Title
Particleboard quality characteristics of saline Jose Tall Wheatgrass and chemical treatment effect

Journal
Bioresource Technology, 98(6)

ISSN
0960-8524

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et al.

Publication Date
2007-04-01

Peer reviewed

Influence of Density, Initial Moisture Content, and Chemical Treatment on the Properties of Particleboard from Saline Jose Tall Wheatgrass

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Abstract

The objective of this research was to characterize the qualities (mechanical properties and water resistance) of particleboard made from saline Jose Tall Wheatgrass (JTW), *Agropyron elongatum*. The effects of NaOH treatment and adhesive type, including polymeric methane diphenyl diisocyanate (PMDI) and urea formaldehyde (UF) resins, on the qualities of finished particleboards were determined. Particleboards made with PMDI showed superior qualities compared with those made with UF, regardless of the use of NaOH treatment. The NaOH treatment deteriorated the qualities of the particleboards, but did not affect the contact angles between the adhesives and JTW. The results, also, showed that both mechanical strength and the water resistance were improved as particleboard density increased. Particleboard using the particles of 8% initial moisture content had the highest qualities.

Keywords: Jose Tall Wheatgrass, Particleboard, Polymeric methane diphenyl diisocyanate, Urea formaldehyde, NaOH treatment, Initial moisture content, Density, Quality, Mechanical strength, Water resistance, Contact angle

1. Introduction

The demand for glued-wood composite products, such as particleboard, medium-density fiberboard, and plywood, has recently increased dramatically throughout the world (Sellers, 2000; Youngquist, 1999). The Food and Agricultural Organization (FAO) of the United Nations reported that the worldwide consumption of particleboards was 56.2 million cubic meters in 1998 (Youngquist and Hamilton, 2000) with the 76 particleboard mills in North America producing 11 million cubic meters of particleboards, which accounted for 19% of the total wood composites produced (Sellers, 2000, 2001). Moreover, the demand for particleboards has continued to increase in demand in housing construction and furniture manufacturing sectors (Sellers, 2000). Currently, the annual wood consumption is about 0.36 billion cubic meters and is expected to reach about 0.47 billion cubic meters by 2010 (Kozlowski and Helwig, 1998). The high worldwide deforestation rate has caused consequent negative impacts on the environment. Therefore, increased interest has been seen in the production of particleboards from straw, plant, and other agricultural residues.

Agricultural residues provide renewable and environmentally friendly alternative biomass resources for easing the huge demand for woody materials (Kozlowski and Helwig, 1998; Sampathrajan et al., 1992). As a result, much research has been focused on making particleboards using rice straw, cotton stalks, sugar cane bagasse (Heslop, 1997; Pan and Cathcart, 2004), wheat straw (Han et al., 1998; Mo et al., 2003; Wang and Sun, 2002), sunflower stalks (Khristova et al., 1998), and maize husks and cobs (Sampathrajan et al., 1992).

Jose Tall Wheatgrass (JTW), *Agropyron elongatum* has a high tolerance to saline, saline-alkali or alkali soils, and it has been used as pasture, silage or "standing hay" for cattle and upland game cover and food, especially in the winter (Sharp Bros. Seed Co., 1997). It can also be used in the reclamation of saline-alkali lands. Currently, JTW is being grown in San Joaquin Valley (SJV), California to help manage saline subsurface drainage water in arid land irrigated agriculture by transpiring water and concentrating salt from drainage water. However, little information is available about the properties of saline herbaceous particleboards, which may have many potential applications. The composition of JTW used for this research was analyzed (Hazen Research, Inc., Golden, CO) and showed that JTW contained about 9% ash primarily comprised of SiO_2, Na_2O, and K_2O. The JTW also had oxidants, such as CuO, CrO_3 and As_2O_5. It has been reported that the presence of oxidants significantly improved the mechanical properties and dimensional stability of particleboard (Huang and Cooper, 2000; Nemli et al., 2004). Therefore, the JTW is expected to be a desirable raw material in particleboard manufacturing.

