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Original Article

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Does the Addition of Cotton Wastes Affect the Properties of Particleboards?

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ABSTRACT

A wide range of materials for the development of new products can be obtained from natural resources. Good examples of these materials are lignocellulosic wastes, which are a good alternative for the production of particleboards. This study aimed to evaluate the feasibility of using cotton wastes in association to eucalyptus particles in the production of particleboards. Cotton waste proportions used were 0, 10, 20 and 30%. Urea formaldehyde (UF) adhesive was applied at 12%, based on dry the weight of particles. Physical and mechanical tests were performed in order to evaluate panels. Water Absorption (2 and 24 h) and Internal Bond (IB) showed not significant effect with increased percentage of cotton waste. Thickness Swelling (2 and 24 h) of particleboards increased with increased percentage of waste material. The Modulus of Elasticity for cotton waste particleboards ranged from 726.47 ± 99.98 to 205.12 ± 66.24 MPa, while the Modulus of Rupture ranged from 8.63 ± 1.39 to 3.87 ± 0.75 MPa. According to results, cotton wastes could be added to particleboards up to the percentage of 9%, being indicated for the manufacture of some types of furniture such as doors and sides.

Keywords: lignocellulosic waste, cotton culture, reuse, biomass.

1. INTRODUCTION

Cotton stands out among Brazilian cultures producing large amounts of waste. Brazil is the world's fifth major cotton producer. In 2014, the Brazilian cotton production was approximately 1,412 t (FAO, 2015). According to CONAB (2016), for each 100 t of cotton, 1 t of waste is generated. "Capucho" is among these residues, which corresponds to cotton fruit after opening. Traditionally, cotton production is mainly intended for the textile industry, while wastes are used by small producers as substrate for planting of agronomic species and improvement of soil properties (Caldeira et al., 2008). Cotton waste presents a certain amount of cotton fibers in its composition that cannot to be removed after processing. The utilization of residues generated by the Brazilian agribusiness may be considered an alternative for the particleboard sector (Mendes et al., 2010). According to Guimarães et al. (2011), any lignocellulosic material has potential for being applied as raw material for particleboard production, which provides an opportunity for the reuse of forest-based and agroindustrial waste. With the growth of the wood panel industry, the demand for planting areas with currently used species of the genera *Pinus* sp. and *Eucalyptus* sp. also increased, as well as the search for new raw material options (Farrapo et al., 2014; Mendes et al., 2014). The literature has reported several attempts to produce more sustainable panels. These alternatives involve the use of natural adhesives (Goulart et al., 2012; Carvalho et al., 2014), low formaldehyde release (Roffael & Behn, 2012) and alternative raw material, derived from lignocellulosic wastes such as sugarcane bagasse (Mendes et al., 2012), rice husk (Melo et al., 2009; César et al., 2017), maize cob (Scatolino et al., 2013, 2015; Sekaluvu et al., 2014), coffee husk (Mendes et al., 2010), peanut husk (Guler & Buyuksari, 2011), corn straw (Silva et al., 2015), vine (*Vitis vinifera* L.) (Yeniocak et al., 2014), castor husk (Silva et al., 2016) and rapeseed straw (Dukarska et al., 2017).

In addition, many studies in literature have shown the mixture of agricultural wastes with wood species such as coffee husks in association to *Eucalyptus urophylla* (Mendes et al., 2010); castor husk and *Pinus oocarpa* (Silva et al., 2016) and maize cob to pine wood (Scatolino et al., 2015). All studies evaluated the influence of different proportions of lignocellulosic waste on the physical and mechanical properties of particleboards.

Cotton waste could be a potential alternative material for being applied in particleboard production due to the fact that it is basically composed of cellulose, hemicellulose and lignin. The aim of this study was to evaluate the potential of using cotton waste as raw material for particleboard production associated to eucalyptus wood through the results of its physical and mechanical properties.

2. MATERIAL AND METHODS

2.1. Particle production and processing

The agricultural waste used for panel production was cotton waste known as "capucho" (Figure 1). The material was provided by producers from the municipality of Chapadão do Sul, state of Mato Grosso do Sul, Brazil. The wood specie was *Eucalyptus urophylla* x *Eucalyptus grandis* hybrid from experimental planting (36 months) located in Jataí, state of Goiás, Brazil. Sliver particles from eucalyptus wood and cotton waste were obtained from processing in a mill. After production, particles were sieved and the content retained between 10 (2.000 mm) and 30 (0.590 mm) mesh sieve were selected for particleboard production. Subsequently, particles were dried to reach moisture content of 3%.

