Use of Scrap Particleboard to Produce Recycled Particleboard

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Recycling is presently the most environmentally friendly approach that deals with wood waste. Each year a huge amount of particleboard completes its service life and needs to be disposed of or recycled. Scrap particleboard has the potential to be reused as raw material for particleboard production. A crucial step for producing particleboards using scrap particleboards is to break down urea-formaldehyde (UF) resins in the scrap particleboards to obtain separated particles. In this study, liquid hot water (LHW) pretreatment was employed to decompose the UF resins to detach and recover wood particles from the scrap particleboards. The recovered wood particles and fresh industrial wood particles in different proportions were used as the raw material for the particleboard. The physical and mechanical properties of the recycled particleboards were evaluated. The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) of the recycled particleboards were lower than those of the particleboards made with fresh wood particles. However, the 2 h thickness swelling (TS) of the recycled particleboards was better than that of the fresh particleboards, indicating that the recycled particleboards were more dimensionally stable. The mechanical properties of the particleboards containing up to 40% recycled wood particles met the minimum Chinese National Standard requirements for general-purpose particleboards. Conclusively, scrap wood particleboards could be utilized as raw material in particleboard production.

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INTRODUCTION

Particleboard is an engineered wood product produced from wood particles bonded with a synthetic resin or another suitable binder and then hot-pressed at a certain pressure and temperature. Urea-formaldehyde (UF) is the most used resin adhesive for particleboard production because of its low cost, water-solubility, ease of use, thermal properties, low cure temperature, and high performance (Hashim *et al.* 2010). Particleboards are widely used as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, countertops, and desktops (Akinyemi *et al.* 2019; Nuryawan *et al.* 2020). The demand for particleboard has grown steadily annually, leading to concerns regarding natural wood resources that are consumed to meet the rising demand and its impact on the environment (Baharuddina *et al.* 2023; Basboga *et al.* 2023).

Meanwhile, a large number of particleboards go out of use every year (Wan *et al.* 2014). These scrap particleboards are mostly dumped in landfills or burnt in a boiler, releasing volatile organic compounds into the environment, doing damage to human health, and polluting the environment (Akinyemi *et al.* 2019; Zimmer and Bachmann 2023). A possible solution to these issues is to recycle and reuse these scrap particleboards to produce value-added particleboards. Using recycled particles to make particleboards can relieve the shortage of raw materials, reduce environmental pressures, and contribute to the realization of a circular economy (Zeng *et al.* 2018).

Researchers have attempted to recycle the scrap particleboards for particleboard manufacture (Lykidis and Grigoriou 2008; Azambuja *et al.* 2018; Nuryawan *et al.* 2020). A crucial step for producing particleboards using scrap particleboards is to break down or remove the UF resins from the scrap particleboards to obtain separated particles (Lubis *et al.* 2018; Nuryawan *et al.* 2020). Hot water soaking at atmospheric pressure (Lubis *et al.* 2018a, 2018b; Zeng *et al.* 2018), aqueous hydrochloric acid solutions soaking (Nuryawan *et al*. 2020), impregnating in a solution consisting of urea, ammonia, and soda (Boehme and Michanickl 1998), steaming (Lykidis and Grigoriou 2008; Hagel and Saake 2020), and steam explosion (Qi *et al.* 2006; Wan *et al.* 2014) pretreatment have been employed to hydrolyze and remove the UF resin from scrap wood composite panels. However, these pretreatment processes comminute the scrap particleboard by grinding or hammermilling. Although comminution of the scrap particleboard promotes decomposition of the UF resin bond, it has a negative effect of severely reducing the fiber length of the particles, by an average of 30% reduction in the fiber length. As the fiber length of the particles directly influences the mechanical properties of the particleboard, the particles with severely shortened fiber lengths resulted in particleboards with weak mechanical properties (Qi *et al.* 2006; Wan *et al.* 2014).

The liquid hot water (LHW) pretreatment, also known as thermo-hydrolytic pretreatment, which employs compressed hot water instead of steam to treat biomass at elevated temperatures for several seconds to several minutes, is used mainly to degrade hemicellulose and partly remove lignin for bioethanol production (Mosier *et al*. 2005; Wan and Li 2011). At high pressure and temperature, water can penetrate the biomass and weaken the fiber structure (González *et al.* 2014). The LHW pretreatment does not use any chemicals and is viewed as an environmentally friendly approach (Luo *et al*. 2020). Although studies on the LHW pretreatment of waste particleboards have not been found in the literature, studies of LHW pretreatment were found to be an effective approach for the disintegration of lignocellulose biomass (Luo *et al.* 2020; Rezania *et al.* 2020), which is much more difficult than removing the UF resin from the particleboards. It has been reported that grave fiber breakage and considerable fiber length reduction of the recycled particles resulting from the pretreatment process, render the particleboard made with the recycled particles with weak mechanical properties (Qi *et al.* 2006; Wan *et al*. 2014). To avoid or minimize damage to the particles by the pretreatment process, this work employs the LHW process to pretreat the scrap particleboards to decompose the UF resins without mechanical comminution.

