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Biodegradability Evaluation of Polylactic Acid Composite with Natural Fiber (Sisal)

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Abstract**—**Due to increasing environmental pressure for biodegradable products, especially in polymeric materials, in order to meet the demands of the biological cycles of the circular economy, new materials have been developed as a sustainability strategy. This study proposes a composite material developed from the biodegradable polymer PLA Ecovio® (polylactic acid - PLA) with natural sisal fibers, where the soybean ester was used as a plasticizer, which can aid in adhesion between the materials and fibers, making the most attractive final composite from an environmental point of view. The composites were obtained by extrusion. The materials tests were produced and submitted to biodegradation tests. Through the biodegradation tests, it can be seen that the biodegradable polymer composition with 5% sisal fiber presented about 12.4% more biodegradability compared to the polymer without fiber addition. It has also been found that the plasticizer was not a compatible with fibers and the polymer. Finally, fibers help to anticipate the decomposition process of the material when subjected to conditions of a landfill. Therefore, its intrinsic properties are not affected during its use, only the biodegradation process begins after its exposure to landfill conditions.

Keywords**—**Biocomposites, sisal, polylactic acid, PLA.

I. Introduction

DUE to the environmental concern and limitations of the world's oil sources, there is increasing interest in alternatives that substitute materials from fossil sources. These materials, although representing a great economic advantage, being produced in large scale, have reduced prices and great versatility of use and durability, are very environmentally harmful in the decomposition cycle, and the quantity of rejects generated. The alternative to this pollution and the materials restriction was the polymers recycling, the other option was the use of polymers, which have a short time of biodegradation, compared with the polymers produced from fossil fuel. This kind of polymer is a biopolymer, which is made from renewable fonts, such as a PLA, which is one of the biopolymers produced wordwide with corn.

To change the conventional polymers with wide degradation time and decrease the scrap that go to landfill, there is the opportunity to introduce some biopolymers that can have their degradation time reduced by 10 times [1].

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Currently, polymers produced from oil and natural sources are rarely used in a pure way, because this limits their application due to intrinsic mechanical properties [2]. To solve this problem minerals and fiber reinforcements can be used. These fibers can be in particles or laminate form and they are used to improve some mechanical properties without changing the materials weight [3]. They can be synthetic fibers, such as fiberglass, or natural fibers like sisal. The natural fiber advantage is the low density, low cost, high specific strength and modulus, no health risk, better adhesion with particles or laminated in to matrix, and the fact that it can be used to reinforce thermoplastics, thermosets, gums and cements [4], [5]. Therefore, they can be sustainable to contribute in a scrap reduction and landfill disposal, because of the biodegradability and low ash production when incinerated. Another positive aspect is the compatibility with natural polymers matrix, because they are less abrasive to production equipment when compared with fiberglass [2]. An example of natural fiber is sisal, which is a monocotyledon native to Mexico, with long narrow leaves. The fiber concentration ranges from 3-5% of the total weight of the sheets. The remaining percentage is for so-called processing residues, which are used as organic fertilizer, animal feed and the pharmaceutical industry [6]. To obtain this fiber, the sisal leaves are cut, collected and transported to a specific place, where they will be processed to defibrillate the leaf. Next they are cleaned and put in to the solar exposure to dry the leaves. And later, they are classified and stored [7].

A study compared neat PLA with the addition of sisal and identified the mass decrease with the fiber increase. It is almost 15%, 24% and 32% of mass lost with PLA and 10%, 20% and 30% of fiber, respectively [8].

Another study with hybrid composites like banana and sisal fiber randomly oriented reinforced polymer composite has been investigated. It is found that 50% of the sisal fiber composite has high flexural property compared to other types of composites with glass, carbon and Kevlar fiber. But the results are not satisfactory with hybrid composites, because it decreases the stiffness of the material. Furthermore, 50 wt% composite was treated with sodium hydroxide. The result shows that chemical treatment increases the modulus of the material as well as the stiffness of the composite [9].

