PULLOUT BEHAVIOUR OF CHAMBIRA FIBER (COLOMBIAN NATURAL FIBER) EMBEDDED IN POLYLACTIC ACID (PLA) MATRIX

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1 Introduction

The interest in the development of composite materials based on renewable resources, such as natural fibers, has increased over the last years [1]. In fact, the depletion of petroleum resources coupled with increasing environmental legislations are forcing industries to seek new materials and end-products that are both compatible with the environment, and independent of fossil fuels.

Natural fibers have been used to reinforce thermoplastics due to many advantages, such as: low cost, low density, acceptable specific strength, good thermal insulation properties, biodegradability, and renewability [2-3]. Among natural fibers, Chambira fiber (Colombian natural fiber) has competitive mechanical properties and low density.

Polylactic acid (PLA) has a special interest as a matrix in natural fiber composites. It is a biodegradable thermoplastic with good mechanical properties that are similar to those of polystyrene; also, it can be processed with standard equipment at temperatures below those at which natural fibers start to degrade [4-5].

In order to produce high performance natural fibres composites, it is important to understand their interfacial properties. A number of experimental techniques have been devised to characterize the interface properties, including fiber pull out tests, fiber push-out test, microbond test and fiber fragmentation tests [6]. Among these, pull out test is considered the most direct and reliable method [7]. In this test, a fiber is partially embedded in a matrix block or thin disc of various shapes and sizes. Then, the fiber is loaded under tension while the matrix block is gripped. The external force applied to the fiber is recorded as a function of time or fiber end displacement during the whole debond and pull-out process [8].

The characterization of the failure mechanism for synthetic fibers embedded in polymeric matrix have been studied by several authors [9-10]. Nevertheless, few investigations have been done on the adhesion between natural fiber surface and a biodegradable matrix. The characterization of this interphase phenomenon is a very challenging problem.

The aim of this work is to measure interfacial shear strength (IFSS) of a Chambira fiber bundle embedded in Polylactic acid (PLA) matrix by pullout test. The maximum embedded length of fiber bundle permitted for pull-out without being broken and fiber–matrix interfacial shear strength were determined. The (IFSS) was calculated using both relationships: the apparent diameter and the perimeter of the fiber cross section. Also, two parameter Weibull distribution was used for the statistical analysis of experimental data.

2 Experimentation

2.1 Materials

PLA Ingeo Biopolymer 2003D was provided by Nature Works LLC; the mechanical properties of the hot press molded material are shown in Table 1: E: tensile modulus, σ: tensile strength and ε: percentage of tensile elongation, these properties were determined following the ASTM standard D-638 using an Instron 3367 tensile testing machine.

The Chambira fiber bundles were provided by the Humboldt Institute of Colombia. Taking into account that the mechanical properties of the fiber are affected by the variability of the plant, tensile properties were determined following the ASTM standard C1557 using an Instron Universal Testing Machine Model 3367. The cross head speed used was 100 mm/min with gauge length of 100 mm. As the use of an extensometer is difficult on such thin specimens, the elongation of the fiber was determined through the displacement of the testing machine cross head. Twenty specimens were tested and two parameter Weibull distribution was used for the statistical analysis of experimental data [11], these results are shown in Table 2.

2.2 Specimen Preparation for Pull-out Test

The pull-out specimens were made using the following procedure:

The PLA granulate was dried for 2 hours at 90°C to reduce their moisture content and it was converted into a sheet of approximately 0.35 mm in thickness using a Brabender Plasticorder 331 single-screw extruder. Extruder temperatures were set at 443 K (zone 1), 453 K (zone 2), 463 K (zone 3) and 473 K (die).

The PLA sheet was cut in rectangles of 2.5 x 7.5 cm and Chambira fibers bundles were cut in fragments with a length of 70 cm. The samples were prepared by placing the Chambira fiber bundle between four PLA sheets (two at the bottom and two at the top) and hot pressing in a conventional molding press (Dake Press, model 44-251) at a temperature of 160°C ± 3°C for 4 min with a minimum pressure of 1.8 bar. The fiber was kept straight and oriented by fixing it both ends using high temperature adhesive tape. Samples were left cooling to room temperature. Then, they were cut by half obtaining two specimens from each molding. The desired fiber length embedded in the matrix was obtained by cutting the fiber punching a hole through the sample as shown in Fig. 1.

