PERFORMANCE RESEARCH ON COIR FIBER AND WOOD DEBRIS HYBRID BOARDS

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In response to increasing awareness of the environment and energy, the fields of application for new types of plant fiber functional materials are expanding. In this study, different weight proportions of coir fiber were added to wood particle debris to produce hybrid boards. The two forms of coir fiber used were random distribution and non-woven needle mat. A mixed orthogonal experiment was designed to use the weight mixing ratio of wood debris and coir, the density of the hybrid boards, and the mixing form of the raw material as the experimental factors. The mechanical and sound absorption performances were evaluated. The experimental results provided evidence that the addition of the coir fibers enhanced the mechanical performance and sound absorption performance of the hybrid boards. The non-woven needle mat form in particular was effective at evenly distributing the fibers. The optimal plan for this kind of hybrid composite was obtained through experimental analysis. The excellent sound absorption performance and sufficient strength of the hybrid boards made them suitable for use on inner walls as sound-absorbing material or on interior trim parts in automotive applications. The research results demonstrated the advantages of using coir fiber and wood debris resources.

Keywords: Hybrid board; Coir fiber; Modulus of rupture (MOR); Sound absorption performance

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INTRODUCTION

At the present time, due to the lack of timber and petroleum resources, as well as the worsening prospects for human survival in such an environment, there is an increased awareness of both the environment and energy. Making full use of certain characteristics of plant fibers such as protection of the environment, lightness of weight, sound absorption, and insulation ability in order to develop new plant fiber functional composites has become a hot topic. More attention has been paid to the hybrid composites of natural fibers and processed wood debris in the production of wood replacement materials. Coir fiber, like other cellulosic fiber, can experience biological degradation and recycled usage. Coir fiber is used for making a wide variety of floor furnishing materials, yarns, ropes, mats, mattresses, brushes, sacking, caulking boats, rugs, geo-textiles, and insulation panels in traditional industries. However, the production of these traditional coir products reaches approximately 450 thousand tons annually, which is only a small percentage of the total world production of coconut husk (Ayrilmis *et al.* 2011). Hence, research and development centers are working to find new markets for additional value products containing coir fibers. More and more of coir fibers are being used to produce all kinds of biomass composites. The application fields of these fibers include the automobile industry, the building industry, and the packaging and insulation industries (Geethamma *et al.* 2005; Monteiro *et al.* 2005, 2008; Yao *et al.* 2012). Due to the composition and morphological features of the coir fiber, the potential for improving the mechanical properties of the composite by using coir fiber as the reinforcement is not great, but the application prospects look good as the functional architecture and decoration materials have been researched (Asasutjarit 2007; Savastano 1999; Joseph 2004; Wang and Huang 2009). In these studies, the tensile, flexural, and impact properties of coir composites have been discussed. Also, thermoset and thermoplastic resins have been adopted to ensure the different actual applications of coir composites. But the sound absorption ability of coir hybrid boards has been discussed little up to now.

In this study, coir fiber was added to wood debris to produce hybrid boards. The effects of the use of different forms of coir fiber were emphasized, and the two forms of coir fiber used were non-woven needle mat and the random distribution. The performance testing confirmed that the improvements in the strength and sound absorption performances were influenced by the addition of the coir fiber. The internal bonding strength (IB), the modulus of rupture (MOR), and analysis of the stress-displacement curve were carried out. The internal porosity of the coir fiber was estimated, and the structural characteristics of coir fiber were found suitable to produce the sound-absorbing material. The better sound absorption performance of the hybrid boards was evidenced by the sound-absorption performance test, which used the impedance tube method. The hybrid composites obtained in the study, which have sufficient strength and good sound-absorption characteristic, can be used as inner wall materials.

EXPERIMENTAL

Materials

The wood debris used in this study consisted of larch broken parts as chips with density 0.65 g/cm^3. The coir fiber came from the Hainan Province of China. The coir fiber used as a raw material was cut into 5 to 10 cm pieces after the impurities had been wiped off. The non-woven needle mats of coir fiber were processed at Juxin Coconut Palm Products. Co. Ltd, Weifang, China. Their density was 1.2 g/cm^3. The drying handling of raw materials have been adopted for both coir and wood debris under 120 ^{o}C for 24 hours, which was an effective method that can both decrease the pretreated cost and improve the interfacial characteristics (Moraes *et al.* 2003). The 14L960 type phenolic resin with 42% solid content, 1.2 g/cm^3 density, and 60 CDS viscosity under 25 ^{o}C was used as the adhesive; the resin is produced by Beijing Dynea Chemical Industry Co. Ltd of China. Liquid paraffin bought from the market was adopted to improve the waterproofing performance of the hybrid boards.

