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Particleboard Panels Made from Sugarcane Bagasse: Characterization for Use in the Furniture Industry

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The objective of this study was to evaluate the physical and mechanical properties of commercial panels produced with sugarcane bagasse to investigate the possibility of us for the production of furniture. We evaluated industrial MDP (*Medium density particleboard*) panels made of *Eucalyptus* and *Pinus* by two Brazilian companies and an industrial MDP panel made from sugarcane bagasse, produced in China. We tested the physical characteristics of water absorption and thickness swelling of the panels after 2 and 24 h of immersion in water. To estimate the moisture content and density, we followed the procedure detailed in NBR 14810-3[1]. The mechanical properties were characterized by performing bending (moduli of elasticity and rupture), compression (moduli of elasticity rupture), internal bonding, screw pullout and Janka hardness tests. We found that panels made from sugarcane bagasse showed comparable with or superior physical and mechanical properties to those made from *Eucalyptus* and *Pinus*.

Keywords: *Sugarcane bagasse, panels, furniture industry*

1. Introduction

The furniture industry is characterized by the combination of several production processes that involve different raw materials and a broad variety of final products. This industry can be classified mainly according to the materials from which the furniture is made (for instance, wood and metal) or how the furniture is used (for instance, home and office furniture). The seven largest economies of the furniture industry (United States, Italy, Germany, Japan, France, Canada, and United Kingdom) produce approximately US$131 billion in furniture[2].

Silva[3] states that solid wood was the first raw material used to produce furniture, but the use of this material has become increasingly rare due to the reduction in the availability of timber. In the opinion of this author, reconstituted wood panels have taken the place of large timber as the main raw material in the furniture industry, as they allow more efficient use of wood. Between 80% and 90% of the particleboard panels produced are intended for furniture production.

With the growth of the wood panel industry due to the demands in the furniture industry, the search for new raw materials has also intensified. In this context, in addition to the increase in areas planted with species of *Eucalyptus* and *Pinus*, there is a search for new fast-growing species that can be used for furniture production and facilitate the development of new products.

Caraschi et al.[4] report that the agroindustry produces many residues that can be used for making particleboard panels such as lignocellulosic materials. Among agricultural residues, sugarcane bagasse has been highlighted due to its large-scale production. According to the data of the Food and Agriculture Organization of the United Nations[5], the amount of sugarcane produced in the world in 2010 was approximately 1711 trillion tons. This amount represents the generation of ~479 trillion tons of sugarcane bagasse, as according to the Sugarcane Research Center[6] each processed sugarcane ton generates 280 kg of residues.

Mendes et al.[7], Freire et al.[8], Tabarsa[9], Mendes et al.[10], Battistelle et al.[11], Barros Filho[12], and Widyorini et al.[13] have already assessed the use of sugarcane bagasse in the production of particleboard panels and their quality in comparison with panels made from other materials, and they found that boards made from sugarcane bagasse are very promising for furniture-based applications.

In addition to adding value to the residue, the production of particleboard panels with sugarcane bagasse may be able to satisfy the growing demand in the wood panel industry for raw materials. Furthermore, the production of particleboard panels with sugarcane bagasse may allow the industry to expand, reduce the use of timber (and thereby, reduce the pressure on forests), and reduce the costs of panel production; these properties have the potential to make such boards very competitive[14].

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With the high consumption of reconstituted wood panels by the furniture industry, the use of panels made from residues in the furniture production process becomes highly economically feasible. Hence, the objective of the present study was to assess the physical and mechanical properties of commercial panels made from sugarcane bagasse in order to investigate the possibility of using these panels for producing furniture.

2. Materials and Methods

2.1. Materials and obtainment of samples

We obtained five industrial MDP panels made from *Eucalyptus* and *Pinus* produced by two Brazilian companies and five industrial MDP panels made from sugarcane bagasse, which were produced in China.

These panels were sent to the Experimental Unit for Wood Panel Production (Unidade Experimental de Produção de Painéis de Madeira) located in the Federal University of Lavras, state of Minas Gerais, where the samples were removed with a sliding table circular saw. Next, the samples were placed in an acclimatization room with controlled conditions of temperature and humidity (20±2°C and 65±5% relative humidity) until reaching a constant mass.

To assess the quality of the sugarcane bagasse panels by comparing them with *Eucalyptus* and *Pinus* panels already used on a commercial scale for furniture production, the three panel types were characterized in terms of their physical and mechanical properties.

