ECO FRIENDLY CORE SANDWICH PANEL REINFORCED WITH MANICARIA FIBER AND PLA MATRIX

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Abstract
This paper presents the development and mechanical characterization of a core sandwich panel fabricated from both renewable resources, and biodegradable materials: Manicaria fiber (Manicaria Saccifera) as reinforcement and Polylactic Acid (PLA) as resin matrix. The potential of the Manicaria/PLA core sandwich panel for structural application was evaluated by subjecting the core to compressive loads according to the ASTM C365 standard. It was found that the average compressive strength and elastic modulus of the Manicaria/PLA sandwich core were 2.85 (±0.17) MPa and 32.68 (±3.68) MPa, respectively. In contrast, the mechanical properties of un-reinforced sandwich core were 1.28 (±0.45) MPa and 12.49 (±4.7) MPa, respectively. These results indicates that the mechanical properties of Manicaria fiber reinforced cores increased to more than twice of those of the unreinforced ones.

1 Introduction
In recent decades, light weight sandwich composite materials are being used more frequently in the aeronautic and aerospace industries, marine and transport applications, due to some of their advantages such as high bending stiffness to weight ratio, good acoustic and thermal insulation, high energy absorption capability, and very good corrosion resistance [1-3].
In general, a structural sandwich consists of three distinctive parts: two thin face sheets, commonly called skin faces, bonded to a relative thick core material with low density. Currently, the most common skin faces consists of metal sheets or synthetic composite material laminates. Typical core materials are honeycombs or expanded synthetic polymer foams cores [4, 5]. Although these type of sandwich panels display high strength to weight ratio, at the end of their service life they generate environmental inconveniences, due to their non-recyclables character.
To overcome this, in the last decade few researchers have used low cost petroleum-based recyclable thermoplastics reinforced with natural fibers to manufacture cores for sandwich panels [6]. One of the most important studies were developed by Rao, S., K. Jayaraman, and D. Bhattacharyya [7]. They fabricated recyclable honeycomb cores using polypropylene (PP) reinforced with short sisal fibers; a relative new concept of hollow cores made from natural fiber composites. They reported that the specific mechanical property values of the reinforced honeycombs after reinforcing the cell walls were more than twice of those of the un-reinforced cores. Moreover, they suggested recyclable sisal–PP sandwich panels suitable in automobile, aerospace, packaging and building - construction industries. Therefore, the

development of core sandwich panels fabricated from both renewable resources, and biodegradable materials is subject of great interest for ecological and engineering perspective.
Approximately 140 million ton per year of petroleum based synthetic polymers are produced worldwide and noteworthy amounts of these polymers are incorporated in the environment as industrial waste products. Nevertheless, greater efforts have been made in developing degradable biological materials without any environmental pollution to replace oil-based traditional plastics, and the bio-plastic market is growing by 20–30% each year. In fact, industries are developing new materials and products that are both compatible with the environment, and independent of fossil fuels. In this way, Poly Lactic Acid (PLA) is a good sustainable substitute to petroleum derived polymers, which is currently considered as the most promising and popular of 'green' eco-friendly material [8, 9].
In Colombia (South America), there are many kinds of natural fibers to explore, due to its large diversity of plants. Specifically, highest diversity of palms has been found in the pacific lowlands. For example, Manicaria Saccifera Gaetner is one of the most used palms in central Choco region. Native population have exploited different parts of the palm for diverse purposes such as food, drink, basic materials, crafts, tools, and utensils [10]. Nevertheless, and to this date, there are no investigations reported on the development of green composites using Manicaria fibers as reinforcement. Hence, the current work presents the development and mechanical characterization of a core sandwich panel fabricated from Manicaria fiber as reinforcement and Polylactic Acid (PLA) as resin matrix. The manufacturing process is illustrated and the potential of the Manicaria/PLA core sandwich panel for structural application is evaluated by subjecting the core to in plane compressive loads. Also, test results were compared to un-reinforced cores and the failure criteria was investigated.

2 Experimental

2.1 Materials

The Poly Lactic Acid (PLA) polymer used in this work was a commercial L-polylactide granulated identified as PLA2003D, it was provided by Quimicoplasticos S.A., Bogota, Colombia. PLA is a thermoplastic resin designed for extrusion/thermoforming applications produced by Natural Works Company.
Manicaria palm (*Manicaria Saccifera Gaetner*) grows, from Central to South America, in mostly swampy conditions. It is known with different names depending of the origin region. The spathe of the Manicaria palm is used as reinforcement in this work. Its length is around 60 to 90 cm and it seems like a brown non-woven textile, constituted of plenty fibers.

