Plastic Wood From Urban Waste Recycled Plastics as a Substitute for Lumber

Eloisa B. Mano, Cláudia M. C. Bonelli, Marco A. Guadagnini, Sand J. M. Luiz

Abstract - The material named IMAWOOD®, developed in this Institute as a fraction of the urban solid waste, is composed of a mixture of partially degraded polymers, mainly low density polyethylene. Its characteristics allow it to be used as a plastic wood. The comparative study of some commercial types of Brazilian woods and the recycled plastic product IMAWOOD® was performed, following an usual method for natural wood characterization.

Keywords: plastic wood, recycled plastics, urban solid waste, recycled polyolefins, post-consumed plastics

INTRODUCTION

The classic natural engineering material, wood, may be considered a composite in which the resistance components are the cellulosic fibers - a polysaccharide - and the matrix, lignin - a macromolecule of phenolic character -, in variable proportions. The attempt to employ an other materials, mostly plastics, for products usually made from wood in applications where physical properties are assumed not to be very critical is under investigation [1-4].

Plastic waste management has become a major strategic issue for the polymer industry; it accounts for approximately 7% of the weight of all discarded products. Their impact on the environment is considerable since, due to the low density and the hollow shape of one-way packaging - bottles, containers, bags, etc - the volume is much greater than other waste products of similar weight. Approximately 65% of all urban plastic waste consist of polyolefins - high density polyethylene (HDPE), low density polyethylene (LDPE) and polypropylene (PP). The reduction of the plastic residues as well as some economic and political aspects are reasons strong enough to justify any type of recycling of polymer materials. The substitution of plastic wood by lumber contributes for environmental protection [2,5-7].

The requisites for success in plastics recycling are: reliable source of plastic residues in economic basis; selected equipment and know-how to process the material and specific markets for the recyclates [8-9]. There are two general approaches to recycle a plastic material: plastics fractionation and processing of the separated plastic fractions - two-step process - and processing of the mixture of plastics residues in strong machinery - single-step process [10].

In the two-step process, the fractionation is usually based on the difference of density of the components. Separation of the plastic fragments within liquid columns of arbitrarily chosen density - hydroalcoholic and saline solutions - or in hydrocyclones - equipments usually used in ore processing - have been investigated [5,11-14]. The single-step process allows the manufacture of profiles with large cross-sectional areas [2,4,15]. The heterogeneity of the product, the presence of non-molten plastic fragments and even metal contaminants, as well as irregular voids in the core of the profiles lead to

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relatively poor mechanical properties [10,15]. The selective and semi-selective collect improve the quality of the recycled material, and is technically important for the single-step process; for the two-step process, this may be omitted. The present paper deals with a two-step process for the manufacture of materials with regular, controllable composition, which allows to obtain homogeneous, high-quality profiles to attain strict specifications.

Processing equipment for recycled plastics is developing fast, in order to permit the best homogenization and the minimum degradation of the material [16-17]. Additives like stabilizers, compatibilizers, impact modifiers, antioxidants can be added to recycled plastics in order to counterbalance an eventual drop of quality due to thermal degradation of the material. The structural changes on the macromolecules that occur by thermal degradation have been reported in the literature [18-20]. Proper formulations extend the range of application of recycled plastics [5].

Thermal, morphological and mechanical studies of recycled polyolefins from urban plastic waste, in comparison to LDPE/HDPE blends, have been reported. In spite of the presence of contaminants as shown by scanning electronic microscopy, the results showed the realistic possibility of recycling [21,22].

In the polymer area it is particularly difficult to obtain the equivalent to virgin components by recycling post-consumed plastics. Important aspects that should be taken into consideration are: the heterogeneous composition of plastic refuse; the large diversity of contaminants in unpredictable amounts; the degradation degree of some components; and the compatibility/incompatibility of the polymers in the mixture [5]. Instead of that, it seems more advisable to look for appropriate applications for specific recycle fractions.

In this paper, we fractionated post-consumed flexible plastic materials in order to investigate the characteristics of the larger fractions to find a convenient market for the recycle. The large polyolefin fraction in the municipal garbage collect was composed mostly of plastic bags and other packaging film residues. The analysis indicated that the main components were polyethylenes, mostly low density polyethylene [1,5].

