatibilization

The best evidence of good blend compatibilization is given by mechanical properties improvement. A good compatibilizer allows enhancing phase dispersion and distribution, reduce phase domains and increase phase adhesion respect to physical blend. Young Modulus (E) that is a zero strain property, just depend on the internal structure of the species and relative concentration of the components in the case of blends. However, phase adhesion improvement is more evident through changes in high strain properties like ultimate strength (σ_u) and elongation at break (ϵ_b). It is important to note that the most sensitive property to the compatibilization is adhesion between phases. So then, the strongest evidence of improved compatibility is obtained by analyzing the variation of σ_u and ϵ_b of compatibilized blends respect to the physical mixture.

Table 3 shows flexural mechanical properties (E, σ_u and ϵ_b) for WEEE initial materials, compatibilizer samples and all blends prepared. Note that according to ASTM D790-03, flexural test for thermoplastics materials takes a maximum elongation of 7%, because that value is sufficient to corroborate the good performance of the material. From these data, HIPSWEEE has lower E and σ_u , and higher ϵ_b than ABSWEEE. This behavior is mainly due to the higher content of filler in ABSWEEE as shown in the first part of this paper.

Table 3

Flexural mechanical properties for plastic WEEE initial materials, compatibilizer copolymers and all blends prepared, according ASTM D790-03.

Sample	E (MPa)	σ_u (MPa)	ϵ_b (%)
HIPSWEEE (H)	2069 ± 186	35.3 ± 1.7	6.56 ± 1.05
ABSWEEE (A)	2313 ± 75	42.0 ± 4.1	2.33 ± 0.31
SBS	670 ± 122	20.1 ± 3.2	Not break
SAN	3234 ± 186	79.8 ± 7.9	2.25 ± 0.67
SBR	^a	^a	Not break
PB	1946 ± 112	37.4 ± 2.0	5.90 ± 0.33
H80/A20-2SBS	1747 ± 100	35.2 ± 2.0	6.01 ± 0.57
H80/A20-2OSBS	1428 ± 100	35.8 ± 1.1	Not break
H80/A20-2SAN	2195 ± 106	40.1 ± 0.9	5.82 ± 0.37
H80/A20-2OSAN	2357 ± 123	42.4 ± 2.4	3.71 ± 0.31
H80/A20-2SBR	4751 ± 247	69.2 ± 2.6	4.70 ± 0.54
H80/A20-2OSBR	899 ± 53	12.4 ± 5.3	2.07 ± 1.15

^a No possible to measure flexural properties at room temperature. Samples deform itself in measure equipment due to its rubbery behavior.

Elastic modulus of physical blend containing 80 wt% of HIPS-WEEE (PB) is lower than HIPSWEEE showing a negative deviation to the rule of mixture. However σ_u and ϵ_b presents values between the corresponding to initial materials, closer to those of HIPSWEEE. This result is not directly expected because ABS has higher filler content than HIPS, then the reduction in E could be explained based on changes in blend morphology respect to initial materials. It seems there is a fillers/rubber relative redistribution during blending. Rubber locates around fillers resulting in blend autocompatibilization. This claim is evidenced in high strain mechanical properties, mainly in ϵ_b of PB. It stays closer to the corresponding value of HIPSWEEE besides having 20 wt% of ABSWEEE which ϵ_b is three times lower. Usually, the ductility of blends is determinate mainly by the more rigid material because of fracture behavior. Then, the previous hypothesis of autocompatibilization is correct; evidencing that direct mixing of HIPS and ABS from WEEE in the proportion used is a possible method to recycling obtaining a material with relative good mechanical properties. This claim agrees with Brennan et al. results, which shows that direct mixing of HIPS/ABS blends, with major content of HIPS, improves mechanical performance of WEEE plastics, mainly impact strength (Brennan et al., 2002).

In order to enhance PB properties and then increment its added value, addition of different compatibilizers were studied. Compatibilizers are copolymers selected based on main components of HIPS and ABS. It is clear that blend morphology and then mechanical behavior will change depending on the amount and kind of copolymer added. Thus, the results obtained are discussed initially by analyzing the influence of each copolymer concentration and then a comparison of compatibilization performance between copolymers at each concentration is presented.