2.2. Physical characterization

To test water absorption (WA) and thickness swelling (TS) after 2 and 24 h of immersion and springback, we followed the ASTM D-1037 standard[15]. To estimate moisture content and bulk density, we followed the NBR 14810-3 standard[1].

2.3. Mechanical characterization

For the mechanical characterization of panels, we performed static bending modulus of elasticity (MOE) and *modulus of rupture (MOR), compression* (MOE and MOR*), internal bond, top and surface screw pullout, and Janka hardness tests, following the* NBR 14810-3 *standard*[1].

The static bending tests were performed with a universal testing machine (Time Group Inc.) with a capacity of two tons, which was equipped with a computerized system for the control of test variables and data collection.

2.4. Statistical analysis

For the data analysis, we used the Sisvar software. For the physical and mechanical characterization, we conducted an analysis of variance at 5% significance, with a post hoc Tukey test at 5% significance.

3. Results and Discussion

3.1. Physical characterization

3.1.1. Bulk density

The average values of bulk density of the industrial MDP panels made from *Eucalyptus*, *Pinus*, and sugarcane bagasse are presented in Figure 1.

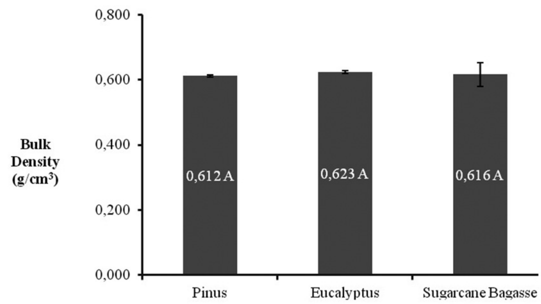

Figure 1: Average values of bulk density. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

The average values of bulk density measured for *Pinus*, *Eucalyptus*, and sugarcane bagasse panels were 0.612, 0.623, and 0.616 g/cm^3, respectively. The panels were classified as medium density panels, which refers to panels with bulk density between 0.60 and 0.80 g/cm^3 [16]. We observed no difference in density among the industrial panels.

The average values of bulk density for industrial panels found by Mendes et al.[17] were 0.683 g/cm^3 for *Pinus*, 0.655 g/cm^3 for *Eucalyptus*, and 0.669 g/cm^3 for sugarcane bagasse. The authors observed no significant difference among panels.

Despite the lack of a significant difference, sugarcane bagasse had a lower density compared with *Pinus* and *Eucalyptus*. When Mendes et al.[7] assessed the use of sugarcane bagasse for the production of particleboard panels, they found an average standard density value of 0.098 g/cm^3; whereas Barros Filho[18] obtained average values of 0.096 g/cm^3 for bagasse from a cane sugar mill and 0.099 g/cm^3 for bagasse from a *cachaça* distillery (locally known as *alambique*).

This ratio between panel density and raw material density, defined as the compression ratio, may directly affect the physicomechanical properties of particleboard panels[19,20].

3.1.2 Panel moisture content

The average values of moisture for the panels made from *Pinus*, *Eucalyptus*, and sugarcane bagasse are presented in Figure 2.

According to the results obtained, all treatments differed from each other. The *Pinus* panels showed the highest moisture value, followed by the *Eucalyptus* panels, and the sugarcane bagasse panels.

The sugarcane bagasse may have presented the lowest average value of moisture for two reasons. The first is related to the type of additives used for panel production;

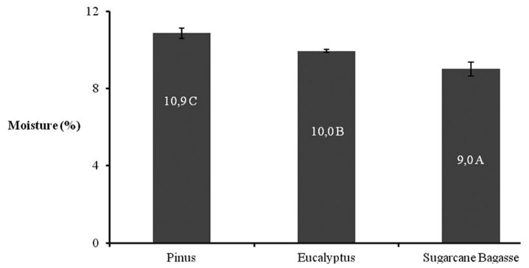

Figure 2: Average values of moisture. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

for example, the chemical formula of the urea-formaldehyde adhesive used in the production of particleboard panels made from sugarcane bagasse. The second is related to the chemical composition of the raw material, as the sugarcane bagasse in general presents higher values of extractives than wood, and this chemical compound may have decreased the moisture of panels[20,21].

