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Possibility of using waste tire composites reinforced with rice straw as construction materials

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Abstract

Agricultural lignocellulosic fiber (rice straw)-waste tire particle composite boards were manufactured for use as insulation boards in construction, using the same method as that used in the wood-based panel industry. The manufacturing parameters were: a specific gravity of 0.8 and a rice straw content (10/90, 20/80 and 30/70 by wt.% of rice straw/waste tire particle). A commercial polyurethane adhesive for rubber was used as the composite binder. The water proof, water absorption and thickness swelling properties of the composite boards were better than those of wood particleboard. Furthermore, the flexibility and flexural properties of the composite boards were superior to those of other wood-based panel products. The composite boards also demonstrated good acoustical insulation, electrical insulation, anti-caustic and anti-rot properties. These boards can be used to prevent impact damage, are easily modifiable and are inexpensive. They are able to be used as a substitute for insulation boards and other flexural materials in construction.

Keywords: Agricultural lignocellulosic fiber; Rice straw; Waste tire particle; Insulation board

1. Introduction

One of the biggest problems facing mankind in recent years, and which will continue to do so for the foreseeable future, is the environmental pollution resulting from industrial wastes and waste living materials etc., and much concentrated effort is being put into solving this problem on a world wide basis, in both advanced and less advanced countries. Particularly among the waste materials in the advancement of civilization, waste tires are a major concern, because the amount of waste tires is increasing more and more due to the increasing demand for tires and because of their short lifetime, it is therefore necessary to develop methods for recycling waste tires. The policy of most countries in the world is evolving such that recycling and, in particular, the use of waste tires as construction material is being encouraged, in order to prevent environmental pollution. As standards of living increase, the number of cars on the roads is increasing, thus increasing the amount of waste tires, however the proportion of these tires being recycled remains negligible.

This study investigated the possibility of using waste tires and rice straws as composite materials, and the potential applications for which these materials could be used after recycling. Waste tires have hardness and elasticity properties superior to those of rubber, good resistance to weathering, can be used for preventing impact damage, and for construction materials, because of their low specific gravity which is lower than that of most construction materials. Moreover, it is possible to use tires in almost any environmental conditions and in any climate, due to their ability to withstand both hot and cold, and to their anti-caustic and anti-rot properties. Finally, tires are easily modifiable, are inexpensive, and it is possible to use them for special purposes such as for electrical insulation and in applications which necessitate low heat conductivity. The recycling of waste

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tires can lead to a decrease in environmental pollution, and recycled composite materials made from waste tires can provide inexpensive construction materials.

In the present study, a rice straw–waste tire particle composite board was manufactured using a method currently used in the wood-based panel industry. The rice straw was used to modify the mechanical properties. The rice straw, agricultural lignocellulosic fiber, can be easily crushed to make chips or particles, which are similar to wood particles or fiber, and such utilization can contribute to the recycling of agricultural wastes. The main purpose of this study was to examine the possibility of making composite materials by recycling large amounts of waste tires and rice straw, thus solving a serious problem of environmental pollution caused by these industrial and agricultural wastes products.

2. Methods

2.1. Materials

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 particles were prepared by cutting each of the sections of the rice straws 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.

The waste tire particles consisted of second milled waste tires with a particle diameter of 3–4 mm. Commercial polyurethane adhesive (97 wt.% of solid content, PANDEX TP-1180, Kangnam Chemical Co., Ltd., S. KOREA) for rubber was used as the composite binder.

2.2. Sample preparation

Rice straw–waste tire particle composite boards of $25 \times 20 \times 1$ (cm) were manufactured at a specific gravity of 0.8 with rice straw contents of 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.

After mixing cut pieces of rice straw and waste tire particles, and placing the mixture into a rotary drum mixer, the mixture was slowly mixed with 10 wt.% (based on the weight of the oven dried raw material) commercial polyurethane adhesive while rotating the mixer. The mixture of rice straw–waste tire particles and adhesives was cold pressed at 30 psi and left for 2 min before hot pressing, which was done to make the mat, which constituted the precursor of the composite products, and the uniform density profile in the composite was maintained using cold pressing prior to hot press.

The mixture was then hot pressed, to form composite boards at a peak pressure of 700 psi and a temperature of 130 °C. Total pressing time was 10 min (1 min to reach full pressure; pressure release was performed in two steps of 7 and 2 min). Board samples were preconditioned at 25 °C and 65% RH for 1 week before testing.

