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NOTE

Sound absorption capability and mechanical properties of a composite rice hull and sawdust board

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Abstract Rice hull–sawdust composite boards were manufactured for sound-absorbing boards in construction. The manufacturing parameters were target density (400, 500, 600, and 700 kg/m^3) and rice hull content as percent weight of rice hull/sawdust/phenol resin (10/80/10, 20/70/10, 30/60/10, and 40/50/10). Commercial gypsum board and fiberboard were also used as comparative sound-absorbing materials. The average modulus of rupture (MOR) of the board with a density of 700 kg/m^3 and rice hull mixing ratio of 10% was 8.6 MPa, and that of the board with a 400 kg/m^3 board density and a rice hull mixing ratio of 40% was 2.2 MPa. The MOR increased with increasing board density or decreasing rice hull mixing ratio. The sound absorption coefficients of some boards (400 kg/m^3 and 10%, 500 kg/m^3 and 30%, and 500 kg/m^3 and 40%) were better than those of the commercial 11-mm-thick gypsum board. Thus, it is concluded that rice hull–sawdust composite boards may be implemented as sound-absorbing barriers in construction due to their high sound absorption coefficients.

Keywords Rice hull–sawdust composite board · Sound absorption capability · Modulus of rupture

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Introduction

The interest in wood and wood-based products for use in building materials is increasing due to concerns with human health. Appropriately harvested wood products also offer the advantage of being borne of a renewable resource. However, worldwide production of wooden building materials has decreased due to industrialization, and this trend is expected to continue into the foreseeable future. Also, the prices of wooden raw materials are increasing, which hampers the growth of the wood product business. Thus, it is necessary to develop methods for recycling waste materials, such as, wood product production waste, building construction waste, and biomass materials. We observed the availabilities of rice hulls and sawdust among those reusable materials.

Rice hull is a by-product of the rice polishing process and consists of 30–40% carbon and 20–30% silica (SiO_2). Annual global rice production is 620 million tons, of which 77% is cultivated in Asia and 7.3 million tons are produced in Korea. It is generally recognized that the rice hull comprises 16–18% of the total rice weight. Reuse of rice hull is uncommon for several reasons including its coarse appearance, low apparent density, low nutritive content, strong decay resistance, and high ash content. The use of rice hull fiber as a raw material in wood-based boards could contribute to lower utilization of raw wood material and help to reduce environmental damage. However, particle boards comprising only rice hull have been shown to posses 1/3 the strength of wood-based particle board due to its porous structure and low bonding strength. Despite many difficulties associated with using rice hull in construction materials, many researchers have attempted various methods for developing rice hull-based particle board. Prior research has examined various manufacturing conditions in an attempt to optimize the manufacturing process and to improve the mechanical properties of rice hull-based boards [2, 4, 7, 8, 10].

Sawdust is a plentiful by-product of timber operations and lumber production. Reuse of sawdust has to date been satisfactory primarily due to the very high water absorption rate of the material. Sawdust is mainly used in the sewage disposal process in industrial farming, and some is used to power manufacturing. According to the Korean Statistical Yearbook of Forestry [5], Korean sawdust outturn is about 1,600 m^3, and the price of sawdust is about 1/5 that of material lumber. A longer pressing time, higher resin content or higher board density is needed to achieve mechanical properties in rice hull-based boards that are equal to those of wood-based boards. Lee and Yoon [6] constructed a sawdust board using MDI (methylene diphenyl diisocyanate) resin and estimated its mechanical properties. Oh [9] made sawdust boards and investigated the relationship between the mechanical properties of the boards and their densities or resin contents. Lee and Han [7] determined the optimum mixing ratio of steam explosion-treated sawdust and wood particles for maximum bending strength and internal bonding strength based on experimental estimation. Ajiwe et al. [1] produced ceiling boards from rice husks and sawdust and reported the boards to be commercially viable. Han et al. [3] showed that an increase in board density in wheat particleboard resulted in an improvement in board mechanical properties.

