Urban Trash Containers Made of Recycled Plastic Lumber

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Abstract

A low-cost and easy-to-handle manufacturing procedure for urban trash containers, made of recycled plastic lumber, was developed focusing on the following aspects: materials selection, materials compounding, plastic sheet manufacturing and mechanical testing, urban trash container design and assembly, and a pilot test. The material, a composite of polyethylene (PE) urban waste, ethylene-vinyl acetate copolymer (EVA) industrial waste and calcium carbonate, was prepared in a Drais batch mixer. The mixture was hot compression molded as rectangular-shaped sheets of 900 mm length, 600 mm width and 12 mm or 7 mm thickness. These sheets were characterized with regard to mechanical properties, microstructure and UV resistance. An urban trash container prototype was prepared from the plastic sheets and a hundred trash containers were submitted to a pilot test. All the steps, material compounding, plastic sheet processing, and trash container design and manufacturing were optimized in order to give the required physico-mechanical properties, functional characteristics and finish of the urban trash containers.

Keywords
Plastics recycling, urban trash containers, PE urban waste, plastic lumber, EVA industrial waste.

I. Introduction

The reuse of industrial and urban plastic residues in the development of products for various ends, through the use of cheap technology and with easy handling, along with a guaranteed product quality, currently presents a challenge [1]–[4]. In this context, the manufacturing of furniture, and household and urban utensils, from recycled plastics is an interesting alternative both from the technical and environmental points of view. In this regard, methodologies for selecting the materials and the processing techniques, adjustments to the processing conditions and material quality tests, among other requirements, need to be established [1]–[9]. Plastic mixtures of recycled polyethylenes (PE) with ethylene-vinyl acetate (EVA) residues originating from the production of shoe soles have good compatibility and a diverse range of properties [10]–[12]. Furthermore, these materials are abundant [10], [12] and relatively cheap, and also one can be easily incorporated into the other in conventional rubber mixers [12]. The EVA is easily obtained from wastes discarded by companies in the shoe sector. Polyethylenes may be found in landfills generally in the form of containers, film packaging or reprocessed by plastics recycling companies. In relation to the properties of plastic mixtures based on polyethylenes, the addition of mineral fillers significantly reduces the cost of the final product and also promotes an improvement in the mechanical properties, such as the flexure and tensile strengths [13], and dimensional stability [14]. Of the mineral fillers most used for this purpose, calcium carbonate is the most notable. Another important feature of plastic materials in relation to their application in products subjected to weather conditions is their resistance to photo-oxidative degradation [13], [15]. This study sought to develop methodologies for the selection of materials, processing and the preparation of plastic lumber from recycled plastic mixtures (polyethylenes and EVA) and calcium carbonate, aiming at their application in urban trash containers. The processing and manufacturing stages of the plastic lumber, as well as their mechanical and morphological properties and resistance to aging by ultraviolet (UV) rays achieved by the materials developed, are discussed. A prototype for an urban trash container made from the material developed is also presented.

II. Experimental

A. Raw materials used

At the stage of selecting materials, the criteria established sought to combine low cost, raw material abundance, ease of processing and compatibility between materials. Thus, the following raw materials were selected: a matrix composed of PE and EVA, polymers with a high compatibility and ease of mixture [10], [12]. Calcium carbonate was used as the reinforcement filler, due to its relatively low price and its efficiency as reinforcement in PE mixtures [13]. The EVA residue used in this study was scraps from expanded sheets used in the shoe industry. This material was shredded in a knife mill until particles of around 25-100 μm in diameter were obtained. The polyethylenes (PE) employed originated from recycled plastic packaging. The calcium carbonate employed was a commercial type suitable for application in polymers.

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B. Processing of materials

The mixing of polyethylene, EVA and calcium carbonate was carried out in a Drais batch mixer. This mixer is composed basically of a closed mixing chamber containing a rotor, which spins at high rotation speeds, promoting the generation of heat and shearing appropriate for fusion and incorporation of the fillers into the plastics. Some preliminary processing tests involving different compositions of polyethylenes, EVA and calcium carbonate were then evaluated and from the mechanical properties generated by these materials the following composition was defined (values in percentage mass): 30 parts of high density polyethylene (HDPE), 20 parts of low density polyethylene (LDPE), 25 parts of EVA and 25 parts of calcium carbonate. For this composition, the processing in the Drais mixer required a time of 3 minutes, with a rotor speed of 5,000 rpm. Under these conditions a homogeneous powder was obtained. The sheets were manufactured by way of compression molding, from the powder obtained after the mixing in the Drais. After several preliminary tests the best conditions for the molding of the material were established according to the formulation obtained in the Drais mixer, in relation to the visual and structural aspects of the plastic lumber. The best conditions for the molding were as follows: press temperature 170ºC, closing pressure of the press of 20 MPa and a compression time of 25 minutes.

