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Eco-friendly polymeric material for horticulture application

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Abstract

Poly(lactic acid) (PLA), was mixed with wood fibers, coffee grounds, fertilizer and a foaming agent to developed a eco-friendly material to be used in horticulture. The developed materials should have mechanical properties similar to PLA, increasing biodegradability and lower price. The materials were prepared by melt processing in an internal mixer at 190ºC and were characterized by several techniques. The mechanical properties of the bio-composites, measured by flexural tests, were similar to neat PLA even with a reduction of 40 wt. % of polymer. Biodegradation assessment by composting tests in aerobic environment demonstrated that the green materials developed exhibited higher biodegradability than PLA.
Bio-composites containing wood fibers and fertilizer revealed to be the most suitable for horticulture application, since these can combine mechanical properties, biodegradability and fertilizer release. Moreover, this green material has two main advantages, it can be prepared using materials from natural resources and does not generate any residue after use.

Keywords: Poly(lactic acid), biodegradation, agriculture, wood fibers, coffee grounds, foaming agent.

1 INTRODUCTION

In horticulture industry the disposal of plastic containers used in greenhouses and nursery crops represents a sensible issue[1]. Generally not reusable, plastic containers are disposal when plants are introduced into the ground.
Aiming to overcome waste production, numerous attempts have been made to develop biodegradable materials that can be buried directly into the soil. Peat, paper and coir fiber are the most common non-plastic materials used to prepare biodegradable containers [2]. However, according to Evans and Hensley [1], these containers are more expensive than the plastic ones and can easily break or tear when wet. To overcome these disadvantages, horticulture industry started to study other biodegradable and compostable biopolymers derived from raw materials, such as, starch (corn, rice hulls, wheat, among others), cellulose, soy protein, and lactic acid [3]. Nonetheless, when compared to conventional polymers, biopolymers have some drawbacks, such as, poor mechanical and barrier properties, processability and thermal stability, which limits its industrial application. Recently, bio-composites, have been prove to be a promising option to improve the properties of biopolymers [4]. Therefore, environmental-friendly materials open a wide range of applications for biodegradable polymers, with potential perspectives for horticulture [5].
Herein, poly(lactic acid) (PLA), used as matrix, was mixed with different amounts of wood fibers, coffee grounds, foaming agent and fertilizer. The obtained bio-composites were characterized by mechanical tests and their biodegradability was assessed in aerobic environment in compost. Gel permeation chromatography (GPC) was performed before and after biodegradation in order to assess changes in PLA molecular weight.

2 MATERIALS AND METHODS

2.1. Materials

The commercial PLA grade (3251D) was acquired by NatureWorks LLC (USA). Coffee ground and wood fibers were dried and used without further treatment. Inorganic fertilizer, *Nitrolusal 20.5* composed by 12, 12, 17, 2 % of N, P_2O_5, K_2O and of MgO, respectively, was supplied by ADP Fertilizantes and used as a powder. The foaming agent, azodicarbonamide, powder, was used as received and was provided by Acros Organics.

2.2. Sample preparation

PLA, coffee ground, wood fibers and fertilizer were were prepared by melt mixing at 190 °C, in a Haake batch mixer (Rheocord 90; volume 60 cm^3. The following procedure was adopted to prepare the different materials, a specific amount of PLA was introduced into the hot mixer, and after melting, the respective additives were added in order to obtain the compositions presented in Table 1. The total sample was removed after 10 minutes of mixing.

PLA was also processed under the same conditions and was called sample A.

Sample E, resulted from the crushed sample removed from the internal mixer blended with a foaming agent and placed in a hot press at 190 ºC.

For all the previous prepared compositions, rectangular specimen samples for mechanical and biodegradation characterization were prepared in a hot press at 190 ºC under 20 ton for 15 min.

Table 1. Sample Compositions (%).

Sample	PLA	Coffee	Wood	Fertilizer	Expander
A	100	0	0	0	0
B	90	0	0	10	0
C	60	30	0	10	0
D	60	0	30	10	0
E	60	0	30	8	2

2.3. Characterization

2.3.1 Density of the PLA and prepared materials were measured using the Archimedes impulsion method for solids, as for the ASTM D 782-00 standard. The immersion liquids were isopropanol and water.

2.3.2 Gel permeation chromatograph was used to assess the molecular weight of the prepared compositions as collected from the mixer (with exception of sample E) and after composting. Solutions were prepared in THF (99.9%) and prefiltered on filter plate before injection.

2.3.3 Mechanical properties of processed PLA and bio-composites were measured using an Instron 4505. The flexion experiments were performed according to ASTM D 790-03, with a deformation rate of 2 mm/min at room temperature under a relative humidity of 45 %. The samples tested have a length of 5 cm, width of 2.5 cm, and a thickness of 0.1 cm. A minimum of five specimens was tested for each material.