The chemical treatment of natural fiber studied by Barreto et al. showed improvement in composites mechanical and thermal properties. The sisal fibers were treated to alkali solutions of NaOH (5% and 10%) and sodium hyplochlorite $NaClO/H_2O$ (1:1) at 60–75°C. The thermal stability for sisal

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treated with NaOH 5% in about 12°C and for sisal treated with NaOH 10% in about 18°C when compared to sisal fiber in its raw state [10].

II. Materials and Methods

All materials used in this paper were donated. They were natural fibers; biopolymer and plasticizer.

The biopolymer used in a composite production was the Ecovio® F2223/4 (polymer that has the same properties of conventional polyetilene from fossil fuel). It has PLA in composition, obtained through starch fermentation. It has 75 wt% of renewable fonts in its composition; it is totally biodegradable in land fill conditions. Its physical properties are: density 0.8-1.7 g/cm^3 and apolar character [11].

The plasticizer used in this paper was soybean ester (Resinflex) that is also produced by renewable materials [12].

The composites formulation was presented in Table 1.

TABLE I
COMPOSITES MATERIALS COMPOSITION

Name sample	Materials composition (wt%)		
	Ecovio ®	Resiflex	Sisal
S1	100	0	0
S2	97	3	0
S3	95	0	5
S4	92	3	5
S5	90	0	10
S6	87	3	10

To prepare the samples, a mill with a cyclone rotor was used to cut the fibers. The cut fiber is presented in Fig. 1.

Fig. 1 Cut sisal fiber

The fibers were cut into small particles and the composite materials compositions were put in the extruder, following an order to S1; S2, and so on until S6, described in Table I.

After each sample extruded, the pure biopolymer was used in the extruder to avoid samples contamination.

The extruder operated at 160ºC to achieve the polymer melting point without fiber degradation. The material were extruded in a ribbon form, and then cut in a mill to produce samples using a hot mechanical press.

The mechanical press works at 160ºC for 15 minutes and another 15 minutes to cool the samples, shown in Fig. 2.

The samples were submitted to mass loss controlled biodegradation test.

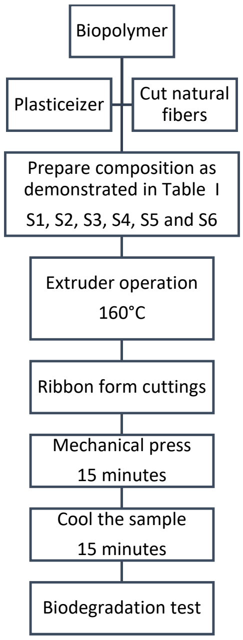

Fig. 2 Process to prepare the composites sample

With the samples, it was possible to prepare the biodegradation test.

A. Biodegradation Test

The samples were buried in a pot containing soil fertilized. The parameter process was controlled by soil relative humidity, time and sample mass loss. The system was moisturized twice per week with 300 mL of water. The humidity test was done with a laboratory muffle furnace. The biodegradation test is shown in Fig. 3.

Fig. 3 Biodegradation test

To calculate the humidity, the soil was collected and placed in a laboratory muffle furnace for about 24 h at around 105 ºC +/- 2°C. The soil samples were weighed before and after laboratory muffle, as calculated in (1).

$$h = ((Wb - Wa)/ Wa). 100 \qquad (1)$$

where "h" is the soil relative humidity; "Wb" the soil weight before muffle; and "Wa" the soil weight after muffle. This equation has multiplication by 100 times, to represent the value in percentage.

The initial and final weights from the composite samples were calculated after nine weeks, which represented the biodegradation test. Some samples were observed in a scanning electron microscope (SEM).

III. Results and Discussion

The average soil relative humidity value calculated week by week was 22.7% +/- 1.72% that indicated the conditions to initiate the degradation test.

The loss mass values of the composite samples were presented in Table II.

