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Bioresource Technology 86 (2003) 117–121

BIORESOURCE TECHNOLOGY

Rice straw–wood particle composite for sound absorbing wooden construction materials

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Received 2 April 2002; received in revised form 10 June 2002; accepted 1 July 2002

Abstract

In this study, rice straw–wood particle composite boards were manufactured as insulation boards using the method used in the wood-based panel industry. The raw material, rice straw, was chosen because of its availability. The manufacturing parameters were: a specific gravity of 0.4, 0.6, and 0.8, and a rice straw content (10/90, 20/80, and 30/70 weight of rice straw/wood particle) of 10, 20, and 30 wt.%. A commercial urea–formaldehyde adhesive was used as the composite binder, to achieve 140–290 psi of bending modulus of rupture (MOR) with 0.4 specific gravity, 700–900 psi of bending MOR with 0.6 specific gravity, and 1400–2900 psi of bending MOR with a 0.8 specific gravity. All of the composite boards were superior to insulation board in strength. Width and length of the rice straw particle did not affect the bending MOR. The composite boards made from a random cutting of rice straw and wood particles were the best and recommended for manufacturing processes. Sound absorption coefficients of the 0.4 and 0.6 specific gravity boards were higher than the other wood-based materials. The recommended properties of the rice straw–wood particle composite boards are described, to absorb noises, preserve the temperature of indoor living spaces, and to be able to partially or completely substitute for wood particleboard and insulation board in wooden constructions.

Keywords: Rice straw–wood particle composite board; Insulation board; Sound absorption coefficient

1. Introduction

In recent years, it has been difficult to obtain solid woods, and this causes problems for wood-based industry. To meet the standards required for a high-class residential environment, substitute wood-based materials (plywood, MDF, and particleboard), including natural materials and composites of steel or chemical materials are required as construction materials. With the increasing consumption of wood-based raw materials, it is inevitable that reasonable substitutions are needed. Agricultural lignocellulosic fibers such as rice straw and wheat straw can be easily crushed to chips or particles, which are similar to wood particle or fiber, and may be used as substitutes for wood-based raw materials. In addition, such systems contribute to the recycling of agricultural wastes. In order to recycle natural resources to meet demand caused by the decrease in supplies of solid wood and wood-based materials, several researches have succeeded in developing substitutes for wood particles, using lignocellulosic fibers. Ajiwe et al. (1998) produced ceiling boards from agricultural wastes, such as rice husks and sawdusts, and tested ceiling boards and commercial samples for moisture content, rate of water absorption, and tensile strength. The results of the tests confirmed that the boards produced were of similar standards to those commercially available (Ajiwe et al., 1998). Han et al. (1998) examined the effects of particle size and board density on reed and wheat particleboard properties. They reported that the properties of particleboard produced from fine particles were better than those made from coarse particles. An increase in board density resulted in a corresponding improvement in the board properties (Han et al., 1998). Viswanathan and Gothandapani (1999) confirmed the dimensional stability and mechanical properties of particleboards made from coir pith with average particle sizes of 0.4, 0.8, 1.2 and 2.1 mm, using phenol–formaldehyde and

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0960-8524/03/$ - see front matter
PII: S0960-8524(02)00163-3

urea–formaldehyde (UF) resins. Water absorption and swelling were least and mechanical properties were best for boards made from the larger particles and phenol–formaldehyde resin (Viswanathan and Gothandapani, 1999; Viswanathan et al., 2000). Yalinkilic et al. (1998) produced particleboards made of waste tea leaves bonded with UF resin adhesives in three densities. As density increased, internal bonding strength and bending strength also increased (Yalinkilic et al., 1998).

In the present study, rice straw was used because of its availability, and a rice straw–wood particle composite board was manufactured as an insulation board using a method currently used in the wood-based panel industry. The physical properties (specific gravity and moisture content), a mechanical property (3-point bending strength), and an acoustical property (the sound absorption coefficients) of the composite were determined, to investigate the possibility of rice straw as a partial or complete substitute for wood particles in particleboard. The effects of rice straw size on mechanical properties of particleboards were examined by studying the mechanical properties of particleboards prepared according to rice straw sizes and those prepared by randomly mixing rice straw of different sizes. The composite may substitute for particleboard and insulation board because of its strength, acoustic, and insulating properties, as well as its cost.