Barros Filho[18] assessed the chemical composition of the sugarcane bagasse from a *cachaça* distillery and cane sugar mill for the production of particleboard panels and obtained average values of extractives of 11.1% and 9.1%, respectively. These values are above those commonly found for softwood (*coniferous wood;* 5% ± 3%*) and hardwood (locally known as madeira de folhosas;* 3% ± 2%*)*[22].

Melo et al.[23] assessed the physicomechanical properties of particleboard panels produced with different proportions of wood (*Eucalyptus grandis*) and rice husk. The values found for moisture varied from 8.3% to 8.6% among treatments.

The EN 312 trading standard[24] defines a suitable panel moisture value as that ranging from 5% to 13%. Hence, all treatments were within this range.

3.1.3 Water absorption

The average values of water absorption 2 (WA2h) and 24 h after immersion (WA24h) are presented in Figure 3.

For both WA times (2 and 24 h of immersion), the average values of all treatments differed from each other. In both cases (WA2h and WA24h), the *Pinus* panels showed the lowest average absorption values, whereas the sugarcane bagasse panels showed the highest average values.

The reason the sugarcane bagasse presents the highest average value of WA could be the low density of the material compared with *Pinus* and *Eucalyptus*. Therefore, a higher amount of particles per area is needed to form a panel mattress of predetermined density, which increases the availability of sorption sites and consequently the WA values.

Pedreschi[25] assessed the properties of industrial panels made from sugarcane bagasse and found average values of 10.7% for WA2h and 40.6% for WA24h. For the industrial panels made from *Eucalyptus*, the author found average values of 12.3% for WA2h and 35.5% for WA24h.

Souza et al.[26] assessed the physicomechanical properties of industrial and experimental panels made from *Pinus* and obtained average values of 14.5% for WA2h and 49.6% for WA24h for industrial panels.

Mendes et al.[7] studied the effect of the addition of sugarcane bagasse on the physicomechanical properties of particleboard panels made from *Pinus* spp. They found higher WA2h and WA24h values as the percentage of sugarcane bagasse was increased, with average values ranging from 32.1% to 54.1% for WA2h and from 49.8% to 64.2% for WA24h.

In general, the data obtained for industrial panels made from *Pinus*, *Eucalyptus*, and sugarcane bagasse are consistent with those reported in the literature, and in some cases, we obtained lower average values.

3.1.4 Thickness swelling and springback

The average values of thickness swelling 2 (TS2h) and 24 h (TS24h) after immersion and the average values of springback are presented in Figure 4.

The industrial panels made from *Pinus* differed from other panels in TS2h, presenting the lowest average value. There was no significant difference in TS between panels made from *Eucalyptus* and sugarcane bagasse.

The industrial panels made from sugarcane bagasse did not differ significantly from the panels made from *Pinus* and *Eucalyptus* in TS24h, but the panels made from *Pinus* and *Eucalyptus* differed significantly from each other in this property. The lowest average value was obtained for *Pinus* panels.

All treatments differed significantly from each other in springback. The *Pinus* panels showed the lowest average value, whereas the *Eucalyptus* panels showed the highest average value and a direct relationship with the property TS24h.

The high TS24h and springback values obtained for the *Eucalyptus* panels may be explained by a lower compaction ratio between particles, resulting in larger empty spaces and therefore better penetration of water in the panel structure. Figures 5 and 6 present the amount of empty spaces in *Eucalyptus* panels.

When comparing the quality of particleboard panels produced with sugarcane bagasse and *Eucalyptus*, Pedreschi[25] found average values of 3.1% for TS2h, 12.5% for TS4h, and 8.0% for springback for sugarcane bagasse panels. For the particleboard panels produced with *Eucalyptus*, Pedreschi[25] obtained average values of 5.8% for TS2h, 17.4% for TS4h, and 17.4% for springback.

Barros Filho et al.[12] assessed the quality of particleboard panels with sugarcane bagasse mixed with *Eucalyptus* using urea-formaldehyde and melamine-formaldehyde as adhesives and obtained average values between 7.0% and 26.5% for TS2h, 16.3% and 36.2% for TS24h, and 11.1% and 27.7% for springback.

Tabarsa et al.[9] assessed the potential use of bagasse as an alternative raw material for the production of panels and obtained values ranging between 15.1% and 18.1% for TS2h, and 22.6% and 24.5% for TS24h.

Mendes et al.[17] compared industrial panels and found average values for TS2h of 5.9% for *Pinus*, 1.8% for *Eucalyptus*, and 4.5% for sugarcane bagasse, and average values for TS24h of 19.7% for *Pinus*, 12.8% for *Eucalyptus*, and 12.0% for sugarcane bagasse.