To prevent severe degradation of thermally unstable hemicelluloses, milder LHW pretreatment temperature of 140 °C was adopted in this study. This study aimed to evaluate the feasibility of producing particleboard with wood particles recovered from the LHW pretreated scrap wood particleboards.

EXPERIMENTAL

Raw Materials

The industrial wood particles used were mixed hardwood species provided by Gushang Particleboard Corporation (Tianjin, China).

The waste desks made from wood particleboards were collected from a refuse site on the campus of Tianjin University of Commerce (Tianjin, China). The waste desks were dismantled into individual pieces of particleboard after manually removing the metal accessories. The waste particleboards were first cleaned of dirt and then sawed into strips 60 mm in width. The initial moisture content of the particles was approximately 7.21%.

Liquid Hot Water Pretreatment

The scrap particleboards were bonded with UF resin, which is well-known and susceptible to boiling water and steam. Hence the LHW approach was employed to dissociate particles of the scrap particleboards in this work. The weighed samples were put in a 15-L batch rotary stainless steel cylindrical autoclave using a 1:3 g/mL solid-to-water ratio. The pretreatment temperature was 140 °C, and the residence time was 30 min. At the end of pretreatment, heating was stopped, and steam was released gradually. When reaching atmospheric pressure, the autoclave was discharged. Due to the impacts of liquid hot water as well as saturated steam, the bonds between the UF resin and the wood particles were disrupted, and the particleboards were dissociated into separate particles. The coated veneers were removed manually from the particles. The particles were oven-dried to 2% to 3% moisture content at 100 °C. Undersized particles were removed manually *via* a screen with 0.8 mm mesh.

Particleboard Fabrication

The commercial UF resin used in this work was purchased from Zhengzhou Kaibang Chemical Products Corporation (Zhengzhou, China). The UF resin was water-dispersed to a solid content of 65%. One percent (based on resin solids) of ammonium chloride was put into the resin as a hardener. The UF resin was uniformly sprayed onto the particles in a mixer with a pneumatic atomizing nozzle. The proportions of UF resin and paraffin were 10% and 1%, respectively, based on the oven-dried weight of the particles.

The single-layer particleboard mats were hand-formed using a laboratory aluminum mold. The mats were hot-pressed at 160 °C for 640 s with a pressure of 3.5 MPa. The board size was 300 mm × 300 mm × 16 mm with a target density of 700 kg/m^3. The LHW pretreated waste wood particles were added in different proportions to the industrial particles (Table 1). For comparison, control particleboards were also made from industrial particles alone. Three replicate panels were fabricated for each condition.

Table 1. Experimental Design

Panel Type	Raw Material	
	Waste Wood Particles (%)	Industrial Wood Particles (%)
A	0	100
B	10	90
C	20	80
D	30	70
E	40	60
F	50	50

Particleboard Evaluation

The particleboards were conditioned under 65% relative humidity and 20 °C for about 2 weeks before being sawn into test specimens. Then, the specimens were tested in line with the China National Test Standard GB/T 17657 (1999) for density, internal bonding strength (IB), modulus of rupture (MOR), modulus of elasticity (MOE), 2 h thickness swelling (TS). The data obtained were statistically analyzed using analysis of variance (ANOVA) and Duncan's mean separation tests with SPSS software (SPSS Inc., Version 19, Chicago, IL, USA).

RESULTS AND DISCUSSION

Table 2 reveals the results of the mechanical properties of the produced particleboards.

Table 2. Properties of Particleboards Made from Scrap and Industrial Wood Particles

Board Type	Actual density (kg/m^3)	MOR (MPa)	MOE (MPa)	IB (MPa)	2 h TS (%)
A	721	16.75 ± 1.28 a	3939.17 ± 383.5 a	0.62 ± 0.055 a	2.86 ± 0.26 a
B	709	15.86 ± 1.54 ab	3466.52 ± 354.8 a	0.55 ± 0.051 a	2.67 ± 0.25 ab
C	718	14.72 ± 1.31 abc	2957.2 ± 282.5 b	0.43 ± 0.045 b	2.59 ± 0.24 ab
D	677	13.81 ± 1.27 abc	2511.5 ± 230.0 bc	0.36 ± 0.035 b	2.52 ± 0.23 ab
E	689	12.76 ± 1.19 bc	2073.3 ± 209.6 cd	0.27 ± 0.029 c	2.43 ± 0.24 ab
F	686	11.63 ± 1.17 c	1660.6 ± 170.2 d	0.21 ± 0.025 c	2.38 ± 0.22 b
	Data shown are mean ± standard deviation; different letters in the same column indicate significant difference at $P < 0.05$				