2.2. Basic density of the raw material

The basic density of cotton waste was obtained by saturation of particles and subsequent volume measurement in a measuring cylinder. Particles were dried (100 ± 5°C) and the dry weight/saturated volume ratio was calculated. Eucalyptus wood was subjected to analysis to determine the basic density values according to procedures in NBR 11941 standard (ABNT, 2003a).

Figure 1. Cotton waste used for particleboard production.

2.3. Chemical analysis of materials

For analysis of the chemical components of eucalyptus and cotton waste, the material retained between 40 (0.420 mm) and 60 (0.250 mm) mesh sieve was used. The material was subjected to analysis to determine the total content of extractives - NBR 14853 (ABNT, 2010a), lignin - NBR 7989 (ABNT, 2010b) and minerals - NBR 13999 (ABNT, 2003b).

2.4. Particleboard production parameters

The UF properties were: solid content 64.07%, pH 8.48 and viscosity 480 cP. The adhesive was applied at content of 12% based on the dry weight of particles. Particles were manually mixed to UF adhesive as proposed by Scatolino et al. (2017) and Guimarães et al. (2016). The mixture was pre-pressed at 0.5 MPa (5 minutes) at room temperature and then, hot pressing was performed at 4.0 MPa and temperature of 180 °C (20 minutes). The experimental design consisted of four eucalyptus wood and cotton waste combinations (Table 1). Three panels were produced for each treatment (250 x 250 x 15 mm).

2.5. Evaluation of panels and statistical analysis

Once panels were acclimatized at temperature of 22 ± 2° C and 65 ± 5% of relative humidity, test samples were obtained using a circular saw. The compaction ratio was obtained by the relationship between the apparent particleboard density and the material used for its production (Equation 1).

Table 1. Experimental design for particleboard production.

Eucalyptus wood %	Cotton waste %
100	0
90	10
80	20
70	30

$$CR = \frac{pd}{cwd\ x(cw\%) + ewd\ x(ew\%)} \quad (1)$$

where: *pd* is the apparent particleboard density (g/cm^3); *cpd* is the basic cotton waste density (g/cm^3); *cp%* is the cotton waste content; *ewd* is the basic eucalyptus wood density (g/cm^3); and *ew%* is the eucalyptus wood content.

The physical and mechanical properties were based on standards provided in Table 2.

The experiment had a completely randomized design. As the aim of this study was to verify variations in the results of physical and mechanical properties as a function of the cotton waste percentage, data were subjected to ANOVA and regression analysis, both at 5% significance level.

3. RESULTS AND DISCUSSION

3.1. Physical properties of particleboards

Variation of the mean WA2h and WA24h values as a function of substitution of eucalyptus wood by cotton waste is shown in Figure 2. In both cases, linear regression was not significant at 5% significance level.

This fact seems to be due to the higher amount of extractives present in cotton waste, which may have increased the hydrophobic characteristics of particleboards produced with the addition of cotton waste. The higher amount of extractives in cotton waste in comparison to wood was considerable and ranged from 5.11 to 22.32% (Table 3).

Extractives are hydrophobic compounds of low molecular weight that can occur in minimal or significant levels and depend of the species and geographical location of plants (Hardell & Nilvebrant, 1999). According to Iwakiri (2005), higher amounts of extractives in lignocellulosic raw materials are related to decreased permeability and hygroscopicity of the material. In addition to the effect of extractives,

Table 2. Physical and mechanical properties of particleboards according to the respective standards.

Properties	Standard
Water Absorption after two and twenty-four hours of immersion (WA2h and WA24h)[a]	ASTM - D1037 (ASTM, 2006)
Thickness Swelling after two and twenty-four hours of immersion (TS2h and TS24h)[a]	
Internal Bond (IB)[b]	
Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)[c]	DIN 52362 (DIN, 1982)

[a]Average of 2 samples per panel; [b]Average of 6 samples per panel; [c]Average of 4 samples per panel.

Table 3. Chemical composition and basic density of lignocellulosic materials.

Material	Basic Density (g/cm³)	Extractives	Lignin	Ashes
		--------------%--------------		
Cotton waste	0.19 ± 0.09*	22.32 ± 1.30	31.07 ± 0.20	7.75 ± 0.09
Eucalyptus wood	0.45 ± 0.03	5.11 ± 0.87	27.27 ± 0.32	0.51 ± 0.08

*Standard deviation.