The average values for the three types of panels studied here are consistent with the literature, and in some cases, we

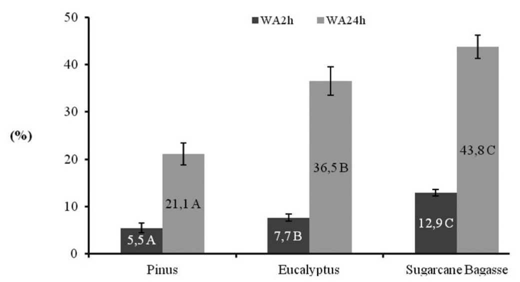

Figure 3: Average values of water absorption two and twenty-four hours after immersion. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

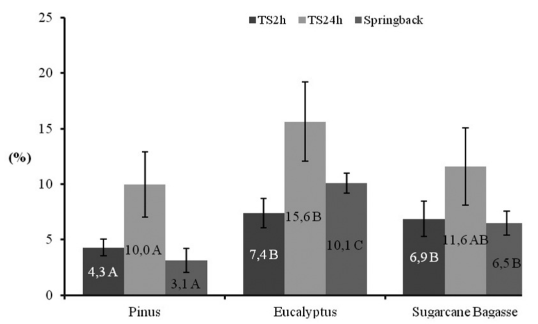

Figure 4: Average values of thickness swelling two and twenty-four hours after immersion and springback. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

obtained lower average values. However, the average values obtained for TS24h in all treatments did not meet the EN 312 standard[24], which defines a maximum value of 8%. All the panels met the Commercial Standard - 236-66[27], which dictates a maximum value of TS 24 h after immersion of 35%.

In general, we observed that in terms of the assessed physical properties, the particleboard panels made from sugarcane bagasse are inferior to the panels produced with *Pinus*. However, sugarcane bagasse panels are equal to or even superior to *Eucalyptus* panels in some properties. Hence, we may say that in terms of quality, sugarcane bagasse panels present properties in accordance with the panels commonly used for furniture production, and are, in terms of their physical properties, suitable for this use.

3.2. Mechanical characterization

3.2.1. Internal bond

The internal bond average values are presented in Figure 7.

The industrial panels made from *Pinus* and *Eucalyptus* did not show significant differences from each other, but differed from the panels made from sugarcane bagasse, which showed the lowest average values. The reason for the lowest average value of internal bond for the panels made from sugarcane bagasse may be related to the lower amount of adhesive available per particle. To obtain a particleboard panel with the same density using this residue, a larger number of particles is required, mainly due to the lower density of the material.

Mendes et al.[17] found average values of internal bond of 0.5 MPa for industrial panels made from *Pinus*, 0.6 MPa for panels made from *Eucalyptus*, and 0.2 MPa for panels made from sugarcane bagasse. Barros Filho et al.[12] assessed the quality of particleboard panels made from sugarcane bagasse mixed with *Eucalyptus* and by using urea-formaldehyde and melamine-formaldehyde as adhesives, and they obtained average values of internal bond ranging between 0.20 and 0.63 MPa.

In general, the characteristics of panels produced with *Pinus*, *Eucalyptus*, and sugarcane bagasse assessed in the present study are consistent with data from the literature. Only the treatments with *Pinus* and *Eucalyptus* met the minimum values established by the A 208.1[28] and NBR 14810-2 standards[29], which is 0.40 MPa, as well as the EN 312 standard[24], which sets a minimum value of 0.30 MPa.

3.2.2. Modulus of elasticity and modulus of rupture to static bending

The average values of the MOE and MOR *are presented in* Figures 8 and 9.

The industrial panels made from *Pinus* and sugarcane bagasse did not differ from each other in MOE and MOR for static bending. However, the *Eucalyptus* panels differed significantly from the other two treatments and showed the highest average value.

The highest MOE and MOR values obtained for the panels produced with *Eucalyptus* may be explained by the physical and anatomical characteristics of this material as well as by associations between these factors and variables of panel production.

The lower average value observed for panels produced with sugarcane bagasse compared with panels produced with *Eucalyptus* may result from the presence of medulla in sugarcane bagasse[30], which is a material with low mechanical resistance, and from the lower internal bond between particles, as observed in Figure 7.