The results suggested that the MOR and MOE values of the particleboards decreased significantly with increasing of the recycled particle content in the mixture. The particleboard made with 100% industrial wood particles demonstrated the highest MOR (16.8 MPa) and MOE (3940 MPa) values. Zeng *et al.* (2018) observed a similar phenomenon when making recycled medium-density fiberboard using boiling water of 100 °C at atmospheric pressure to dissociate fibers of the waste medium-density fiberboard. The decrease in MOR and MOE is related mainly to the reduction in the length of wood particles resulting from the hydrolytic degradation after hydrothermal processes (Moezzipour *et al.* 2017; Zeng *et al.* 2018). The decrease in lignin and hemicellulose contents was responsible for the decrease in the length of the wood particles (Moezzipour *et al.* 2017). The minimal requirement of MOR for general purpose, and furniture and interior fitments are 11.5 and 13 MPa according to GB/T 4897.2 (2003), and GB/T 4897.3 (2003), respectively. Average MOR values of all the particleboard produced satisfied the minimum requirements for general purpose use, while A, B, C, and D type particleboards satisfied the minimum requirement for furniture and interior fitments. The minimal requirement of MOE for furniture and interior fitments is 1600 MPa by GB/T 4897.3 (2003). All the particleboards produced had MOE higher than the requirement for furniture and interior fitments. The MOR and MOE values of the particleboards made with incorporation of the LHW pretreated wood particles were considerably better compared to other pretreatment processes reported (Boehme and Michanickl 1998; Qi *et al.* 2006; Lykidis and Grigoriou 2008; Wan *et al.* 2014; Lubis *et al.* 2018a, 2018b; Zeng *et al.* 2018; Hagel and Saake 2020; Nuryawan *et al.* 2020). The less damaged particles resulting from the LHW pretreatment should be responsible for the improvement of the MOR and MOE values.

The IB values of the produced particleboards ranged from 0.21 to 0.62 MPa. The highest IB value was observed for particleboard made with 100% industrial wood particles. The increase of the recycled wood particle content in the particleboards lowered the IB values. Similar observations were reported by Lykidis and Grigoriou (2008) and Zeng *et al.* (2018). They reported that there were small quantities of paraffin and cured UF resin that remained on the surface of the recycled wood particles after steam and hot water soaking pretreatment. The small quantity of cured UF resin that remained on the surface of the recycled wood particles might interfere with the interface bonding of wood particles. As a result, the IB strength of the particleboards made with the recycled wood particles showed decreased IB values. The IB minimal requirements for general purpose and furniture and interior fitments are 0.24 and 0.35 MPa according to GB/T 4897.2 (2003) and GB/T 4897.3 (2003), respectively. Particleboard types A, B, C, D, and E satisfied the minimum IB requirements for general purpose use and particleboard types A, B, C, and D satisfied the minimum IB requirements for furniture and interior fitments required in the Chinese National Standard GB/T 4897 (2003). It was noted that IB values of the particleboards made with incorporation of the LHW pretreated wood particles were considerably improved in comparison to other pretreatment processes reported (Boehme and Michanickl 1998; Qi *et al.* 2006; Lykidis and Grigoriou 2008; Wan *et al.* 2014; Lubis *et al.* 2018a, 2018b; Zeng *et al.* 2018; Nuryawan *et al.* 2020; Hagel and Saake 2020). This improvement in IB values could be attributed to the mild severity of the LHW pretreatment without comminution, which made the recycled particles less damaged.

The particleboards made with the incorporation of recycled wood particles showed their 2 h TS lower than that of particleboards made with 100% industrial wood particles. Enhancing the recycled wood particle content in the particleboards led to a decreased 2 h TS value. The current result was consistent with the studies of Zeng *et al*. (2018) and Zimmer and Bachmann (2023), who declared that hydrothermally pretreated wood particles contain less hemicellulose compared to fresh wood particles. The lower hemicellulose content potentially decreases water absorption and thickness swelling (Zeng *et al.* 2018). The small amount of paraffin and cured UF resin that remained on the surface of the recycled wood particles also contributed to the water resistance of wood particles and hence the particleboards (Lykidis and Grigoriou 2008; Zeng *et al.* 2018). As a result, less water absorption and thickness swelling were observed for particleboard made with hydrothermal pretreated wood particles. The maximal requirement of 2 h TS for general purpose and furniture and interior fitments is 8% by GB/T 4897.2 (2003) and GB/T 4897.3 (2003). The 2 h TS values of all particleboards produced met the requirement for general purpose use and furniture and interior fitments stipulated in the Chinese National Standard GB/T 4897 (2003).

CONCLUSIONS

This study aimed to analyze the potential of recycled particles from the LHW pretreated scrap wood particleboards for manufacturing particleboards and evaluate physical and mechanical properties.

1. The results of this study showed that the mechanical properties of the particleboards produced were negatively influenced by use of the recycled wood particles. The mechanical properties of the produced particleboard decreased as the recycled wood particle content increased.
2. Produced particleboards containing up to 40% recycled wood particles met the mechanical property requirements for general purpose and interior boards, as defined in Chinese National Standard GB/T 4897 (2003). The results indicate that it is possible to produce particleboards from the recycled wood particles and industrial wood particles by using urea formaldehyde resin.
3. Dimensional stability of the produced particleboards improved as the recycled wood particle content increased. All the produced particleboards satisfied the 2 h thickness swelling for general purpose use and furniture and interior fitments according to the Chinese National Standard GB/T 4897 (2003).
4. Using scrap wood particleboards in particleboard production not only alleviates wood shortage but also results in potential environmental and socioeconomic benefits.

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