Wang and Sun (2002) and Papadopoulos et al. (2002, 2004) reported that the density of particleboards made from wheat straw, coconut chips, and bamboo chips significantly effected on the particleboard properties. The initial moisture content (MC) of raw materials could also significantly influence the quality of the particleboards. The tensile strength of particleboard decreased from 4888 kPa to 3967 kPa when the initial MC of wheat straw increased from 10% to 40% (Mo et al, 2001). In addition, particleboard quality depends on the properties of adhesives and their compatibility with fibers or particles. The contact angles between the outer surface of straw and the adhesives have been used as indicator of fiber/adhesive compatibility (Boquillon et al., 2004). Urea-formaldehyde (UF) is the major adhesive for wood-based particleboards, but it has a low compatibility with wheat straw, due to the relative high concentrations of extractives, such as wax and some alkaline substance on the surface of wheat straw (Heslop, 1997; Vick, 1999). Wheat straw particleboard bonded with polymeric methane diphenyl diisocyanate (PMDI) had mechanical properties 3-10 times better than that with UF (Heslop, 1997), but the cost of PMDI is about ten times that of UF (Cathcart, 2003; Zhang et al., 2003). This situation leads to considerably higher production costs for PMDI-bonded panels. Therefore, the price and type of adhesive are of concern in the particleboard industry (Zhou and Mei, 2000). The mechanical properties of wheat straw particleboards bonded by UF can be improved by removing wax and ash from the wheat straw surface through blanching with oxidizing agents and alkaline (e.g. H_2O_2 and NaOH, respectively) (Mo et al., 2003; Wu and Gatewood, 1998).

The objectives of this study were to (1) characterize the mechanical properties and water resistance of particleboard made from JTW as affected by adhesives (PMDI and UF), NaOH treatment, initial MC of JTW particles, and density of particleboards; and (2) determine the contact angles between the adhesives (PMDI and UF) and JTW (with and without NaOH treatment) and investigate the relationship between the contact angle and particleboard properties.

2. Material and Methods

2.1. Materials

The UF resin (C-TH39, 65.6% solid content) and PMDI (100% solid content) were used as adhesives for making the particleboards in this study. They were obtained from

Borden Chemical Company (Hope, AR) and Bayer Polymers LLC. (Pittsburgh, PA), respectively. Both ammonium sulfate [$(NH_4)_2SO_4$], used as curing agent, and sodium hydroxide (NaOH), used for washing treatment were purchased from Fisher Scientific Chemical Co. (Fair Lawn, New Jersey).

The JTW used in the study was collected from Red Rock Ranch (RRR) located on the Westside of the San Joaquin Valley (SJV), California. The as-received moisture content (MC) of JTW was determined to be about 11% (wet basis) according to ASTM standard method (D4442-92, American Society for Testing and Materials, 1997). All reported moisture contents in this study were on wet basis unless specified otherwise. The JTW was cut, field dried, and baled in May 2004, with an average straw length of 0.5 m. Bales were stored indoors in an un-air-conditioned building until used. Bales were milled into particles using a hammer mill (Model C269OYB, Franklin Co. Inc., Buffton, IN) equipped with a screen that has 0.32 cm openings. After milling, the fiber particles were classified into three groups based on the particle size, > 10, 10 ~ 40 and < 40 mesh, using a sieve shaker (RO TAP, The W. S. Tyler Company, Cleveland, OH) with corresponding sieves (Newark Wire Cloth Co.). The particles of 10 ~ 40 mesh were further dried to 8% MC using ambient air and then stored in plastic bags kept in the Biomass Laboratory at University of California, Davis, under 62±1% RH and 22±1°C until being used.

2.2. NaOH treatment for JTW

Bleaching has been used to remove wax and purify straw, which improves the compatibility between adhesive and fiber particle surfaces (Mo et. al, 2001, 2003; Wang and Sun, 2002; Wu and Gatewood, 1998). NaOH was used to remove the wax and ash from the JTW surface in this study. 1M NaOH solution was prepared with 50°C distill water. The JTW particles were soaked in NaOH solution at a ratio of 1:10 (g/ml) at 50 °C for 30 min. The treated JTW particles were washed three to five times using 50°C water until the pH of washing water reached about 7. The washed particles were then dried in ambient air to a MC of 8%.