2.3 Pull-Out Test

Pull-out tests were carried out in an Instron tensile testing machine (model 3367), at controlled temperature (23°C±2°C) and relative humidity (50%±5%), with a constant cross-head speed of 2 mm/min obtaining the load-displacement curves. A two parameter Weibull distribution was used for the statistical analysis of experimental data.

The interfacial shear strength (IFSS) was calculated using both the apparent diameter and the perimeter of the fiber cross section. Equation 1 was used to determine the IFSS using the apparent diameter:

$$\tau = \frac{F_f}{\pi d l} \qquad (1)$$

where F_f is the maximum tensile load at the debonding point, d is the diameter of the Chambira fiber, and l is the fiber embedded length.

Equation 2 was used to calculated the IFSS using the perimeter instead of the diameter:

$$\tau = \frac{F_f}{P l} \qquad (2)$$

where P is the measured perimeter of the Chambira fiber.

3 Results

The maximum embedded length of fiber L_{max} permitted for pull-out without being broken is usually very short, which causes experimental difficulties. For Chambira fiber the maximum embedded length was approximately 7 ± 0.67 mm. Therefore, the embedded fiber length used was 6.29 ± 0.786 mm. Also, it was found that the apparent diameter was 1.23 ± 0.27 mm and the perimeter of the cross section fiber bundle was 3.79 ± 1.09 mm.

The typical load-displacement curve for Chambira fiber bundle embedded in PLA matrix obtain from the pull-out test is shown in the Fig. 2. The interface debond process is identified as partially stable in the literature [8]. Four stages of fiber pull out process were observed: first, the stress increase until debonds initiates (A). Second, the debond crack propagates in a macroscopically stable manner, represented by the “stick – slips” in the rising curve (B), then a maximum debond stress is reaches (C); followed by an initial frictional pull-out stress after complete debonding (unstable debonding) (D).

The experimental fiber interfacial shear strength distribution yielded by pull-out test is shown in Weibull coordinates in Fig. 3. The Weibull distribution parameters were determined by the maximum likelihood estimation (MLE). The shape parameter and the scale parameter values for both the apparent diameter and the perimeter of the fiber cross section are summarized in the Table 3. It can be seen that the two parameter Weibull distribution approximates the experimental data reasonably well. Deviations from Weibull distribution can be explained for the damage done to the fiber during the specimen preparation process.

The IFSS calculated by both perimeter and apparent diameter method are similar: 1.19 MPa and 1.17 MPa, respectively. Nevertheless, from photo - micrographs of Chambira cross-section, it was observed that they are not circular (Fig. 4). Therefore, this result suggests that the perimeter could be a better parameter for calculation of the interfacial shear strength.

4 Conclusions

The interfacial shear strength (IFSS) between Chambira natural fibers and PLA biodegradable matrix was determined using both apparent fiber diameter and natural fiber perimeter relationships. It was found that the later relationship presented better results, due the cross-section of the natural fibers can not be considered as circular. Also, the interfacial shear strength fit well the two-parameter Weibull distribution.

The curve load – displacement exhibited four stage interface debond process: A) initial debond stress, B) partial debond stress, C) maximum debond stress and D) initial frictional pull out stress after complete debonding., this debond process was identified as partially stable.

	E	σ	ε
A	53	3.5	6
B	58.06 ±1.12	3.16 ±0.12	5.79 ±0.52

Table 1. Mechanical properties for the PLA. A: Technical Data Sheet, B: Molded PLA.

	E	σ	ε
β	9.65	9.84	10.19
α (MPa)	2678.94	438.64	15.70
m (MPa)	2544.69	417.02	14.95
SD (MPa)	316.70	50.94	1.77

Table 2. Parameters of Weibull distribution functions for the mechanical properties of the Chambira fiber bundle. β: shape parameter, α: scale parameter, m: mean, SD: standard deviation.

Weibull Distribution	Perimeter	Apparent Diameter
β	1.96	1.90
α (MPa)	1.19	1.17
m (MPa)	1.05	1.04
SD (MPa)	0.56	0.57
N	21	21

Table 3. Weibull distribution parameters for IFSS of Chambira fiber bundle. β: shape parameter, α: scale parameter, m: mean, SD: standard deviation, N: number of specimens.