C. Characterization of mechanical properties of the formulated material

The mechanical characteristics of the formulated materials were evaluated through several tests, aiming at measuring the structural resistance of the plastic lumber and evaluating the potential for their use in urban trash containers. These tests were carried out from specimens taken from the plastic lumber molded by compression. Flexural tests were carried out at a crosshead speed of 1 mm/min according to the standard ASTM D 790. Impact tests were carried out with a CEAST instrument, model Resil 25, using a 2.0 J pendulum, according to the standard ASTM D 256. Hardness tests (Shore D) were carried out in a Teclock durometer, according to the standard ASTM D 2240. The results were obtained through the arithmetic mean of five determinations.

D. Characterization of the phase morphology of the formulated material

The degree of mixing and the compatibility of the materials were evaluated through Scanning Electron Microscopy (SEM), from samples fractured in liquid nitrogen. The fractured surfaces were covered with a layer of gold in order to make them conductive and they were then analyzed using a JEOL (JSM 5800) scanning electron microscope, with an acceleration voltage of 10kV.

E. Resistance of the formulated material to ultraviolet (UV)

The test for the resistance to UV in polymers is one of the main techniques used to aid the development of products and their expected lifespan. The exposure of the material to weather conditions aimed to evaluate the effects on its properties, obtaining a prediction of the behavior of the product during its application. The test for the resistance of the formulated material to UV was carried out in a C-UV instrument with a system of accelerated aging for non metals, according to the standard ASTM G53. The tests were carried out for a period of 240 hours, which corresponds to a maximum time of six months under direct exposure to the action of weather. The destructive effect of light was simulated through UV-B radiation sources, exactly in the range where the photochemical reaction occurs.

F. Prototype manufacturing

To manufacture the urban trash container two plastic lumber with a thickness of 12 mm, length of 900 mm and width of 600 mm and half a sheet with a thickness of 7 mm, length of 900 mm and width of 600 mm are needed. The body of the trash container was manufactured from the two thicker sheets while half of the thin sheet was used to make the container lid. The trash container prototype was dimensioned according to the size and geometry of the sheets as shown in Figure 1. The sheets were cut with the aid of molds made from a template. The parts for the trash container were cut with a carpenter's saw and then polished with 60-grain sandpaper. For the assembly of the urban trash container developed, it was not necessary to follow any logical sequence, apart from the fact that the body and the lid are assembled separately. The lid is held to the body of the trash container by metal screws. The views of the project are presented in supplementary files.

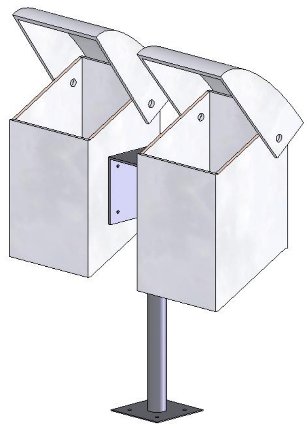

Fig. 1: Urban trash container design.

III. Discussion of results

In Figure 2, micrographs of the PE/EVA/calcium carbonate mixtures are shown. The level of phase dispersion in a mixture depends on the compatibility between the polymers which comprise the mixture [16], [17]. In Figure 2 (a) it can be seen that the mixture of PE and EVA is homogeneous and has particles of calcium carbonate dispersed in the PE/EVA matrix. The particle size of the calcium carbonate was determined using an image analyzer and it was verified that the average diameter of the particles was in the range of 0.17–0.20 μm. This homogeneous morphology highlights the good compatibility of the formulated mixture, which will reflect in a synergism in relation to the mechanical properties.

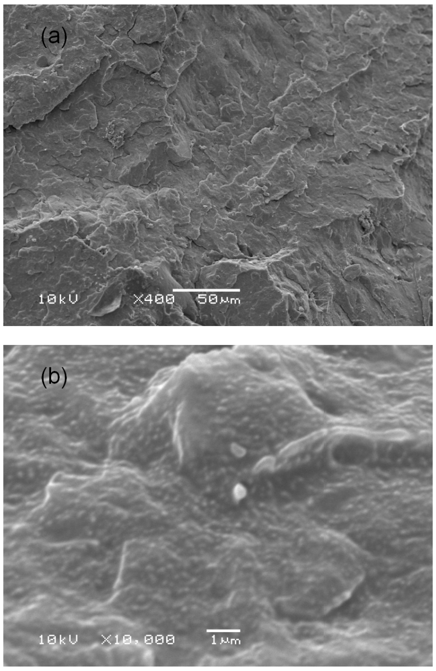

Fig. 2: Micrographs of the PE/EVA/calcium carbonate mixtures with a magnification of 400 X (a) and 10,000 X (b).

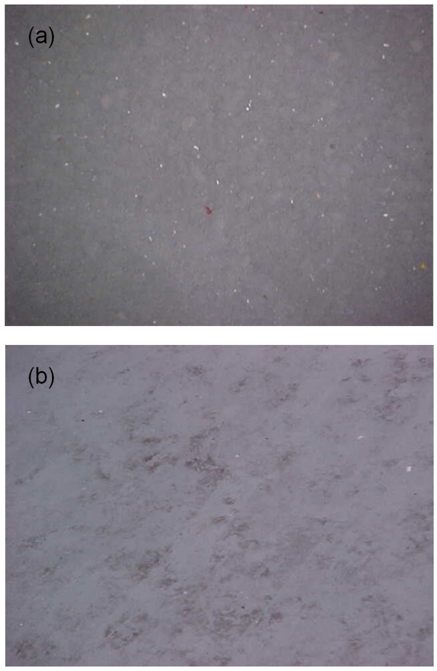

Fig. 3: Visual comparison of surface finish (16.5x14 cm2) of sample without (a) and after (b) accelerated aging.

