

## THE INFLUENCE OF TOTAL AND SPOT EXPOSURE OF UVA RADIATION, FOR HIGH IMPACT POLYSTYRENE RECYCLING

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### ABSTRACT

Plastics materials derived from electronic devices are discarded daily and yet have a great potential for recycling. The degradation effect caused by photo-oxidation is a factor that can influence the properties and recycling of polymers that composing pieces of electronic equipment. This factor exists even indoors, because UVA is able to travel across glass windows. This study analyzes some aspects of the photo-oxidation of high impact polystyrene (HIPS) recycled from printer carcasses that were exposed to UVA according ASTM G24 and G154 aging standards tests. Virgin and recycled HIPS samples produced by injection molding were exposed to an accelerated aging process in the laboratory through the use of pallets, with the total exposure of the samples, and masks with the targeted UVA exposure at certain points of the samples. The consequences of the photo-oxidation on the properties of the samples were characterized by: infrared spectroscopy (FTIR) and Dynamic-Mechanical Thermal Analysis (DMTA) with the objective of characterizing the differences between pallet and mask exposure. The results showed that the recycled samples exposed to UVA radiation did not show considerably changes in terms of the properties or processability when compared to the virgin material. By using FTIR analysis, the UV additive from recycled material did recombine and then improved the UV resistance in new compositions using virgin HIPS.

**KEYWORDS:** HIPS, recycling, photo-oxidation, UVA

### I. INTRODUCTION

In the constant quest for better-performing products, today more than ever, it is indispensable to consider the environment while developing such products. Sooner or later products will be discarded, becoming either waste or returning to the market as raw materials. Developing products with the minimum of interference and impact on the environment requires professionals with knowledge in properties of recycled materials. Additionally, recycling can be used as an important tool to link new products, materials and technology in terms of environmental preservation and then sustainable development.

Electronics, which compose an important part of people's routines, are products that depend on electrical current or electromagnetic fields in order to function. Upon reaching the end of their lifetime, electronic products are denominated as Waste from Electronic Equipment (in portuguese *Resíduos de Equipamentos Eletroeletrônicos - REEE*). Many of these products have a short life cycle and quickly become obsolete due to new technology being introduced to the market, as well as the

lack of availability of replacement parts. Thus, electronics are replaced frequently and discarded after short periods of time [1]. The report released by the United Nations Environment Program (UNEP) warns that predictions indicate fifty million tons of electronic waste generated in the world by 2017 [2]. The UN report estimates that out of the developing nations, Brazil is the biggest generator of electronic waste, discarding 1.4 million tons per year. Among this total 17.2 thousand tons are printers [3].

In the case of printers, mechanical recycling is an alternative that is both socioeconomically feasible and environmentally sustainable because the printer carcasses are normally manufactured using thermoplastics. Additionally, the thermoplastic commonly used is high impact polystyrene (HIPS), due to the polymer's great physical and chemical properties, as well as its affordability and processability [4]. Throughout the printer's life cycle, the polymers in the equipment are affected by the environmental conditions to which they are exposed.

High impact polystyrene is a copolymer of polystyrene and polybutadiene and is a thermoplastic, biphasic material with very versatile properties resulting from variations in composition and morphology of the rubber particles that are dispersed in the styrene matrix [4, 5, 6, 7, 8].

The rubbery polybutadiene phase that is dispersed in the rigid continuous polystyrene matrix offers excellent impact resistance and elongation at break, however the double carbon-carbon bonds (C=C) are especially susceptible to thermal and oxidative degradation. The degradation and cross-linking of the polybutadiene phase that result from the degradation process can reduce the toughening effect and increase the polymer's viscosity [5, 7, 9, 10].