Experimental Design

Two forms of coir fiber were used, random distribution and non-woven needle mats, and this coir fiber was added to the wood particle debris in different weight proportions to produce the hybrid boards. A mixed orthogonal experiment (Cheng 2005) of the type L_{18} ($6^1 \times 3^3$) has been designed that uses the weight mixing ratio of wood debris and coir, the density of the hybrid boards, and the mixing form of the raw material as the main experimental factors. The weight mixing ratios of wood debris to coir fiber were 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100. The densities were 0.4, 0.6, and 0.8 g/cm^3, which is consistent with the realization that different sample densities depended on the different quality of raw materials. There were three mixing forms: coir fiber mats on both sides (CS) of the composite, coir fiber mats in the middle (CM) of the composite, and uniform mixing of random distribution coir fiber with wood debris (UM). The detailed experimental design is shown in Table 1. The total gluing content was 10 wt% for both wood debris and coir fibers, and 1 wt% liquid paraffin was added as waterproofing. The pre-pressure had to be done before the hot-press in order to make the raw materials maintain a certain shape. The hot-press temperature was then set to 140℃ for 8 minutes under 10 MPa pressure. The thickness gauges were adopted to ensure the 1 cm thickness of the samples.

Table 1. Experimental Design and Results

No.	Wood Debris:Coir (wt%)	Density (g/cm^3)	Mixing Form	IB (MPa)	MOR (MPa)
1	100:0	0.4	CS	0.35	2.5
2	100:0	0.6	UM	0.44	4.0
3	100:0	0.8	CM	0.60	6.1
4	80:20	0.4	CM	0.25	3.1
5	80:20	0.6	CS	0.39	8.2
6	80:20	0.8	UM	0.44	9.8
7	60:40	0.4	CS	0.16	6.4
8	60:40	0.6	UM	0.24	8.2
9	60:40	0.8	CM	0.33	10.0
10	40:60	0.4	CM	0.15	6.3
11	40:60	0.6	CS	0.19	8.5
12	40:60	0.8	UM	0.25	12.4
13	20:80	0.4	UM	0.14	7.4
14	20:80	0.6	CM	0.19	12.2
15	20:80	0.8	CS	0.32	20.1
16	0:100	0.4	UM	0.20	8.0
17	0:100	0.6	CM	0.33	13.2
18	0:100	0.8	CS	0.44	22.3

Test Method

In accordance with the wood-based panel standard GB/T17657-1999 of China and EN 312-1:1997 of Europe, the MOR values were obtained using three-point bending destruction testing, and the IB values were also obtained. The SANS-CMT5504 universal mechanical testing machine was adopted as the testing device. Sample sizes were made according to the above standard. The number of samples was five for each test. SEM was used to investigate the morphology of the coir fiber with the FEI Model Quanta 200 (FEI Company, USA), and the samples were observed using an applied tension of 12.5 kV. In order to evaluate the acoustical properties of the composites, the sound absorption coefficients were determined by the impedance tube method according to ASTM C 384-98 and GBJ 88-85 of China.

An AWA6122A impedance tube (as in Fig. 1) made by Aihua Instrument Co., LTD, Hangzhou, China was adopted. The sample diameter was 96 mm, and each value represented the average of three samples. The sound absorption coefficients were measured in six frequencies: 125, 250, 500, 1000, 2000, and 4000 Hz. The noise reduction coefficient (NRC) of a sample was the mean value of the sound absorption coefficients of 250, 500, 1000, and 2000 Hz.

