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Pineapple Leaf Fibers for Composites and Cellulose

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Pineapple leaf fiber (PALF) which is rich in cellulose, abundantly available, relatively inexpensive, low density, nonabrasive nature, high filling level possible, low energy consumption, high specific properties, biodegradability and has the potential for polymer reinforcement. The utilization of pineapple leaf fiber (PALF) as reinforcements in thermoplastic and thermosetting resins in micro and nano form for developing low cost and lightweight composites is an emerging field of research in polymer science and technology. In this paper we examines the industrial applicabiliy of PALF, mainly for production of composite materials and special papers, chemical feedstocks (bromelin enzyme) and fabrics.

Keywords Composites; nanocellulose; natural fibers; PALF; pineapple

Introduction

Environmental and economical concerns are stimulating research in the development of new materials for construction, furniture, packaging and automotive industries. Particularly, there are a lot of attractiveness for new materials in which a good part is based on natural renewable resources, preventing further stresses on the environment by depleting dwindling wood resources from forests or increasing the demand over fossil finite resources. Examples of such raw material sources are annual growth native crops/plants/fibers, which are abundantly available in tropical regions. These plants/fibers (like jute and sisal) have been used for hundreds of years for many applications such as ropes, beds, bags, etc. If new uses of fast growing, native plants

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can be developed for high value, non-timber based materials, there is a tremendous potential of creating jobs in the rural sector. These renewable, non-timber based materials could reduce the use of traditional materials such as wood, minerals and plastics for some applications.

The materials made through the combination of native fibers with different plastics, such as Polyvinylchloride (PVC), Polypropylene (PP), and Polyethylene (PE) are composites that have wide application possibilities, having a potential of developing new industries in the near future using local crops, wastes and labor, and helping to reduce the demand for tropical hardwoods (housing, furniture, pellets, etc.), and plastics.

The utilization of agricultural wastes from two of the most popular fruits around the world, banana and pineapple represents of the biggest source of biomass for natural fiber production. The pseudo-trunks from the banana trees and the leaves from the pineapple plants after the fruits are harvested represents a problem for many farmers and its utilizations will bring a new source of income for both production chains.

These fibers, which are also referred to as 'hard fibers', are the most commonly employed as reinforcing agents in plastics. Natural staple fibers are found worldwide around the planet under different forms of vegetation. Some staple fibers occur naturally in the wild state and/or are cultivated as agricultural activity. The natural staple fibers can also be called by cellulosic staple fibers, since the cellulose is the main chemical component; or still for lignocellulosics staple fibers. The field of application of natural staple fibers is sufficiently ample, since classic applications as in the textile industry, as reinforcement in thermoplastic polymeric matrices and thermosetting and more recently as material metal absorbents weighed in the treatment of industrial residues, among other applications. In this paper, the pineapple and banana fibers will be considered.

The total pineapple area planted in Brazil is about 150,000 hectares, where is estimated a production of 15–20 tons of dry fiber, depending on the crop variety and agricultural practices. This biomass has been used mainly for animal feeding. The main states that cultivate the fruits are: Minas Gerais, São Paulo, Paraiba, Rio de Janeiro, Bahia and Pará.

For the banana, the total cultivated area is about 65 millions hectares, with an average production of 1500 kg/ha. Brazil is the second world producer, but only 2% is exported, with the rest used for internal consumption. The main producer states are SP, with 17%, Bahia, 12%, Parana, 10% and Santa Catarina, 9%. These figures represent an immense potential for biomass and natural fibers production.

The main challenge to use these agricultural residues is to develop a technology for production of bleached softwood from the leaves of the pineapple. Approximately, 95% of the pulp produced in the world today comes from wood fibers, and the major technological developments are dedicated to these fibers. There are some low level technologies available to use agricultural waste such as rice, wheat and rye straw, sugar cane bagasse, bamboo, abaca, banana, sisal, etc. Recently much work has been done to extract the nanocellulose for composite applications [1]. Nevertheless, little has been done about the utilization of long fiber derived from the leaves of pineapple.

Literature Review

Environmental and economical concerns are stimulating research in the development of new materials for construction, furniture, packaging and automotive industries. There is a tremendous interest by the pharmaceutical industry as well as the material companies. In applications such as ropes, new materials, such as nylon, have replaced locally grown fibers like sisal and jute. The advantages of these plants are that they are fast-growing and renewable, and sometimes is also a source of food supply for animals and even humans.

