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Sound Absorption and Physical Properties of Carbonized Fiberboards with Three Different Densities[1]

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ABSTRACT

Characteristics of carbonized fiberboard such as chemical materials absorption, electromagnetic shielding, and electrical and mechanical performance were determined in previous studies. The carbonized board therefore confirmed that having excellent abilities of these characteristics. In this study, the effect of density on physical properties and sound absorption properties of carbonized fiberboards at 800℃ were investigated for the potential use of carbonized fiberboards as a replacement of conventional sound absorbing material. The thickness of fiberboards after carbonization was reduced 49.9%, 40.7%, and 43.3% in low density fiberboard (LDF), medium density fiberboard (MDF), and high density fiberboard (HDF), respectively. Based on SEM images, porosity of carbonized fiberboard increased by carbonization due to removing adhesives. Moreover, carbonization did not destroy structure of wood fiber based on SEM results. Carbonization process influenced contraction of fiberboard. The sound absorption coefficient of carbonized low density fiberboard (c-LDF) was higher than those of carbonized medium density fiberboard (c-MDF) and carbonized high density fiberboard (c-HDF). This result was similar with original fiberboards, which indicated sound absorbing ability was not significantly changed by carbonization compared to that of original fiberboards. Therefore, the sound absorbing coefficient may depend on source, texture, and density of fiberboard rather than carbonization.

Keywords : carbonization, low density fiberboard, medium density fiberboard, high density fiberboard, sound absorption, physical property

1. INTRODUCTION

Noise and vibration control has been the biggest issue in indoor systems due to the high density of dwelling pattern and demands for a better environment. Sound absorption and sound insulation are the key points in evaluating the sound environmental index in South Korea (Kang *et al.* 2012). Therefore, isolation from external sound sources and absorption of sound generated within a space are the two main techniques for noise control in buildings (Godshall and Davis 1969). Sound absorption techniques are more applicable in general use for construction rather than isolation from external sound, which needs extremely complex techniques, time, and money. For that reason, variety of materials were attempted to

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use as sound absorbing material.

In earlier times, glass- or mineral fiber products were used in the sound absorbing material market, but wood or wood-based materials were developed and used for sound absorbing material in construction sites (Wassilieff 1996; Kang *et al*. 2010). Watanabe *et al*. (1967) studied the normal incidence sound absorption coefficient of 6 different types of wood. Wood or wood-based materials have lower sound absorbing coefficients compared to glass- or mineral fiber and polymer products (Zhou *et al*. 2005; Watanabe *et al*. 1967). According to Wassilieff (1996), high density wood products have inherent sound reflecting property rather than sound absorbing due to compression of wood fibers or chips by the manufacturing process.

The techniques for increasing the sound absorbing coefficient of wood based materials have been developed in different ways (Lee *et al*. 2005; Byeon *et al*. 2010; Hwang *et al*. 2008). Improvement of sound absorption coefficient of wood or fiberboards was conducted by making a resonator by simple perforation (Kang and Park 2001). The concave hole-structures on a board surface can improve sound absorption ability (Suh *et al*. 2004). According to Godshall and Davis (1969), porous materials can provide the best sound absorbing result by frictional drag of sound waves through the material.

Carbonized fiberboard, which has the same abilities of charcoal and contains mostly carbon, is one of the candidates for a sound absorbing material because carbon based materials had high porosity, heat resistant, fireproof, anti-oxidation, heat shock resistant, biodeterioration resistant, and dimensional stability (Kwon *et al.* 2013; Park *et al*. 2013). Therefore, carbonized fiberboard is used in environmental remediation industry because of high absorption ability of toxic substances, and it is used as residence environment controller in different form. Carbonized fiberboard was introduced and it can be easy transformed to other shape due to panel form. Specially, fiberboard which is carbonized above 800℃ has significant characteristics such as high porosity, light weight, deodorization, humidifying, far-infrared radiation emission, and electromagnetic interference shielding (Kwon *et al.* 2013).