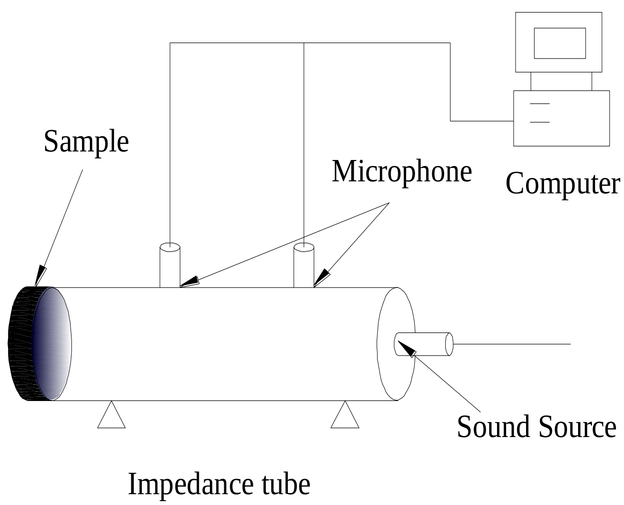

Fig. 1. Schematic diagram of the impedance tube method

RESULTS AND ANALYSIS

SEM Observation

Figure 2 shows the inner structure of sample 11, with 40:60 wood debris and coir ratio, 0.6 g/cm^3 density, and CS mixing form as in Table 1. The chips feature of wood debris can be observed, and the interwoven nature of the warp and weft in the coir non-woven needle mat can also be observed. There were many voids in the boards which were useful for the sound absorption and heat insulation ability of the samples but were harmful for the mechanical properties. A more intuitive idea can be obtained for the samples in the study from SEM observation.

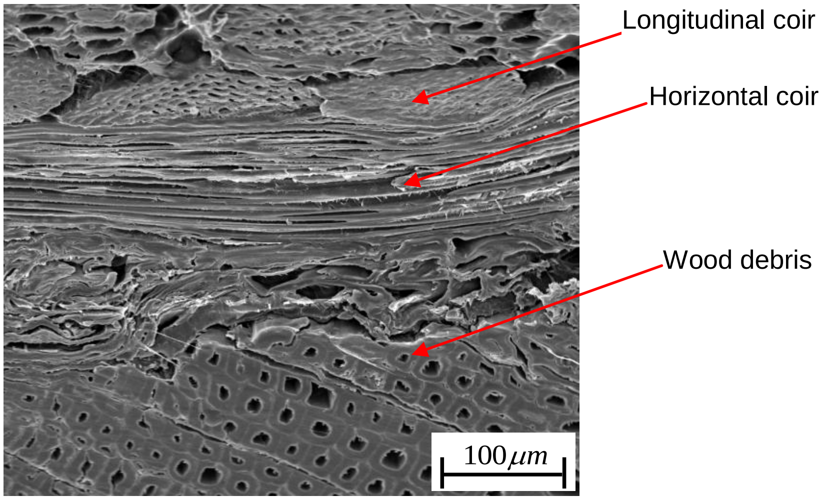

Fig. 2. SEM observation of sample 11

Extreme Difference Analysis

The extreme difference analysis method can be adopted to determine the optimized scheme of the orthogonal experiment. The extreme difference is determined by the difference between the maximum and minimum values, values that are the sum of the test index of each factor under different levels. The extreme difference analysis of the mixed orthogonal experiment (Cheng 2005) of the IB and MOR was done according to the experimental data shown in Table 1. The same impact principles could be concluded for both the IB and MOR, and the order of impact for the different factors was: mixing ratio > density > mixing form. The optimized scheme for the MOR was determined where the mixing ratio was 0:100, the density was 0.8 g/cm^3, and the pattern of assembly CS was used. Meanwhile, the optimized scheme for the IB was determined where the mixing ratio was 100:0, the density was 0.8 g/cm^3, and the pattern of assembly CS was used. The main difference between the two parameters was that the coir fiber was better able to enhance the MOR values than the wood debris, but did not effectively enhance the IB values in comparison to the wood debris.

Internal Bond (IB)

When the mixing ratio of wood debris to coir increased, as shown in Fig. 3, the IB values first decreased, then increased for all the three densities. It was obvious that the bonding performance of the wood debris was better than that of coir fiber. The hybrid effect did not benefit the IB; the IB values were much higher for both the pure wood debris boards and the pure coir fiber boards. For the same mixing ratio, the increase in density made the IB increase. The impact of the mixing form factor was also observed in the change in values under different densities. The CS pattern was better than the CM pattern and the UM pattern. The IB values decreased because the coir fiber in the UM pattern was not evenly distributed.