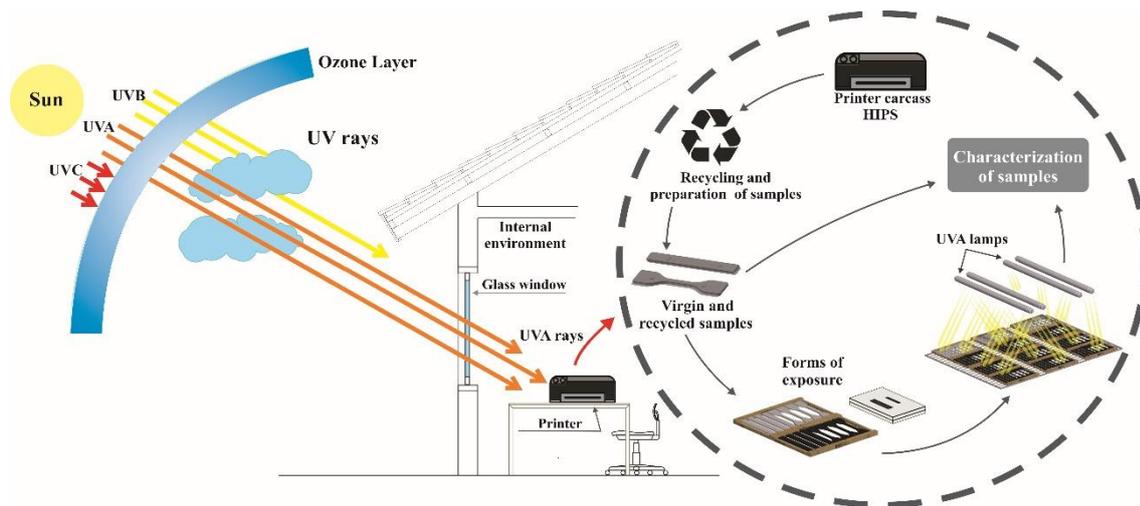
Ultraviolet radiation is the greatest effect on the degradation of organic materials by photo-oxidation. It is important to consider this in regard to the lifetime of polymers that will be subjected to weathering. Ultraviolet radiation causes irreversible chemical changes that affect mechanical and chemical properties of polymeric materials. Degradation by photo-oxidation can make the materials brittle and then loss of mechanical resistance and color [11].

Among the wavelength of radiation emitted by sun, UVA (315 to 400 nm) radiation has the highest wavelength and is also the most penetrating. UVA radiation passes through the atmosphere and clouds, reaching places, where polymeric products are used and thus provoking changes to the chemical properties of polymers, destroying polymeric chains [5,12]. It should be noted that UVA radiation has an increased potential to travel through glass windows, which highlights the potential of the radiation to degrade polymers of the electronic equipment even inside homes. Therefore, it is fundamental to evaluate the exposure of HIPS equipment to UVA radiation affects the material. Additionally, the understanding of these implications of the exposure have in the recycling process, in terms of the application as a new material to manufacture technical products.

In order to evaluate the properties of polymer that are used to produce electronic devices, it is necessary to subject the polymer to tests that simulate the conditions that the material will be exposed during its lifetime [5].

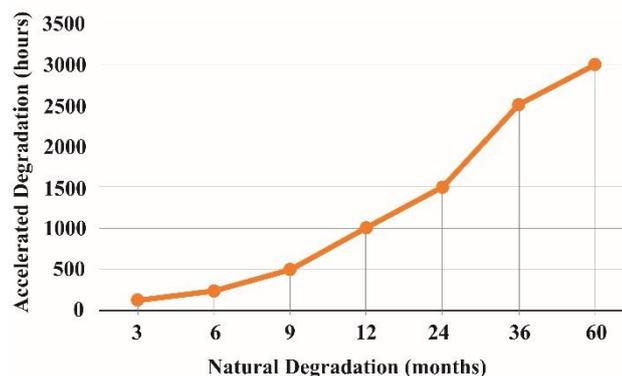
Along with other effects, the photo-oxidation of polymers can result in the oxidation of double bonds and the splitting of polymer segments. In other words, photo-oxidation results in the rupture of chemical bonds [13]. Most polymers that come from discarded items have additives for UV protection in their composition. The most commonly used stabilizers in the protection of polystyrenes are HALS (hindered amine light stabilizers) [14], which act both on the surface and inside the material [15]. These protective additives have the compatibility and chemical ability to create bonds with the matrix, as well as to self-heal through recombination with oxygen. [16, 17, 18].

In this context, UV radiation is a possible factor responsible for the yellowing and degradation of polymer surfaces, since photo-oxidation starts on the surface of the material [19]. In Figure 1, we can observe the diagram of a simulation of accelerated aging test.



**Figure 1.** Virtual simulation of the accelerated aging test.

Among climatic conditions and parameters related to the destructive effects of nature, it is difficult to obtain real data about the weather on the accelerated aging system in relation to the exposure time. Thus, based on a statistical study demonstrated by Author et al [20,21] the Figure 2 shows a graph which correlates the accelerated degradation with the natural degradation, taking into account the number of hours of exposure. The graph was developed as established by the ASTM - G53 standard.



**Figure 2.** Accelerated degradation versus natural degradation. Adapted [20,21].

The data presented in Figure 2 was used as a parameter for research and analysis of the samples exposure in climatic chamber focused on the photo-oxidative degradation.

The changes of a polymer induced photo-oxidation can be detected by Fourier Transform-Infrared Spectrometer (FTIR) and dynamic-mechanical thermal analysis (DMTA), allowing the degradation to be studied and well understood.