Widyorini et al.[13] assessed the quality of particleboard panels produced with sugarcane bagasse with and without medulla in association with some processing variables and obtained MOE values between 400 and 1600 MPa and MOR values between 2 and 11 MPa for static bending.

Mendes et al.[7] assessed the effect of the percentage of addition of sugarcane bagasse to *Eucalyptus* (25, 50, and 75%) with different adhesive types (urea-formaldehyde and phenol-formaldehyde) and contents (6, 9, and 12%) on the production of particleboard panels. They obtained MOE values between 915.3 and 1064.7 MPa and MOR values between 9.5 and 11.5 MPa for static bending.

Mendes et al.[31] assessed different types of lignocellulosic materials produced in Brazil for the production of particleboard panels with urea-formaldehyde adhesive. For static bending, they obtained average MOE and MOR values of 1643.2 and 20.9 MPa for panels produced with sugarcane bagasse, 1622.6 and 19.9 MPa for panels produced with *Pinus*, and 1654.8 and 21.8 MPa for panels produced with *Eucalyptus*, respectively.

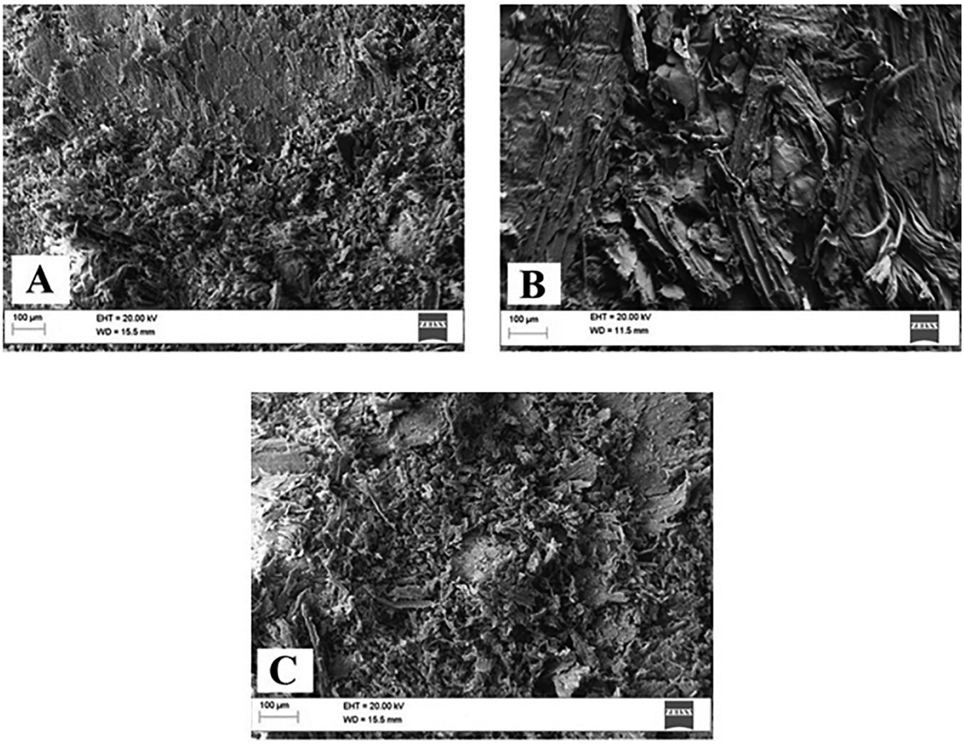

Figure 5: Scanning electron micrographs (SEM) (100µm) of the core of the panels A: *Pinus*; B: *Eucalyptus*; C: Sugarcane bagasse.