There is a significant deficit of bleached softwood in the Brazilian market. Brazil has only a producer of this type of fiber, with a daily capacity of 200 tons per day. Much of the domestic demand for softwood bleached is supplied by imports from Argentina, Chile and Canada. Bleached softwood is required to produce white papers and packaging that require high mechanical strength [2]. The limited production of bleached softwood in Brazil is due to the low availability of softwood (pine, pines and bamboo, etc. . . .) and its high production cost compared, for example, with bleached hardwood Eucalyptus pulp. The Brazilian business community has focused on the production of bleached hardwood eucalyptus, because the cost of production is at least the half of that of long fibers. The causes of the lower cost of short fibers are derived from the increased productivity of forest plantations over most of the long fibers and the highest yield of converting wood into pulp. Moreover, the international market is hungry for hardwood pulp, which guarantees good prices for these fibers, compatible with those of long fibers.

The culture of pineapple generates post-harvest residues with the significant amount of fibers that are usually wasted and in many cases, cause inconvenience to farmers to dispose them. Fibers derived from pineapple leaves are long and slender, with excellent characteristics for use in pulping processes. It is estimated that the production of pineapple fiber per hectare per year reaching figures of around 15–20 tons per hectare. This productivity is similar to that of softwood that achieves at its mature age. In addition, the fibers of the pineapple are from agricultural residues that would be discarded, since the main objective of the crop is the production of food articles (juice, pulp, jelly, etc. . . .). Other by products are been studied mainly the enzyme bromelin with its many applications. Therefore, these fibers are very low cost, around US$ 10 per ton in the field, in comparison to the softwood costs of about US$ 80 per ton in the field [2].

The banana trees generate the rachis, which is the part of the plant where the fruits are linked to the pseudo trunk and the fiber leaves, which comes from the pseudo trunk.. Both materials can be used in industrial applications. The rachis has a high cellulose content, and can be used for handmade paper, cardboard boxes, biogas, organic compost and the most valuable one, in textile fibers. The pseudo trunk is the source of the fibers from the banana plants. The pseudo stem is a bundle of huge leaf stems wrapped around a soft central corm. Initially the leaves develop in a circular pattern around a central growing region and emerge as a shoot from the underground corm. Eventually, these leaves mature as overlapping leaf sheaths, made up of the leaf base, leaf base, and the petiole that supports the blade. The banana fibers are produced from these leaf sheaths extracted mechanically in most cases, since the pseudo stem is cut after the banana fruit harvesting to allow the sprout to grow. From these pseudo stems is possible to extract several types of fibers, each one with particular characteristics. The pseudo stem is constituted of three layers: the external, where is found the mechanical bundles. These mechanical bundles are unique in such a sense that they are responsible to sustain the plant, sometimes up to four meters height. These fibers are among the longest of the hard fiber group after abaca. The banana fibers were extracted from the leaves, but the rachis is also a source of pulp material, which composition is shown in Table 1.

Table 1. Chemical composition of a banana rachis

Itens	Percent (dry mass)
Holocellulose	79.9
Cellulose	64.4
Lignin	13.3
Ash	2.1
Extractives	4.7

Results and Discussion

The first activity to use the natural fibers in industrial applications is to determine its chemical composition, which is shown at Table 2. In this table is shown the chemical composition for both fibers used in this paper.

The pineapple fibers were used to make non-woven mats using polypropylene as the matrix and the banana fibers were tested as the reinforcement agent in composites using polypropylene as the matrix, but in the extrusion process. This process has been applied in much research and the natural fiber properties are one of the most important variables [3].

The fiber components were mixed on a dry weight basis and mixed by hand prior to the picker, which cuts the fibers to 5 cm in length, also giving more mixing. After the picker, the mixture goes to the cards, where more mixing can be obtained, and finally it goes to the needle machine. The mats were cut and pressed at different temperature, densities, pressure and time of heating and cooling. The heating time was 30 to 180 seconds. The pressure varies from 3.25 MPa up to 9.8 MPa. The pressure time in the cold press was 20–30 seconds. The samples were taken from the boards using a pressing knife. The parameters evaluated were EMC (Equilibrium Moisture Content), bending (ASTM D790 M-93), tension (ASTM D638 M-89) and dimensional stability.