2.2 Composite preparation

The core sandwich panels were made using the following procedure:
First, 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 0.4 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).
Second, the PLA sheet and Manicaria non-woven textile were cut in rectangles of around 15 x 10 cm, because the production of sandwich cores panels primarily involved the manufacturing of both thin corrugate (sinusoidal core material) and laminate (face sheets) composites by thermoforming, and after that bonding them in order to form sandwich panels. An Aluminum mould was designed for the manufacture of corrugate core material.
The corrugated (half – hexagonal profile) and laminated Manicaria/PLA composites were producing using a film staking procedure. In this research, 2-ply of Manicaria and 3-ply of PLA sheets were used. The layers of Manicaria non-woven orientated at same direction and

PLA sheets were plied alternately, and hot compressed using a conventional molding press (Dake Press, model 44-251) at temperature of 160°C ± 3°C for 8 min with a minimum pressure of about 2 MPa.

Finally, the face sheets were bonded to the core material using acrylic based adhesives DP8005. In the Figure 1 are shown the Manicaria non woven textile, PLA laminate matrix, the aluminum mould, and the reinforced corrugated core material.

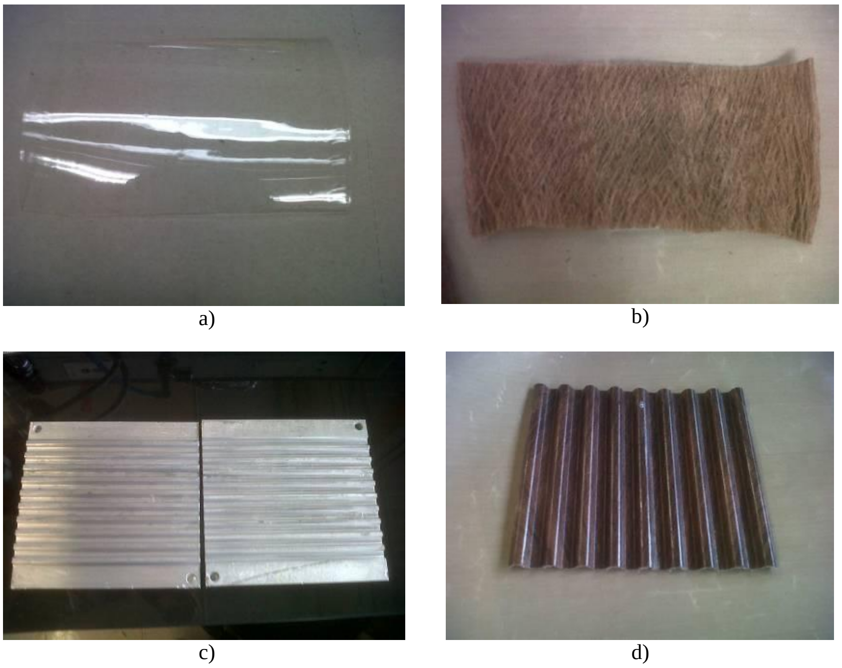

Figure 1. a) Manicaria non-woven. b) PLA sheet. c) Aluminum mould. d) Manicaria/PLA corrugated core.

2.3 Mechanical properties

The potential of the Manicaria/PLA core sandwich panel for structural application was evaluated by subjecting the sandwich core panel to compressive loads. Compressive tests were conducted according to the ASTM C365 standard using an Instron Universal Testing Machine Model 3367, with the crosshead speed set to 0.5 mm/min. The in-plane compressive properties of the core sandwich panel were determined using specimens with nominal size of 50 mm x 50 mm x 11 mm. The compressive strength and elastic modulus were determined for both the reinforced and unreinforced sandwich cores panels. Five specimens were tested to obtain average compressive properties. In the Figure 2 are shown the Manicaria/PLA core sandwich specimen and the geometry of the half-hexagonal cell wall profile conformed. From this figure, it is clear that manufacturing system ensures a uniform thickness profile.

Figure 2. a) Manicaria/PLA core sandwich specimen. b) half- hexagonal cell walls

3 Results and discussion

The quasi-static in –plane compression behavior of both Manicaria/PLA and PLA cores are shown in Figure 3 and Figure 4; a typical stress-strain curve of sandwich panels with plastic cores. Three distinct phases can be identified from the strain – stress curve: an initial elastic region up to initial failure, followed by a plateau of roughly constant stress, leading into a final steeply rising stress called densification.