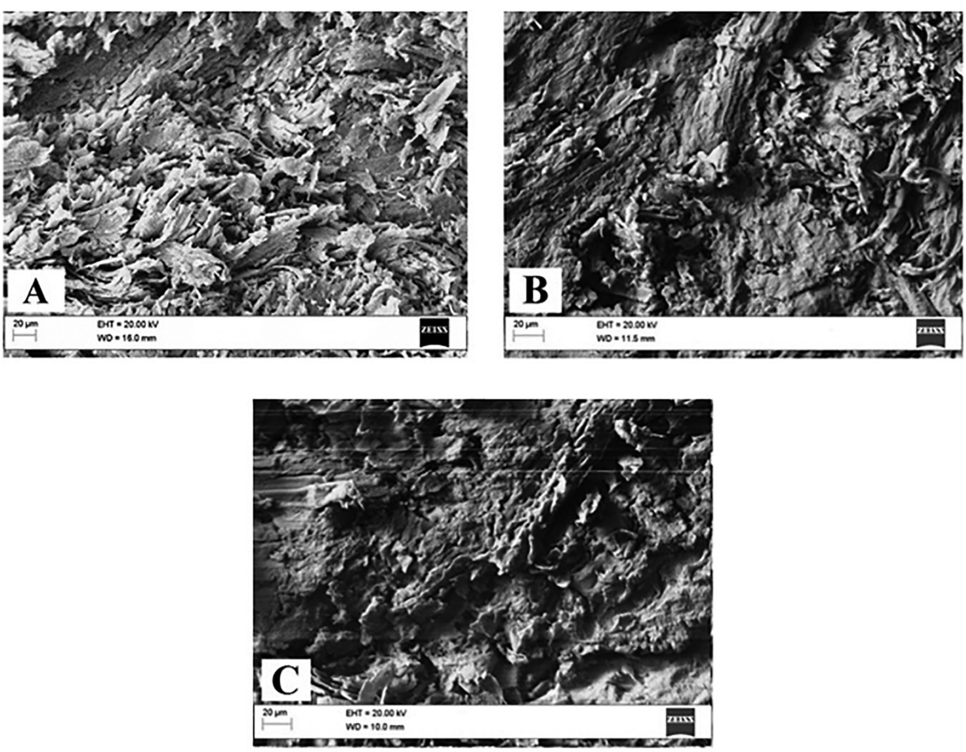

Figure 6: Scanning electron micrographs (SEM) (20µm) of the core of the panels A: *Pinus*; B: *Eucalyptus*; C: Sugarcane bagasse.

For static bending, the average values of MOE and MOR for the three types of panels assessed in the present study are consistent with the literature. All the panels met the ANSI A208-1 trading standard[28], which defines minimum values of 1943.8 MPa for MOE and 12.8 MPa for MOR, for standard panels (M-S). All the panels also met the EN

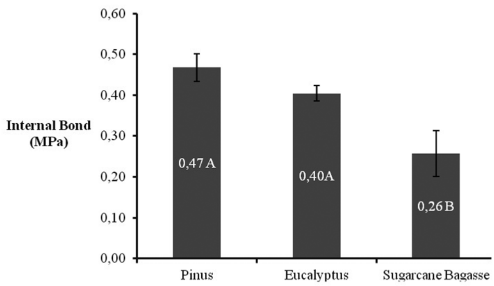

Figure 7: Average values of internal bond. Average values followed by the same letter did not differ from each other in the Tukey test at 5% of significance level.

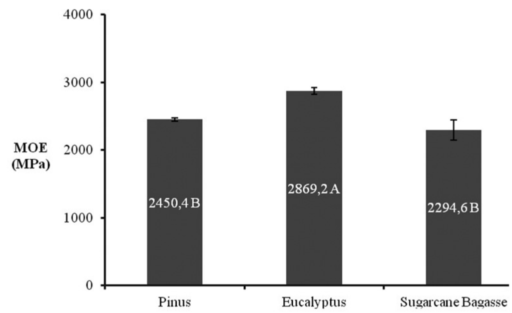

Figure 8: Average values of the modulus of elasticity (MOE) to static bending in MPa. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

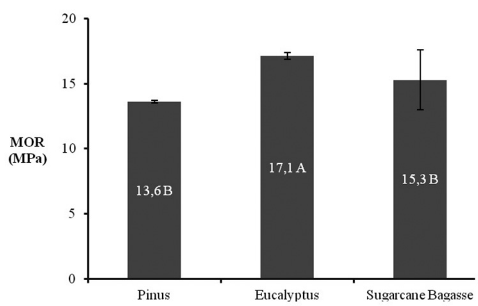

Figure 9: Average values of the modulus of rupture (MOR) to static bending in MPa. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

312 standard[24], which defines minimum values of 1800 MPa for MOE and 13 MPa for MOR for particleboard panels intended for internal use.

3.2.3. Modulus of elasticity and modulus of rupture for parallel compression

Figures 10 and 11 indicate average values for the MOE and MOR for compression.