3.2.1. Influence of the amount of compatibilizer

3.2.1.1. Styrene-Acrylonitrile copolymer (SAN). This copolymer is a stiff material by itself, having a E of 3500 MPa, σ_u of 90 MPa and ϵ_b of 2%, approximately. Taking into account that SAN includes styrene (St) and acrylonitrile (AN) molecules, and it is more rigid than the WEEE resins, the hypothesis is that SAN could act as compatibilizer and reinforcing agent at the same time.

Flexural mechanical behavior of blends with the addition of 2 wt% and 20 wt% of SAN, and PB are included in Fig. 3. Is possible to note that both compatibilized blends (Table 3) increase their E and σ_u respect of the PB. This behavior is expected because a stiffer material has been incorporated into the mix. These properties increase as the amount of SAN increase, in other words, the higher SAN content the higher E and σ_u . Adhesion properties do not improve because elongation at break ever decreases. This behavior

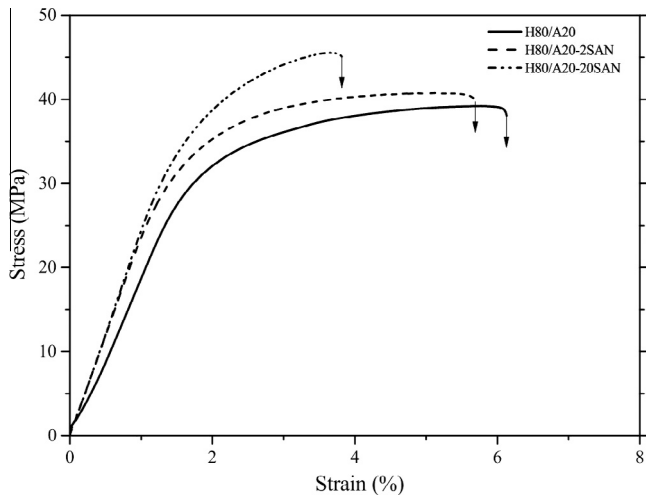


Fig. 3. Flexural stress-strain curves of physical and compatibilized blends with 2 wt% and 20 wt% of SAN.

indicates that probably SAN is segregating into a separate phase and not reaching the interface.

Besides SAN inclusion improves E and σ_u , blends became more fragile. Performance of these blends indicates that from the point of view of compatibilization this material is not appropriate to use it as a compatibilizer, but it could be take it into account to use in other applications as a reinforce material mainly by using in small quantities.

3.2.1.2. Styrene-Butadiene-Styrene copolymer (SBS). This material is a copolymer with low E and σ_u but good ϵ_b , typical rubbery behavior. Its molecules contain butadiene and styrene blocks but not acrylonitrile. The hypothesis is that butadiene and styrene blocks could act as compatibilizer because HIPS_{WEE}, the major component of PB to compatibilize, contains these molecules.

Flexural stress-strain curves for blends with of 2 wt% and 20 wt% SBS compared with PB one, are reported in Fig. 4. E and σ_u in H80/A20-2SBS lightly decrease respect to PB as expected because a small amount of rubbery material is being added. However, this decrement could be considered within experimental error. ϵ_b does not suffer considerable changes, evidencing that interface has not been modified by the SBS. This fact probably happens because of,

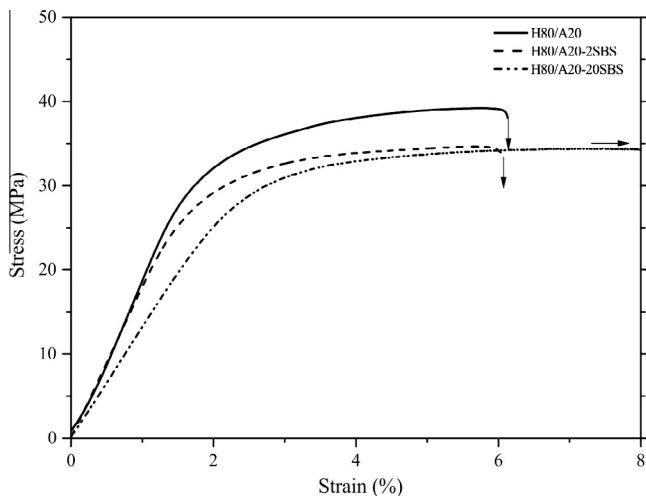


Fig. 4. Flexural stress-strain curves of physical and compatibilized blends with 2 wt% and 20 wt% of SBS.

as the added SBS amount is so small, the molecules are not being able to locate at interface and have remained as a phase by itself. Then, at this concentration, SBS does not act as a compatibilizer.