The characteristics of the material named IMAWOOD® suggest the application in some products made of wood. There are intrinsic advantages, such as resistance to biological degradation and environmental despollution. Comparative data between some mechanical properties of IMAWOOD® and some commercial types of Brazilian woods - parana-pine, cedar and peroba - are discussed.
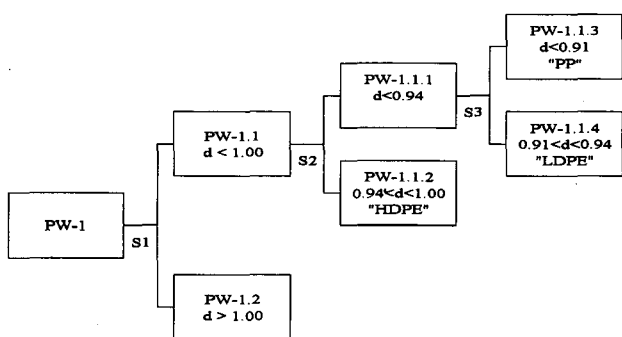
EXPERIMENTAL

The basic raw material for the preparation of IMAWOOD® was flexible plastic waste from the Municipal Company of Urban Solid Waste - COMLURB in Rio de Janeiro. One bale of about 200 kg collected on November 20-23, 1990 (Figure 1) was submitted to cutting, washing with water and drying in industrial equipment. A representative sample of the resulting flakes was taken according to method ABNT NBR 10007.

Figure 1. Flexible plastic waste from COMLURB

Preliminary experiments were run in 8-liter, transparent, plastic containers to observe the floating behavior of 20 g plastic fragments using water and hydroalcoholic solutions of 0.91 to 0.96 specific gravity. Tanks of 150-200 liters were used to separate the different polymers in water and hydroalcoholic solutions by the difference of density between the probable polymer components - LDPE, HDPE and PP at room temperature (26 - 31°C). The density was controlled to 0.91 and 0.94 by densimeters. Figure 2 shows the scheme of separation of plastic waste based on density. The expected polymer is indicated between quotation marks - "LDPE", "HDPE", "PP". The fractionated waste samples were subdivided by visual inspection and the main components of each fraction were identified mostly by thermal analysis in a Perkin Elmer, model DSC-2 calorimeter [5].

CAPTION:

PW = plastic waste
S1 = water (d=1.00)
S2 = hydroalcoholic solution (d=0.94)
S3 = hydroalcoholic solution (d=0.91)

Figure 2. Separation of different types of polyolefins basedon density [5]

The dry polyolefin fraction was agglutinated to increase the apparent density of the fragments then extruded in an industrial Matteo Unia single-screw extruder, with L/D = 26 and screw diameter 80 mm, at 140/150/160/170/180°C. The composition of the fraction was based on DSC data of known LDPE and HDPE samples [5,20]. Ring-and-ball test was run according to ASTM E28-67 with some modifications [20]; samples were cut from 0.1 x 15.0 x 15.0 cm plates, molded in a Carver press at 190°C and 10 kg/cm^2, for 5 minutes. Melt flow index (MFI) tests were performed in a Tinus Olsen equipment according to ASTM D1238, procedure A, condition E (190°C/ 2,16 kg).

Test samples from air dried lumber of three species - parana-pine (Araucaria angustifolia), cedar (Cedrella fissilis) and peroba (Sweetia elegans) - and from

IMAWOOD® extruded bars were prepared according to ABNT NBR 6230 method [1]. A Brabender equipment, model PVL 151, with L/D=25 and screw diameter 19 mm, was used. Table 1 shows the dimensions and number of specimens for each test.

RESULTS AND DISCUSSION

The flexible plastic waste was highly contaminated. The industrial grinding, washing and drying was out of our control. Assuming that the calculated total loss is acceptable, we found about 60% loss in weight.

The separation of the fragments by density in water resulted in two fractions: an upper layer, representing 98%, 1.5% ash content, and a lower layer, about 1%, with high inorganic contaminations, 38% ash content, due to the presence of sand and soil particles which deposited in the tank during the process. The loss in the process was approximately 1% [5].