The three types of panel differed significantly in both properties. The *Eucaliptus* panels had the highest average values, followed by *Pinus* panels and sugarcane bagasse panels, which had the smallest MOR and MOE values in the compression test. This may be explained by the lower

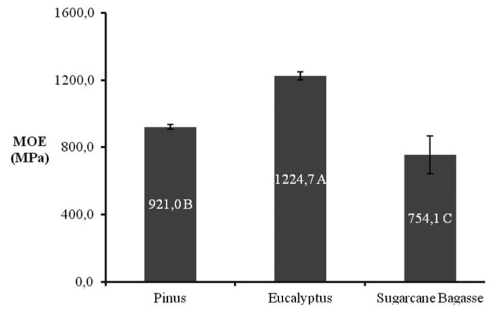

Figure 10: Average values of the modulus of elasticity (MOE) to compression in MPa. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

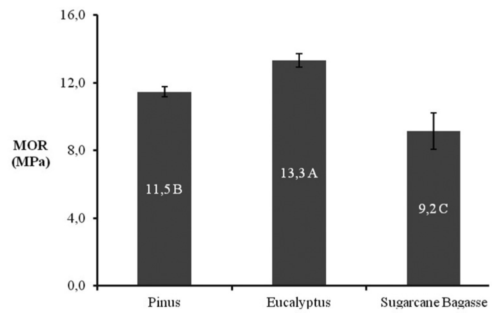

Figure 11: Average values of the modulus of rupture (MOR) to compression in MPa. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

density of sugarcane bagasse, which requires a larger volume of particles to produce a panel of predetermined density, which reduces the amount of adhesive per particle, and thus decreases the bond among particles (Figure 7) and consequently the parallel compression.

Iwakiri et al.[32] assessed particleboard panels of *Pinus* spp. produced with 8% of urea-formaldehyde adhesive, with densities between 0.60 and 0.90 g/cm³, and found average values of MOR for compression between 6.6 and 15.9 MPa, respectively.

Mendes & Mendes[33] produced particleboard panels made from sugarcane bagasse from industry and a *cachaça* distillery, with a nominal density of 0.70g/cm³ and by using a content of 9% urea-formaldehyde adhesive. The average value of MOR for compression was 6.2 MPa for the panel made from industrial sugarcane bagasse and 5.2 MPa for the panel made from sugarcane bagasse from the *cachaça* distillery.

Pedreschi[25] found average values of MOR for compression of 7.3 MPa for particleboard panels made from sugarcane bagasse. For the industrial particleboard panels made from *Eucaliptus*, the average value was 9.1 MPa.

In general, the average values of the three panels studied here are consistent with the literature.

3.2.4. Janka hardness

The average values for Janka hardness are presented in Figure 12.

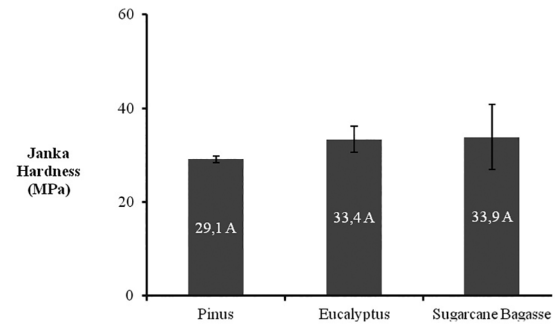

Figure 12: Average values of Janka Hardness in MPa. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

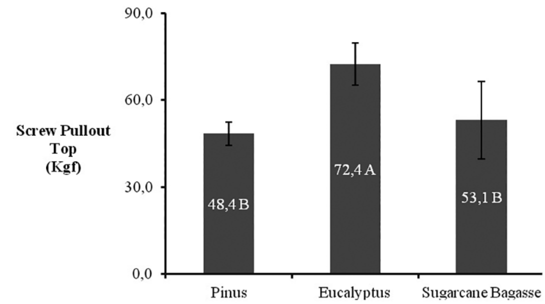

Figure 13: Average values of screw pullout – top in Kgf. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

There was no significant difference between treatments. However, we obtained higher average values for *Eucalyptus* and sugarcane bagasse panels. The higher average value for *Eucalyptus* panels may be explained by anatomical factors such as higher wall fraction, whereas the higher average value for sugarcane bagasse panels may be explained by a higher compaction ratio of the panels, as reported by Mendoza[34].

Bianche et al.[35] assessed the quality of particleboard panels produced with *Eucalyptus urophylla* and *Schizolobium amazonicum* woods mixed with broom fibers *(Sida* spp.) and 6% or 8% of urea-formaldehyde adhesive, and they obtained Janka hardness values between 34.1 and 50.5 MPa.