On the other hand, when the amount of SBS is 20 wt% (H80/A20-20SBS), mechanical behavior is different, as expected. E presents notable decrease because of the high amount of rubber added. This could be explained initially by the segregation of SBS into a new phase. However, ϵ_b is highly improved, indicating that SBS act as a good compatibilizer. This no-breaking indicates that the SBS is reaching the interface improving interfacial adhesion.

The bigger content of compatibilizer the better phase adhesion and load transfer. Even E of blend with 20 wt% is lower, the global behavior is better than the 2 wt% SBS blend. Is important to note that with these results is clear that the performance of SBS as a compatibilizer it has to be consider, but is necessary to optimize the amount of this copolymer, because from the point of view of recycling it does not make any sense to add 20 wt% of a virgin material. It is probably that with lower concentrations, SBS get to interface and not segregate in phases.

3.2.1.3. Styrene-Butadiene-Rubber copolymer (SBR). This random copolymer presents a typical rubbery behavior because it contain up to 70 wt% of rubber phase; in fact it is not possible to measure flexural properties at room temperature. Its modulus is considerable low, which makes the sample bends before being deformed by the machine.

Mechanical behavior of blends with the addition of 2 wt% and 20 wt% of SBR compared with PB are shown in Fig. 5. When a lower concentration of SBR is added to the initial PB, it results in unexpected mechanical behavior. E and σ_u at least duplicate those values for PB and elongation at break only decrease 17%. These results evidence that SBR migrates to the interfaces compatibilizing the blend, increasing the influence of fillers in blend strength and dispersing in small domains. The final blend results in a more rigid and stiff material without significant loss of ductility. SBR migration is enhanced by its low viscosity.

However, when 20 wt% of this rubber is added to de PB, ϵ_b , σ_u and E decrease notably, all of them in a 50% approximately, giving a blend with poor mechanical properties. This occurs because SBR segregate into a new phase and its properties prevalent in the final blend which indicates that SBR is not acting as a compatibilizer at high concentration.

Addition of just 2 wt% of SBR considerable improves mechanical performance of PB. This is a very interesting fact for recycling these

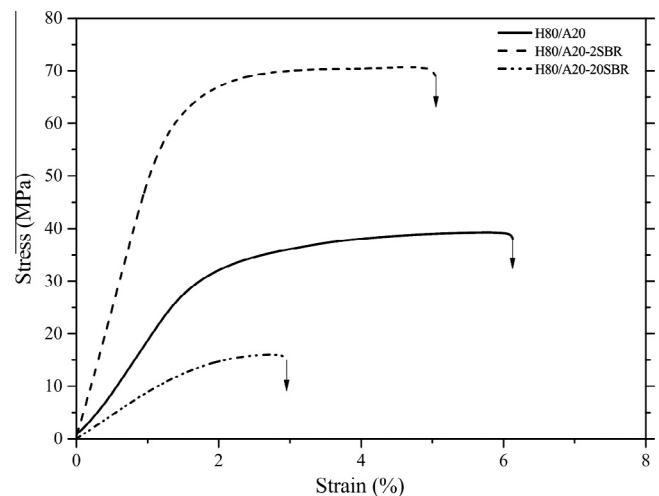


Fig. 5. Flexural stress-strain curves of physical and compatibilized blends with 2 wt% and 20 wt% of SBR.

kinds of blends because besides SBR is a virgin material, according suppliers, its cost is accessible. The improvement of mechanical properties generates a wide application field of recycled WEEE material.

