Particleboard Based on Rice Husk: Effect of Binder Content and Processing Conditions

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ABSTRACT: In the development of materials based on renewable resources, the search for lignocellulosic substitutes for wood is one of the biggest challenges that academia and the particleboard and wood industries are facing. In this article, particleboards were processed using rice husk, an agricultural waste, as a substitute for wood. Rice husk without any further treatment was processed into particleboards using phenol-formaldehyde resin as binder. The effect of the processing parameters, pressure and binder content (BC) on the density, water absorption (WA), thickness swelling (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) was analyzed. The performance of the obtained panels was evaluated in comparison with the US Standard ANSI/A208.1. Particleboards with 11% of BC met the minimum requirements of MOR and MOE recommended by the ANSI specifications for commercial use, while particleboards with high BC (14%) also accomplished the requirements for industrial use, finding a resourceful use for this agricultural waste.

KEYWORDS: Flexural properties, natural materials, particleboard, physical properties, rice husk

1 INTRODUCTION

Particleboards are one of the primary products used in the building and furniture sectors [1]. These materials are manufactured under pressure, essentially by combining wood particles and/or other lignocellulosic fibrous materials with an adhesive [2]. The extensive use of particleboards can be related to the economic advantage of the low cost of wood raw material, inexpensive agents and simple processing [3]. The demand for these products has increased substantially throughout the world, representing 57% of the total consumption of wood-based panels, a percentage that is continuously growing at a rate of 2–5% annually [4, 5].

Approximately 95% of the lignocellulosic material used for particleboard production is wood. However, at the present time, environmental concerns have increased the interest in manufacturing sustainable materials based on renewable resources other than wood, like agricultural wastes [3, 4]. Agricultural wastes, such as wheat straw, fruit bunch, hazelnut shell and husk, peanut shell, kenaf, coffee husk, rice husk, rice straw, maize husk among others [1–3, 6–11], not only provide a renewable material source, but also generate a non-food source of economic development for farming and rural areas. One of these agricultural residues, which can be potentially used to produce particleboards, is rice husk (RH), the hard protective shell of the grain which is the main by-product of the rice milling process, a waste that represents 22% of rice production [12–14]. The Food and Agriculture Organization (FAO) had forecast that the rise in global rice trade would reach 742 million tons (milled basis) by 2015 [15]. In Argentina, according to the Ministry of Agriculture and Livestock (MAGyP), the rice production in the period from 2013–2014 was about 1582 thousand tons [16, 17]; and particularly in the North East region, the agricultural industries generate high amounts of this type of residue [16]. Rice husks and other lignocellulosic wastes in this region are used as fuel, animal bedding, or simply left in the field after harvest, causing environmental consequences. The use of this renewable source for industrial applications in the production of light boards can help to reduce the impact on the environment, providing economic dividends [18–20].

The basic components of rice husk are the same as wood but in different proportions [12, 16, 19–22]. The approximate composition of RH is cellulose

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(25–35%), hemicelluloses (18–21%), lignin (26–31%), inorganic compounds (15–17%), and soluble materials (2–5%) [21, 23]. In our previous research, soy protein concentrate-based (SPC) adhesives and rice husk were successfully used as raw materials for making medium-density particleboards, with appropriate mechanical performance, but low water resistance, which made them an alternative for indoor applications [23–25].

The main goal of this study was to produce rice husk-based particleboards for external applications, using phenol-formaldehyde resin as binder. Limited studies have explored the combined effect of processing parameters, such as pressure and binder content, on the properties of these boards. The effect of these processing parameters, mainly on the modulus of rupture and elasticity, needs to be studied further and understood before proposing any future technological applications. Therefore, the effect of the processing parameters, such as pressure and binder content, on density, water absorption, thickness swelling, flexural modulus and strength of the rice husk boards, were studied, and the performance of obtained panels was evaluated in comparison with the US Standard ANSI/A208.1 specifications for particleboards [26] in order to determine the density designation and grade of the obtained boards and establish a potential technological application.

2 EXPERIMENTAL

2.1 Materials

Phenol-formaldehyde (PF) (RESOL 472, Atanor, Argentina) was used as adhesive. The PF has a viscosity of 230 mPa.s at 20 °C, a solid content of 51 wt% and a gelation time of 30 min at 100 °C. Rice husk (RH) was supplied by a local rice mill in Entre Ríos, Argentina. The RH was dried at 100 ± 3 °C until constant weight and average moisture content was about 3–4%. Dried samples were stored in hermetically sealed glass boxes to prevent further moisture absorption.

