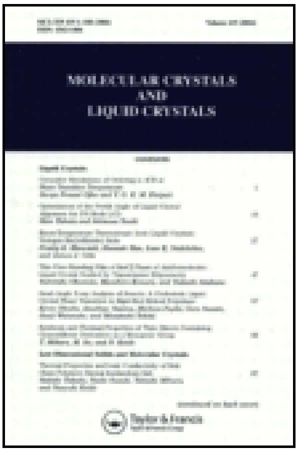

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Panels Produced from Thermoplastic Composites Reinforced with Peach Palm Fibers for Use in the Civil Construction and Furniture Industry

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In order to cooperate in minimizing the problems of the current and growing volume of waste, this work aim at the production of panels made from industrial waste –thermoplastic (polypropylene; polyethylene and acrylonitrile butadiene styrene) reinforced with agro-industrial waste - peach palm waste (shells and sheaths). The properties of the panels like density, thickness swelling, water absorption and moisture content were evaluated using the ASTM D1037; EN 317; and ANSI A208.1 standards regarding particle boards. Good results were obtained with formulations of 100% plastic waste; 70% waste plastics and 30% peach palm waste; and 60% waste plastics and 40% peach palm waste.

Keywords Civil construction; natural fiber; composites; furniture; panels; peach palm; polymers

Introduction

New products are developed to supply growing market demands. This increases the consumption of natural resources and raises the impact on the environment owing to increases in the generation of solid waste from municipal, industrial and agribusiness sources. Waste plastics are the most conspicuous component of such generated garbage. Plastics are derived from non-renewable (oil) sources. Improper disposal in cities causes obstruction of drains that contributing to flooding. The consequently is a proliferation of mosquitoes and other vectors, causing diseases and other inconveniences to residents.

A huge amount of floating garbage has been found in the Pacific Ocean. It is estimated that 90% of this is plastic waste. It causes the death of marine animals and changing their way of life [1]. Even in landfills plastic waste forms an impermeable layer that hinders the compaction of waste and affects the exchange of the fluids and gases generated. This decreases the efficiency of biodegradation of organic matter.

Waste plastics from recycling have new applications and can be used for the manufacture of different materials such as composites. The latter are formed by joining two or

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more elements of different natures (the matrix and reinforcement) to improve the properties of the components taken separately (matrix or reinforcement). They can be used in civil construction and industries such as furniture, automotive, sports, aviation, etc.

To make the composites more economically feasible and superior to other conventional materials, there is a need for alternative low-cost reinforcements, such as natural fibers (jute, sisal, banana, pineapple, coconut, curaua, wood, bamboo, etc.). In addition, these fibers are biodegradable and originate from renewable sources.

Several Brazilian agro-industrial residues are being used for panel manufacturing such as the pseudo stems of banana, rice husk, coconut shells, peanut hulls and bagasse from sugar cane. Other sources also provide a good use of waste materials, such as the residue of peach palm that can be used as reinforcement in lignocellulosic composites. The peach palm (*Bactris gasipaes* Kunth) (Fig. 1) is from the family *Arecaceae* or *Palmae* species. Following extraction of the palm oil, the waste generated accounts for 80% to 90% of the gross weight (a stem weighs about 4 kg and generates approximately 3.5 kg of waste) [2].

According to Jiang and Kamdem [3], the U.S. market for thermoplastic cellulose with application in construction materials showed an annual growth of 60% in recent years. In 2002, about 400 thousand tons of polymers loaded with different lignocellulosic reinforcements were used. This fact could be confirmed by the increase in demand for these raw materials for use as fillers in thermoplastics and by the increase in the number of patents filed in the U.S. devoted to the topic. Correa et al. [4] reported that the greatest market share of lignocellulosic thermoplastic composites with reinforcements is still in civil construction, with materials like polyethylene, polypropylene and PVC extruded with wood waste in the form of profiles for floors and flooring, window and door jambs, coatings and many other applications.

Market studies conducted in the U.S. and Europe about the use of wood waste flour (WWF) as filler and reinforcement in thermoplastics show that the substitution of raw wood for this composite is presented as a viable alternative to the reuse of waste, with many advantages like greater resistance to moisture and environmental deterioration, resistance to pests and insects, and can be extruded into profiles with diverse shapes; better dimensional stability, resistance to warping and cracks, lower cost of routine maintenance; greater durability in an aggressive surrounding such as marinas and swimming pools; full recyclability and mimicking the appearance of wood; and absence for the need to use of surface protection such as paints and varnishes [5,6].