The HIPS photo-oxidation bands can be identified by FTIR in the range of the hydroxyl ( $3450 - 3200 \text{ cm}^{-1}$ ) and carbonyl ( $1725 \text{ cm}^{-1}$ ) groups that increase with aging. Changes in the band that corresponds to the unsaturated bonds of carbon trans-1,4 ( $966 \text{ cm}^{-1}$ ) suggest degradation, which occurs mainly in the polybutadiene phase with formation of carbonyls and hydroxyls [7,8]. As the time of UVA irradiation increases, the changes in the spectra also tend to increase [22].

Through DMTA technique, it is possible to correlate chemical and morphological structure of the polymers, making it possible to determine the  $\tan \delta$ , storage modulus ( $E'$ ) and the loss modulus ( $E''$ ). The  $\tan \delta$  peak ( $T_g$ ) of the polymeric material is the average value of the temperature range that allows the amorphous phase of polymer chains to acquire mobility [23,24].

All the effects of the degradative process start on the surface of the analyzed material, with variations depending on the distance of the affected surface and the interior of the sample [24, 25].

The aim of this study is to reuse printer carcasses and subject to UVA radiation in order to measure the photo-oxidation as well as measure the effect on the HIPS chemical and thermo-mechanical

properties. Additionally, this work aim to develop a fast and reliable characterization technique for quality assessment of recycled plastics.

For a better understanding of the study, in addition to the introduction, the structure of the article is given as follows. Section II is the experimental portion which describes the materials and sample preparation. Section III contains the degradation study with aging test, Section IV, the characterization by FTIR and DMTA analyses, Section V, results and discussion, and finally the conclusion and future work.

## II. EXPERIMENTAL

### MATERIALS AND SAMPLE PREPARATION

To study chemical changes caused by UVA radiation in polymers, both virgin and recycled HIPS were employed.

Virgin HIPS a commercial grade PS-HI825 with melt flow index of 5.5 was obtained from Videolar Brazil. The recycled HIPS coming from carcasses of damaged or obsolete inkjet printers were manually disassembled to separate the components. The HIPS polymer was visually identified by the PS-HI, HIPS or PSAI (*poliestireno de alto impacto* - high impact polystyrene in Portuguese) symbols named on the material's surface (Figure 3).

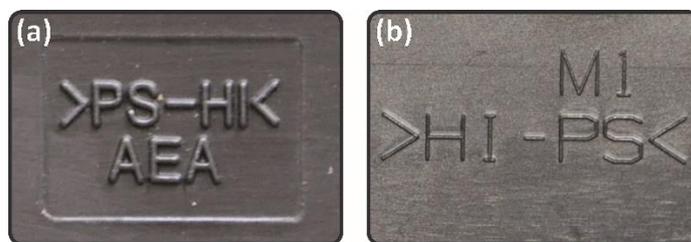


Figure 3. Identification of the material printed on the surface of the printer carcasses.

After separation, the carcasses were ground and then homogenized through the use of a single screw extrusion Seibt ES-35 L/D 30, operating at 20 rpm and temperature profile: 180, 190, 210 220 e 220 °C. In the extrusion no additives were added. After extrusion the homogenized material was manually mixed with parts of virgin material, as shown in Figure 4 and subsequently molded in an AxPlásticos injection molding machine using constant injection temperature of 235 °C; injection pressure (bar), hold (bar), cooling time and mold temperature of 2, 3, 22s and 35 °C, respectively. The specimen employed to perform the aging test was prepared according ASTM D256, specimen for impact Izod test.

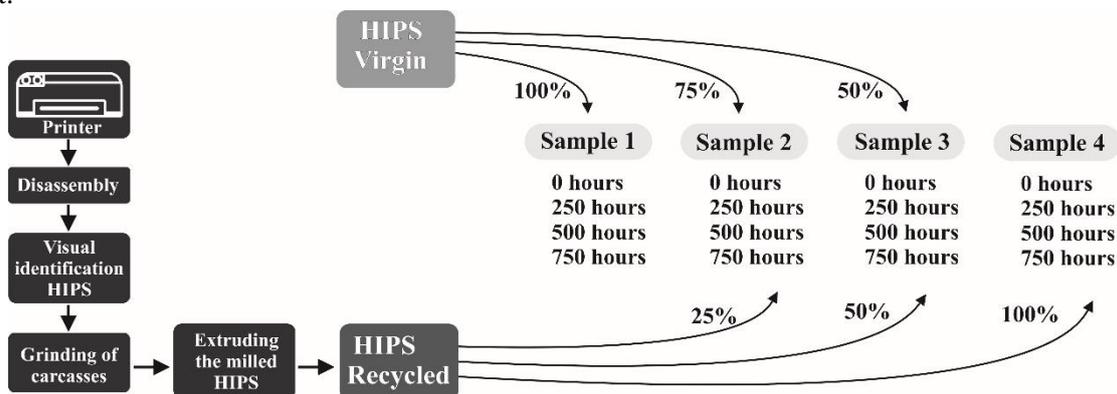
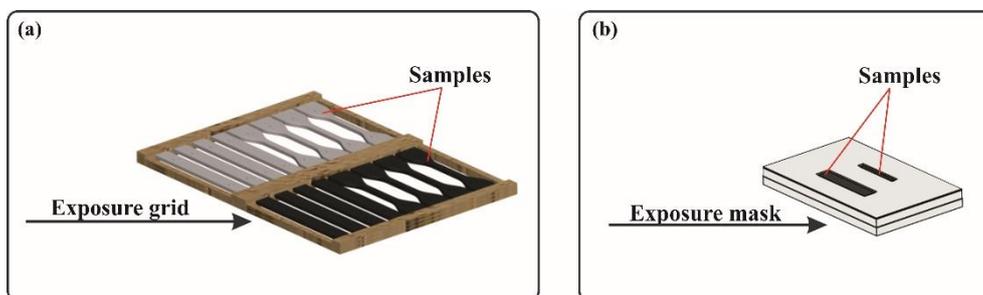