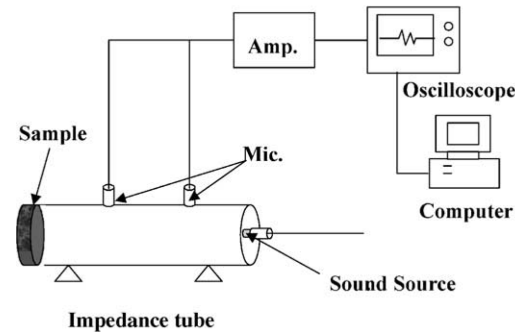

Fig. 1. Schematic diagram of apparatus used for measuring sound absorption coefficient.

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

Three-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 for use as insulating material, 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.

3. Results and discussion

3.1. Physical properties

The moisture content of the composite boards was $1.61 \pm 0.64\%$ and that of the control boards (wood particleboards) was $5.05 \pm 2.79\%$. The specific gravity of the composite boards was 0.77 ± 0.11 and that of the control boards was 0.80 ± 0.02, and the target SG of the composite board was 0.8.

3.2. Mechanical properties

The bending modulus of rupture (MOR) of the rice straw–waste tire particle composite boards is shown in Fig. 2. The bending MOR increased slightly when the rice straw particle length and content were increased. Composites with longer and wider rice straw particles showed better bending MOR values, and this was in agreement with the results obtained from previous studies, wherein the particleboard made from larger particles showed better mechanical properties (Viswanathan and Gothandapani, 1999; Viswanathan et al., 2000). Compared with the control board, lower bending MOR values were observed in the composite, but these values were higher than those of insulation board (International Organization For Standardization, 1972). The composite boards could be used as insulation boards for use in construction. Since those composite boards prepared with rice straw which was cut into certain specific 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. The bending modulus of elasticity (MOE) of the rice straw–waste tire particle composite boards is also shown in Fig. 2. The bending MOE results showed the same pattern as the bending MOR results. Compared with the control board, lower bending MOE values were observed for the composite, but the composite material has other unique properties such as flexibility.

Fig. 3 shows the typical stress–strain curve for a wood particleboard and that of a composite board prepared with rice straw and waste tire particles. The bending MOR was proportional to the maximum load (F_{max}) and was lower for the composite board than for the wood particleboard. 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 their MOE value is high, and tend to be ductile or flexible when this value is low. The composite board prepared with rice straw and waste tire particles had a lower MOE value than the wood particleboard. The composite boards showed a lower bending strength, but