2.3. Experimental design and data analysis

To determine the effect of density on the properties of JTW particleboard, the PMDI content and the MC of particles were controlled at 4% based on the dry weight of JTW particles and 8%, respectively. Five densities of the particleboards were studied: 0.71, 0.72, 0.73, 0.74 and 0.75g/cm^3. The results of density tests showed that the properties of particleboards with density of 0.73g/cm^3 were sufficient to meet the M-2 mechanical requirement for industrial usage. Therefore, a density of 0.73g/cm^3 was chosen for all the subsequent experiments unless specified otherwise.

Because MC was expected to have significant effect on the properties of finished particleboards, the initial MC of JTW particles were adjusted to 2%, 4%, 6%, 8% and 10% by oven drying and used to produce particleboards, using 4% PMDI and 0.73g/cm^3 density.

To determine the effect of adhesives and NaOH treatment of JTW on the mechanical strength and water resistance of particleboards, a 2×2 factorial experimental design was conducted for evaluating the qualities of particleboards. The two factors were PMDI and UF, with two levels of NaOH treated and non-treated particles. The UF and

PMDI resin contents were kept at 7% and 4%, respectively (Mo et al., 2003; Youngquist, 1999). The initial MC of particles and finial density of particleboards were 8% and 0.73g/cm^3, respectively.

For all the experiments described above, data were analyzed using a SAS software package (SAS Institute, Raleigh, N.C., 1992). Analysis of variance (ANOVA) and least significant difference (LSD) (α=0.05) were used to differentiate the treatment means. All reported values are the average of three replicates.

2.4. Particleboard manufacturing

Particleboards were fabricated according to the procedures outlined in the W*ood Handbook* (Youngquist, 1999). The UF or PMDI was mixed with the JTW particles using a mixer (Model KP267XBK; KitchenAid, Greenville, OH) for 8 min at room temperature. When UF resin was used, 1% (w/w) $(NH_4)_2SO_4$ based on the solid weight of UF was used as a curing catalyst. The particles with resin were then prepressed into a single layer mat in a 22.8cm×22.8cm wood mold.

To study the effect of density on the properties of particleboards, different densities were achieved by using the theory proposed by Yossifov (1988) to calculate the amount of resin and wood particles required to achieve a specific particleboard density for a given resin content. The prepressed mat was then put into hot press (Model 3891 Auto "M", Carver, Inc., Wabash, IN) to make the final particleboard. The hot press used removeable steel stops to achieve a constant volume (thickness) of particleboard. For PMDI particleboards, the pressure, temperature and time were set at 2 MPa, 140°C, and 8 min, respectively (Mo et al., 2003). For UF particleboards, 2 MPa, 160°C, and 4 min were used (Mo et al., 2003; Youngquist, 1999). The presence of both catalyst [$(NH_4)_2SO_4$] and the low viscosity of UF resin, reduced the processing time required for UF-bonded particleboards, compared to the PMDI-bonded particleboards (Harper, 1998; Xing, et al., 2004). The thickness of the finished particleboards was 0.53 cm. The particleboards were trimmed, to avoid edge effects, and then cut into various sizes for property evaluation.

2.5. Evaluation of particleboard properties

Mechanical properties, including modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), tensile strength (TS), water absorption (WA), and thickness swelling (THS).were evaluated to assess particleboard qualities. These properties were measured for each finished particleboard using the methods described in the following sections.

2.5.1. Mechanical properties

Finished particleboards were cut to various specifications according to ASTM standard method (D1037-99, American Society for Testing and Materials, 1999). Rectangular 3.8 cm×15.2 cm and 5.1 cm×17.8 cm pieces were used for TS determination and three point bending measurement of MOR and MOE, respectively. The 5.1 cm×5.1 cm pieces were used for IB measurement. Prior to testing, the specimens were conditioned for 72 hours in a Fisherbrand® Desiccator Cabinet maintained at 65% RH and 20°C to achieve equilibrium moisture content (EMC) of 3.9%, as per Rowell et al. (1995). The mechanical properties were determined using an Instron testing machine (Model 1122; Instron Corporation, Canton, MA) with movable crosshead speed of 4 mm/min for TS test and 5 mm/min for three point bending and IB tests.