The moisture content (MC) in the air at uncontrolled conditions, after 10 days of pressing was very low for all the treatments, and therefore, it will not be considered as a variable. The results obtained varied from 1.6 to 2.8%, showing that there was no significant variation among the treatments, and according to the objectives of obtaining a stable composite. The limit for natural fiber content, at the processing conditions, where 60% with the blend of 20% polypropylene, a strong reduction in tensile and flexural strength was found, much more than for tensile and flexural modules (Table 3). The thickness was not important for the levels studied (1.8–3.0 mm), showing, that it is closely related to basic weight, but it is not so sensible

Table 2. Chemical composition of some natural fibers

Item	Pineapple	Banana
Extractives Hot Water	5.5	6.4
Lignin Klason (%)	10.5	32.8
Holocellulose (%)	80.5	56.3
Cellulose (%)	73.4	44.2
Ashes (%)	2.0	2.2

Table 3. PALF fibers in non-woven mats

Ratio PALF/PP (%)	Tension strength MPa	Tension modulus GPa	Flexural strength MPa	Flexural modulus GPa
80/20	18.98	1.16	12.67	1.12
70/30	20.13	1.42	22.73	2.83
60/40	48.73	3.12	21.77	2.23
50/50	42.17	3.42	31.01	2.32

to small variations. Above 3.0 and below 1.5 mm, the properties have a significant reduction. The pressure at the values tested, varying from 3.25 MPa up to 9.8 MPa, at the forming press (cool) was not significantly different. The heating pressure was used only to compress the mats and carry the heat throughout, with values varying from 0.82 to 3.67 kg/cm^3. The cooling time at the forming press also was not significant at the values tested, showing that it was above the minimum limit.

Composites were also compounded in a twin-screw extruder, model ZSK-25, Coperion, L/D ratio of 25, at 300 rpm and the temperature profile of 190, 190, 180, 180 and 190°C. This equipment was used to compound the natural fibers with the resins and subsequent formation of pellets. The feeding process was the one in which both components are introduced on the same time to avoid overheating. The ratio used as 50/50 PALF/Polypropylene. The extruded pellets dried at 105°C for 4 hours to eliminate residual humidity from the fiber before the injection molding of the samples.

The sample specimen were molded at 190°C in an automatic injection molding machine, Sandretto, 65 Micros. Prior to mechanical testing, the samples were conditioned at (40) (5)% relative humidity, (25) (2) (C for 40 hours). The mechanical properties were evaluated according to ASTM standards. Notched Izod Impact tests were made using a CEAST Resil 25 pendulum type impact machine according to ASTM Standard D-256. At least ten specimens of every composite were tested to obtain the impact strength. The other testing properties were performed following ASTM standards: tensile testing (ASTM D638); flexural testing (ASTM D790); and impact testing (ASTM D256).

The natural fibers are a source of environmental materials, but are high variation in data can be a problem for industrial application. It is observed a large strength distribution into the fibers [4].

Below are, presented in Table 4, the properties obtained to the tensile strength and tensile modulus for the injection molded samples in PP matrix.

For the property flexural strength it was observed an increase when compared to the net resin, showing a significant improvement due to the addtion of the PALF fibers into the composites (Table 5).

Table 4. Tensile properties

Polypropylene matrix	PALF/PP	PP
Tensile Strength (MPa)	25	35
±SD	.83	
Young Modulus (GPa)	2.8	1.1
±SD	.09	

Table 5. Flexural properties

Polypropylene matrix	PALF/PP	PP
Flexural Strength (MPa)	34	28
±SD	.44	
Young Mod (GPa)	1.9	.95
±SD	.23	

Table 6. Impact resistance

Polypropylene matrix	PALF/PP	PP
Impact Resistance	51	21
Notched	1.44	0.88
Impact Resistance	140	538
Unnotched	2.28	1.7

For the property unnotched impact resistance, it was observed a large difference between the polypropylene and the PALF. Although, for the notched resistance it was observed an improvement with the addition of the PALF, as can be seen at Table 6.

Conclusions

By the obtained results, the residue can represent interesting sources of raw material for industrial applications, mainly for production of composite materials and special papers, chemical feedstocks (bromelin enzyme) and fabrics. The development of new value added products and opening of new market niches are expected to have a positive impact in the pineapple and banana production chain. The beneficiaries will be the small producers that will end up with a commodity that nowadays has an almost zero value.

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