Currently, there are a growing number of studies involving composites with natural fibers, mainly concerning the replacement of synthetic fibers. The use of these fibers in place of fiberglass, asbestos, kevlar, nylon, boron and carbon and other fibers present one or more of the following characteristics: high cost, abrasiveness to processing equipment, high density, bio degradable less, and high cost of recycling and potential risks to health and to the environment. The use of vegetable fibers is advantageous as they have just the opposite characteristics: low cost, low density, non-abrasiveness; they are sources of renewable natural resources, biodegradable, nontoxic and can be incinerated and easily modified by chemical agents [7]. Often, the consumer is unaware that natural fibers are used in the plastic matrices. Greater awareness of the advantages of this material will fuel demand.

Some say that the development of new technologies of polymers reinforced with lignocellulosic materials will be one of the reasons for the growth of the plastic's market in the coming years. Polymers loaded with lignocellulosic reinforcements are part of a new class of materials that combine the favorable attributes of both natural fibers and plastics [8].

The aim of this study is related to finding a noble end to industrial waste (plastic) and agro-industrial waste (peach palm). The solution was to construct composite panels from raw (mixed) material plastic waste as binder ((Polypropylene–PP; Polyethylene–PE and Acrylonitrile Butadiene Styrene - ABS supplied by a recycling company) and lignocellulosic material - scrap of peach palm (shells and sheaths) as reinforcement. The composites were pressed from the crushed materials and used to substitute more expensive and less efficient materials and can be used in various areas, including: automotive, sports, aviation, and especially in the furniture industry and civil construction, where there is a greater demand for this type of material, as it offers low-cost, higher performance and may even provide more comfortable homes.

Secondary objectives are to replace the predatory and illegal extraction of native heart of palm by the more common peach palm plantation and also to show that industrial and agro-industrial waste can be reused by being transformed into environment friendly products.

Materials and Methods

Industrial wastes of thermoplastics were used: Polypropylene - PP, Polyethylene–PE and Acrylonitrile Butadiene Styrene - ABS, provided by Caio, resulting from the manufacture of bus bodies, and a recycling company Plastitech Ltda, both located in Botucatu-SP-Brazil [Fig. 2(a)]. The agro-industrial wastes were residual shells and sheaths of peach palm (*Bactris gasipaes* Kunth). These residues arose from palm heart (*Geonoma edulis*) extraction. They were provided by Palmitos Rosolen Industry and Trade Ltda, located in the municipality of Cajobi-SP-Brazil [Fig. 2(b)].

Making Panels

The panels were prepared by using different proportions of the matrix (RP) and reinforcement element (CP). The experimental conditions are shown in Table 1. The operating process variables were similar in all treatments and were defined in a pilot study. Preliminary testing showed that, although all the polymers melt at or below 175°C (LDPE = 110°C; HDPE = 130°C; PP = 165°C and ABS = 175°C) a pressing temperature of 200°C was

Table 1. Experimental Design: Matrix + Reinforcement

Treatment	Code 1 a 7	Matrix (matrix element) % Waste plastic (RP) PP + PE + ABS	Load Increase (structural component) % shell and sheath of the peach palm (CP)
RP100	1	100	0
CP100	2	0	100
RP30CP70	3	30	70
RP40CP60	4	40	60
RP50CP50	5	50	50
RP60CP40	6	60	40
RP70CP30	7	70	30

Figure 1. Peach palm.

necessary. Thus, the optimum temperature observed was 200°C, for all polymer melts and does not degrade them or peach palm fiber. From tests already developed in the laboratory, it was found that to have complete fusion of the polymer with the fiber of the peach palm, pressing time of 10 minutes is the ideal at a pressure of 100 kg/cm^2. In order to improve the accuracy of the results, three replicate per treatment was made, giving a total of 21 panels.