Figure 4: Scheme of the defines samples and exposure times.

### III. DEGRADATION STUDY (AGING TEST)

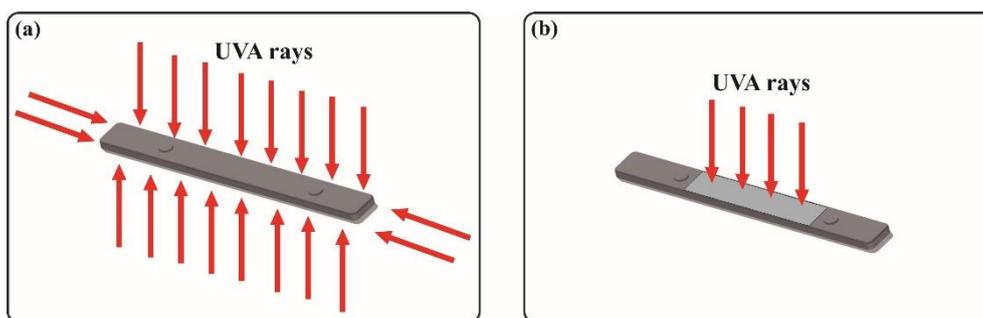
The UVA test in climatic chamber was performed by two methods: samples were placed on pallets (Figure 5-a) and also in exposure masks (Figure 5-b). The pallets have the function of stabilizing the samples during the test, in order to avoid any movement of the samples due to vibration of the

equipment. The masks were made by MDF wood shaped using laser cutting and also have the function to guide UVA radiation at a specific spot on the sample, as shown in Figure 5. As indicated by ASTM G154 the MDF mask was covered with aluminum foil to concentrate the UVA radiation just in the sample.



**Figure 5.** Methods of exposure to UVA radiation, (a) exposure pallets, (b) exposure masks with targeted exposure windows.

Figure 6 shows a representation of the difference between the incidence of radiation on the sample's surface based on the method of exposure. The samples exposed on the pallets (Figure 6-a) were hit with UVA radiation in all surfaces. On the other hand, with the exposure mask (Figure 6-b), the radiation is concentrated at the opening of the mask while the rest of the sample is protected from the radiation.



**Figure 6.** Scheme of the UVA radiation subjected in the samples; (a) full exposure, achieved by the exposure pallets, (b) spot exposure, achieved by the exposure masks.

The accelerated aging test was performed in three cycles of 250 hours of exposure each. The climatic chamber used was a Marconi MA835/UR and the parameters used were: 30°C, humidity 50% and 75% UVA radiation using a UVA lamp Sylvania Black Light 15W and UVA wavelength emission of 315 – 400 nm. This totaled 750 hours of exposure are equivalent of 10 months in natural exposure to UVA radiation in the environment.

#### IV. CHARACTERIZATION

FTIR analyses were performed to study the evolution of the photo-oxidation in the samples after aging test. The absorbance spectrums of the HIPS sample's surfaces that underwent photo-oxidative aging were characterized and studied, with emphasis on the bands that are possibly susceptible to photo-oxidation. The equipment used a Shimadzu IRAffinity<sup>-1</sup> with resolution of 4 cm<sup>-1</sup> which was performed 16 averaged scans per sample, in the range of 4000-600 cm<sup>-1</sup> using ATR mode.

In the specific absorption regions among 4000-600 cm<sup>-1</sup> that were analyzed, special emphasis was given to the regions that correspond to the hydroxyl groups (spectrums between 3600-3100 cm<sup>-1</sup>), Carbonyl groups (spectrums from 1900 cm<sup>-1</sup> to 1600cm<sup>-1</sup>) and the unsaturated groups from the polybutadiene phase (spectrums between 1400 cm<sup>-1</sup> to 600 cm<sup>-1</sup>).