2. Methods

2.1. Materials

Commercial wood particles were used. The agricultural lignocellulosic fibers used in this study were rice straws. After removing the top 10 cm the rice straw stalks were cut into three sections top, center and bottom, the rice straw particle was prepared by cutting each of the sections of the rice straw into 2 or 4 cm lengths. The particle width depended on the native straw stem, which was wider at the bottom than at the top.

Commercial UF resin adhesive (65 wt.% of solid content) was used as the composite binder added with 10 wt.% NH_4Cl solution as a hardener.

2.2. Sample preparation

Rice straw–wood particle composite boards of $25 \times 20 \times 1$ cm were manufactured at a specific gravity of 0.8 with rice straw contents of 0, 10, 20, and 30 wt.%. Rice straws were cut as above to examine the effect of rice straw particle width (as the straw width), and length. Rice straw–wood particle composite boards were manufactured as insulation board at SG of 0.4 and 0.6 with rice straw contents of 10, 20, and 30 wt.%. Rice straws (as the raw material) were random cut and then mixed without screening.

After mixing cut pieces of rice straw and wood particles, and placing the mixture into a rotary drum mixer, the mixture was slowly sprayed with 10 wt.% (based on the weight of the oven dried raw material) commercial UF resin adhesive while rotating the mixer. The mixture of rice straw–wood particles and adhesives was cold pressed at 30 psi and left for 2 min before hot pressing.

The mixture was then hot pressed, to form composite boards at a peak pressure of 500 psi and a temperature of 140 °C. Total pressing time was 4 min (1 min to reach full pressure; pressure release in two steps of 1 min each). Board samples were pre-conditioned at 25 °C and 65% RH for one week before testing.

2.3. Physical properties

Moisture content and specific gravity were examined using the ASTM D 1037-99 (American Society for Testing and Materials, 1999) method. Specific gravity was controlled by quality control testing, each value represents the average of five samples.

2.4. Mechanical properties

3-point bending strength was determined using a Universal Testing Machine (Zwick Co., NICEM at Seoul National University) using the ASTM D 1037-99 (American Society for Testing and Materials, 1999) method. Each value represents the average of five samples.

2.5. Acoustical property

To determine the acoustical property of the composites as insulation boards, the sound absorption coefficients were determined by the impedance tube method, ASTM C 384-98 (American Society for Testing and Materials, 1999) (Fig. 1). Each value represents the average of three samples.

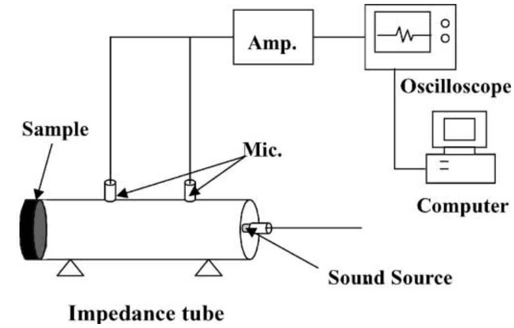


Fig. 1. Schematic diagram of apparatus for measuring sound absorption coefficient.

3. Results and discussion

3.1. Physical properties

The moisture contents of the composite boards ranged from 7.28 to 9.53 wt.%. The specific gravities were 0.35, 0.57, and 0.79 of the board prepared with the target SG of 0.4, 0.6, and 0.8, respectively.

3.2. Mechanical properties

The bending modulus of rupture (MOR) of the rice straw–wood particle composite boards with a specific gravity of 0.8 is shown in Fig. 2. Bending MOR increased slightly with the rice straw particle length and width. Composites with longer and wider rice straw particles showed better bending MOR, and this was in agreement with results previously obtained, where particleboard made from larger particles showed better mechanical properties (Viswanathan and Gothandapani, 1999; Viswanathan et al., 2000). Compared with the control board, a slightly better bending MOR was shown in the composite prepared with 10 wt.% rice straw and although slightly low, MOR was not different in the composite prepared with 20 wt.%. Therefore, composites could be prepared by mixing rice straw up to 20 wt.% with no decrease in composite strength. Since composite boards prepared with rice straw cut into certain sizes and those prepared with random size rice straw showed no difference in strength, we believe that composite boards could be prepared using rice straw without considering the straw size.