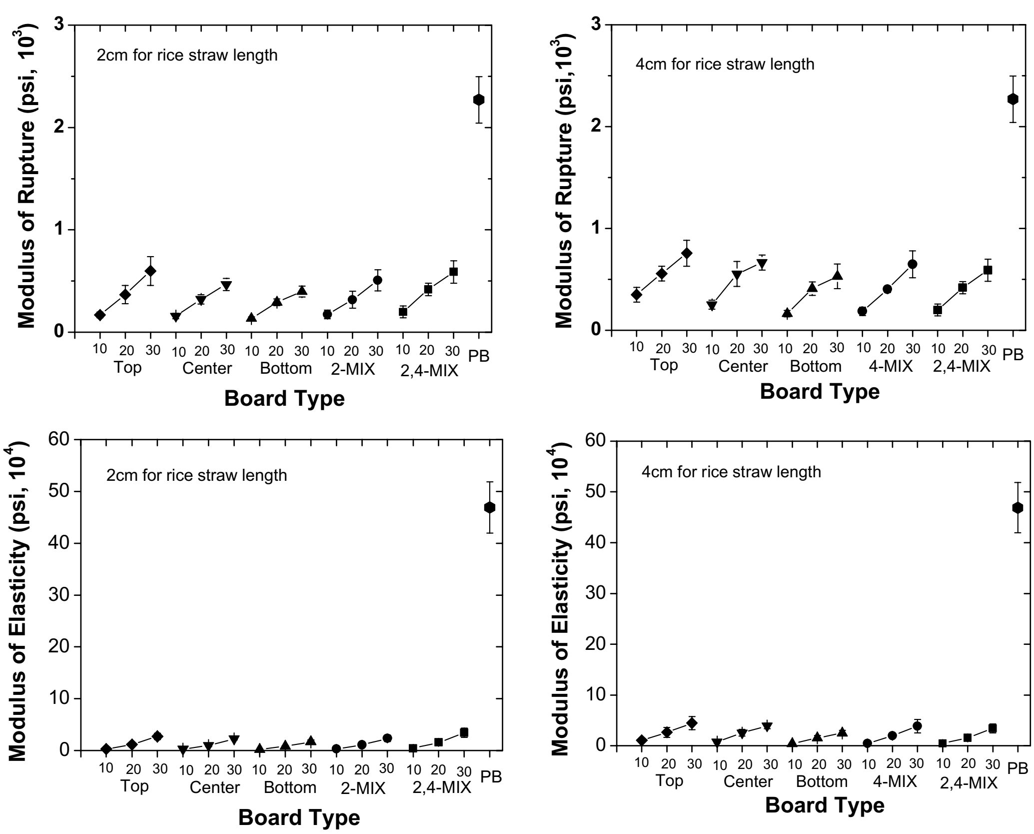

Fig. 2. Bending modulus of rupture and modulus of elasticity of the composites. (◆): Top part of the rice straw, (▼): center part of rice straw, (▲): bottom part of the rice straw, (●): random mixed (top, center, bottom part of the rice straw), (■): random mixed (2, 4 cm of length, and top, center, bottom part of the rice straw). (*) 10, 20, 30: 10, 20, 30 wt.% 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 wood particleboard.

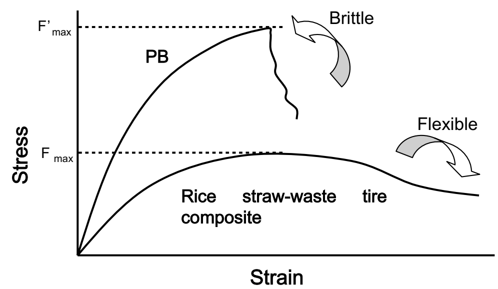

Fig. 3. Typical stress–strain curves of commercial particleboard (PB) and rice straw–waste tire particle composite boards.

had better flexural properties than the wood particleboard. As the rice straw–waste tire particle composite board had better flexural properties than the wood particleboard, it can be used for specific purposes, such as for producing flexural materials. Thus, the composite board can be used as an insulation board in construction.

3.3. Acoustical property

The sound absorption coefficients of the rice straw–waste tire 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 their being used as substitution insulation material and insulation board in construction. The results are shown in Fig. 4. Test samples were prepared from the 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 of the larger pores.

The composite boards were found to have higher sound absorption coefficients than particleboard, fiberboard, rice straw–wood particle composite board with a specific gravity of 0.8 (Yang et al., 2003), or plywood, in the 2000–8000 Hz frequency range. This can be attributed to the rice straw particles and the waste tire particle in the composite board being more porous than the elements that made up the particleboard, fiberboard, and plywood. In addition, the composite boards showed higher sound absorption coefficients than ceramic tiles, wooden floor, and concrete over the entire frequency range (125–8000 Hz) which was measured. The sound absorption coefficients of the composite boards increased as the frequency increased. However, they decreased somewhat at a frequency of 1000 Hz and then increased again. This point of inflexion was due to the specific characteristic of rice straw reflecting sound at around 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. The ceramic tiles and concrete showed increasing sound absorption coefficients as the frequency increased, due to their specific characteristic of reflecting sound in the low frequency range, but absorbing sound in the middle and high frequency ranges.

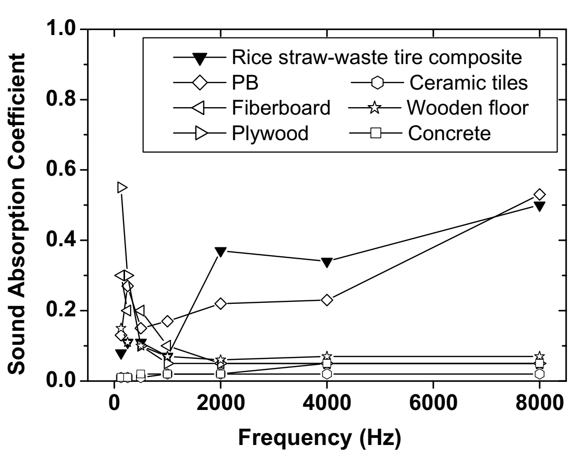

Fig. 4. Sound absorption coefficients of the rice straw–waste tire particle composite boards (30 wt.% of rice straw).

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. Conclusion

The rice straw–waste tire particle composite boards had better flexural properties than wood particleboard, insulation board, fiberboard, plywood and various other construction materials. This means that they can be used for specific purposes, for example as flexural insulating materials for curved walls, etc. The composite boards containing random-cut rice straws were similar to the other boards in strength and, consequently, there could be no need to screen the agricultural fibers for size during the manufacturing process, which should allow for cost benefits to be realized.

All of the composite boards had higher bending MOR values than the insulation board. The sound absorption coefficients of the composite boards were higher, in the middle and high frequency range, than those of commercial wood-based materials, such as particleboard, fiberboard and plywood. In addition, the composite boards showed higher sound absorption coefficients than ceramic tiles, wooden floor and concrete over the entire frequency range.

These composite boards, which were prepared using random cut rice straws, without size screening, and waste tires, were found to be suitable for use as sound absorbing insulation boards and as flexural materials in construction.

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