2.4 Biodegradability

Biodegradation in compost was performed at 40 °C using compression molded (25 x 25 x 0.125 mm) samples. Samples were placed in a composting medium made of soil, activated sludges from waste water treatment, straw and animal manure. The composting medium was kept in a relative humidity of approximately 50 – 70 %. Around 20 samples of each material were vertically buried at 6 – 8 cm depth to guarantee aerobic degradation conditions at a horizontal distance of 5 – 6 cm between samples according to Fukushima[6]. Based on the sample weight before and after composting, the average percentage of residual mass for each material was calculated.

3 RESULTS AND DISCUSSION

The density values of all the bio-composites prepared are presented in Table 2. As expected, with the exception of the bio-composite prepared with a foaming agent, which has a cellular structure, all bio-composites exhibited higher density than PLA.

Table 2. Sample Compositions (%).

Sample	A	B	C	D	E
Density	1.24 ± 0.02	1.30 ± 0.02	1.32 ± 0.01	1.34 ± 0.01	0.88 ± 0.03

As expected, with the exception of the bio-composite prepared with a foaming agent, which has a cellular structure, all bio-composites exhibited higher density than PLA.

Molecular weight distribution results in GPC showed that all bio-composites prepared exhibit a shift to the higher retention time, which can be associated to pronounced decrease in molecular weight due to chain scission. A similar molecular weight decreased was observed with coffee ground and wood fibers. This can be associated to a small amount of residual moisture containing in both compounds, which triggered the PLA chain scission through hydrolysis at the high processing temperature.

The relative flexural properties of PLA and bio-composites are shown in Figure 3. The addition of other particles to PLA has a slightly influence on its modulus and strength flexural properties. Sample B has a slightly higher modulus and strength than PLA. Conversely, samples C and D present a small decrease of PLA mechanical properties. Between these two composites, and taking into account the error associated with the measurements, sample D exhibits properties quite similar to PLA. Green composite containing foaming agent is too brittle, it breaks almost immediately when the force is applied. For this reason its flexural properties are not present in **Error! Reference source not found.**.

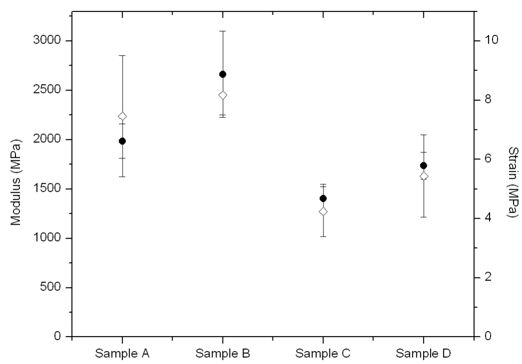

Figure 1. Flexural properties of PLA and prepared bio-composites.

Error! Reference source not found. depicts PLA loss weight profiles of the developed materials along composting times. The presence of wood fibers and foaming agent (samples D and E) enhances the PLA degradation and consequently these exhibited higher weigh lost. Furthermore, the cellular structure created by the foaming agent accelerated the moisture diffusion through the samples. In contrast PLA with fertilizer and ground coffee (samples B and C) exhibit a slower degradation rate. PLA (sample A) weight loss was not very significant along the composting time period.

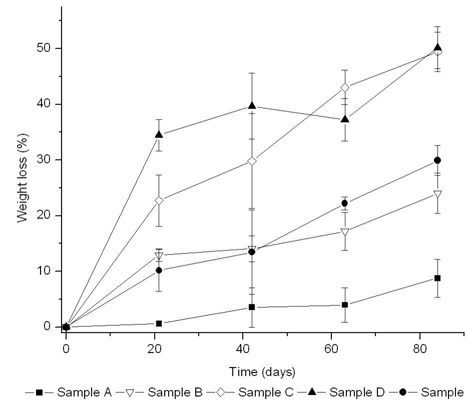

Figure 2. Composting of processed PLA and bio-composites.

PLA and bio-composites after compost were analysed by GPC. Results revealed that the unimodal initial distribution, after composting, became bi- in the case of sample B, D and E, indicating the presence of different types of molecules with lower molecular weight, where sample D and E presented higher molecular weight reduction.

4 CONCLUSIONS

Bio-composites with wood fibers and fertilizer presented to be the more suitable to be used as green biodegradable materials for horticulture, with good mechanical properties, high biodegradability and able to release fertilizer.

Moreover, this green material has two main advantages, it can be prepared using materials from natural resources and does not generate any residue after use.

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