The manufacturing of the panels was developed at the Laboratory of Solid Waste and Composites (RESIDUALL) at the Department of Natural Resources, College of

Figure 2. (a) Plastics wastes before crush. (Source: Lorenzi, H. *et al.* (2004). Palmeiras brasileiras e exóticas cultivadas. Nova Odessa-SP-Brazil); (b) Peach palm waste (trunk, bark, leaves and sheaths); (c) Peach palm waste crushed (trunk, bark, leaves and sheaths); (d) Plastics wastes crushed.

Agricultural Sciences - FCA–UNESP (São Paulo State University, Botucatu, São Paulo, Brazil). The nominal density desired for the panel made was set at 0.70 g/cm^3, considered by the ANSI A208.1 [9], medium-density panel. The panel dimensions were set at 35 cm long × 35 cm wide × 1 cm thick.

To obtain particles of the raw materials for production of the panels, a horizontal mill granulator Seibt, model 6/230 was used. Both residues of the peach palm (shells and sheaths—Fig. 2(c)) and waste of thermoplastics (PP, PE and ABS—Fig. 2(d)) were ground. Before grinding the shells and sheaths of peach palm it was necessary to dry them in the oven with circulating air at a temperature of 70 ± 3°C, and average humidity of about 5%. For the fabrication of the panels, the residues were weighed separately on a digital balance and then mixed and homogenized by shaking in accordance with the proportions specified in Table 1. Subsequently, a portion of the prepared sample was removed to check the moisture content, using moisture measurer Denver Instrument IR-200.

For assembly of the mattress, the residuals were randomly distributed inside a wooden box. The initial conformation of the mattress was made by manual pressure exerted on the lid of the box. Once performed the mattress, the wooden box was removed, and the precast mattress was taken to the press. The panels were prepared using a hydraulic laboratory press OMECO with simple closure and two plates with dimensions of 60 cm × 60 cm. To limit the thickness of the panel spacers were placed at 1 cm thick. At the end of the press, the panel was subjected to a load through an iron plate of 20 kg for 15 minutes. The reason for this is to avoid the charging effect "spring back", i.e., the mattress back to the initial conditions before pressing. After cooling at room temperature, the panel was prepared in the final dimensions (35 cm long × 35 cm wide × 1 cm thick) for the physical tests.

Physical Tests of the Panels

The panels were evaluated according to ANSI A208.1 [9] standard that specifies the necessary properties for the plates of particles. Six samples were taken for each experiment, measuring 5.0 cm long × 5.0 cm wide × 1.0 cm thickness, according to EN 317 [10]. These specimens were submitted to the physical tests like density, moisture content, thickness swelling and water absorption of 2 and 24 hours.

For tests of thickness swelling and water absorption, the specimens were saturated in distilled water at 20°C for 2 and 24 hours. After this period, the specimens were removed from the water and placed in a vertical position for surface drying and, subsequently, were weighed and measured (at four different points of the sample) for determining the swelling in thickness after 2 and 24 hours of submersion.

To evaluate the physical properties of the panels, we used as a reference the ASTM D1037 [11] and EN 317 [10] standards used for particle boards. Their use is justified by the similarity of the product developed in this study with a sheet of particles. For final framing of the panels of each experiment, we used the ANSI A208.1 [9] standard.

Results and Discussion

The Tables 2 to 4 shows the physical properties of fabricated panels. Table 2 lists the average values of moisture content and density of the panels for each treatment. The moisture contents of the samples indicate that mean value is between 0.31% and 8.10%. The treatment that contained only plastic waste plastic (RP100) showed the best result for moisture content. This occurred because the plastic material is practically waterproof. This treatment showed significant difference with respect to all other treatments. Treatment 2 had the worst result of moisture content. The best results were those that contained the highest percentage of plastic (RP100, RP70CP30 and RP60CP40).

Regarding the density, the values showed no significant difference. By ANSI A208.1 [9], only one treatment was classified as the medium-density panel (0.75 g/cm^3) for the commercial and industrial use. The other treatments were classified as the high-density panel (0.81 to 0.87 g/cm ^{3}), intended for industrial use. Although the values are covered by

Table 2. Mean values of moisture content and density

Treatments	Code	Moisture content (%)	Standard Deviation	Density (g/cm^3)	Standard Deviation
RP100	1	0.31	3,91	0,87	0,09
CP100	2	8.10	2,41	0,85	0,04
RP30CP70	3	6.15	7,12	0,75	0,05
RP40CP60	4	4.84	1,63	0,81	0,03
RP50CP50	5	4.23	2,82	0,85	0,02
RP60CP40	6	3.55	2,47	0,86	0,03
RP70CP30	7	2.94	2,09	0,84	0,02

