USE OF BUCKWHEAT STALK IN PARTICLEBOARD BONDED WITH UREA-FORMALDEHYDE RESIN ADHESIVE

YONG-SUNG OH and SUNG-SUK LEE[*]

Department of Forest Resources, College of Natural Resources, Yeungnam University, Gyeongsan 712-749, Korea
[*]*Department of Forest Products, Korea Forest Research Institute, Seoul 130-712, Korea*

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Buckwheat stalks were used as a raw material for particleboard. A urea-formaldehyde resin was synthesized in the laboratory with a 50% content of resin solids as particleboard binder. The laboratory particleboards were made using buckwheat stalks and hybrid poplar bonded with urea-formaldehyde resin, at a buckwheat stalk content of 0, 23, 48, 73 and 100% oven-dry weight. The physical and mechanical properties of the particleboards were tested according to the ASTM D 1037-99 procedure. The internal bond and flexural strength properties of the particleboards decreased gradually with an increasing buckwheat stalk content. However, the properties of all the particleboards exceeded the minimum requirements for the Korean Standard KS F 3104 for particleboard type 8.0. These results demonstrated the potential of buckwheat stalk as an alternative raw material for particleboard manufacture.

Keywords: buckwheat (*Fagopyrum esculentum* L.), agricultural residues, hybrid poplar, urea-formaldehyde resin, particleboard

INTRODUCTION

Particleboard (PB) is primarily manufactured by hammer-milling wood into small particles, applying wax and urea-formaldehyde (UF) resin adhesive to the particles, and consolidating a mat of particles into a panel with heat and pressure in a hot-press. PB can be produced from various types of wood residues and low-quality logs, such as sawdust, planer shavings, plywood trims, thinning logs, and other waste materials generated by wood product industries.[1] Some recycled wood material is useful for the raw material supply. PB is widely used as core material in furniture, floor underlayment, kitchen cabinets, and mobile home decking.[2]

Globally, UF resin adhesive has been extensively used as a binder in the wood products industry. About 90% of the world's wood-based panel products are glued with UF resins. PB manufacturers are the largest consumers of UF resins. In spite of the formaldehyde emission problem, UF resin has a number of advantages for its use as a wood adhesive. UF is easy to handle and ideal for interior application panels, due to the virtually colorless glue line of the final panels after hot-press curing. UF resin can be successfully bonded with most species of wood in many combinations. The low price of UF resins makes them very useful for the production of relatively inexpensive reconstituted wood-based composites.[1]

A variety of agricultural crop residues after harvesting can be readily used as raw materials for global panel industries. With an increasing global population, there will be a greater need to grow agricultural crops for food, resulting in grain production that will increase the supply of stalk and husk fiber residues. In wood-deficient countries, the use of agro-based fibers as alternative renewable sources for panel products has increased.[3] In order to use various bio-based fibers for panel products, many studies have evaluated a wide range of renewable agricultural residues fibers, such as banana stem, cereal straw, coffee husk, coconut coir, corn stalks, cotton stalks, jute, kenaf, kiwi branch, reed stalks, rice husk, and sugar cane bagasse.[4,5] The agro-based fiber composites, which have rapidly expanded in recent years, have a tremendous potential for future growth.[4]

Buckwheat is one of the earliest crops introduced by Europeans to North America. Buckwheat, which is a short season crop, was domesticated in the Yunnan region of China, Russia, United States, Ukraine, and Poland. Buckwheat plant grows quickly in the field, ripens seeds at 10 to 11 weeks, and grows to approximately 75~125 cm tall. In 2009, the world production of buckwheat was 1.65 million metric tonnes with 1.5 thousand metric tonnes being produced in Korea.[6] After harvesting the buckwheat seed, the large yield of buckwheat stalk fibers can be used as an alternative fiber resource for commercial engineered panel production, such as PB, which is the best way of using the material.

The objective of this research was to evaluate buckwheat stalks as a substitute raw material for hybrid poplar in UF-bonded PB manufacture. UF resin was synthesized in the laboratory for bonding the PB.

EXPERIMENTAL

UF resin synthesis

UF resin was formulated in the laboratory with a target resin solids content of 50% and a formaldehyde/urea (F/U) mole ratio of 1.15. To calculate the targeted resin solids contents, the charged urea solid value was taken, and the formaldehyde-derived solids were taken as the methylene group (CH_2) values, which were obtained by multiplying the charge weights by a factor of 14/30.[2]

