CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci
 ISBN 978-88-95608-01-3 ISSN 1974-9791
DOI: 10.3303/CET0917296

Mechanical Properties of Pupunha (*Bactris gasipaes*) Palm

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Composites reinforced by lignocellulosic fibers and structural cellulosic materials, such as bamboo, are being increasingly used in many industrial fields, owing to the growing society need to use materials from renewable natural resources. This work aims to analyze a waste of the agribusiness sustainable production of heart of palm, namely the trunk of the pupunha (*Bactris gasipaes*) palm.
The main objective was to characterize the mechanical behavior of the "timber like" material obtained after the pupunha palm is cut. This material has an appearance similar to some hardwood planks, and can be an alternative route for obtaining wood-like materials, considering the following: availability, preservation of the environment, performance of the material and relative low cost. In this work, the flexural and compression strengths, and the abrasion resistance of pupunha specimens are reported. The results obtained are compared with the mechanical performance of bamboo and several woods (both hardwood and softwood) commonly used at furniture manufacture.

Key words: mechanical properties, physical properties, pupunha

1. Introduction

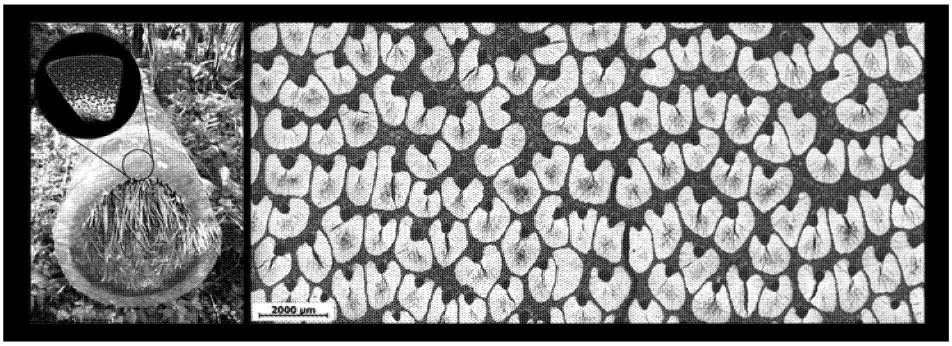
For many centuries the structural materials used by mankind varied from place to place, since their use was dependent of their local availability, and their choice was also influenced by cultural and social aspects. Industrialization brought a rupture of the way materials were handled and also contributed to the concentration of the population in large urban areas. These aspects lead to a steadily loss of cultural heritage including the use of traditional natural materials, that were gradually substituted by industrialized materials. Industrial materials enable, without a doubt, a widespread of wealth, but in many instances they consume huge financial resources and large amounts of energy, and cause pollution, as well. The use of natural cellulosic based materials both as reinforcement in resin matrix composites or as structural materials has, therefore, several advantages (Bledzki and Gassan, 1999).
In this work we report on the mechanical properties of the wood-like material obtained from the pupunha (*Bactris gasipaes*) palm. This palm is, nowadays, harvested in large plantations, and is used for the sustainable production of heart of palm, avoiding the predatory exploration of other native palms, such as açaí (*Euterpe oleraceae*) and

Please cite this article as: Bacellar R. and D'Almeida J., (2009), Mechanical properties of pupunha (bactris gasipaes) palm, Chemical Engineering Transactions, 17, 1771-1776 DOI: 10.3303/CET0917296

jussara (*Euterpe edulis*), that have longer growing cycles and that were being exploited to exhaustion.