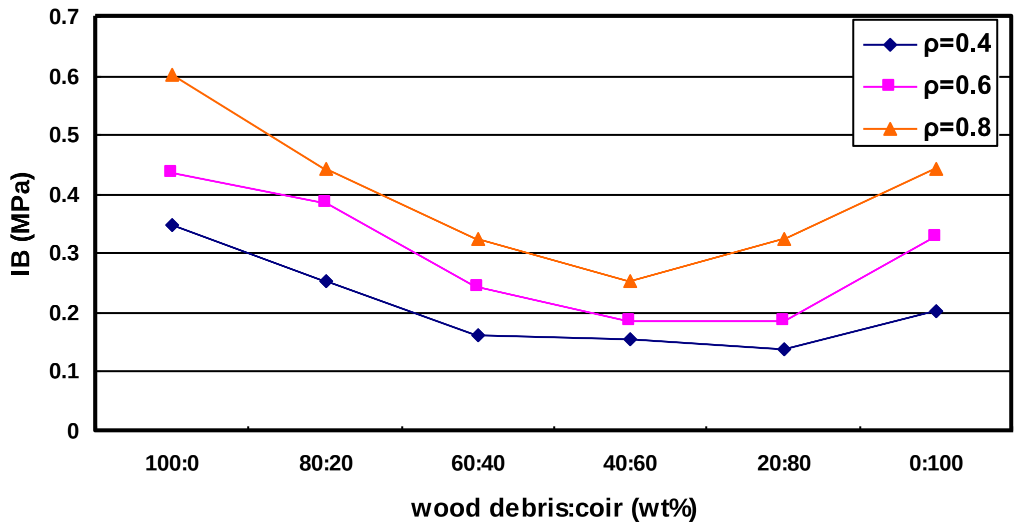

Fig. 3. The changing tendency of the IB under different densities

Modulus of Rupture (MOR)

The three curves in Fig. 4 represent the changing tendency of the MOR under the same density respectively. When the weight mixing ratio of the wood debris to coir fiber increased, the MOR values increased. The MOR values of the pure coir fiber boards were much greater than those of the pure wood debris boards; thus, the coir fiber was better able to enhance the MOR values than was the wood debris. The coir fiber in the non-woven needle mats formed a two-dimensional structure, and a mutual constraint relationship existed among these fibers. The fibers were arranged in flat surface without any adhesive, and the fiber distribution was more even in the process technology of the non-woven mats. Each fiber could be fixed by the loop bonding of the longitudinal fibers, so the total strength of the material could be improved more easily than for random distribution fibers.

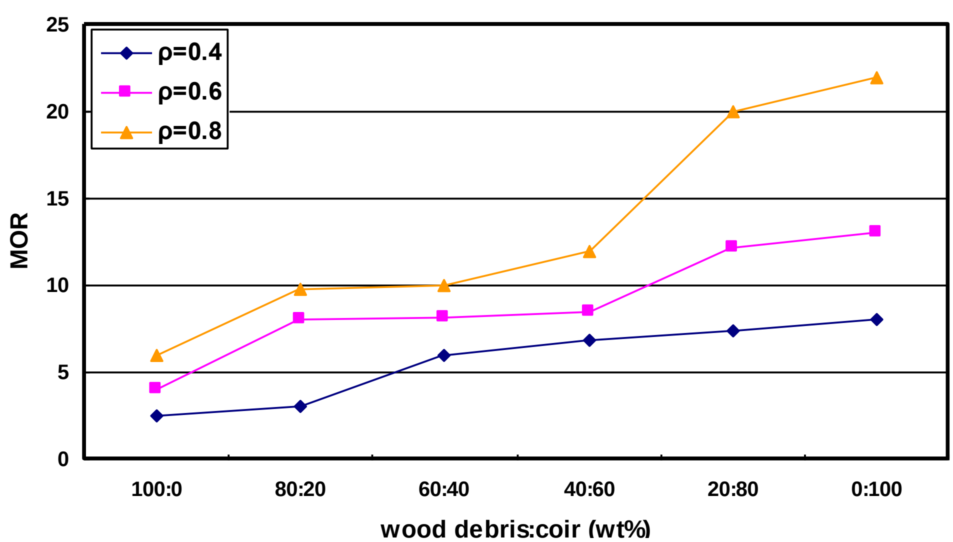

Fig. 4. The changing tendency of the MOR under different densities

Under the same mixing ratio, the density affected the MOR significantly, and the MOR increased as the density increased. Therefore, the hybrid boards in the study were superior in their ability to bend and could be used as a replacement material for wood particleboard.