3.2.2. Comparative analyzes of compatibilization effectiveness

Fig. 6 presents mechanical behavior of compatibilized blends with 20 wt% of each copolymer compared with PB. This screening experiment evidence that in all of the cases, 20 wt% of compatibilizer exceeds the optimal concentration and segregate in new phases. SAN added blend results in a more rigid and poor compatibilized material because of the intrinsic fragile behavior of this copolymer. In the case of the addition of SBS, segregation occurs but copolymer also reaches the interfaces compatibilizing the blend. However, this amount of SBS exceeds the optimum one which must be obtained. Finally, segregation in SBR added blend decays all mechanical properties resulting in a global deterioration of initial PB.

Blends with 2 wt% of each compatibilizer compared with physical blend are shown in Fig. 7. In this case is possible to note that the addition of a very low concentration of compatibilizers results in small variations for SAN and SBS. However, the addition of small amount of SBR results in a blend with remarkable properties in comparison to the others. This blend has a high improvement of E and σ_u , and the elongation at break decrement is low, staying within the acceptable value for many electronic and electrical.

The addition of only 2 wt% of SBR to PB notably improves its flexural properties, resulting in a material even better than initial ABSWEEE. H80/A20-2SBR is twice rigid and ductile than ABSWEEE while strength is 1.5 times greater (Table 3). In comparison to HIPSWEEE, is twice rigid and tough but 30% less ductile. This claim confirms the importance of a good selection of the kind and amount of compatibilizer.

3.3. Blends morphology

In order to corroborate claims made from mechanical tests a morphological analysis were performed, which is an independent test. This study was carried out by using SEM micrographs from surfaces of cryogenic fractured blends. Fig. 8 shows a micrograph (10,000 \times) of PB surface where it is possible to note rubber domains with a defined interface and good dispersion and distribution, but with a wide dispersion in size domains. It is possible to identify

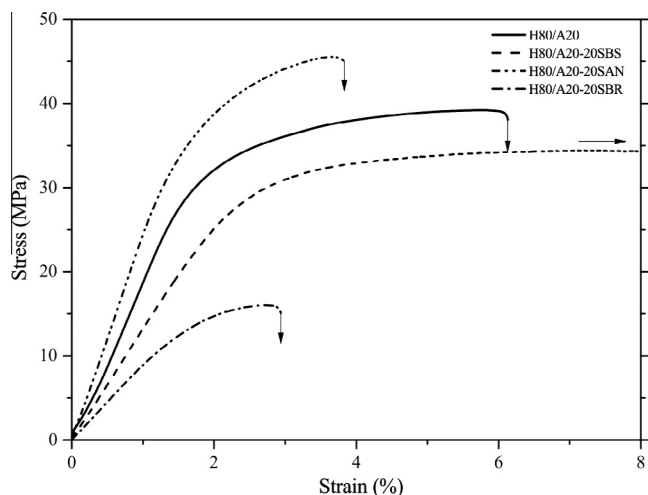


Fig. 6. Flexural stress-strain curves of physical and compatibilized blends with 20% of SAN, SBS and SBR (named PB, H80/A20-20SAN, H80/A20-20SBS and H80/A20-20SBR, respectively).

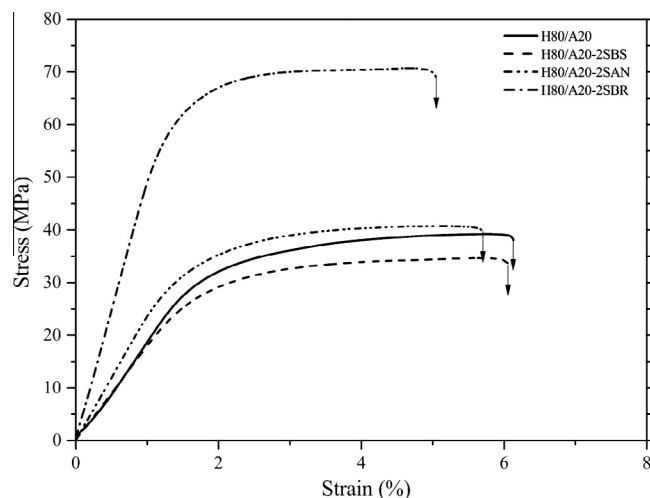


Fig. 7. Flexural stress-strain curves of physical and compatibilized blends with 2% of SAN, SBS and SBR (named PB, H80/A20-2SAN, H80/A20-2SBS and H80/A20-2SBR, respectively).