Milagres et al.[36] determined the properties of panels produced with 8% urea-formaldehyde adhesive with a mixture of particles of *Eucalyptus grandis*, high-and low-density polyethylene, and polypropylene. In the panels composed of wood only, the average value of Janka hardness was 49.6 MPa.

The trading standard ANSI A280-1[28] determines a minimum value of 22.7 MPa for Janka hardness of particleboard panels.

The average values obtained in the present study for the three types of panels were below the values reported in the literature but met the trading standard.

3.2.5. Screw pullout - top and surface

The average values of the top and surface screw pullout tests are presented in Figures 13 and 14, respectively.

The panels made from *Pinus* and sugarcane bagasse did not differ from each other in resistance to screw pullout, whereas the panel made from *Eucalyptus* differed significantly from the other two, as it had a higher average value.

In general, the average values obtained for screw pullout on the surface of panels were higher than the average values obtained for screw pullout on the top. This difference may be explained by a lower densification of the particles in the core of the panel by the smaller size of particles on the surfaces, which promotes their higher compaction, and by the density gradient created in the pressing of the panels.

Iwakiri et al.[37] assessed the quality of homogeneous and multilayer particleboard panels produced with the wood of

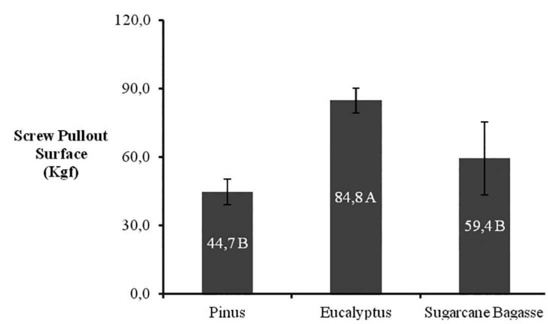

Figure 14: Average values of screw pullout – surface in Kgf. Average values followed by the same letter did not differ from each other in the Tukey test at 5% significance level.

Melia azedarach and *Pinus taeda* with 6%, 8%, and 10% of urea-formaldehyde adhesive. In multilayer panels, the average values ranged between 103.2 and 182.6 Kgf for screw pullout on the surface and between 75.4 and 174.2 Kgf for screw pullout on the top.

Weber[38] assessed the potential use of residues originated in the production of plywood panels, MDF (*Medium density fiberboard*), and MDP to produce particleboard panels with 6% and 10% of urea-formaldehyde adhesive and recorded average values for screw pullout on the surface between 73.2 and 117.7 Kgf and for screw pullout on the top between 58.0 and 132.0 Kgf.

Silva et al.[39] assessed the screw pullout of particleboard panels made from sugarcane bagasse mixed with *Eucalyptus* (25%, 50%, and 75%) and with 6%, 9%, and 12% of urea-formaldehyde adhesive. They found average values of screw pullout on the surface between 32 and 110 Kgf and for screw pullout on the top between 25 and 78 Kgf.

The ANSI A208.1 trading standard[28] defines a minimum value of 92 Kgf, whereas the NBR 14810-2 standard[29] defines a value of 81.6 Kgf.

The average values obtained in the present study for the three types of panels were close to or below those reported in the literature. No treatment met the value defined by the ANSI A208.1 standard[28], and only the *Eucalyptus* panels met the NBR 14810-2 standard[29].

4. Conclusion

We observed that the panels made from sugarcane bagasse were inferior to the panels made from *Pinus* in terms of their physical properties. However, they were equal or even superior to the panels made from *Eucalyptus* in some properties. The three panels met the CS 236-66 trading standard[27].

In a general analysis of all mechanical tests, we observed that the particleboard panels made from sugarcane bagasse were only inferior in terms of average values to those of *Pinus* and *Eucalyptus* for internal bond and MOE and MOR for parallel compression. For other properties, the performance of these panels was similar to those made from *Pinus* and *Eucalyptus*. The sugarcane bagasse panels did not meet the requirements of the standards for internal bond and screw pullout.

In general, we observed that the panels made from sugarcane bagasse showed physical and mechanical properties close or even superior to those measured for *Pinus* and *Eucalyptus* panels, which are commonly used for furniture production. Hence, we conclude that sugarcane bagasse panels have great potential for use in the furniture industry.

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6. Conflict of interest

The authors declare that they have no conflicts of interest.

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