The dynamic-mechanical thermal analysis (DMTA) was used to evaluate the mechanical performance of the samples after aging test and then correlate aging and degradation. DMTA test was carried out using a PerkinElmer DMTA 8000 operation in a single cantilever for 25mm × 13mm × 3mm specimens. Strain was set at 0.02% with a frequency of 1 Hz and a temperature ramp of 3°C/min,

from 25 to 155°C. From the experimental data, the storage modulus ( $E'$ ),  $T_g$  and  $\tan \delta$  values were obtained.

The comparative analysis of the  $\tan \delta$  and storage modulus ( $E'$ ) versus sample temperature were performed in reference to the Sample 1 (100% virgin).

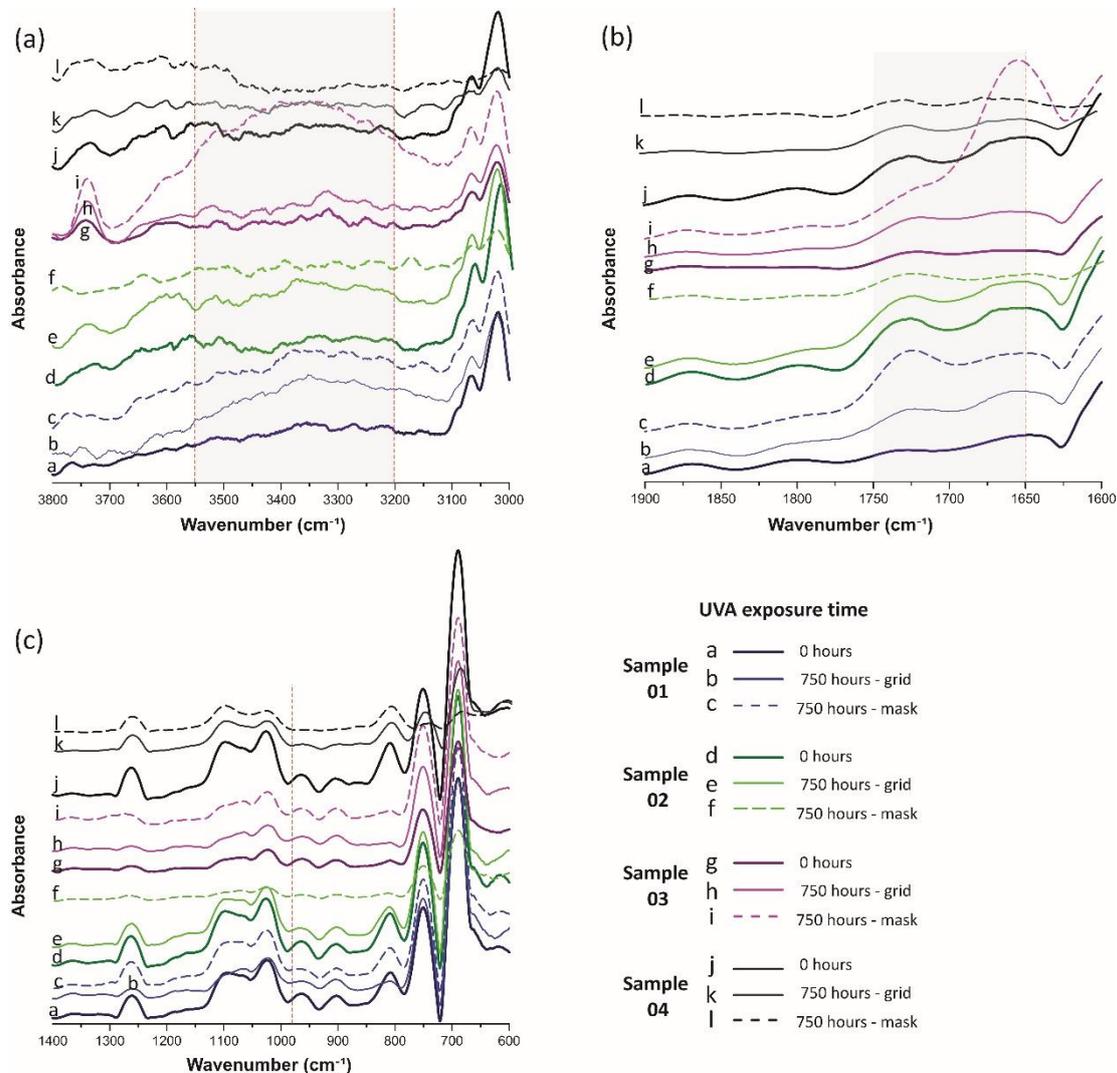
## V. RESULTS AND DISCUSSION

### Fourier Transform Infrared Spectroscopy – FTIR

The influence of the aging measured for the HIPS samples respecting to the UVA exposure periods (0 to 750 hours) in the absorption region between 3600 and 3100  $\text{cm}^{-1}$  is shown in Figure 7-a corresponding to the hydroxyl groups. Figure 7-b shows the absorption region between 1900 to 1600  $\text{cm}^{-1}$ . In this region there was an alteration in the peak of the carbonyl band at 1725  $\text{cm}^{-1}$ . This higher absorbance in the Carbonyl region represents oxidative degradation [22].