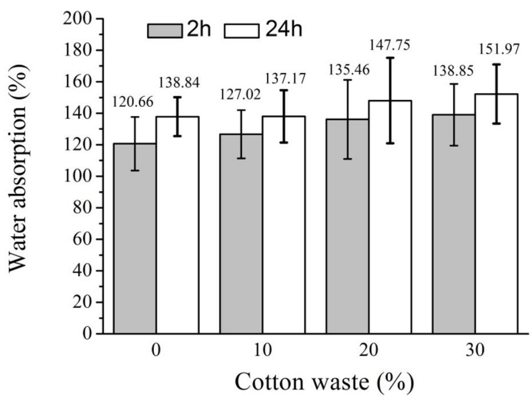

Figure 2. Water absorption of particleboards after 2 and 24 h of immersion in water; Not significant at 5% significance level.

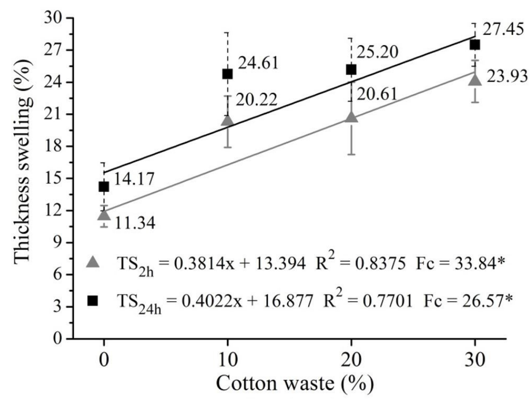

Figure 3. Thickness swelling of particleboards after 2 and 24 h of immersion in water; *Significant at 5% significance level.

the high amount of lignin in cotton waste may have influenced the non-significant increase in water absorption values. Lignin is a hydrophobic material, with three-dimensional structure and highly branched, being classified as a polyphenol, which is composed of an irregular arrangement of several phenylpropane units (Silva et al., 2009). Cotton is known to have high cellulose values. Commonly, industrial cotton waste consists of 40% cellulose and 30% hemicelluloses (Sharma-Shivappa & Chen, 2008). In addition, Wanassi et al. (2016) calculated the weight yield of fibers and found value of 61.20%. Fibers are basically composed of hemicellulose and cellulose, which are able of absorbing water, influencing water absorption and swelling properties of panels.

Although the addition of waste did not significantly affect water absorption, linear regression adjusted for thickness swelling showed significant increase (Figure 3).

This fact is related to the low density of cotton waste. Low density values mean higher volume of particles in panels with higher residue proportions, consequently greater swelling. The increase of 1% in the amount of cotton waste in panels provides an increase of 0.3814 and 0.4022% in TS2h and TS24h, respectively. Mendes et al. (2010) found an increasing trend for the thickness swelling values when evaluating the association of coffee husk and *Eucalyptus urophylla*. The TS24h values ranged from 26 to 34%, which were higher in comparison to those obtained in this study.

The mean apparent density values ranged from 0.52 to 0.55 g/cm³, which characterized panels as low density (up to 0.55 g/cm³) according to NBR 14810 standard (ABNT, 2013) (Table 4). The CS 236-66 standard (CS, 1968) stipulates maximum TS24h values of 30%, considering low density particleboards produced with UF adhesive. Therefore, all treatments obtained values below those determined by the standard. The low cotton waste density value resulted in a significant increase in compaction ratio values as the waste percentage in panels was increased. Particleboards exclusively composed of eucalyptus wood showed compaction ratio values below the ideal range of 1.3-1.6 recommended by Maloney (1993). The low density of particleboards, in addition to the high density obtained for eucalyptus wood caused this effect.

3.2. Mechanical properties of particleboards

Variation of the mean internal bond values as a function of the percentage of substitution of eucalyptus wood by cotton waste is shown in Figure 4. Linear regression was not significant at 5% significance level.

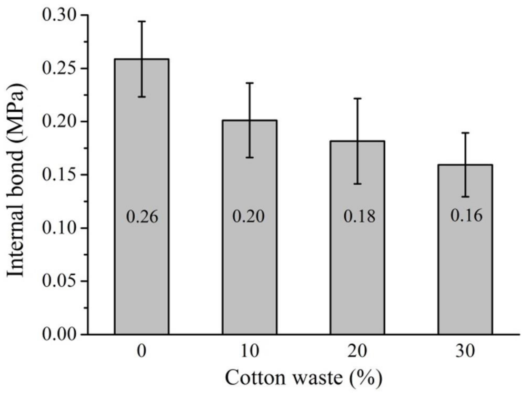

Figure 4. Internal bond of particleboards; Not significant at 5% significance level.

Table 4. Apparent density and compaction ratio of particleboards.