Curve of Stress and Displacement

The technical conditions of sample 9 consisted of a weight mixing ratio of 60:40, a density of 0.8 g/cm^3, and the mixing form CM, as in Table 1. The three-point bending damage of this sample can be seen in Fig. 5. The load did not decrease linearly after reaching the maximum load. This was because the coir fiber mats, which were in the middle of the composite, endured a large deformation and then finally failed. The load suffering process could be maintained for a longer duration with the displacement from 7 to 15 mm as in Fig. 5; so the destructive harm decreased accordingly and a better cushion effect was obtained. Thus, adding coir fibers with CM form had advantages as far as improving the toughness of the hybrid boards.

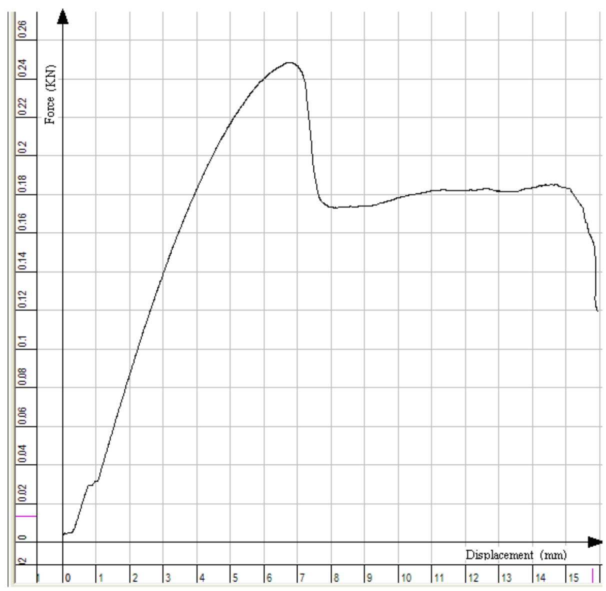

Fig. 5. The curve of stress and displacement of sample 9

Sound Absorption Performance

Because of natural growth characteristics, coir fiber has a lumen and many lacunas within its cellular structure, as seen in Fig. 6, which is what leads to the better sound absorption and heat insulation characteristics. For coir fiber, the major constituents are 36 to 43 wt% cellulose, 0.15 to 0.25 wt% hemicellulose, 41 to 45 wt% lignin, 3 to 4 wt% protein and related components, 2.22 wt% ash, and 7 to 8 wt% moisture content (Satyanarayana *et al*. 2009). The coir fiber's density is 1.15 g/cm^3, the densities of lignin, hemicellulose, and cellulose vary with values from 1.387 g/cm^3, 1.559 g/cm^3, and 1.520 g/cm^3 (Ehrnrooth 1984), and the water density is 1.0 g/cm^3.