The spectrums analyzed indicated that in sample 1, (100% virgin material exposed in a mask), the absorbance band was larger than in the samples exposed in pallets, after 750 hours of UVA exposure. This indicates that the radiation was more aggressive in the spot exposure procedure.

Polybutadiene is the main oxidation point of HIPS [7, 8]. This statement can be confirmed by the change in absorbance spectrums in samples 1 and 4, in the region of butadiene-related double bonds, bands at 966 and 911  $\text{cm}^{-1}$  as shown in Figure 7-c for mask and pallet exposed samples.



**Figure 7.** Results of the FTIR: (a) region between 3600 and 3100  $\text{cm}^{-1}$ , (b) region between 1800 and 1400  $\text{cm}^{-1}$  and (c) region between 1400 and 600  $\text{cm}^{-1}$  of the samples: (a) sample 1 (0 horas), (b) sample 1 (750 hours), (c) sample 2 (0 hours), (d) sample 2 (750 hours), (d) sample 3 (0 hours), (e) sample 3 (750 hours), (f) sample 4 (0 hours), (g) sample 4 (750 hours) exposure to UVA radiation.

The FTIR showed that chemical changes occurred in specific regions that are referenced as important in the photo-oxidative process. However, the photo-oxidation after aging showed intensity in mask exposed with the targeted spot radiation. Also, the results of FTIR showed that photo oxidation of the HIPS did not causes severe degradation.

The effect that possibly occurred was recombination of the UV additive presented in the recycled material. As a commercial material, the printer carcasses have UV additives. Thus, after extrusion the additive did recombine with the oxygen from degradative process of HIPS within the extruder. Additionally, samples with parts of the recycled HIPS showed less intensity of the degradative process. Thus the additive presented in the carcasses did help to reduce the intensity of the degradative process by aging test. In comparison, the degradation level measured for the virgin sample was more severe that for recycled ones (Sample 4) because of the portion of the UV additive that did recombine after extrusion and injection processing.

### Dynamic-Mechanical Thermal Analysis (DMTA)

The results of the DMTA tests presented similar behavior among the samples, as shown in Figure 8. It can be seen from Figure 8-a Tan  $\delta$  and Figure 8-b storage modulus related to the temperature that the levels of degradation did not significantly affect the dynamic-mechanical behavior of the material.