2.5.2. Water absorption and thickness swelling

Water absorption and thickness swelling were determined according to the ASTM standard method (D1037-99, American Society for Testing and Materials, 1999). Particleboards were cut into 15.2 cm×15.2 cm squares and soaked in water at room temperature (20±2°C) for both 2 h and 24 h durations to determine short- and long-term absorption and thickness swelling properties, respectively. The thickness and weight of the particleboard samples were measured before and immediately after soaking and used to calculate the water absorption and thickness swelling, which were calculated based on the values before soaking.

2.5.3. Density of finished particleboard

The densities of the finished particleboards were obtained by measuring the average thickness, width, and length with digital calipers (500-196^{CE}, MyCAL CD-6CS, Mitutoyo Inc.) to calculate the particleboard volume. The board density was determined as the ratio of the mass of the board to the volume after the particleboard was conditioned at 65% RH and 20°C for 72 h.

2.6. Contact Angle Measurements

Contact angles between adhesives and JTW (treated and untreated) were measured to determine the compatibility between the adhesives and JTW particles, using a contact angle goniometer (Model 100, Ramé-hart Instrument Co.), under standard conditions (50% RH at 23°C) (Boquillon et al., 2004). Relatively large leaf sheathes of JTW flake were flattened and cut into 1 cm×3 cm rectangular pieces. Structurally, JTW differs from wheat straw. The inner surface of JTW leaf sheath is more visibly glossy than outer surface, which means the inner surface has more wax than outer surface. Therefore, the method described by Boquillon et al (2004) was modified and applied in this study. The outer surface was attached to 5 cm×5 cm square glass using epoxy resin. Immediately after attachment, 5 μl of resin was dropped onto the JTW inner surface by syringe. The contact angle between JTW inner surface and adhesives, UF or PMDI, was then observed over a 2 min period, with a measurement recorded every 5 s.

3. Results and Discussions

3.1. Effect of particleboard density

The mechanical properties and water resistance of particleboards increase significantly with the increase of particleboard density (Table 1). At constant volume, higher density particleboard has larger contact surface area between particles, making the adhesive function more effectively, compared with the lower density particleboard. In addition, high density particleboard has less void volume, which results in better water resistance. Choosing proper particleboard density is a very important step in particleboard industry, and proper level of density may be determined based on the intended application requirements (Youngquist, 1999). For example, particleboards with low density often are used as soundproofing materials. The JTW particleboard with density of 0.72g/cm^3 met the requirements of grade M-S particleboard for commercial usage based on the mechanical properties. Moreover, under the same board density (0.72g/cm^3) and PMDI content (4%), the mechanical properties of JTW particleboard, including MOR, MOE and TS, are comparable to those of wood, Athel tree (*Tamarix aphylla, L*) particleboard, whose respective MOR, MOE and TS are 19.6 MPa, 2052.4MPa and 11.59MPa (Zheng et al., 2005). But the IB of JTW particleboard is only 25% of IB of Athel tree particleboard. The JTW particleboard with density of 0.73g/cm^3 is strong enough to meet the M-2 mechanical requirement for industrial usage (Table 2) (CPA, 1999). Schneider et al. (1996) recommended property requirements for furniture boards of IB > 0.4MPa, THS (24h) < 25%, and WA (24h) < 60%. Therefore, the relative properties of JTW particleboards with density higher than 0.74g/cm^3 exceed the minimum recommended requirements for furniture boards.

3.2. Effect of particle moisture content

The initial MC of JTW particles had significant effects on the qualities of finished particleboards. When the initial MC increased from 2% to 8%, the properties of particleboard were improved (Table 3). However, as the MC increased from 8% to 10%, board qualities diminished. As MC varied from 8% to 10%, the MOR and MOE significantly decreased by 7.8 MPa and 757.4 MPa, respectively, and both TS and IB decreased by about 50%. These results are consistent with those of wheat straw particleboard reported by Mo et al. (2001) and Wang and Sun (2002). It appears that 8% MC was an optimal initial MC of the JTW particles for producing high strength particleboards with 4% PMDI.