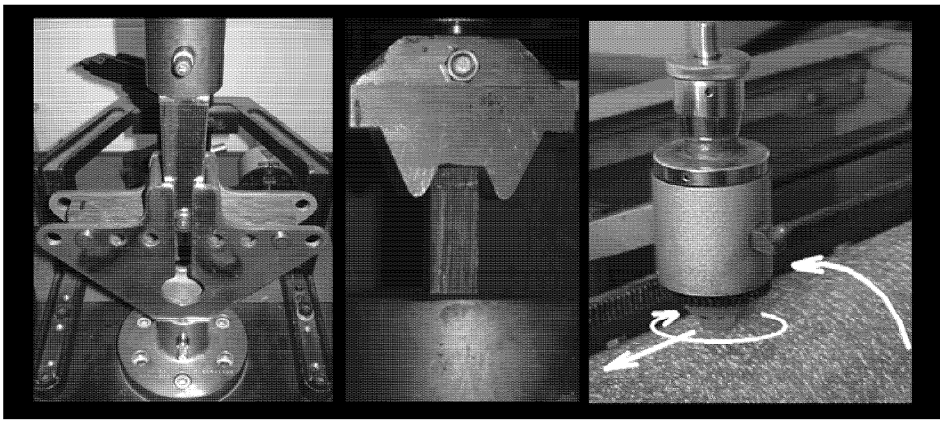
2. Material and experimental procedures

Figure 1*a* shows an overall view of the palm trunk after it have been cut. The inset shows the structural aspects of the cross section, and the region from where timber like planks can be extracted. One can see that the cross section of the outer portion of the pupunha trunk is characterized by fibers aligned parallel to the trunk axis, Fig.1*b*. A complete description of the structure of the pupunha palm is described elsewhere (Bacellar and d'Almeida, 2008). From this outer region flexural specimens (180 mm long, 25.4 mm large and 10 mm thick) and compression specimens (with a rectangular cross section of 20 mm x 30 mm and 50 mm long) were machined.
The three bed point flexural tests were performed on a mechanically driven testing machine with 10 kN of capacity. Six specimens were tested, using a test velocity of 2.56 mm/min and a span to depth ratio of 16, as recommended by ASTM standard D 790. Figure 2*a* shows the experimental setup used.
The compression tests were performed according to the Brazilian standard NBR 7190. Five specimens were tested using a test speed of 10 mm/min. Figure 2*b* shows the experimental setup.
The abrasion resistance was performed following the recommendations of the DIN 53 516 standard. Cylindrical specimens 6 mm height and with an average diameter of 16 mm were used. The test was performed using an apparatus equipped with a rotary drum covered with sand paper (#180 grit), and a specimen holder, as depicted in Figure 2*c*. The specimen is moved along the length of the rotary drum, while spinning in respect to its own vertical axis, covering a 40m long run. The axial force exerted by the specimen holder on the specimen against the rotary drum was of 1 kgf (9.81N). The performance of the material in respect to its wear behavior was determined from the weight loss. Thus, before and after the tests the specimens were weighted within ± 0.0001 g.



(*a*) (*b*)

Figure 1. (a) The transversal section of the pupunha trunk. The inset highlights the variation of the microstructural features along the thickness of the outer wall. (b)Magnification of the fiber like structures aligned along the axis of the pupunha trunk.



(a) (b) (c)

Figure 2. Experimental setups used: (a) flexure test; (b) compression test; and (c) abrasion test.

3. Experimental results

Table I shows the experimental results found when the pupunha specimens were tested in flexion, where σ_r is the flexural strength, E is the flexural modulus and e is the deformation at the point of maximum strength. A comparison is made with two common Brazilian species of hardwoods, namely jatobá (*Hymenaea courbaril*) and maçaramduba (*Manilkara amazonica*) (Dias and Lahr, 2004), and also with a glass-fiber (GF) composite with a volume fraction of fibers of 35% (Chacón et al, 2007). Figure 3 shows, as an example, the flexure behavior observed for all the tested pupunha specimens. A very well defined initial linear portion is followed by a non linear region where serrations indicate stable crack propagation. It is worth saying that the specimens did not break into two pieces after the final abrupt load drop at the end of the test.

Table 1 Experimental results. Three point bending flexural test.

Material	σ_r (MPa)	E (GPa)	e (%)
pupunha	214.3 ± 12.3	20.3 ± 1.1	1.79 ± 0.14
jatobá	159	22.9	-
maçaranduba	136	21.9	-
GF composite	358 ± 56	20 ± 2,17	3.9 ± 1,4

From Table I one can also notice that pupunha has high mechanical properties when compared to other lignocellulosic materials, and even a similar stiffness when compared to usual glass-fiber composites. Moreover and very interesting from a practical point of view, very small standard deviations were obtained for all flexural mechanical properties determined. This is not commonplace when lignocellulosic materials are under analysis, and can be an advantage to this material if further analysis confirms a constancy of its flexural mechanical behavior.