The acoustic properties of board material are well defined and are gauged in terms of absorption, reflection, impedance, admittance, and transmission loss. Sound-absorbing materials are those materials designed and used for absorbing sound that might otherwise be reflected. Sound is absorbed when part of the energy striking a surface or an object is converted into heat energy in the pores of the material. Therefore, sound absorption is described as heat conversion of energy. The sound-absorbing characteristics of acoustical materials vary significantly with frequency. For the vast majority of conventional acoustical materials, material thickness has the greatest influence on the material's sound-absorbing qualities. The absorption coefficient also varies with the frequency and angle of incidence of the sound. Generally, higher frequencies are more easily absorbed than the low frequencies. Materials that are good absorbers allow sound to pass through them relatively easily. Sound-absorbing materials commonly used in construction include porous materials such as glass wool, gypsum, and similar materials.

In this study, we investigated the possibility of using waste sawdust and rice hulls as composite materials, and we evaluated applications for which these recycled materials could be used. The sawdust and rice hull composite board was evaluated for specific use as a sound-absorbing barrier in applications which necessitate a low specific gravity and high sound absorption capability. We estimated the mechanical and sound-absorption properties of boards with various material mixtures and offer an optimal manufacturing condition for sawdust and rice hull composite boards for use as inexpensive and highly sound absorptive construction materials.

Materials and methods

Materials

Larch wood (*Larix kaemferi* C.) sawdust and rice hull material were obtained from log and rice-hulling mills, respectively. The rice hull material was dried in the shade and pulverized using a crusher. These rice hull particles were screened using an 18 mesh wire screen. The moisture contents of the prepared sawdust and rice hulls were controlled to be less than 6 and 5%, respectively. Commercial powder type phenol resin (KNB-100PL, Kolon Chemical Co. Ltd., S. Korea) was used as the composite binder. The phenol–formaldehyde resin used for the test had a solids content of 99%, a melting point of 80–95°C, a gelation time of 80–120 s at 180°C by ASTM D4640, and a plate flow of 20–35 mm by ASTM D4242.

Sample preparation

Rice hull–sawdust composite boards of 260 mm × 260 mm × 14 mm were manufactured using a stainless-steel foursquare mold at a 10% resin content and several specific gravities and rice hull contents; a total of eight composite board types were manufactured. The manufacturing parameters were target density of 400, 500, 600, and 700 kg/m^3 at a rice hull content of 10%, and rice hull content as percent weight of rice hull/sawdust/phenol resin of 10/80/10, 20/70/10, 30/60/10, and 40/50/10 at a target density of 500 kg/m^3, respectively. Screened sawdust, rice hull, and phenol resin were mixed and then hot pressed at 190°C to form composite boards. The hot pressing was performed in three steps, first at a pressure of 40 kg/cm^2 for

6 min, then at 30 kg/cm^2 for 5 min, and finally at 20 kg/cm^2 for 4 min, with a total pressing time of 15 min.

Cylindrical test samples for the measurement of sound absorption coefficients were mill cut from each composite board. The sawdust and rice hull composite board samples were cut to a diameter of 29 mm and a thickness of 14 mm, and those of the gypsum boards and fiberboard were cut to diameters of 29 mm and thicknesses of 6, 11, or 18 mm.

Mechanical properties

Three-point bending tests were performed using a Universal Testing Machine (AGS-10 KN, Shimazu Corporation, Japan). The modulus of rupture (MOR) in bending was estimated at the 120 mm span and a 5 mm/min crosshead speed according to KSF 2208 (Korean Standard for Testing Wood and Wood-based Materials 1995).

Sound absorption capability

Sound absorption is defined as the incident sound that strikes a material and is not reflected. The absorption coefficient of a material indicates the proportion of sound absorbed by the material relative to the total incident sound. There are many different methods that can be used to determine the acoustic properties of materials, most of which involve exposing the materials to known sound fields and measuring the effects. There is a range of standards for material testing which prescribe well-controlled acoustical conditions and special instrumentation to ensure accuracy and repeatability. There are two common methods for measuring the sound absorption coefficient. Usually the measurement of absorption coefficient is conducted in a reverberant room, according to the ISO 354 standard, or using the traditional standing wave tube method described in the ISO 10534 standard. Neither method allows in situ measurement, and the standing wave tube method requires single frequency measurements, thus it takes a long time to complete and requires small samples.