The results for the mechanical properties of the PE/EVA/calcium carbonate mixtures with and without exposure to accelerated aging are given in Table 1. The elastic modulus (E) is the ratio within the elasticity limit between flexural stress and the corresponding strain. Its calculation is carried out by drawing the tangent to the initial linear part of curve stress versus deflection [18]. The hardness is the resistance to indentation of a material and the impact strength is the capacity which a polymeric material has to withstand accidental impacts [18]. On comparing the values for the mechanical properties of a plastic generally employed in the making of conventional trash containers, such as HDPE, it can be observed that the formulated material has a lower rigidity value (flexural modulus). On the other hand, the impact strength value is higher and the hardness value is almost the same. These differences in the properties result from the behavior of the PE/EVA/calcium carbonate mixtures. The addition of EVA produces a reduction in rigidity and an increase in the impact strength in relation to pure PE [10], [12], while the addition of calcium carbonate produces the opposite effect. The sample exposed to the accelerated aging showed little variation in the mechanical properties of the formulated material, except in its impact strength, which showed a drop, however, without compromising the structural quality of the material. In general, polymers are degraded when exposed to solar light and oxygen. Photo-oxidative degradation depends on the nature of the polymer. During the degradation process physical and chemical changes in the polymers occur, such as: decolorization, fissuring, loss of shine and decrease in the mechanical properties. These phenomena are almost always associated with chain scission processes and, in some cases, crosslinking also occur [13]. Another important aspect is that the surface finish of the sheets was not damaged after being submitted to the accelerated aging, as can be observed through the visual comparison of the sheet samples with and without aging (Figure 3).

After the evaluation of processability, the mechanical characteristics and the finish of the plastic lumber, the stage of creating the urban trash containers commenced. The production of the trash containers was composed of an initial creation phase with the objective of listing the greatest possible number of ideas and aims relating to the product. A large number of sketches were produced, without any judgment upon them, in order to show the possible solutions and opportunities available. Later, the best solution was selected from a systematic evaluation, considering the aspects of ease of assembly, structural requirements, functionality and esthetics. Through this process, and according to the approval of people from all areas involved in the project, the "Tucano" (a Portuguese word that means toucan) trash container was chosen, according to the sketch shown in Figure 4.

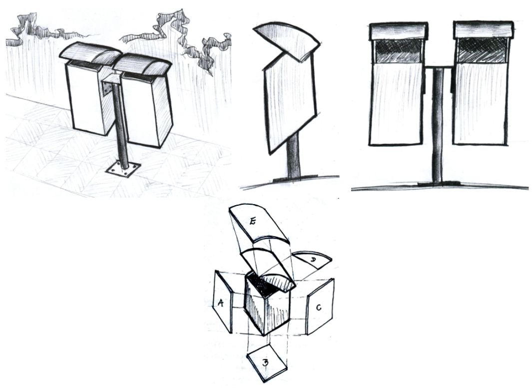

Fig. 4: Sketch of the "Tucano" urban trash container.

From this design, the prototype of the urban trash container was developed. The wall was thicker in relation to conventional trash containers, since the formulated material had lower rigidity values than those of the conventionally used plastics. From the prototype developed, 100 units were produced for the pilot test at the university. The pilot test showed that, after six months of exposure to different environmental conditions of temperature and humidity, the 100 trash containers were approved according to a technical evaluation which took into consideration the physico-mechanical requirements, functional characteristics and surface finish. A structural integrity with low shape distortion, the absence of warping, the absence of fissures or cracks, and little loss of surface finish was verified.

TABELA I: Mechanical properties of the PE/EVA/calcium carbonate mixtures

Sample	Flexural modulus (MPa)	Izod impact strength (J/m)	Hardness (Shore D)
PE/EVA/calcium carbonate(without aging)	367±37	158±2	56±2
PE/EVA/calcium carbonate(after aging)	470±28	64±11	58±5
Pure HDPE	800±30	35±3	64±2

Fig. 5: Prototype of urban trash container undergoing pilot test.

IV. Conclusions

Urban trash containers made of recycled plastic lumber were developed through a low-cost and easy-to-handle manufacturing process. Aspects such as materials selection, materials compounding, plastic sheet manufacturing and mechanical testing, urban trash container design and assembly, and a pilot test, were considered. According to the morphological analysis, the sheet surface showed homogeneity between the phases and good dispersion of calcium carbonate in the polymer matrix. This characteristic resulted in satisfactory mechanical properties of the material for the manufacturing of urban trash containers. The material exposed to accelerated aging did not show adverse effects with regard to its properties during the analysis period, showing that the sheets can be used in the manufacture of this type of object, with low cost and useful application.

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V. References

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