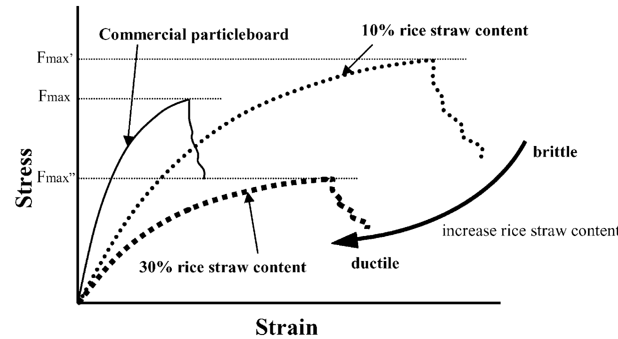
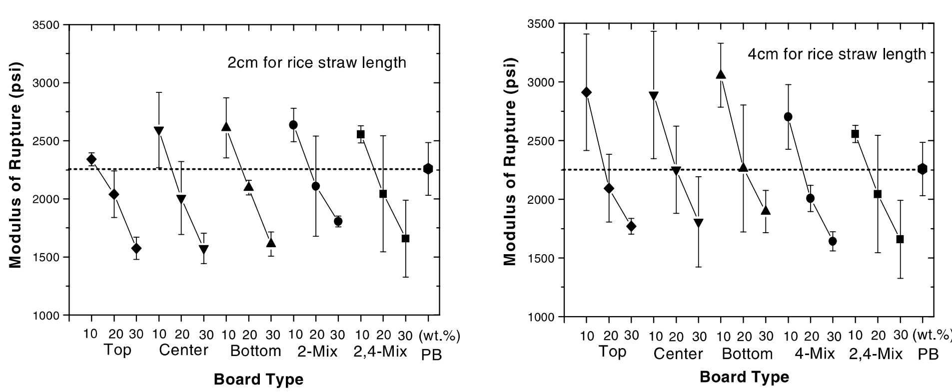


Fig. 3. Typical stress–strain curves of commercial particleboard and rice straw–wood particle composite boards.

Fig. 3 shows the typical stress–strain curves of a wood particleboards and a composite board prepared with rice straw and wood particles. Bending MOR was proportional to the maximum load (F_{max}) and was the lowest in the composite board prepared with 30 wt.% rice straw, followed by the control board prepared only with wood particles, and the composite board prepared with 10 wt.% rice straw. The bending modulus of elasticity (MOE) is the slope of the tangent line at the stress point of proportional limit. Generally, boards tend to be brittle when the value of MOE is high and tend to be



◆ : top part of the rice straw
▼ : center part of the rice straw
▲ : bottom part of the rice straw
● : random mixed (top, center, bottom part of the rice straw)
■ : random mixed (2, 4 cm of length, and top, center, bottom part of the rice straw)

* **10, 20, 30** : 10, 20, 30wt.% of rice straw content

Top, Center, Bottom : top, center, bottom part of the rice straw

2-Mix : 2 cm of length, random mixed (top, center, bottom part of the rice straw)

4-Mix : 4 cm of length, random mixed (top, center, bottom part of the rice straw)

2, 4-Mix : random mixed (2, 4 cm of length, and top, center, bottom part of the rice straw)

PB : commercial particleboard

Fig. 2. Bending MOR of composites with an SG of 0.8.

ductile or flexible when the value is low. The composite board prepared with 30 wt.% rice straw showed the lowest MOE, followed by the composite board prepared with 10 wt.% rice straw and the control board prepared with wood particles. The composite board containing 10 wt.% of rice straw showed a slightly better bending strength and had flexural properties comparable with the control board. This means that the wood-based composite board made from a mix with a small amount of agricultural fibers gives better mechanical properties than the wood particleboard. As previously stated, the rice straw–wood particle composite with 20 wt.% of rice straw is not different from the control, which means that agricultural fibers can substitute for wood particles as raw materials up to the 20 wt.% level.