The use of a wide band signal in the tube method enables rapid measurement and the collection of values at each frequency under the same environmental conditions. These improvements can be achieved using the transfer function method described in the ASTM E-1050 standard, which requires a two-channel FFT analyzer and two closely spaced microphones that must be calibrated for phase and gain matching. Also, the ASTM standard method involves the separation of stationary, random, and broadband signals into their incident and reflected components. This method is based on the frequency response function between the two sound pressure signals measured by two microphones placed along the tube wall.

As shown in Fig. 1, the experimental set-up employed herein consisted of a straight impedance tube with a loudspeaker connected to one end as an excitation source. In the tube, a white noise was formed by the signal generator, amplified by the power amplifier and then induced to the loudspeaker. At the other end, a sample specimen was connected to measure the sound absorption coefficient. A two-channel FFT analyzer was used to obtain the transfer function between the microphones. The reflection coefficient versus the material frequency is determined from the transfer function, while the sound absorption coefficient can be determined from the reflection coefficient as a function of the frequency of the sample specimens. In this study, the estimation frequency range was from 500 to 6,400 Hz, and the atmospheric pressure, temperature, relative humidity, sound velocity, air density, and characteristic acoustic impedance were 1,009 hPa, 28°C, 40%, 347.89 m/s, 1.177 kg/m^3 and 409.4 Pa/(m/s), respectively.

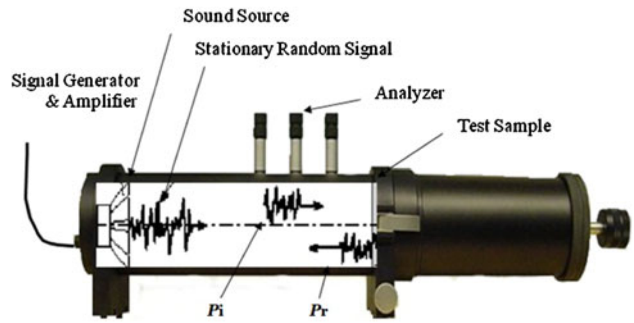

Fig. 1 Schematic diagram of the sound absorption coefficient measuring apparatus. *Pi* pressure of incident sound, *Pr* pressure of reflect sound

Results and discussion

Mechanical properties

The moisture contents of the composite boards ranged from 3.24 to 5.13%. The actual densities of the boards prepared to achieve target densities of 400, 500, 600, and 700 kg/m^3 with 10% rice hull contents and 10% resin content were 432, 506, 550, and 647 kg/m^3, respectively. The actual densities of the composite boards prepared with rice hull contents of 10, 20, 30, and 40% by weight and a target density of 500 kg/m^3 and 10% resin content were 538, 537, 539, and 553 kg/m^3, respectively.

The relationship between board density and bending MOR of the rice hull- sawdust composite boards is shown in Fig. 2. Among the evaluated composite boards, the maximum bending strength was 9.3 MPa for the board with a density of 700 kg/m^3 and a rice hull mixing ratio of 10%. On the contrary, in the case of the board with a density of 400 kg/m^3 and a rice hull content of 10%, a