Cotton waste (%)	Apparent density (g/cm³)	Compaction ratio
0	0.53 ± 0.02* A	1.2 ± 0.04 A
10	0.54 ± 0.02 A	1.3 ± 0.05 B
20	0.55 ± 0.06 A	1.4 ± 0.09 C
30	0.52 ± 0.02 A	1.4 ± 0.06 C

*Standard deviation; Means followed by the same letter in the column do not differ statistically by the Scott-Knott test at 5% significance.

Considering low-density particleboards, Guler & Buyuksari (2011) found values close to 0.16 MPa for IB when evaluating particleboards produced with peanut husk. Similarly, Guler & Ozen (2004) obtained 0.25 MPa for particleboards produced with cotton stalk. Silva et al. (2016) found no significant effect on IB values associating castor husk to eucalyptus wood for particleboard production (from 0.91 to 1.1 MPa). The CS 236-66 standard (CS, 1968) establishes 0.14 MPa as minimum IB value considering low density panels produced with UF adhesive. Therefore, all treatments reached values established by the standard.

Variations in the mean modulus of elasticity (MOE) and modulus of rupture values (MOR) to static bending as a function of the percentage of substitution of eucalyptus wood by cotton waste are shown in Figures 5 and 6, respectively. Quadratic regression was significant at 5% significance level in both cases.

This result was due to the higher compaction ratio of panels with addition of cotton waste. As previously discussed, higher compaction ratios indicate higher number of particles per panel. Under these conditions,

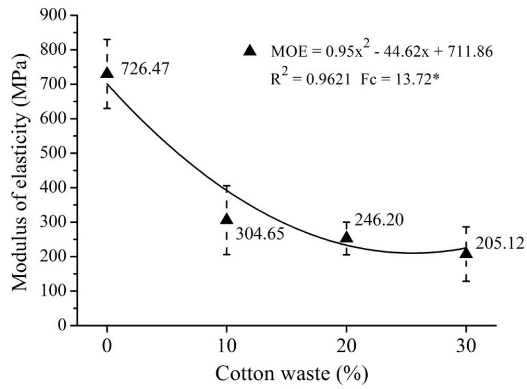

Figure 5. Modulus of elasticity of particleboards; *Significant at 5% significance level.

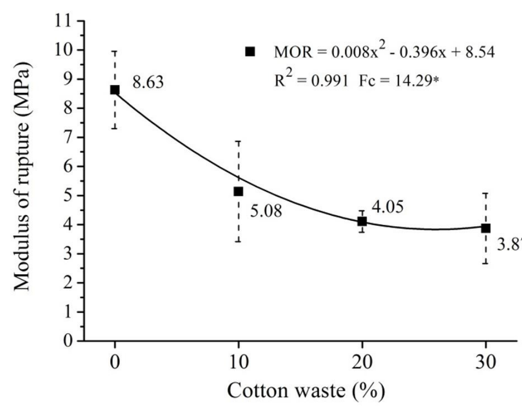

Figure 6. Modulus of rupture of particleboards; *Significant at 5% significance level.

the application of the same content of adhesive decreases its availability per particle, resulting in lower values for these properties. In addition, the low basic cotton waste density directly influences the cell wall thickness and therefore the strength and stiffness of the material. This may be another determining factor for the decreasing MOE and MOR values.

Scatolino et al. (2013) evaluated different proportions of maize cob in association with *Pinus oocarpa* wood for particleboard production (8% UF adhesive) and found the same trend observed in this research. Similarly, Mendes et al. (2012) added sugarcane bagasse to particleboards (25, 50 and 75%) and found values from 842.5 to 825.7 MPa and 11.4 to 9.5 MPa, respectively for MOE and MOR. Guler & Ozen (2004) found values of approximately 7.32 for MOR when evaluating particleboards added of cotton stalk. The MOE values were lower than the minimum value required by CS

236-666 standard (1968) (CS, 1968) (1052 MPa) for all treatments. When investigating the minimum value required for MOR (5.6 MPa) considering the same standard, the quadratic regression adjusted for this property indicates 9% as the limit for the addition of cotton waste in particleboards.

4. CONCLUSION

Particleboards were successfully produced associating several percentages of cotton waste to eucalyptus wood and their physical and mechanical properties were evaluated. The increased addition of cotton waste did not compromise the physical properties of particleboards; however, caused reduction of their mechanical properties. All treatments were consistent with CS 236-66 commercialization standard (1968) for thickness swelling and internal bond, considering low density particleboards. None of the treatments met the requirements of the standard for MOE, while the maximum cotton waste content that could be added to reach requirements for MOR is 9%. In general, particleboards with the addition of cotton waste may be indicated for the manufacture of some types of furniture such as doors and sides.

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