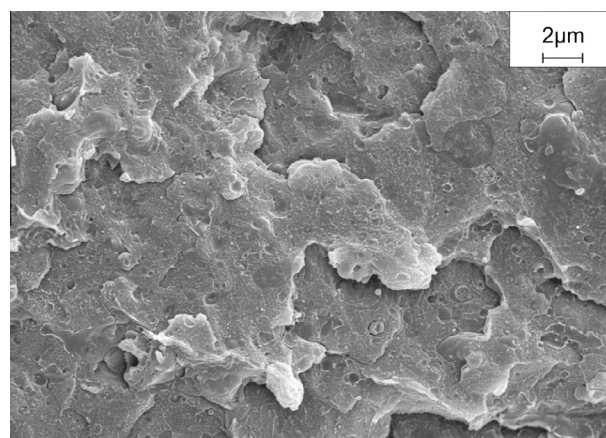


Fig. 8. SEM micrograph (10,000 \times) of cryo-fracture surface of physical blend.

salami structures typical of this kind of copolymers. Also, fillers with different sizes can be observed. It seems that big particles are small particles agglomerates, which cannot disperse during blending.

SEM micrographs for blends with 2 wt% and 20 wt% of SAN are showed in Fig. 9 with the same magnification. Salami structures are conserved and its size and amount increase as SAN concentration increase. In comparison with morphological aspects of PB both blends with SAN present a typical fractography of a stiffer material, increasing its rigidity conforming the amount of compatibilizer increases. A typical fragile fracture in both samples compatible with mechanical behavior is evidenced. There are sharpened edges in both, and with 20 wt% of SAN it can be seen net fracture surfaces. Morphology of blends with SAN as a compatibilizer corroborate the mechanical behavior described above, demonstrating that SAN became blends more rigid, improving E and σ_u but decreasing the elongation at break.

A completely different fracture surface aspect present SBS compatibilized blends in Fig. 10. In the blend with 2 wt% of SBS it is possible to note big rubber domains, some of that bigger than those in the PB. Also, can be appreciated that there is a good distribution of them along the sample, and the interfaces are well defined. Is important to note that the fracture behavior of the blend with 2 wt% evidenced by the micrograph seems more ductile than the

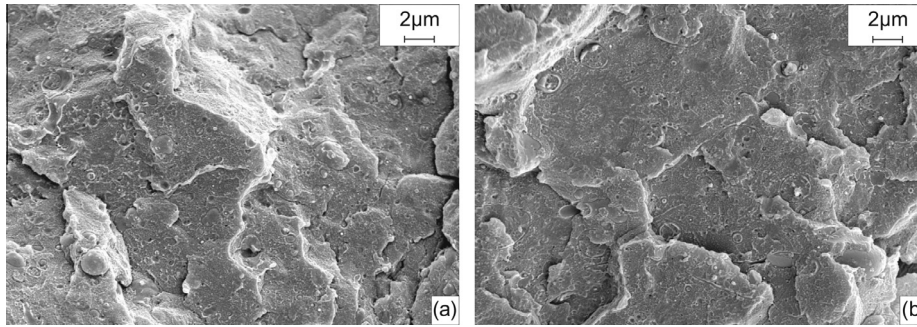


Fig. 9. SEM micrographs (10,000 \times) of cryo-fracture surface of SAN compatibilized blends with: (a) 2 wt% (H80/A20-2SAN) and (b) 20 wt% (H80/A20-20SAN).

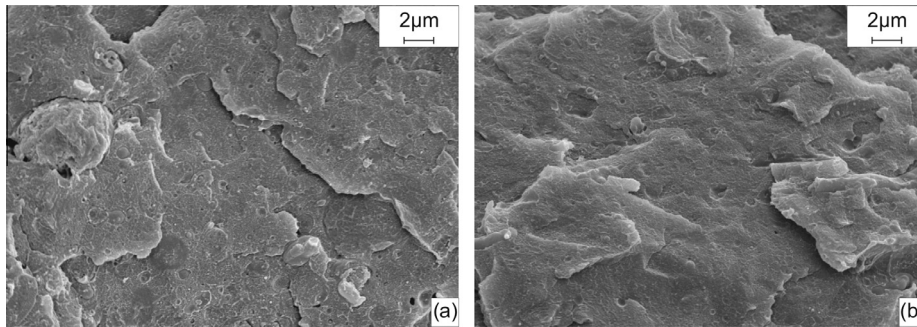


Fig. 10. SEM micrographs (10,000 \times) of cryo-fracture surface of SBS compatibilized blends with: (a) 2 wt% (H80/A20-2SBS) and (b) 20 wt% (H80/A20-20SBS).