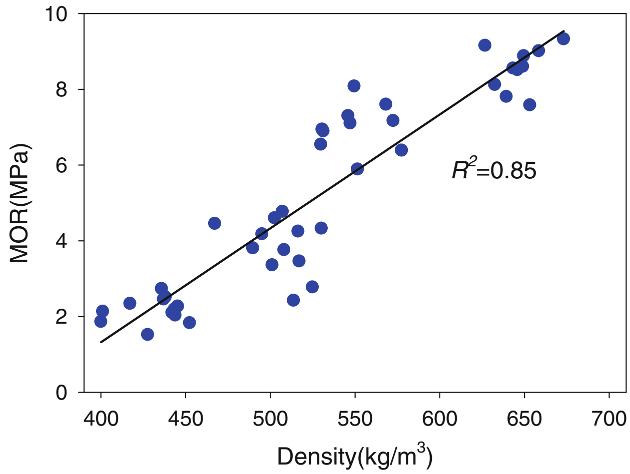

Fig. 2 Relationship between board density and MOR in bending of composite boards

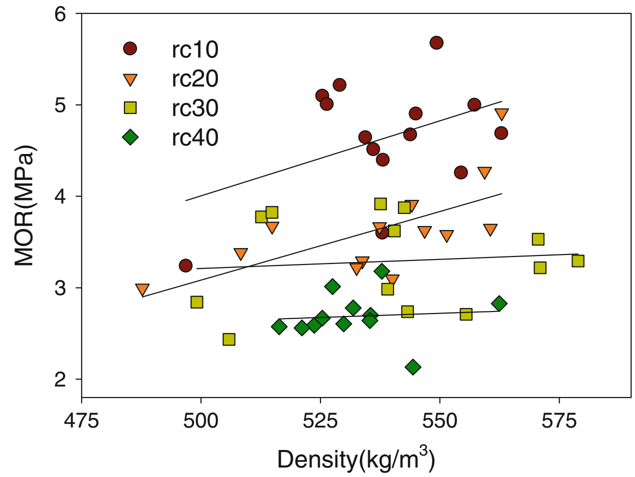

Fig. 3 Relationship between board density and MOR in bending of composite boards by rice hull mixing contents. *rc* rice hull content (%)

minimum bending strength of only 1.5 MPa was achieved. The MOR in bending was found to increase with increasing board density, which is in agreement with the results of previous studies [3, 7].

Regarding the relationship between rice hull and sawdust mixing ratio and bending MOR, the bending MOR increased slightly with decreases in rice hull content, although the relationship weakened with increasing rice hull content, as shown in Fig. 3. The maximum bending strength among the evaluated composite boards was 5.6 MPa for the board with a density of 553 kg/m^3, and sawdust and rice hull contents of 80 and 10%, respectively. Significantly lower at 2.1 MPa was the bending strength of the board with sawdust and rice hull contents of 50 and 40%, respectively.

Although the MOR in bending of the rice hull–sawdust composite board increased with increasing board density or decreasing rice hull content, the MORs in bending strength of all of the evaluated composite boards were lower than those of other wooden construction materials such as fiber board, OSB, plywood, and commercial particleboard. Therefore, the rice hull–sawdust composite boards evaluated herein are not suitable for use as construction materials that endure heavy structural loads. For this reason, the rice hull–sawdust composite boards are considered for their potential as sound-absorbing materials, perhaps for wall sheathing, ceiling boards, or other settings that require superior sound absorption properties, but that do not require robust mechanical properties.

Sound absorption capability

The sound absorption coefficients of rice hull-sawdust composite boards were measured via the transfer function method using an impedance tube. This method is widely used for its time and labor savings compared to those of either the standing wave or reverberation room method for estimating material sound absorption. The sound absorption coefficients of several types of rice hull–sawdust composite boards were measured and compared to those of commercial gypsum board to investigate the potential for the novel composite boards to be used as comparable sound-absorbing materials in the construction industry.

Figure 4 shows the overall results, in which each line represents the average sound absorption coefficient determined from five samples of boards prepared with target densities of 400, 500, 600, and 700 kg/m^3 over a continuous frequency range. As shown in the figure, the sound absorption coefficient of all of the specimens increased with increasing frequency. In general, porous materials have good sound absorption capabilities over a wide frequency range, and sound absorption performance increases with material porosity since larger pores provide for improved acoustic insulation. In this study, the rice hull–sawdust composite boards with the target board density of 400 kg/m^3 had higher sound absorption coefficients than did the denser composite boards, which affirmed that the boards of a lower density were also more porous than the other evaluated boards. The composite boards with a target board density of 700 kg/m^3 showed lower sound absorption coefficients than did those of the 400 kg/m^3 boards, which reduces the total pore volume of the composite board. Thus, although the denser boards offered slightly increased mechanical properties, they had the disadvantage of a lower sound absorption coefficient.