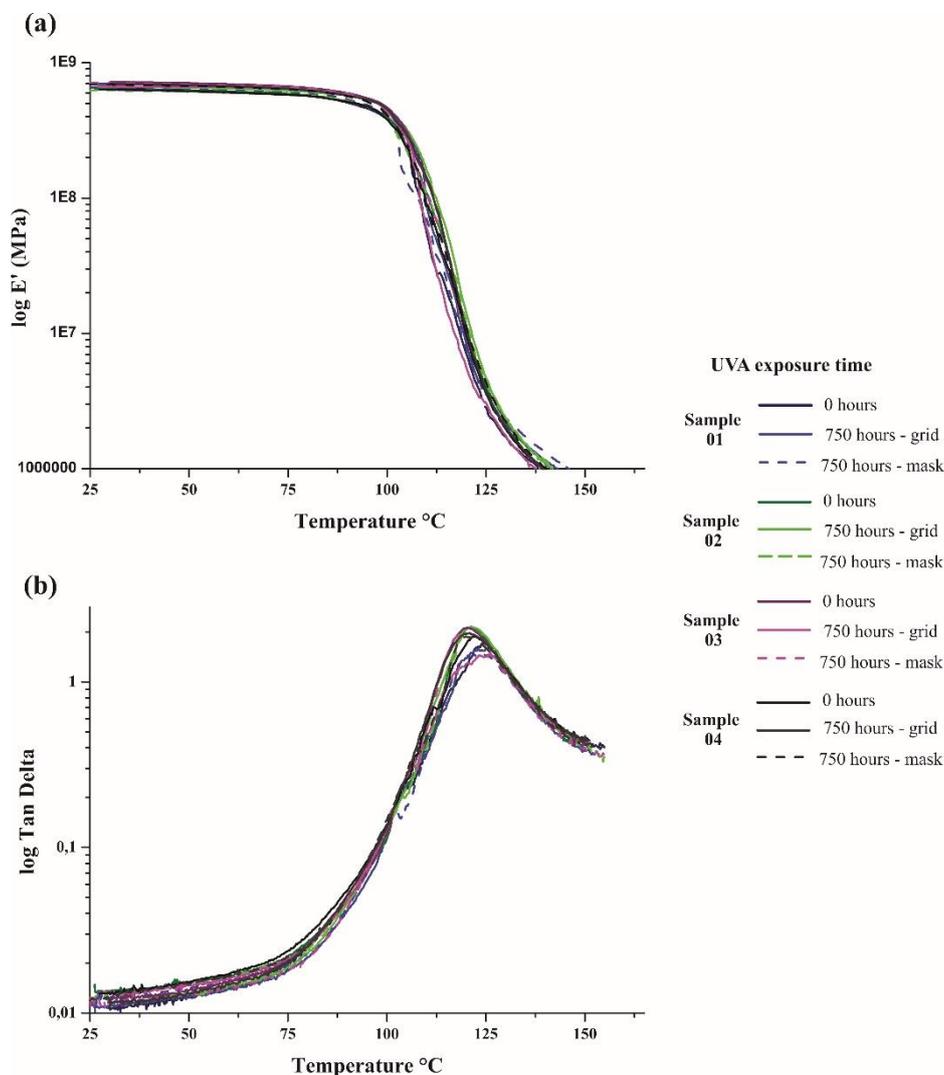


Figure 8 – DMTA, (a) Tan  $\delta$  results of samples 1,2,3 and 4 exposed in both pallet and mask for the times 0 and 750 hours of UVA radiation, (b) Storage modulus ( $E'$ ) results of samples 1,2,3 and 4 exposed in both pallet and mask for the times 0 and 750 hours of UVA radiation

Possibly, the degradation occurred just in the surface of the samples. Additionally, the core of the material did not show the degradation levels that might influence dynamic-thermal properties.

Some studies have shown that the degradation by oxidative process can hit just the surface of the polymeric material. Additionally, the recombination effect of the UV block additive also acts in the surface of the material. Thus, the UV additive can block the radiation absorption in the surface avoiding photo degradation to start and degradative process within the material [15].

## VI. CONCLUSION

The recycled samples exposed to UVA radiation did not show considerable changes in terms of the properties or processability when compared to the virgin material.

By exposing targeted areas of the samples through masks, it was observed that in a single product coexist different levels of degradation due to the spot exposure. This fact should directly influence the physical properties of the material to be reused, and therefore influence the material's application. Additionally, by the additive recombination effect, it was possible to use recycled material in new compositions and also increase resistance in terms of the photo-oxidation without needing the addition of UV additive. The results showed that when comparing the recycled samples to virgin ones, the recycled samples that underwent either modes of exposure to UVA radiation for a 750 hour period can be used in products with higher added value. This work also showed the feasibility of using FTIR and DMTA as techniques to help measure the level of degradation of reused plastics materials.

## VII. FUTURE WORK

In this study, the proposed technique focuses on HIPS recycled printer housings. Future work will be extended to study and characterize the influence of photo-oxidation on the recycling of other plastics materials.

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## REFERENCES

- [1]. ABDI. Agência Brasileira de Desenvolvimento Industrial. Logística Reversa de Equipamentos Eletroeletrônicos: Análise de Viabilidade Técnica e Econômica. Brasília 2012.
- [2]. Pnuma - Programa das Nações Unidas para o Meio Ambiente. Disponível em: <http://www.pnuma.org.br>
- [3]. Abrelpe. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. Disponível em: <http://www.cve.saude.sp.gov.br/htm/doma/simposio/LOG%20DSTICA%20REVERSA%20DE%20RES%20CDDUO%20EE-ABRELPE.PDF>
- [4]. Amani, M., Sharif, M., Kashkooli, A., Rahnama, N., & Fazli, A. (2015). Effect of mixing conditions on the selective localization of graphite oxide and the properties of polyethylene/high-impact polystyrene/graphite oxide nanocomposite blends. *RSC Advances*, 5(95), 77723-77733.
- [5]. De Paoli, Marco Aurelio (2009). Degradação e estabilização de polímeros. São Paulo: Artliber. Disponível em: <http://www.chemkeys.com/blog/wp-content/uploads/2008/09/polimeros.pdf>
- [6]. Vianna, Wladimir L.; Correa, Carlos A.; Razzino, Carlos A. (2004). Efeitos do tipo de poliestireno de alto impacto nas propriedades de compósitos termoplásticos com farinha de resíduo de madeira. *Polímeros*, 14(5), 339-348.
- [7]. Israeli Y, Lacoste J, Lemaire J, Singh RP, Sivaram S. (1994). Photo-and thermoinitiated oxidation of high-impact polystyrene. I. Characterization by FT-IR spectroscopy. *Journal of Polymer Science Part A: Polymer Chemistry*, 32(3), 485-493.
- [8]. Vilaplana F, Ribes-Greus A, Karlsson S. (2006). Degradation of recycled high-impact polystyrene. Simulation by reprocessing and thermo-oxidation. *Polymer degradation and stability*, 91(9), 2163-2170.
- [9]. Pascault, J. P., Williams, R. J. J., Paul, D. R., & Bucknall, C. B. (2000). Polymer blends, vol. 1.
- [10]. Prasad, A. Vishwa; Singh, R. P. (1998). Photooxidative degradation of styrenic polymers: <sup>13</sup>C-NMR and morphological changes upon irradiation. *Journal of applied polymer science*, 70(4), 637-645.