The UF resin cooking procedure was similar to that outlined by Oh and Lee.[7] Briefly, 725.8 g of formaldehyde solution (37% conc.) was charged into a stirred reactor, heated to 50 °C, and the solution was adjusted to pH 7.8 with a 6% sodium hydroxide solution. Then, 268.5 g of first urea (U_1) was then added to bring the initial F/U_1 mole ratio to 2.0 over a period of 15 min, while the reaction temperature was held at 70~80 °C with the heating control of the exothermic reaction. After the reaction temperature was increased gradually to 90 °C, the reaction mixture was then acidified to pH 5.1 by using 8% sulfuric acid solution. This reaction temperature was maintained by intermittent cooling and heating until the resin was polymerized in approximately 30 min. Then, the pH was increased to 7.4 by adding an aliquot of 6% sodium hydroxide solution in order to end the polymerization reaction. The reaction product was cooled to below 80 °C, and 198.6 g of second urea (U_2) was charged to give a final $F/(U_1+U_2)$ mole ratio of 1.15, while the cooling was continued. Resin synthesis was completed by cooling further to about 20 °C. The resin product was stored at around 9 °C for analysis and use.

UF resin analysis

The viscosity of the UF resin was measured using a Brookfield RVF viscometer, spindle number 1 at a rotation of 2.09 rad/s (20 rpm). The free formaldehyde content was measured using the hydroxylamine hydrochloride method.[8] After the pH meter was calibrated with standardized buffer solutions, the pH of the resin was measured at 25 °C. The gel time was measured for the UF resin with 1 ml of 0.375% NH_4Cl solution to harden at 100 °C, and the specific gravity was determined at 25 °C. The resin solids content was determined by drying 1 g of resin in an aluminum pan at 125 °C for 2 h and calculated as follows:

$$\text{Resin solid level (\%)} = \frac{\text{sample weight after 2h}}{\text{initial sample weight}} \times 100$$

PB manufacture

Buckwheat (*Fagopyrum esculentum* L.) stalks were collected from Gyeongsan, South Korea. The buckwheat stalks particles (12~3.5 Tyler mesh, 1.4~5.6 mm, USA Std.) were dried to a 4~5% moisture content prior to use. The determinations of cold water extractive and ethanol-benzene extractive of the buckwheat stalk were carried out according to TAPPI T 207 OM-88 and TAPPI T 204 OM-88 test methods,[9] respectively. The lignin content and the ash content of the buckwheat stalk were determined by TAPPI 222 OM-88 and TAPPI T 211 OM-85 test methods,[9] respectively. *Populus alba* x *glandulosa* (Korean hybrid poplar) particles for the core layer were obtained from a commercial PB plant in South Korea. Table 1 shows the experimental design of the PB made in this study. To obtain a better mixture of the hybrid poplar and buckwheat stalks, the two types of particles were hand-mixed and blended with the laboratory-synthesized UF resin in a rotary drum blender. The liquid UF resin was applied with an air spray system at the pressure of 172 kPa (25 psi). Then, single-layer homogeneous PBs were manufactured using the processing parameters shown in Table 2.

PB performance test

The test specimens were cut from the manufactured boards. The internal bond (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) values were determined in accordance with the ASTM procedure D 1037-99.[10] The panel water absorption and thickness swelling properties were observed after 2-h and 24-h soaking tests.

Statistical analysis

The panel property test results were analyzed using the Statistical Analysis System (SAS) programming package.[11] An analysis of the variance (ANOVA) was used to determine the differences within each panel type. Significant differences ($P<0.05$) were further compared using t-test for the least significant differences (LSDs) from the SAS programming.[12]

Table 1
Experimental design of the particleboards

Board type	Buckwheat stalk (%)	*Populus alba* x *glandulosa* (%)
1	0	100
2	23	77
3	48	52
4	73	27
5	100	0

Table 2
Particleboard manufacturing parameters

Panel dimensions	250 by 250 by 6.3 mm
Mat moisture content	8 to 9%
Wax & resin solids loading	1 & 8%, respectively, based on oven-dry wood weight
Target board density	700 kg/m^3 objective
Catalyst	None
Resin flow rate	130 mL/min
Hot press temperature	170 ^oC
Hot press times	4 min
Replication	5 boards per condition (total of 25 boards)

Table 3
Properties of synthesized UF resin

Property	Unit	UF resin
Solid content	%	50.7
Specific gravity	-	1.18
pH	-	7.6
Gel time (at 100 ^oC)	min	21.3
Viscosity	mPa·s	156
Free formaldehyde	%	0.5

RESULTS AND DISCUSSION

UF resin properties

The synthesized UF resin viscosity was 156 mPa·s, which was suitable for resin spray application to wood particles with a compressed air sprayer (Table 3). As expected, the resin produced in this study had a very low free formaldehyde content, of 0.5%. The resin had a pH of 7.6, gel time of 21.3 min (at 100 ^oC), solid content of 50.7%, and specific gravity of 1.18.