The qualities of particleboards bonded by PMDI depend on both PMDI's affinity to water and its reaction with active hydrogen atoms that are present on the surface of JTW in the form of hydroxyl (–OH) groups (Simon et al., 2002). PMDI could not completely cure at initial MC less than 8%, because PMDI could not form necessary chemical bonds such as polyurethane covalent bonds, due to limited availability of water of JTW particles. However, at 10% MC, swelling and cracking in panels from the high water vapor pressure produced and accumulated in the particleboard during the hot press process was observed. The bonding strength of particleboards is reduced at high MC due to more isocyanate groups in the PMDI reacting with water than with JTW. The adverse effect of high MC of particles could be partially reduced by increasing the pressing time. Decreasing the pressure releasing rate can also help prevent panels from cracking, and reducing the size of finished particleboards may be effective in reducing water vapor build-up in the particleboards. Based on these results, 8% MC was used to study the effect of NaOH treatment on particleboard quality.

3.3. Effect of NaOH treatment

In general, particleboards manufactured from NaOH treated particles showed lower qualities than those made from untreated particles (Table 4). But there was no significant difference for either MOR of PMDI-bonded particleboard or IB of PMDI and/or UF-bonded particleboards. For PMDI-bonded particleboard, the MOE and TS significantly decreased by 570.5 MPa and 1.47 MPa, respectively, with NaOH treatment. The short and long term water absorption and thickness swelling, however, increased by about 200% compared to the particleboard with untreated particles (Table 4). Compared with PMDI-bonded particleboards, the quality changes of UF-bonded particleboards showed similar trends. These results did not agree with those found in the literature (Mo et al., 2001, 2003; Wang and Sun, 2002; Wu and Gatewood, 1998). It is believed NaOH may have reacted with some components of JTW, changing the surface and/or the internal structure of JTW, which prevented the adhesives from bonding with JTW particles effectively. NaOH treatment might have destroyed the capabilities of JTW to hold water during the hot-press and decreased the affinity between PMDI and JTW, which would have prevented PMDI from forming cross-linked polyureas with water in JTW and reduced the number of chemical binding sites. Meanwhile, NaOH treatment increased the pH value and buffer capacity of JTW, which inhibited the curing of the pH-sensitive UF, and led to a lower quality of UF-bonded particleboard (Sauter, 1996).

Regardless of NaOH treatment, the particleboards bonded with PMDI were of better quality than those bonded with UF at the tested adhesive levels (Tables 4). The MOR and TS of PMDI-bonded particleboard was about 3~4 times and 9~10 times, respectively, greater than those of the UF-bonded particleboards. The PMDI-bonded particleboards had much lower short and long term water absorption and thickness swelling compared to UF-bonded particleboards. PMDI was more effective in wetting the surface of the JTW than UF, which enhanced chemical bonding through hydrogen bonds and polyurethane covalent bonds. The isocyanate groups of PMDI could also react with water in the JTW to generate cross-linked polyureas for better mechanical bonding (Chelak and Newman, 1991). On the contrary, the water-based UF could not effectively wet the JTW surface, penetrate, and bond to the JTW hydroxyl groups due to the presence of hydrophobic and inorganic silica on the JTW surface (Hague et al., 1998).

3.4. Contact angle

Contact angle measurements between the JTW inner surface and the adhesives confirmed the results of Section 3.3 (Table 4). As shown in Figure 1, for untreated JTW, the initial contact angle of UF was 82° compared with 41° for PMDI, which indicates that the wettability of the JTW by PMDI was much higher than that by UF because the PMDI molecules were small and had both mechanical and chemical bonding abilities (Mo et al., 2001). The poor wetting between JTW and UF partially explains the poor particleboard qualities. For both adhesives, the contact angle reduction was 1° after 2 min, indicating a very low adhesive absorbed by the JTW. This could be attributed to the low wettability caused by extractives such as hydrophobic wax and inorganic silica at the JTW inner surface. After NaOH treatment, the initial contact angle was reduced by 2° and 12° for PMDI and UF, respectively. This indicates that the effect of NaOH treatment for UF was more significant than for PMDI. However, the quality of particleboards with treated particles was not improved even though the contact angle was decreased. For both PMDI and UF, the contact angle reduction was less than 1° after 2 min. This result indicates that the NaOH treatment did not enhance the wettability of the JTW surface.