Table 3. Mean values of thickness swelling

Treatments	Code	Swelling 2h (%)	Standard Deviation	Swelling 24h (%)	Standard Deviation
RP100	1	0,60	0,20	1,21	0,16
CP100	2	61,15	4,04	66,57	4,66
RP30CP70	3	15,63	1,04	16,83	0,70
RP40CP60	4	7,98	2,30	9,42	2,09
RP50CP50	5	6,72	1,84	7,80	2,80
RP60CP40	6	3,05	1,52	5,29	2,27
RP70CP30	7	3,19	0,72	3,88	0,68

the rule, almost all the panels have values above the desired value of 0.70 g/cm^3. Only one treatment had the approximate value of 0.75 g/cm^3.

When the panels are exposed to moisture, they undergo major changes with respect to water absorption and thickness variations due to swelling. These properties may limit the use of panel having greater swelling. These tests provide information about the conditions of accession and the resistance of the particles that constitute the panel when subjected to water immersion. These tests are carried out systematically by industry, for quality control of products.

According to Table 3, the best results for the thickness swelling after 2 hours immersion in water treatments were 1, 4, 5, 6 and 7, presenting the significant difference from other treatments. The ANSI A208.1 [9] specifies that the maximum thickness swelling permitted is 8% for high density panels. Thus only treatments 1, 4, 5, 6 and 7 comply with the standard. Treatment 2 showed the highest percentage of thickness swelling after 2 and 24 hours of immersion in water. This behavior is expected since it contains 100% crushed shell peach palm, material that absorbs water. Treatments that contained a greater percentage of plastic waste were observed to have the better performance.

The treatments that showed swelling values after 24 hours immersion in water less than 8% was 1, 5, 6 and 7. The values obtained for water absorption after 2 and 24 hours of immersion varied from 1.9 to 111% and 5.5 to 121% respectively, as shown in the Table 4. Treatment 1 had the lowest percentage of water absorption after 2 hours of immersion. This treatment showed significant differences from all other treatments.

Table 4. Mean values of water absorption

Treatments	Code	Absorption 2 h (%)	Standard Deviation	Absorption 24 h (%)	Standard Deviation
RP100	1	1,87	2,17	5,48	3,92
CP100	2	111,17	6,76	120,80	5,01
RP30CP70	3	55,96	5,40	60,89	5,82
RP40CP60	4	36,01	1,71	39,93	1,49
RP50CP50	5	28,27	3,57	31,82	2,65
RP60CP40	6	17,90	5,45	22,92	2,38
RP70CP30	7	15,01	3,06	20,26	2,02

Treatment 2 had the highest percentage of thickness swelling and water absorption after 2 hours of immersion. After 24 hours of immersion, this treatment also presented the largest percentage of water absorption. The high values of thickness swelling and water absorption is due to the fact that all treatments, except treatment 1, contain a high percentage of natural fibers, the material that absorbs water.

From the results presented as the thickness swelling and water absorption can be concluded that the panels made with the highest percentage of waste plastics are better than one that contains more fiber percentage. It was also found that the treatments that resulted in enhanced swelling were the same ones that presented a higher rate of absorption.

Conclusion

Among the fabricated panels, treatments 1 (100% plastic waste), 6 (60% waste plastics and 40% shell and sheath of peach palm) and 7 (70% waste plastics and 30% shell and sheath of peach palm) showed the best results in physical tests. The other treatments had much higher levels of thickness swelling, water absorption and increase in moisture content, because they had the highest percentage of natural fibers, in other words, absorbed more moisture. However, this can be solved by adding a larger percentage of plastic and decreasing the percentage of natural fibers and/or adding additives to improve the adhesion between the matrix and reinforcement. These panels can be used as partitions, lines, filling doors, objects, decorative coating and other applications that require the same physical properties.

The production technology of composite panels having as raw material municipal solid waste, industrial and agro industrial represents a potential new market. These wastes may represent more profitable alternatives to traditional applications. It was also concluded that plastic wastes can be used as raw material for the production of alternative materials in architecture in urban or rural areas focusing on the concept of eco-friendly products.

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