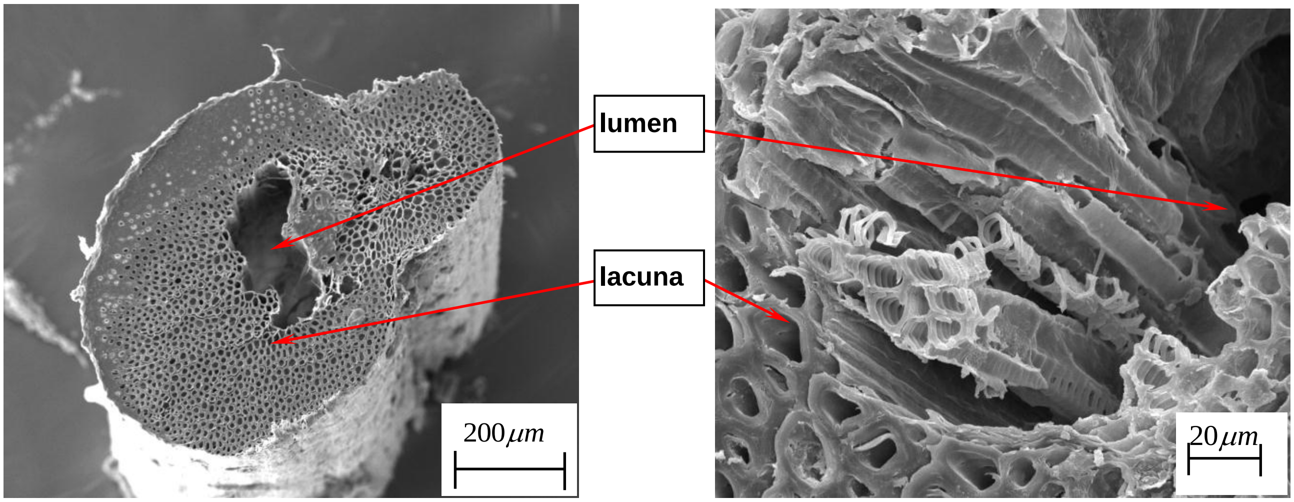

Fig. 6. Cross-section of a coir fiber

According the calculation of the void content fraction of lightweight composites described in the literature (Bhatnagar and Hanna 1995), the supposed densities of the other constituents are about 1.0 g/cm^3. The inner porosity of coir fiber can be calculated as,

$$V_{CP} = 1 - \sum_{i=1}^{n} V_i / V_{total} = 1 - \sum_{i=1}^{n} W_i \rho_{total} / \rho_i \qquad (1)$$

where V_{CP} is the inner porosity of coir fiber, V_i is the volume of a different constituent, V_{total} is the volume of coir fiber, W_i is the weight fraction of a different constituent, ρ_{total} is the density of coir fiber, and ρ_I is the density of a different constituent.

The higher lignin contents and the lower density of lignin are two factors that cause the greater inner porosity of coir fiber. The inner porosity of coir fiber was calculated to be 16% to 25% using Eq. 1. The greater holes ratio inside the fiber was the main reason for the better sound-absorption ability.

The quality of better sound absorption caused by the addition of coir fiber to the wood debris boards was demonstrated by the impedance tube method. The samples can be measured in two ways: real stick to the tube wall, as shown in Fig. 1, and a 50 mm air cavity can be reserved. The sound absorption ability is effectively reflected by the NRC, which is the more useful parameter for expressing reduction of noise in the range of human hearing.

The comparisons of results from the two methods are shown in Fig. 7. Both an air gap and the added coir fibers have the significant meaning to enhance the noise reduction coefficient of the hybrid boards. The density played an important role in the sound absorption performance; in this study's investigation of density ranges, when density was the lowest, sound absorption performance was the best.

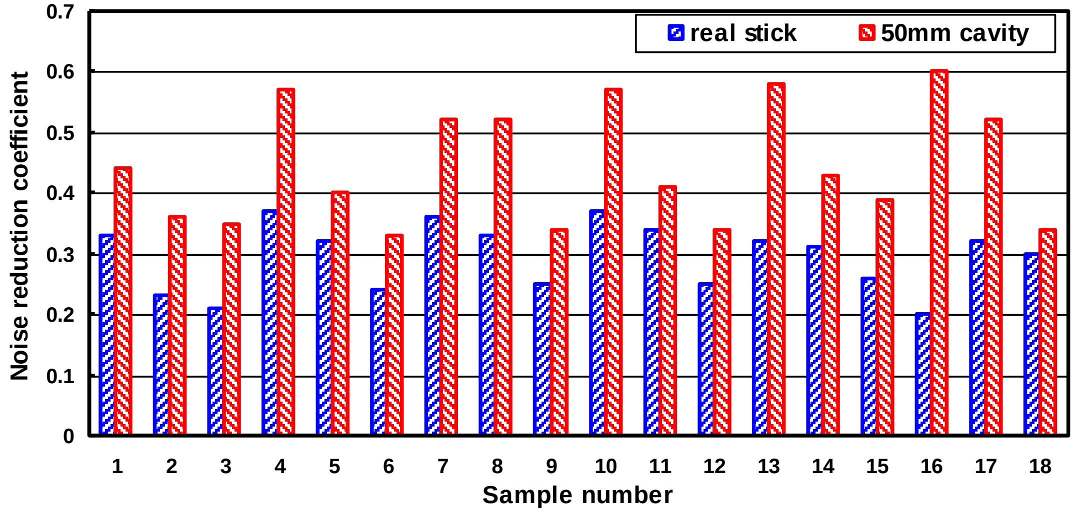

Fig. 7. NRC comparisons of real stick and 50 mm cavity

The samples 1, 4, 7, 10, 13, and 16 as in Table 1 with specific gravity 0.4 g/cm^3 were tested for the sound-absorption coefficient using the impedance tube method from 125 Hz to 4000 Hz as in Fig. 8.