4. Conclusion

The JTW is a suitable material for making high-quality PMDI-bonded particleboards. The properties of PMDI-bonded particleboards were improved as the density of finished particleboards was increased. Particleboards with density of $0.73 g/cm^3$ or higher exceeded the minimum mechanical property requirements for MOR, MOE, and IB for type M-2 particleboard for industrial usage, based on U.S. Standard ANSI/A208.1. In the tested range of initial particle MC (2% to 10%), 8% MC resulted in the best qualities of PMDI-bonded particleboards. The UF-bonded particleboards made from NaOH treated and untreated JTW had much lower qualities than boards bonded with PMDI. The results of contact angles between JTW and adhesives showed better compatibility between JTW and PMDI than that between JTW and UF. Regardless of board adhesive, NaOH treatment reduced the qualities of the particleboards.

Acknowledgement

The authors would like to thank the California Department of Water Resources for providing partial funding support and Red Rock Ranch for providing raw materials for this research. In addition, the authors would like to thank Dr. Kuhl (Chemical Engineering and Material Science, University of California, Davis) for providing contact angle goniometer for compatibility determinations.

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Figure caption

Figure 1. Contact angle between JTW inner surface and UF or PMDI

Table 1. Properties of particleboard with different densities*

Density (g/cm^3)	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h)(%)
0.71	12.4±0.4e	1710.2±1.8e	9.39±0.03e	0.25±0.03e	19.67±0.03a	57.13±0.04a	19.04±0.06a	40.45±0.08a
0.72	16.6±0.3d	1936.8±1.3d	10.26±0.15d	0.41±0.03d	19.05±0.25b	55.82±0.41b	16.07±0.12b	39.49±0.51a
0.73	18.1±0.2c	2291.3±1.8c	11.08±0.04c	0.62±0.03c	15.21±0.24c	44.51±0.55c	13.30±0.55c	26.74±1.02b
0.74	19.6±0.2b	2313.3±2.8b	12.93±0.07b	0.78±0.03b	14.62±0.12d	40.65±1.01d	10.45±0.06d	22.05±0.07c
0.75	21.7±0.4a	2380.1±1.6a	13.66±0.31a	1.04±0.06a	13.07±0.14e	36.93±0.14e	9.20±0.08e	20.55±0.78c

* Data are mean ± standard deviation of triplicates tests (n=3); values within the same column followed by different letters are significant different at $P<0.05$; Initial MC – 8%; PMDI resin content - 4%; Particles – untreated; WA – water absorption; THS - thickness swelling.

Table 2. IB, MOE, MOR and thickness swelling values required to meet ANSI A208.1

Usage	Grade*	MOR (MPa)	MOE (MPa)	IB (MPa)	THS (%)**
Commercial	M-1	11.0	1725	0.4	8
Commercial	M-S	12.5	1900	0.4	8
Industrial	M-2	14.5	2225	0.45	8
Industrial	M-3	16.5	2750	0.55	8

* M-1 and M-S are for commercial usage and M-2 and M-3 are for industrial usage.