2.2 Board Preparation and Testing Methods

Conventional single-layer particleboards were obtained by varying the adhesive content (BC) between 8% to 14% and the processing pressure (P) in the range of 0.28 MPa to 1.38 MPa, in order to study the effect of both variables on the board performance. Rice husk and PF were mixed for 15 minutes using an orbital paddle mixer (M.B.Z., San Justo, Buenos Aires, Argentina). The resinated mixture was placed in a steel mold (dimensions: 300 × 300 mm^2) and pressed at 130 °C for 20 min. The total mass was adjusted in order to obtain boards with a thickness of approximately 5 mm. After pressing them, the boards were trimmed to avoid edge effects and then cut for evaluation. Three replicates of each combination (adhesive content and pressure) were made, giving a total number of 27 samples. The specimens were conditioned at 20 °C and 65% relative humidity for seven days.

Density determinations were done on specimens with dimensions 50 × 50 × 5 mm^3. The same samples were dried until constant weight to calculate the initial moisture content (MC). Each value represents the mean of five samples.

Samples with dimensions 190 × 50 × 5 mm^3 were used to obtain the modulus of rupture (MOR) and modulus of elasticity (MOE) of boards. Three-point bending tests were performed on an Instron 4467 Universal Testing Machine (Buckinghamshire, England) according to ASTM Standard D 1037-93 in order to obtain the MOR and MOE of boards. The displacements in the load application point were measured with a linear variable differential transducer (LVDT) previously calibrated. Samples with dimensions 190 × 50 × 5 mm^3 were used. Each reported value represents the mean of nine specimens.

Preconditioned samples with dimensions 50 × 50 × 5 mm^3 were soaked in distilled water for 2 h and 24 h for determination of water absorption and thickness swelling (TS). Reported values were the mean of three samples.

Fracture surfaces of the different boards were observed with a Joel model JSM 6460-LV scanning electron microscope at an acceleration voltage of 15 kV. Surfaces were coated with a gold layer of approximately 100 Å to avoid charging under the electron beam.

3 RESULTS AND DISCUSSION

Average apparent density and initial moisture content values for boards manufactured with different BC and assembly pressures are shown in Table 1. All samples presented similar initial moisture content, around 5–6%. Particleboards with a wide range of density values were obtained (from approximately 550 to 950 kg/m^3), mainly affected by the processing pressure. Low-, medium- and high-density boards (LD, M and H, respectively) according to the classification defined by the US Standard ANSI/A208.1 [26] were obtained as the applied pressure increased from 0.28 MPa to 1.38 MPa. For a given binder content (i.e., 11 wt%), as the assembly pressure increased, average density increased from 576 kg/m^3 to 931 kg/m^3, due

Table 1 Physical, mechanical properties, ANSI designation and grade [26] for RH boards manufactured with different BC and assembly pressures.

P (MPa)	BC (%)	Density (kg/m^3)	MC (%)	MOR (MPa)	MOE (MPa)	ANSI designation [26][a]	ANSI grade [26][b]
0.28	8	553 ± 21	5.0 ± 0.2	4.6 ± 1.1	775 ± 117	LD	LD-1
0.28	11	576 ± 19	6.0 ± 0.2	6.7 ± 2.3	953 ± 230	LD	LD-1
0.28	14	589 ± 17	5.8 ± 0.2	8.5 ± 1.8	1392 ± 108	LD	LD-1, LD-2
0.83	8	799 ± 11	5.7 ± 0.1	10.1 ± 3.8	1253 ± 216	M	None
0.83	11	820 ± 10	5.8 ± 0.3	15.6 ± 4.9	2122 ± 226	M	M-1, M-S
0.83	14	831 ± 14	5.5 ± 0.1	21.5 ± 5.2	2624 ± 271	M	M-1, MS, M-2
1.38	8	896 ± 18	5.2 ± 0.2	16.1 ± 3.4	1889 ± 234	H	None
1.38	11	931 ± 8	5.7 ± 0.3	20.6 ± 5.3	2546 ± 247	H	H-1, H-2
1.38	14	956 ± 6	5.5 ± 0.2	22.4 ± 4.0	3836 ± 345	H	H-1, H-2

[a]LD: Low density; M: Medium density; H: High density
[b]LD-1 and LD-2: door core use; M-1 and M-S: commercial use; M-2: industrial use; H-1 and H-2: high-density industrial use.