TABLE II
LOSS MASS VALUE OF COMPOSITES SAMPLE

Sample	Materials composition (wt%)			wt% loss mass
	Ecovio ®	Resiflex	Sisal	
S1	100	0	0	0.3
S2	97	3	0	1.5
S3	95	0	5	12.4
S4	92	3	5	0
S5	90	0	10	0
S6	87	3	10	0

After the biodegradation test the sample that has only biopolymer in the composition did not show signs of degradation at nine weeks, once no mass loss was observed. The same result was found by STASCHOWER (2009) [13]. This corroborates with the manufacturer's specifications indicating that this biopolymer has almost 12 years for degradation [11].

No loss mass was identified for samples S4, S5, and S6. However, S6 sample surface has changed, inicialy the sample had smooth surface and after test it showed a porous surface.

The micrographs of S5 (biopolymer with natural fiber); S4 (biopolymer, plasticizer with natural fiber) and S3 (biopolymer with natural fiber) were presented in Fig. 4. As it can be observed, the natural fiber had good adhesion in the biopolymer, as well as homogeneous surface.

Apparently the plasticizer did not aid in neither degradability nor fiber adhesion on the PLA.

Even though the S3 sample showed the largest degradation of samples, it wasn't possible to conclude that this was due to the presence of the natural fiber, since the S5 sample did not showed compatible results.

IV. Conclusion

Through this study it was possible to identify that the composition with 5% natural fibers has more biodegradability than other composites samples tested.

Composite with nature fibers seams to enable the biodegradation process. Probably because this material can initiate the degradation process itself.

The plasticizer used does not have a good influence in the biodegradation process.

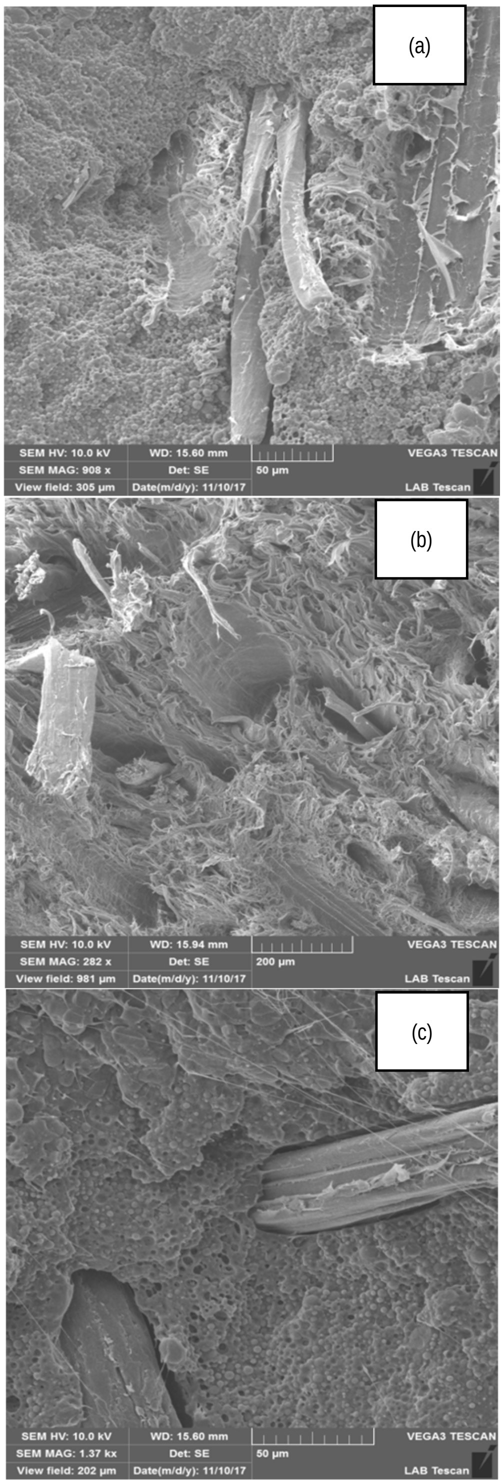

Fig. 4 (a) biopolymer with natural fiber, (b) biopolymer, plasticizer with natural fiber, (c) Biopolymer natural fiber

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