Regarding the relationship between rice hull–sawdust mixing ratio and sound absorption potential, the sound absorption coefficient of boards with 30 and 40% rice hull contents were higher than those of boards with rice hull

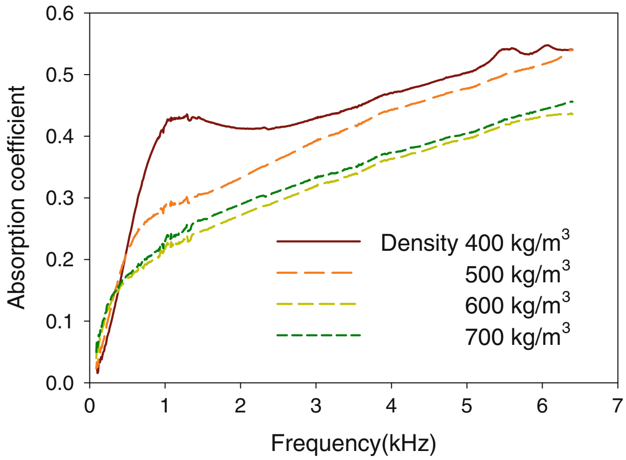

Fig. 4 The frequency versus sound absorption coefficients of rice hull-sawdust composite boards prepared with target densities of 400, 500, 600, and 700 kg/m^3. Note: rice hull content and resin content of all boards were 10%

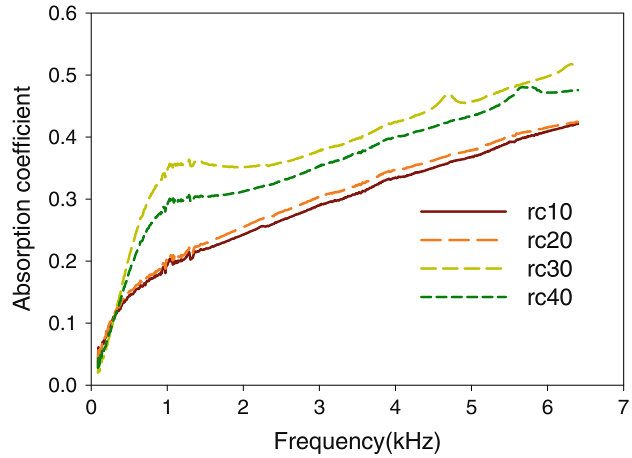

Fig. 5 The frequency versus sound absorption coefficients of rice hull-sawdust composite boards prepared with rice hull contents of 10, 20, 30, and 40%. Note: resin content and target density of all boards were 10% and 500 kg/m^3, respectively

contents of 10 and 20% over the evaluated frequency range as shown in Fig. 5. This result is consistent with the density results presented above, as the rice hull particles are coarser and have larger pores than the sawdust, thus the composite boards with higher rice hull contents have more and larger pores than those with more sawdust, and thus provide for better sound absorption. For the boards with rice hull contents of 30 and 40%, the sound absorption coefficient of the former was only slightly higher than that of the latter, and the difference decreased with increasing frequency. Still, it is worth noting that the sound absorption coefficients of all boards increased with increasing frequency.

Regarding the effect of material thickness on the sound absorption of a material, porous absorbers are most effective when placed so that they intersect a sound wave at its point of maximum particle velocity. This position is one-quarter of a wavelength from a reflecting surface, at which point maximum absorption will occur when a wave is incident at the right angle. The quarter wavelength frequency values estimated from the peak sound absorption coefficient lengths are 7,300, 5,300, and 4,700 Hz for the samples of gypsum board (11 mm thickness), rice hull–sawdust composite board (14 mm thickness), and fiber board (18 mm thickness). Since a frequency range of 500–4,000 Hz is commonly accepted for sound absorption evaluation, the board thickness variation in this study may be insufficient to observe significant differences in sound absorption.