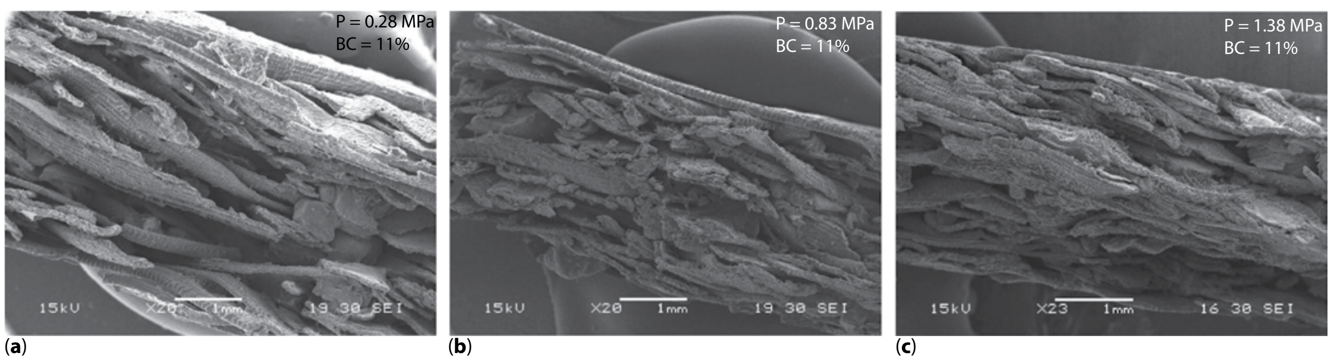

Figure 1 Structure of particleboards obtained with a BC of 11% and an assembly pressure of (**a**) 0.28 MPa, (**b**) 0.83 MPa and (**c**) 1.38 MPa.

to the development of a more compacted structure, as can be observed in SEM microphotographs (Figure 1). On the other hand, for a constant pressure, the increment in BC induces a slight increase in board density.

Flexural properties were evaluated as a function of consolidation pressure (P) and binder content (BC). The MOR and MOE (Table 1) increased as P or BC was augmented. The main parameters that influence the bonding performance, and as a consequence the mechanical properties, are the flow of the adhesive between the particles and its penetration around the particles. It is important to have a good flow and contact of the adhesive on the surface; if a larger area is covered it is possible to have stronger bonds [27]. At higher pressures or binder content the flow and contact among particles increase, thus improving the mechanical bonding performance [28–34].

Low-density boards met the minimum requirements of MOR and MOE recommended by the ANSI specifications for low-density, Grade 1 particleboards (LD-1), regardless of the binder content, and accomplish Grade 2 (LD-2) for boards with a BC of 14% [26]. LD-1 and LD-2 are generally intended to be used as door core [26]. Medium-density boards with the lowest binder content did not meet the minimum requirements recommended by the ANSI specifications. However, when BC was raised to 11% the boards resulted in MOR and MOE values high enough to meet the requirements for M-1 and M-S grades, which are grades for commercial medium-density particleboards [26]. Moreover, medium-density boards with the highest binder content accomplished the requirements for M-2 grade (industrial use) [26]. High-density boards with BC of 11% and 14% met the minimum requirements recommended by the ANSI specifications for high-density industrial use: H-1 and H-2 grades. On the other hand, high-density boards with the lowest binder content (8%) failed the MOR and MOE ANSI

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specifications [26]. This mechanical behavior is similar to the results reported in the literature using rice husk and other wastes as a replacement for wood, in particular for MD particleboards [4, 5, 11, 20, 35].

Figure 2 shows the WA after 2 h and 24 h of water immersion, as a function of binder content and pressure. The WA decreased as P or BC was increased. As was discussed above, the increment in both parameters leads to a more compacted structure. Since water can penetrate through capillary voids, the decrease in WA with the increment of BC or P is mainly attributed to the densification of the structure [28, 29]. In our previous work we showed that PF-bonded boards resulted in the lowest WA in comparison with urea-formaldehyde and soy-based adhesives [24]. These findings were attributed to the greater attraction of cellulose for PF oligomers rather than water molecules, which implies that PF oligomers are likely to displace water to adhere to the cellulosic material surface. If water resistance is important for particleboard applications, PF appears to be the preferred adhesive despite its higher cost [5, 10, 23, 24].