Given the results of composite boards with an SG of 0.8, board samples were prepared with SG of 0.4 and 0.6. Rice straws were random cut, without size screening and mixed with wood particles. It was found that rice straw content did not affect the bending MOR of the composite at low specific gravity (0.4 and 0.6) as shown in Fig. 4. As the specific gravity of the composite was increased, the bending MOR also increased, as shown in Fig. 5. Composite boards with low specific gravity had a lower bending MOR than composite boards with an SG of 0.8. However, all of the board samples had significantly higher bending MOR than the insulation board (International Organization for Standardization, 1972), thus, the composite board can be used as an insulation material in wooden constructions.

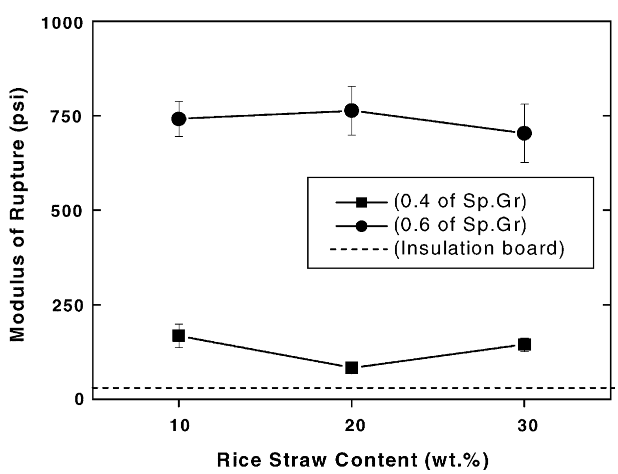


Fig. 4. Bending MOR of composites with SG of 0.4 and 0.6.

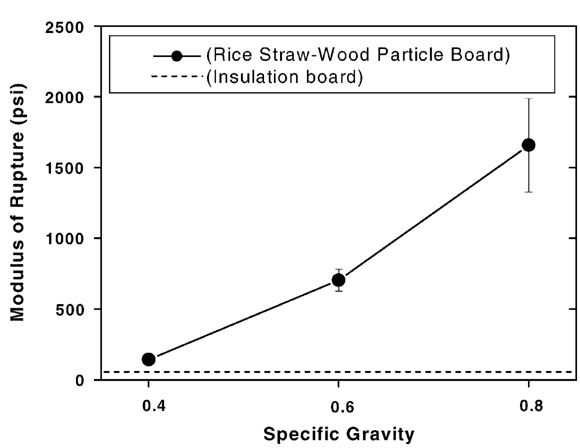


Fig. 5. Bending MOR of composites (30 wt.% of rice straw content).

3.3. Acoustical property

Sound absorption coefficients of rice straw–wood particle composite boards were measured by the impedance tube method (ASTM C 384-98, American Society for Testing and Materials, 1999) to investigate the possibility of substituting insulation material and insulation boards in wooden constructions. The results are shown in Fig. 6. Test samples were prepared from composite board containing 30 wt.% of random cut rice straws, without size screening. In general, porous sound absorbing materials have good acoustic insulating properties over a wide frequency range, because the larger pores give better acoustic insulating properties. Composite boards with SG of 0.4 and 0.6 have higher sound absorption coefficients than particleboard, fiberboard, and plywood in the 500–8000 Hz frequency range, which is caused by the low specific gravity of composite boards, which are more porous than particleboard, fiberboard, and plywood. Composite boards with an SG of 0.8 show lower sound absorption coefficients than particleboard in the 1000–8000 Hz frequency range. In these boards, many of the pores are filled, which reduces the total pore volume of the composite board, and though the mechanical properties are slightly improved, the sound absorption coefficient is reduced.

The sound absorption coefficients of composite boards with SG of 0.4 and 0.6 increased as the frequency increased. However, they decreased at the frequency of

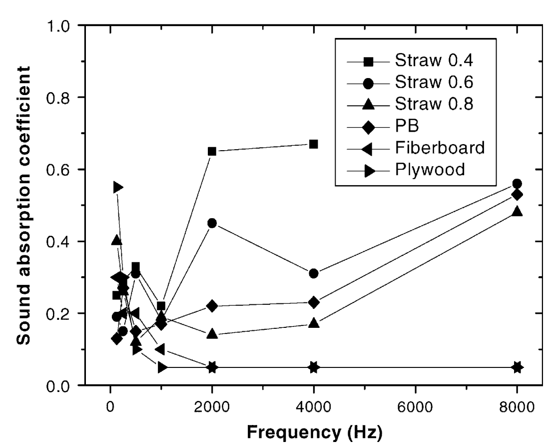


Fig. 6. Sound absorption coefficients of composite board (without screening for size, and with 30 wt.% of rice straw content).