Comparison of the sound absorption coefficients of the various materials tested herein indicates that the composite boards with a target density of 400 kg/m^3 have the greatest absorptive potential. Absorption coefficient according to frequency is shown for commercial gypsum board in

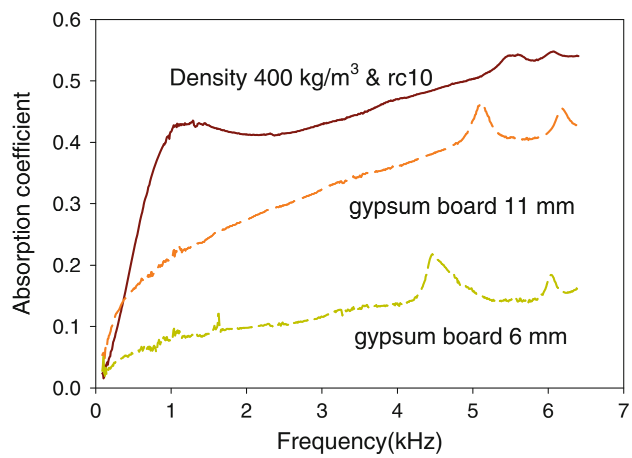

Fig. 6 Comparison of the frequency versus sound absorption coefficients between rice hull-sawdust composite boards prepared with target densities of 400 kg/m^3 and commercial gypsum boards

Fig. 6. The material has a density of 478 kg/m^3 and is commonly used as sound-absorbing board for ceilings. The sound absorption coefficients of gypsum board with a 6 mm thickness (density of 1,500 kg/m^3) and fiberboard with an 18 mm thickness (density of 600 kg/m^3) have relatively poor absorption coefficients over the evaluated frequency range. These boards are not considered to be appropriate sound-absorbing materials for use in construction. On the contrary, the gypsum board with an 11 mm thickness shows higher absorption values over the entire frequency range that are similar to those of the composite boards with a 20% rice hull content near 1,000 Hz, 0.25–0.30 greater from 1,000 to 3,000 Hz and 0.40–0.50 greater near 3,000 Hz. The sound absorption coefficient of the composite board with a target density of

400 kg/m^3 is higher over the evaluated frequency range compared to that of the gypsum board with an 11 mm thickness. The sound absorption coefficients of the composite board are about 0.20 at 500 Hz, 0.40 at 1,000 Hz, and 0.40–0.55 at over 1,000 Hz. The sound absorption coefficient of the composite board is about two times higher than that of the gypsum board with an 11 mm thickness, especially at a frequency of 1,000 Hz.

The composite boards show higher sound absorption coefficients than do the commercial gypsum boards over the frequency range from 500 to 4,000 Hz. The overall results show that the rice hull–sawdust composite boards may be used as a replacement material for sound-absorbing purposes in non-structural construction applications, such as ceilings, wall sheathing and interior wall surfaces.

Conclusions

The rice hull–sawdust composite boards had lower mechanical properties than wood and various other wood-based materials; thus, these composites are limited in application to specific, non-structural applications such as a sound-absorbing barrier. The sound absorption coefficients of the composite boards increased with decreasing board density or increasing rice hull content.

The sound absorption coefficients of the low density or high rice hull content composite boards were higher in the frequency range of 1,000–6,400 Hz than were those of commercial gypsum board. In addition, the composite boards showed higher sound absorption coefficients compared to those of ceramic tiles, wooden floor, and concrete over the entire frequency range. It is considered that the composite boards were suitable for use as sound-absorbing materials in construction.

The sound absorption depends on the porosity, airflow resistivity, and tortuosity as well as pore-shape distribution, which will be considered in the future study.

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