- [11]. Kasper, A. C., Gabriel, A. P., de Oliveira, E. L. B., de Freitas Juchneski, N. C., & Veit, H. M. (2015). Electronic waste recycling. In *Electronic Waste* (pp. 87-127). Springer International Publishing.
- [12]. Duarte, C., Santos, J.A. (2013). Degradação e proteção superficial da madeira em exterior. *Corrosão e Proteção de Materiais*, 32(1), 10-18.
- [13]. Fragata, F., Amorim C.C., Ordine A.P. (2010). Desempenho de tintas de acabamento frente às radiações ultravioleta, UVA e UVB, e condensação de umidade. *Corrosão e Proteção de Materiais*, 29(3), 91-98.
- [14]. Yousif, Emad; Haddad, Raghad (2013). Photodegradation and photostabilization of polymers, especially polystyrene: review. *SpringerPlus*, 2(1), 1.
- [15]. McCusker, M. (1999). A UVA/HALS Primer: Everything you've ever wanted to know about light stabilizers-Part I. *Metal finishing*, 97(5), 51-53.
- [16]. Lombardo, Patrícia Coelho (2015). Influência de estabilizantes na degradação foto-oxidativa de filmes de compósitos de SWy-1/poli (óxido de etileno) Influence of stabilizers on photo-oxidative degradation of SWy-1/poly (ethylene oxide) composite films. *Polímeros*, 25(1), 101-108.
- [17]. Lonkar, S. P., Kushwaha, O. S., Leuteritz, A., Heinrich, G., & Singh, R. P. (2012). Self photostabilizing UV-durable MWCNT/polymer nanocomposites. *RSC Advances*, 2(32), 12255-12262.
- [18]. Gugumus, F. (1995). The performance of light stabilizers in accelerated and natural weathering. *Polymer degradation and stability*, 50(1), 101-116.
- [19]. Saron C., Felisberti M.I. (2004). Dynamic mechanical spectroscopy applied to study the thermal and photodegradation of poly (2, 6-dimethyl-1, 4-phenylene oxide)/high impact polystyrene blends. *Materials Science and Engineering: A*, 370(1), 293-301.
- [20]. Rios, Alexandre de Souza. Estudo do envelhecimento acelerado em materiais compósitos revestidos com poliuretano aplicados em aerogeradores. 2012. 147 f. Dissertação (Mestrado) – Universidade Federal do Ceará, Centro de Tecnologia, Departamento de Engenharia Metalúrgica e de Materiais, Programa de Pós-Graduação em Engenharia e Ciência de Materiais, Fortaleza. 2012. Disponível em: <[http://www.repositorio.ufc.br/bitstream/riufc/3874/1/2012\\_dis\\_asrios.pdf](http://www.repositorio.ufc.br/bitstream/riufc/3874/1/2012_dis_asrios.pdf)>. Acesso em 13 março 2015.
- [21]. Brandalise, Rosmary Nichele. Avaliação da degradação biótica e abiótica da mistura polimérica de polietileno de alta densidade com o poli (álcool vinílico). Tese de Doutorado. UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL.
- [22]. Kushwaha, O. S., Ver Avadhani, C., Tomer, N. S., & Singh, R. P. (2014). Accelerated degradation study of highly resistant polymer membranes for energy and environment applications. *Advances in Chemical Science*, 3(2), 19-30.
- [23]. Canevarolo JR, Sebastião Vicente. (2007). Técnicas de caracterização de polímeros. *Editora Artiber*.
- [24]. Cassu, Silvana Navarro; Felisberti, Maria Isabel (2005). Comportamento dinâmico-mecânico e relaxações em polímeros e blendas poliméricas. *Química nova*, 28(2), 255-263.
- [25]. Sanchez, E. M., Felisberti, M. I., Costa, C. A., & Galembeck, F. (2003). Avaliação da degradação térmica e fotooxidativa do ABS para fins de reciclagem. *Polímeros Ciência e Tecnologia*, 13(3), 166-172.

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