PB one (Fig. 7). This behavior increase and turns much rubbery when a 20 wt% of SBS is added confirming the discussion done from mechanical curves.

Fig. 11 shows SEM micrographs for blends with 2 wt% and 20 wt% of SBR. Blend with 2 wt% of this compatibilizer shows a notable reduction in rubber size domains respect on the PB, and seems better dispersed and distributed. No filler agglomeration and less salami structures is observed. It is expected as the overall amount of acrylonitrile decrease. This morphology agrees with the unexpected mechanical results discussed above. In contrast, blend with 20 wt% of SBR show big rubber domains evidencing SBR phase segregation with wide size domains distribution and fillers agglomerations. The morphology observed correspond to a bad compatibilized blend agreeing with mechanical performance.

4. Conclusion

In this work, a systematical study of different compatibilizers for blends of HIPS and ABS from WEEE was performed in order to increment added value of plastic e-scrap. A screening analysis

using two different compatibilizer concentration on a physical blend with same HIPS/WEEE/ABS/WEEE proportion (80/20) were carried out. Three copolymers were selected as possible compatibilizers and the concentrations used were one very low (2 wt%) and other bigger enough (20 wt%). Compatibilizers were chosen by their possible affinity with initial plastic WEEE. A complete characterization of each WEEE was performed and compatibilization efficiency was assessed by comparing either mechanical or morphological blends aspects. An accurate results discussion were performed above. From the overall study the main conclusions obtained allows to claim that initial Plastics WEEE are complex copolymers filled with carbon black and other minerals. All of them were identify in this study. This minerals change either mechanical or morphological performance of base polymers. Physical blend with HIPS as main component present a lack of “auto compatibilization” behavior, given a possible market for direct recycling of mixed WEEE plastics of this kinds of blends.

Regarding the performance of the compatibilizers selected, at higher concentrations the best compatibilization performance was obtained by using SBS, but the addition of 20 wt% of a pure

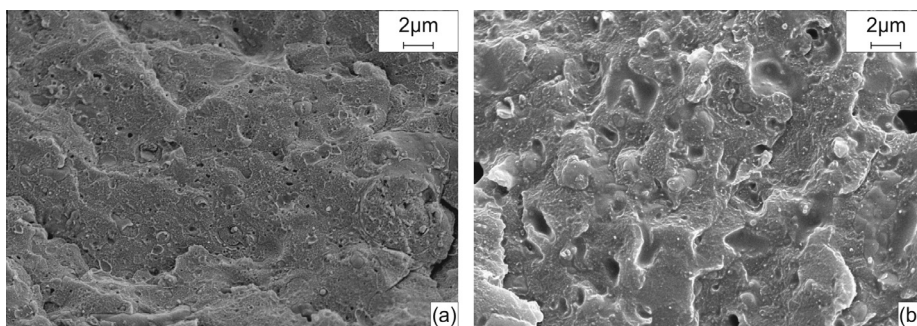


Fig. 11. SEM micrographs (10,000 \times) of cryo-fracture surface of SBR compatibilized blends with: (a) 2 wt% (H80/A20-2SBR) and (b) 20 wt% (H80/A20-20SBR).

copolymer is neither economically nor ecological viable, then this solution is not sustainable. Better results were obtained with the addition of 2 wt% of pure SBR. Mechanical properties of this blend strongly improved physical blend and each initial plastic WEEE ones. This result allows increment recycling mixed plastic WEEE market because the amount of SBR added is very low and their cost too. The proposed way is a promise route to improve benefit of e-scrap with sustainable, low costs and easy processability. Consequently, social recycling interest will be encouraged by both ecological and economical points of view.

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