Thickness swelling as a function of binder content and processing pressure after 2 h and 24 h of immersion in distilled water is shown in Figure 2. The TS values after long periods of water immersion (24 h) were higher as BC or P were increased. Higher swelling ratio was reached at higher densities since there was more material (for the same thickness) available for water absorption. However, whereas high-density boards resulted in higher TS, WA decreased at higher densities because of limited void spaces, as observed in Figure 2 [28, 29].

By contrast, TS values at 2 h of immersion showed a different tendency, indicating that most compacted boards did not experience a complete swelling. It is clear that this behavior responds to the effect of density on the water absorption rate. In medium- and high-density boards the impregnation at 2 h was not completed. In addition, the higher bonding strength may have played a more important role than the compaction ratio during brief periods of time. Similar behavior at 2 h and 24 h was observed by Yalinkilic *et al.* [36] for particleboards with densities between 550 kg/m^3 and 750 kg/m^3. Also, all samples showed very low TS compared to rice husk particleboards obtained with urea-formaldehyde and soy-based adhesives [5, 24]. These particleboards have a better dimensional stability than panels obtained from other agro-industrial wastes. This fact may have been related to the silica content and the waxy water repellent cuticle that covers almost the entire outer layer of the RH [5]. The outer thin waxy layer of the RH particles also lowers their wettability, which may influence the bond quality of the water-based formaldehyde resins [11, 20].

4 CONCLUSION

Particleboards were manufactured using rice husk without any further treatment and phenol-formaldehyde resin as binder. Processing pressures of 0.28 MPa, 0.83 MPa and 1.38 MPa resulted in low-, medium- and high-density particleboards, respectively, according

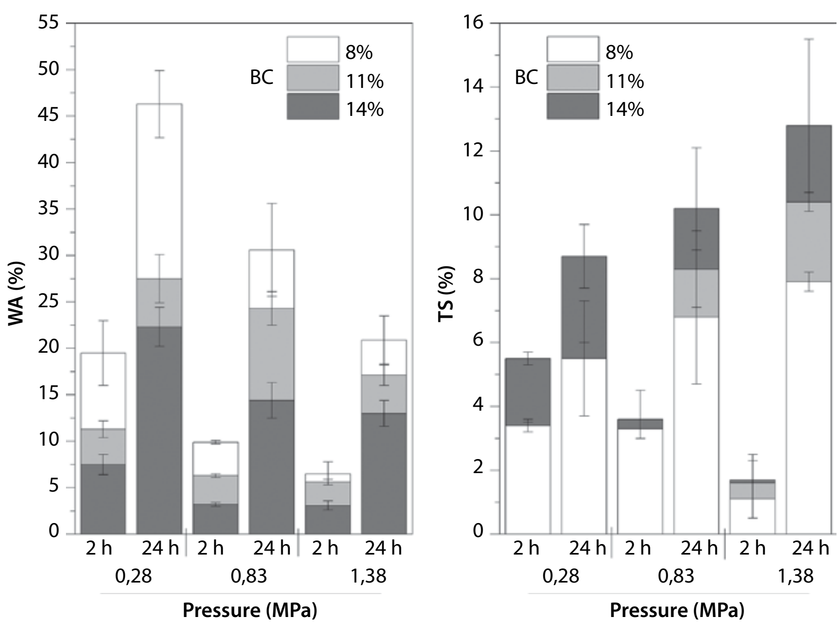

Figure 2 The WA and TS values obtained after 2 h and 24 h of water immersion as a function of BC and pressure.

to the ANSI specifications. Varying adhesive content from 8% to 14% resulted in particleboards that accomplished different grades of the US Standard ANSI/A208.1 specifications for particleboards. In general, particleboards with 11% of BC met the minimum requirements of MOR and MOE recommended by the ANSI specifications for commercial use, while particleboards with high binder content (14%) also accomplished the requirements for industrial use. An additional advantage of the use of rice husk in particleboard formulations is the valorization of a natural residue, which can be applied in ceiling boards or partition-wall for building, only by controlling the processing conditions, thus decreasing production cost.

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