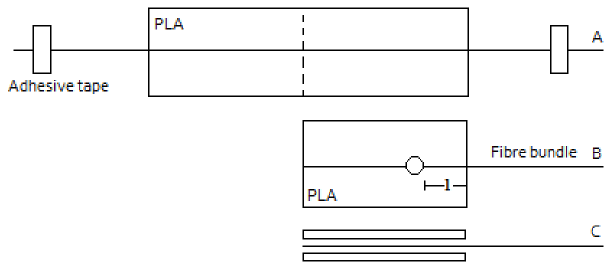


Fig. 1. Schematic of pullout specimen. A. Specimen after hot pressing B. Top view of the final specimen. B. Front view of the final specimen. l: desire fiber embedded length.

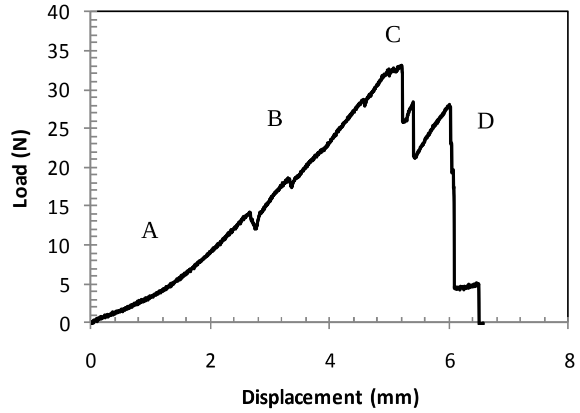
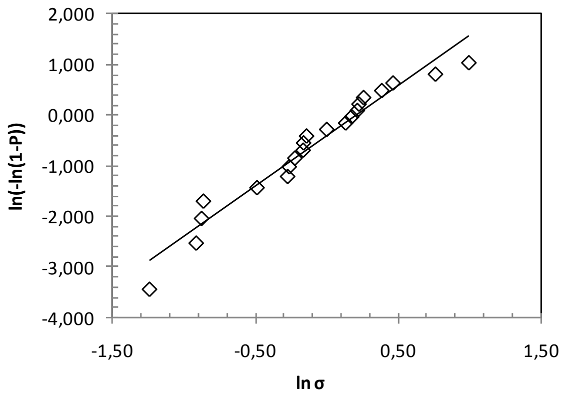


Fig. 2 Load versus displacement curve for the Chambira fibers embedded in PLA. A) Initial debond stress, B) partial debond stress, C) maximum debond stress and D) initial frictional pull out stress after complete debonding.

(A)



(B)

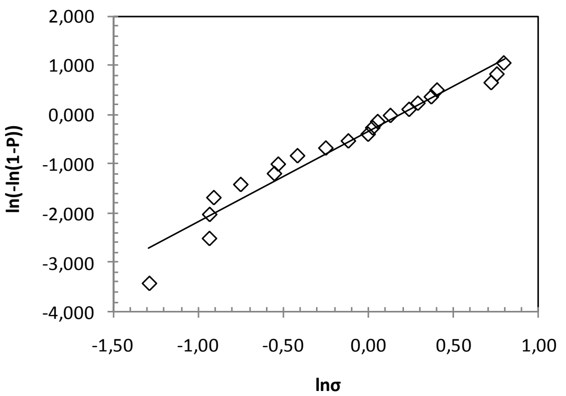


Fig. 3. Interfacial shear strength (IFSS) distribution for Chambira fibers and PLA matrix. (A) Perimeter and (B) Apparent diameter.

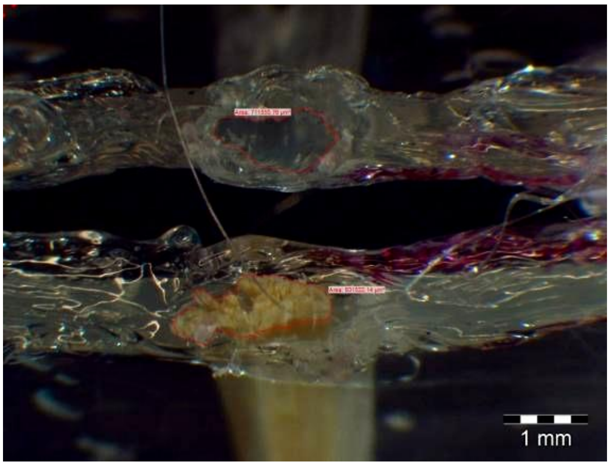


Fig. 4. Chambira bundles cross-section of the pulled-out fiber

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