Characteristics of buckwheat stalk

The cold-water extractive and ethanol-benzene extractive of the buckwheat stalk were of 4.8% and 2.1%, respectively. The lignin content and the ash content of the buckwheat stalk were of 17.2% and 3.6%, respectively. The pH of buckwheat stalk was 5.8, which is similar to the 5.2 pH value of Korean hybrid poplar wood. The fiber length of the buckwheat stalk was of 0.39 mm, which is shorter than the fiber length of the Korean hybrid poplar wood – 1.2 mm.[13] In general, the fiber length affects the physical and mechanical properties of panel products.[14]

PB performance test

The PB densities in this study ranged from 684 to 709 kg/m^3 (Table 4). The LSD test showed that panel density differed significantly ($P<0.05$) according to the board type, with board type 1 density being higher than that of board type 4. However, the panels of board types 1, 2, 3, and 5 had equivalent densities. The panel density was relatively constant regardless of the buckwheat stalk content.

Table 4
Performance test results of the PBs made from buckwheat stalks

Board type	Panel density (kg/m^3)	IB (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)	Thickness swelling (%)		Water absorption (%)	
					2 h	24 h	2 h	24 h
KS type 8.0	500~800	0.15	NS	8.0	NS	NS	NS	NS
1	709 (0.9) A	0.87 (5.2) A	2527 (11.8) A	16.2 (9.8) A	12.0 (3.2) D	32.7 (4.9) E	11.4 (7.2) D	65.2 (5.1) E
2	704 (1.3) AB	0.72 (7.8) B	2274 (7.6) B	14.4 (12.3) B	12.8 (11.5) C	35.8 (8.9) D	13.6 (8.9) C	70.8 (6.3) D
3	697 (1.2) AB	0.70 (6.3) B	2197 (12.7) B	14.0 (10.6) B	14.9 (6.5) B	42.3 (9.1) C	14.5 (6.8) B	74.6 (5.7) C
4	684 (0.8) B	0.65 (11.6) C	2021 (13.1) C	12.9 (9.4) C	15.1 (11.1) A	43.1 (11.9) B	14.8 (8.3) B	77.9 (8.5) B
5	700 (0.7) AB	0.62 (13.1) D	1852 (7.9) D	12.1 (8.7) D	15.4 (6.7) A	44.8 (5.3) A	15.7 (6.2) A	83.1 (5.7) A

NS: Not specified; Values in parentheses are coefficients of variations;
Means with the same letter are not significantly different (0.05 level)

The IB range for all panels was 0.62 to 0.87 N/mm^2 (Table 4). In general, the IB value decreased with increasing buckwheat contents. The LSD test showed that IB was significantly affected by the buckwheat particle content. This decreasing trend of IB with increasing buckwheat particle content suggests that buckwheat particles require a larger resin loading to obtain the same IB as that of hybrid poplar wood particles. However, the panels exceeded the minimum strength requirements (0.15 N/mm^2) for IB, according to Korean Standard KS F 3104 for PB type 8.0.[15]

MOE for all panels ranged from 1852 to 2527 N/mm^2 (Table 4). The LSD test for the MOE of board type 1 showed significant variations from those of the other board types, but board types 2 and 3 showed no significant variations. There were also significant differences in MOE between board types 3 and 4.

The MOR range for all panels was 12.1 to 16.2 N/mm^2 (Table 4). The LSD test for MOR showed that board type 1 differed significantly from the other board types. However, the MOR of board type 2 was similar to that of board type 3. The relatively large amount of the smaller fiber length and total fiber surface area in the buckwheat stalks had an adverse effect on the flexural strength properties, such as MOE and MOR. However, the panels exceeded the minimum strength requirements (8.0 N/mm^2) for MOR, according to Korean Standard KS F 3104 for PB type 8.0.[15]

Thickness swelling for all panels ranged from 12.0 to 15.4% for the 2-hour test and 32.7 to 44.8% for the 24-hour test (Table 4). The LSD test for thickness swelling after the 24-hour water soak test showed that board type 1 had significantly lower thickness swelling values than board types 2, 3, 4 and 5.

The water absorption range for all panels was 11.4 to 15.7% for the 2-hour test and 65.2 to 83.1% for the 24-hour test (Table 4). The LSD test for 24-hour water absorption showed that board type 5 absorbed significantly more water after 24-hour soaking than the other types, whereas board type 1 absorbed significantly less water. The thickness swelling and water absorption of the panels decreased with increasing fiber length or decreasing total fiber surface area.

CONCLUSION

Buckwheat stalks were examined as a potential raw material for the manufacture of PB. Five different types of PB were produced with buckwheat stalks and Korean hybrid poplar wood. The performance test evaluation showed that the mechanical properties of the resulting PBs decreased gradually with increasing buckwheat stalk content. Although the physical and mechanical properties of the PBs differed significantly according to the board type, all board types showed good physical and mechanical properties. Thus, these test results demonstrated the potential of buckwheat stalks as a raw material for PB manufacture.

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