In order to check the composition of the three polyolefin fractions as concluded by the sink-float procedure, sub-samples were selected by visual inspection, and identified by DSC. The histogram in Figure 3 indicates diversification of components present in the mixture: LDPE-type polymers, with melting temperature around 109°C, and HDPE-type polymers, with melting temperature around 125°C, with irrelevant contamination of PP-type polymers.

The segregation of individual polymer plastics by the sink-float process was not satisfactory under the experimental conditions. The fractions expected to be composed of "HDPE", "PP" and "LDPE" were in fact a mixture of mostly LDPE and HDPE. It was concluded that the polyolefin mixture should be used without further segregation, for specific applications. The presence of air entrapped in film folds and greases reduces irregularly the density of the flakes, misleading the results [4,9].

Table 1. Dimensions and number of specimens of natural wood and IMAWOOD® according to ABNT NBR 6230 method [1]

Test	Specimen		
	Dimension (cm)	Number	
		Lumber	IMAWOOD®
Specific gravity [a]	2.0 x 2.0 x 3.0	40	10
Compression (parallel to grain) [b,e]	2.0 x 2.0 x 3.0	40	10
Static bending [b,f]	2.0 x 2.0 x 30.0	40	10
Impact bending [c,g]	2.0 x 2.0 x 30.0	24	6
Tension (perpendicular to grain) [b,h]	2.0 x 2.0 x 4.5 [d]	48	12
Cleavage [b,i]	2.0 x 2.0 x 4.5 [d]	40	10

[a] Breuil-volumenometer; [b] Amsler Universal Machine; [c] Charpy machine; [d] Test samples with special shape; [e] responding to ASTM 143 (lumber maximum crushing strength) and ASTM D695 (plastics compressive strength at failure); [f] Corresponding to ASTM 143 (lumber modulus at rupture) and ASTM D790 (plastics flexural strength); [g] NBR 6230 (work to maximum load at rupture), corresponding to ASTM D143 (lumber height of drop for complete failure) and ASTM D256 (plastics impact strength); [h] Corresponding to ASTM 143 (lumber maximum tensile strength) and ASTM D638 (plastics tensile strength at break); [i] Corresponding to ASTM 143 (lumber cleavage maximum load); there is no corresponding ASTM method for plastics.
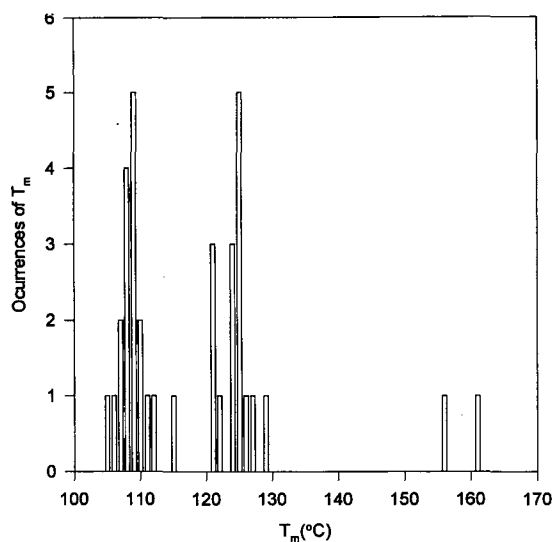
Figure 3. Diversification of olefin-type polymers in the flexible plastic waste material [5]

The polyolefin fraction was agglutinated on appropriate industrial equipments, extruded and evaluated. The extrusion temperature on the matrix - 110°C - is related to the first softening temperature of the polymer melt; for low and high density polyethylenes, it is about 50°C higher [20]. It resulted on gray, smooth and homogeneous filament, assuring the validity of the proposed method. The addition of 0,5% of an orange pigment resulted in a chestnut color, which could be expected for a wood-like recycled plastic material.