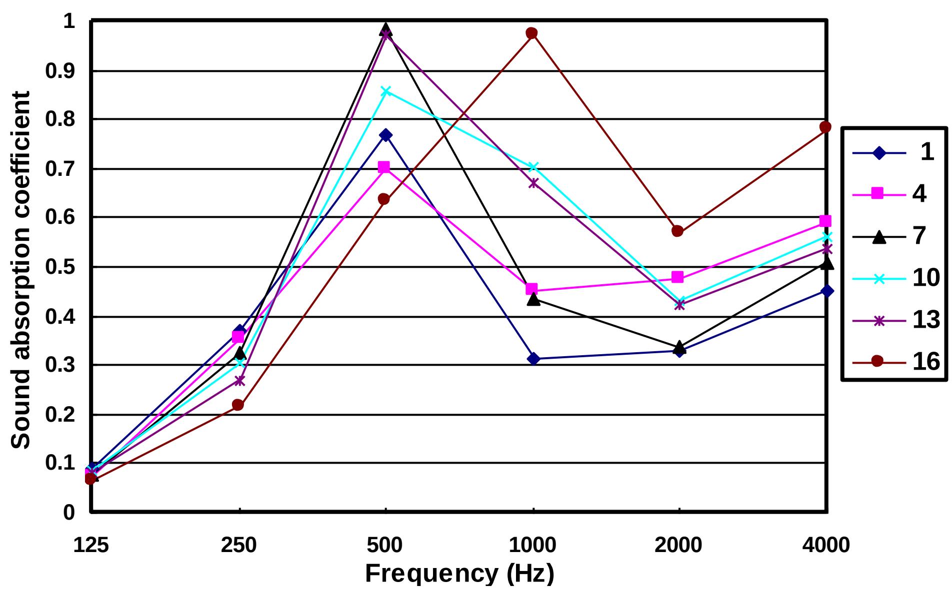

Fig. 8. The sound-absorption coefficients of the hybrid broad

Sample 16, with 100% coir fiber content, had the best sound absorption performance. Because of the problems with processing technology and the natural growth characteristics of natural fibers, porosity is inevitably generated in natural fiber composites (Peijs 1998), and the porosity no doubt plays a certain role in improving the performance of sound absorption. In this study, the porosity in the non-woven mats of coir was more even and better for the sound absorption characteristics. The sound-absorption coefficient increased with the decrease in wood debris in the samples. The reasons were perhaps due to the poorer acoustical property of wood debris. The wood debris could have filled the pores of the coir fiber mats, lowering the porosity of composite so that the incident sound waves could not enter into the composite as easily. Therefore, the appropriate addition of coir can promote the sound absorption performance. Good sound absorption characteristics and certain mechanical strength inherent in the material itself can be useful in the preparation of a sound absorption board. The research was very meaningful relative to the reasonable use of coir fibers in the artificial board industry.

CONCLUSIONS

1. For the preparation of coir fiber and wood debris hybrid composite boards, experimental results showed that the added coir fiber can increase the MOR values and maintain the IB values when the amount that was added is large enough.
2. Coir fiber can be used as a good sound absorption material. The hybrid boards possessed sufficient strength and good impact resistance properties, which could meet the requirements for interior wall materials. Through the reasonable selection and design of density and thickness, the hybrid boards can be produced as sound absorption boards with easy installation characteristics.
3. Through this research, the sound absorption advantage was confirmed. In particular, the sound absorption performance of wood debris board was improved by added coir. For future applications of coir fiber, the hybrid composites could be studied with other plant fibers that complement them. The thermal insulation performance should be detected further. Also, the optimization design of the coir fiber hybrid composite must be performed.

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