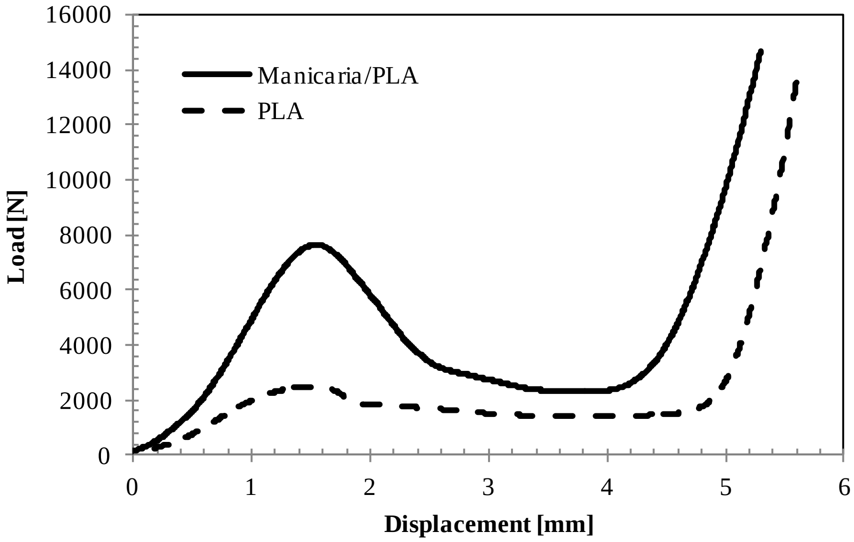

Figure 3. Compressive load vs displacement curve of Manicaria/PLA and unreinforced PLA cores

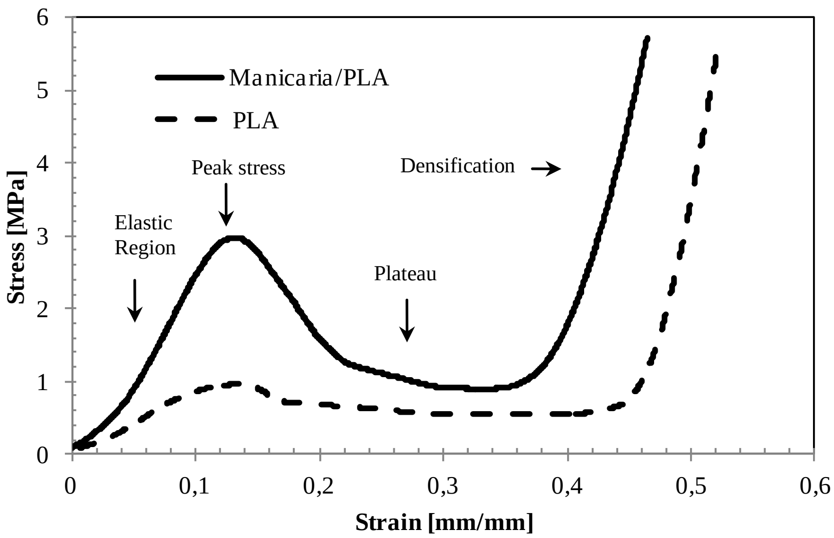

Figure 4. Stress – strain graph showing the compression stages of both Manicaria/PLA and PLA cores sandwich

As it is shown in the Figure 5, on the first loading the cell wall bends. Then, when a critical stress is reached the cell begins to collapse by the formation of plastic hinges at the section of maximum moment in the bent member. After that, the cells collapse sufficiently that opposing cell wall touch, until the structure densifies.

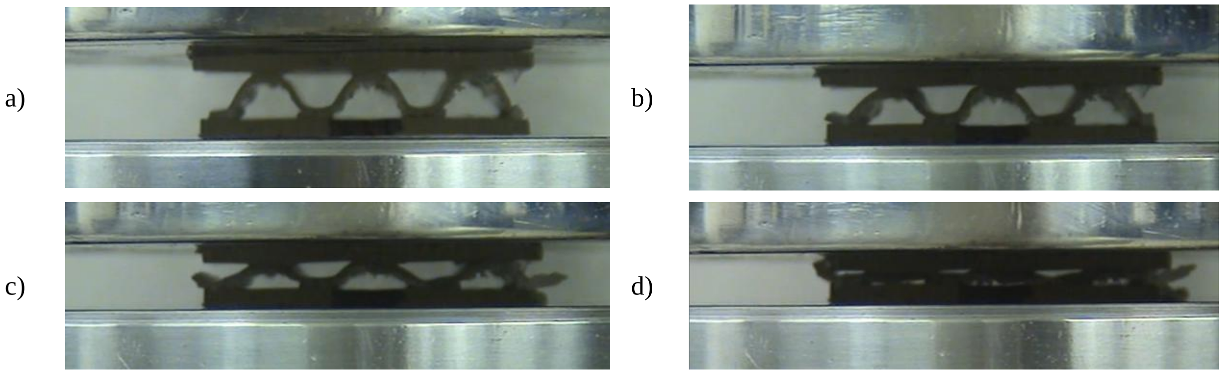

Figure 5. Core failures in sequence. From the beginning of the test to until de end of the test