1000 Hz and increased again. This decrease and increase was due to the specific characteristic of rice straw reflecting sound at 1000 Hz but absorbing sound in the middle and high frequency ranges. In addition, the fiberboard and plywood showed decreasing sound absorption coefficients as the frequency increased due to their specific characteristic of absorbing sound in the low frequency range but reflecting sound in the middle and high frequency ranges.

As previously stated, composite boards with SG of 0.4 and 0.6 showed higher sound absorption coefficients than particleboard, fiberboard, and plywood in the 500–8000 Hz frequency range, and had higher bending MOR than insulation board (International Organization for Standardization, 1972), thus, composite board can partially or completely substitute for insulation material in wooden constructions.

Low specific gravity boards are classified as rigid insulation materials. Commercial insulation materials are made of glass fibers, glass foam, mineral fibers, rock wool, etc. These materials possess good heat and acoustical insulating properties, but they are noxious to human beings and cause environmental pollution. Rice straw–wood particle composites for insulation board can solve these problems. Rice straws and wood particles are not noxious, are products of renewable bio-resources, and are biodegradable. Moreover, rice straw–wood particle composites can be used as both insulation materials and as insulation boards. Insulation boards may be used for many purposes including roof and wall sheathing, sub-flooring, interior surfaces for walls and ceilings, as bases for plaster, and as insulation strips for foundation walls and slab floors (Wagner, 1998).

4. Conclusions

The composite boards with an SG of 0.8 have slightly better bending MOR than wood particleboard (as control board) at a rice straw content of 10 wt.%, and show no differences from the control board at a 20 wt.% rice straw level. Rice straw can partially substitute for wood particles as raw materials at up to 20 wt.% without reducing the bending strength. Composite boards mixed with random cut rice straws were similar to the other boards in strength, and thus, there is no need to screen agricultural fibers for size in the wood-based panel industry, which would have cost benefits.

All of the composite boards with low specific gravity had a higher bending MOR than insulation board. The sound absorption coefficients of rice straw–wood particle composite boards were higher in the middle and high frequency range than commercial wood-based materials, such as particleboard, fiberboard, and plywood.

These composite boards prepared with rice straw without considering the size and wood particles, with the specific gravities of 0.4 and 0.6, were found to be suitable as a sound absorbing insulation material in wooden constructions.

Acknowledgements

This work was supported by the SNU Development Foundation and the Research Fund of the Seoul National University under grant no. 500-20001023. H.-J. Kim would especially like to thank Seoul National University for providing the funds for this project and Professor Jin-Yong Jeon (Hanyang University) for measuring the acoustic properties of the composites.

References

Ajiwe, V.I.E., Okeke, C.A., Ekwuozor, S.C., Uba, I.C., 1998. A pilot plant for production of ceiling boards from rice husks. Biores. Technol. 66, 41–43.

American Society for Testing and Materials, 1999. Annual Book of ASTM Standards, Philadelphia, PA.

Han, G., Zhang, C., Zhang, D., Umemura, K., Kawai, S., 1998. Upgrading of urea formaldehyde-bonded reed and wheat straw particleboards using silane coupling agents. J. Wood Sci. 44, 282–286.

International Organization for Standardization, 1972. Fibre building boards—Determination of bending strength. ISO 768-1972 (E).

Viswanathan, R., Gothandapani, L., 1999. Mechanical properties of coir pith particle board. Biores. Technol. 67, 93–95.

Viswanathan, R., Gothandapani, L., Kailappan, R., 2000. Water absorption and swelling characteristics of coir pith particle board. Biores. Technol. 71, 93–94.

Wagner, W.H., 1998. Modern Carpentry—building construction details in easy-to-understand form. The Goodheart–Willcox Company, Inc. pp. 325–333.

Yalinkilic, M.K., Imamura, Y., Takahashi, M., Kalaycioglu, H., Nemli, G., Demirci, Z., Ozdemir, T., 1998. Biological, physical and mechanical properties of particleboard manufactured from waste tea leaves. Int. Biodeterior. Biodegrad. 41, 75–84.