The percentual composition of the fraction was determined by the areas under calorimetric curves in comparison to known LDPE/HDPE mixtures [23,24]. The cristallinity of polyethylene mixtures increases the melting temperature and the area under the calorimetric curve [25]. Under 20% the presence of LDPE is not detected by the curves [24]. The application of this method for LDPE/HDPE 75/25, 50/50 and 25/75 mixtures was not satisfactory [20]. However, based on DSC data, we estimate that the polyolefin fraction under investigation contains about 75% LDPE (Table 2).

The material exhibited melt flow index of 0,6 g/10 min, which is a low value as compared to virgin LDPE used for films - 2 to 3 [26]. The recycled plastics may have been exposed to natural environmental degradation, envolving macromolecular chain cleavage, by radical mechanism, probably with oxidation to some extent and crosslinking. The final result is an increase in molecular weight and the consequent decrease in the melt flow index.

Table 3 presents the results of the analysis performed on the natural/synthetic materials. The heterogeneity of the natural material is taken into consideration; the 25% highest values were considered for the median.

Table 2. DSC analysis of polyolefin mixtures [5,20]

Sample	DSC* Thermogram	T_m (°C)
LDPE 100		106
LDPE/HDPE 75/25		104,126
LDPE/HDPE 50/50		106,125
LDPE/HDPE 25/75		131
HDPE 100		129
Recycled polyolefin fraction		105,122

* Differential scanning calorimeter, Perkin Elmer DSC-2; second heating; temperature range, 50 to 150°C ;energy variation, mcal/s; endothermic; typical curves; two calorimetric curves taken for each sample.

The recycled product has higher moisture content than the natural products; this is due to residues not completely removed by the preliminary washing treatment of the plastic waste. The ash content of the recycled product is within the values presented by the different lumber samples. The specific gravity of several natural woods is smaller than plastic wood, due to the porous texture resulting from the aggregation form of cellulosic fibers. The synthetic materials, however, have a more compact texture, despite of the moisture content which may cause interstices within the molded article. Concerning compression (parallel to grain),

Table 3 - Physical and mechanical tests of natural woods and IMAWOOD®

Test	Natural wood			IMAWOOD®
	Cedar	Parana-pine	Peroba	
Moisture (%)	0,5	0,2	0,2	0,6
Ash (%)	0,6	0,2	2,0	1,9
Specific gravity (g/cm^3)	0,6	0,6	0,8	0,9
Compression (parallel to Grain) (kg/cm^2)	433,0	485,0	505,0	17,0
Static bending (kg/cm^2)	715,0	825,0	1268,0	**
Impact bending (kg.m)	1,9	2,5	2,9	4,0
Tension (perpendicular to grain) (kg/cm^2)	9,0	11,0	21,0	17,0
Cleavage (kg/cm^2)	0,5	0,5	10,0	6,8***

* For lumber only, the 25% highest values were taken for the median[4]. ** Specimens did not break. ***some specimens did not break completely

IMAWOOD® exhibits much lower resistance than lumber, while impact resistance, or impact bending test, which represents an important characteristic for the service performance, shows for the plastic wood about the same resistance found in the natural material. Concerning static bending, it should be pointed out that IMAWOOD® samples did not break under tests conditions; on the other hand, among the studied woods, peroba shows the higher values. IMAWOOD® exhibits intermediate tensile strength when compared to lumber - less resistant than peroba and more resistant than cedar and parana-pine. The same was observed in cleavage test.

From the above, it can be concluded that, at the present development stage, IMAWOOD® may be used as a substitute for natural wood in several goods exposed to tension perpendicular to grain, cleavage and impact bending conditions. However, IMAWOOD® is less resistant to compression forces than natural woods; this problem may be overcome by proper formulation of recycled polyolefin products through the incorporation of low cost mineral fillers. Work proceeds on this line in this laboratory.

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Resumo

O material denominado IMAWOOD®, desenvolvido no Instituto de Macromoléculas como uma fração dos resíduos plásticos urbanos, é composto de uma mistura de polímeros parcialmente degradados, principalmente polietileno de baixa densidade. Suas características possibilitam sua utilização como "madeira plástica". Este trabalho apresenta um estudo comparativo entre alguns tipos de madeiras comerciais brasileiras e o produto reciclado IMAWOOD®, utilizando-se para caracterização método comumente adotado para madeiras.