The in-plain compressive properties of sandwich cores are shown in Table 1. The average compressive strength and elastic modulus of the Manicaria/PLA core were 2.85 (±0.17) MPa and 32.68 (±3.68) MPa, respectively. In contrast, un-reinforced PLA sandwich core display lower mechanical properties; the compressive strength of the core was 1.28 (±0.45) MPa and the elastic modulus was 12.49 (±4.7) MPa. These results indicated that the mechanical properties of Manicaria fiber reinforced cores increased to more than twice of those of the unreinforced cores. Therefore, this result shows the high potential of Manicaria fiber as reinforcement in cores and it is the basis for a large work in determining all aspects of the structural design of eco-friendly sandwich panels.

Properties	**Manicaria/PLA core panel**	**Un- reinforced PLA core panel**
Compressive strength (MPa)	2.85 ± 0.17	1.28 ± 0.45
Elastic modulus (MPa)	32.68 ± 3.68	12.50 ± 4.72

Table 1. Mechanical properties (in – plane compressive) of reinforced and unreinforced cores

The next step in this research is study the compressive behavior of Manicaria/PLA honeycombs when subjected to out-plane compressive loading, taking into account that according to the literature the out of plane in plane stiffness and strengths are much longer than the in plane, due to require the compression of the cell walls, instead of bend.

4 Conclusions

Eco friendly sandwich cores panels fabricated from both renewable resources and biodegradable materials were produced. The cores were thermoformed from Manicaria fiber reinforced Polylactic Acid (PLA), using a film staking procedure. The mechanical behavior of the sandwich core panel subjected in-plane compressive loading was investigated. A typical stress-strain curve was obtained from the test and three distinct regions were identified; linear-elastic, plateau and densification regions. Also, the cell wall collapsed by the formation of plastic hinges. As well, the reinforced cores were mechanically superior, provided an improvement in the strengths and module of more than twice those of the unreinforced core. All above indicate that Manicaria fiber have great potential as reinforcement in cores sandwich panels.

References

[1] Lestari W., Qiao P. Damage detection of fiber-reinforced polymer honeycomb sandwich beams. *Composite Structures*, **67**(3), pp. 365-373 (2005).
[2] Herrmann A., Zahlen P., Zuardy I. Sandwich structures technology in commercial aviation. *Sandwich Structures 7: Advancing with Sandwich Structures and Materials*, **1**, pp. 13-26 (2005).
[3] Knox E., Cowling M., Winkle I. Adhesively bonded steel corrugated core sandwich construction for marine applications. *Marine structures*, **11**(4-5), pp. 185-204 (1998).
[4] Rizov V.I. Non-linear indentation behavior of foam core sandwich composite materials - A 2D approach. *Computational Materials Science*, **35**(2), pp. 107-115 (2006).
[5] Dattoma V., et al. Thermographic investigation of sandwich structure made of composite material. *NDT & E International*, **34**(8), pp. 515-520 (2001).
[6] Spengler, E. *Composite structural panel with thermoplastic foam core and natural fibers, and method and apparatus for producing the same*. U.S. Patent, 6 287 678, (2001).
[7] Rao, S., Jayaraman K., Bhattacharyya D. Short fibre reinforced cores and their sandwich panels: Processing and evaluation. *Composites Part A: Applied Science and Manufacturing*, **42**(9), pp. 1236-1246 (2011).
[8] Madhavan Nampoothiri K., Nair N.R., John R.P. An overview of the recent developments in polylactide (PLA) research. *Bioresource technology*, **101**(22), pp. 8493-8501 (2010).
[9] Graupner N., Herrmann A.S., Müssig J. Natural and man-made cellulose fibre-reinforced poly(lactic acid) (PLA) composites: An overview about mechanical characteristics and application areas. *Composites Part A: Applied Science and Manufacturing*, **40**(6-7), pp. 810-821 (2009).
[10] Linares E.L., et al. *Fibras vegetales empleadas en artesanías en Colombia*. Instituto de Ciencias - Universidad Nacional de Colombia, Bogotá (2008).