The compression strength of the pupunha specimens, σ_c, tested along the length of the fibrous structures depicted in Figure 1*b* are listed in Table II along with the properties of jatobá and maçaranduba (Dias and Lahr, 2004), and with the properties of a bamboo laminate (Oliveira, 2005).

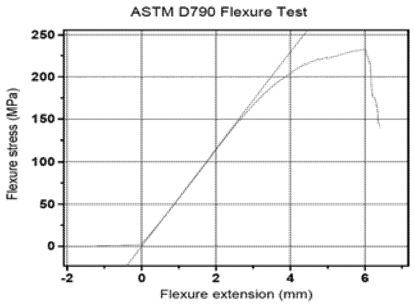


Figure 3. Typical flexural stress-deflection curve obtained for pupunha specimens.

Table II Experimental results. Compression test.

Material	σ_c (MPa)
pupunha	83 ± 0.2
jatobá	91
maçaranduba	83
bamboo laminate	40.7

From the data listed in Table II it can also be observed that the mechanical behavior of the pupunha is similar to that presented by common structural woods material. Also, a very low standard deviation was obtained, indicating that the timber like material obtained from the trunk of pupunha palm presents a highly uniform microstructure.
The results of the abrasion tests are presented as the mass loss percentage, Table III, obtained directly from the simple equation

$$\Delta m = \frac{m_i - m_f}{m_i} \times 100(\%) \quad (1).$$

Other lignocellulosic materials were also included for comparison. It is worth saying that for a material to be considered as a possible candidate for flooring, the mass loss after a 40 m long run test must be lower than 60% (Koga and Bittencourt, 2002). It is clear, from the data in Table III that pupunha, as well as the other lignocellulosic materials listed, show considerably smaller numbers, fulfilling the condition predicted by the test. In respect to the abrasion resistance of pupunha a point of concern must be raised here. The value presented here is the mass loss measured perpendicularly to the fibrous structure, that runs along the palm height, see Fig.1*b*. Since planks and laminated flooring materials will be easily obtained along the trunk, and parallel to the fibrous structure, different abrasion values can be obtained. The abrasion characterization parallel to the fibrous structure is under way, and further results will be present in another publication.

Table III Abrasion test. Sand paper and 40 m long run.

Material	Mass loss (%)
pupunha	2.5 ± 0.6
bamboo	20.3
ipê (*Tabebuia impetiginosa*)	12.6
Sucupira (*Bowdichia nitida*)	15.7
jatobá	23.7

4. Conclusions

From the mechanical properties evaluated in this work it can be concluded that the timber like material obtained from the trunk of pupunha palms presents strength values comparable to the ones presented by several hardwoods commonly used as structural elements, furniture and also as flooring. Therefore, it is a promising environmentally clean and renewable material, that can substitute with advantage other lignocellulosic materials. In fact, since the pupunha trunk comes from the sustainable production of heart of palm, its use does not pose any environmental pressure. By the contrary, its use can even help to reduce pressure over native hardwoods and other native palms.
The low standard deviation obtained for all the properties evaluated is also to be highlighted, since large deviations are commonly found when lignocellulosic materials are under consideration, and this is a characteristic always cited as one of the common disadvantages of using lignocellulosic materials.
Finally, and no more important when flooring or furniture are under consideration the visual aspect of this timber like material is both unique and beautiful, and also mimics wooden surfaces, as shown in Fig. 4.

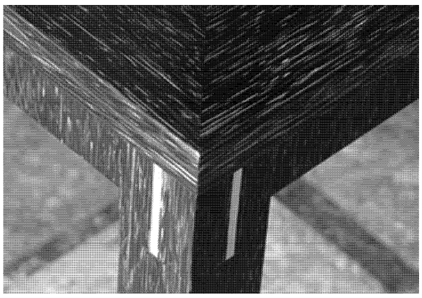


Figure 4. Visual aspect of the timber like pupunha plank machined along the pupunha trunk length.(www.lets-evo.net/skateboard/2007/01/23/compensado-de-pupunha)

Acknowledgement

The authors acknowledge financial support from the Brazilian Agency CNPq.

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