** THS standard is special for manufactured home decking particleboard.

Table 3. Particleboard properties made from JTW particles with different initial MC*

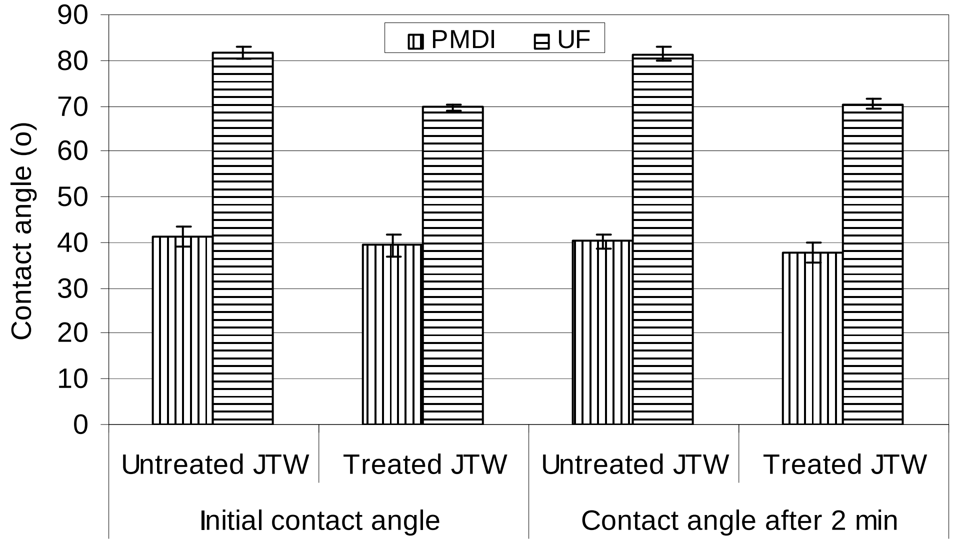
MC (%)	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h) (%)
2	13.3±0.7d	1683.5±2.7d	7.93±0.02c	0.43±0.02c	25.79±0.10a	64.04±0.57a	18.20±1.01b	46.19±1.71a
4	15.9±0.5b	1854.6±2.4c	8.55±0.04b	0.49±0.05bc	20.96±0.64b	58.94±0.60b	16.87±0.32bc	40.41±0.58b
6	16.5±0.5b	2017.5±5.0b	10.98±0.11a	0.53±0.04ab	18.26±0.08c	52.35±1.01c	15.46±0.64c	37.10±0.56c
8	18.1±0.2a	2291.3±1.8a	11.08±0.04a	0.62±0.03a	15.21±0.24d	44.51±0.55d	13.30±0.55d	26.74±1.02d
10	10.3±0.6c	1533.9±2.8e	5.29±0.05d	0.31±0.01d	26.64±0.57a	64.79±0.58a	20.22±0.98a	41.66±1.51b

* Data are mean ± standard deviation of triplicates tests (n=3); values within the same column followed by different letters are significant different at $P<0.05$; Particleboards: 4% PMDI, density of 0.73g/cm^3, untreated particles.

Table 4. Effect of NaOH treatment on particleboard mechanical and water resistance properties*

Adhesives	Treated method	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h) (%)
PMDI	Untreated	18.1±0.2a	2291.3±1.8a	11.08±0.04a	0.62±0.03a	15.21±0.24a	44.51±0.55a	13.30±0.55a	26.74±1.02a
	NaOH	18.9±0.2a	1720.8±4.4b	9.61±0.06b	0.61±0.05a	34.33±0.25b	90.40±0.57b	24.27±0.78b	47.25±2.61b
UF	Untreated	6.1±0.6b	1312.9±4.8c	1.98±0.08c	0.13±0.04b	65.48±0.21c	139.84±0.41c	55.13±0.37c	94.13±2.64c
	NaOH	4.4±0.4c	1256.6±1.1d	1.09±0.04d	0.13±0.01b	89.16±1.53d	161.03±0.26d	67.28±0.85d	101.44±1.91d

* Data are mean ± standard deviation of triplicates tests (n=3); values within the same column followed by different letters are significant different at $P<0.05$; PMDI-4%; UF - 7%; Particle initial MC - 8%; Particleboard density - 0.73g/cm^3.


PMDI
UF
Contact angle (o)
90
80
70
60
50
40
30
20
10
0
Untreated JTW
Treated JTW
Untreated JTW
Treated JTW
Initial contact angle
Contact angle after 2 min

Influence of Density, Initial Moisture Content, and Chemical Treatment on the Properties of Particleboard from Saline Jose Tall Wheatgrass

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Figure 1. Contact angle between JTW inner surface and UF or PMDI