To our knowledge, use of carbonized fiberboard as a sound absorbing material has not been tried before even though it is widely used for other purposes. According to Woods and Byrne (2010), the carbonization process of wood material leads to the reducing of acoustic velocity by converting to anisotropy cell wall, which means sound absorbing ability may increase from carbonization. Therefore, carbonized boards may be an acceptable material to replace sound absorbing materials due to they made of natural resources, non-human harmful, cost efficiency, dimensional stability, water resistance, and durability. We therefore tried to utilize carbonized fiberboards as sound absorbing material. The objective of this study was to evaluate possibility of highly porous carbonized fiberboard as a sound absorbing material by measuring sound absorbing coefficient and changes of physical properties.

2. MATERIALS and METHODS

2.1. Materials

Low density fiberboard (LDF, Soundstop®, Blue Ridge Fiberboard, Inc., USA), medium density fiberboard (MDF, Sunchang Corp., South Korea), and high density fiberboard (HDF, Donghwa Enterprise Co., Ltd., South Korea) were used in this study and were commercially manufactured and purchased. LDF was manufactured with mixed softwoods and used for all sound deadening, soundproofing, or sound insulation needs. MDF and HDF were manu-

Table 1. Characteristics of three fiberboard samples used in this study

Test samples	Density (g/cm^3)	Size (W × L × T)
Low density fiberboard (LDF)	0.25 ± 0.09*	130 mm × 260 mm × 12 mm
Medium density fiberboard (MDF)	0.59 ± 0.16*	130 mm × 260 mm × 12 mm
High density fiberboard (HDF)	0.92 ± 0.05*	130 mm × 260 mm × 7.7 mm

Note: * means standard deviation

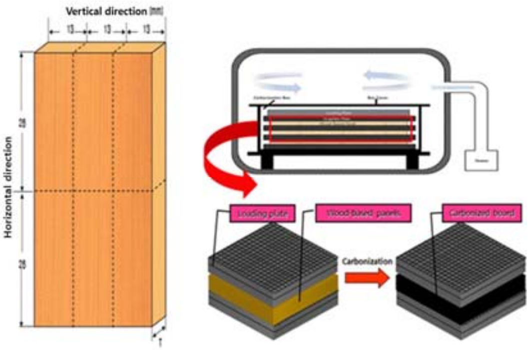


Fig. 1. Cutting size of fiberboard samples and manufacture of carbonized boards.

factured with mixed softwoods and used for construction site or furniture materials.

2.2. Carbonization Process

Physical properties of three different density fiberboards before carbonization are summarized (Table 1). Each fiberboard was cut into 130 (W) × 260 mm (L) and wrapped with aluminum foil. Carbonization of fiberboard was conducted in a vacuum furnace under nitrogen gas flow (200 mℓ/min). Fiberboards were stacked between two graphite sheets (1 cm thickness) in order to prevent distortion and crack. Carbonization schedule was as follows: rate of temperature was 50~100℃/hour, maximum temperature and time were set to be 800℃ and 2 hours. After thermal schedule was done, carbonized fiberboards were cooled down in ambient condition and Fig. 1 shows a diagram of the carbonization process.

2.3. Physical Property of Carbonized Boards

Shrinkage of carbonized boards in width, length, and thickness after carbonization was measured. Scanning electron microscopy (SEM) was used to visualize the surface of carbonized boards. The test specimens of carbonized boards were cut into 10 mm (W) × 10 mm (L) × 5 mm (T) with no coating. SEM images were taken at 500 magnification with 20 kV condition using a Hitachi S-3000N (Hitachi Science System, Ltd., Japan).

2.4. Sound Absorption Coefficients

Five pieces of each carbonized board sample were cut into 63.5 mm diameter and stored in a thermo-hygrostat (20℃ and 65% humidity) for 7 days. Dimension and weight were measured first and then sound absorption was evaluated. The sound absorption coefficients were determined with two microphone transfer function method (ASTM C 384-04, American Society for Testing and Materials, 2011) using an impedance measurement tube. The frequency was recorded the range from 500 Hz to 3200 Hz. The sound absorption coefficients were calculated by average of 100 times recording data after calibration with sponge.

3. RESULTS and DISCUSSION

3.1. Changes of Physical Characteristics

The original board and carbonized boards were

Table 2. Dimensional and weight changes of carbonized fiberboard at 800℃

Samples	Type	Width (mm)	Length (mm)	Thickness (mm)	Weight (g)	Volume (cm^3)	Density (g/cm^3)
LDF	BC	131.00 ± 0.21	262.00 ± 0.13	12.98 ± 0.06	109.48 ± 0.16	446.57 ± 0.14	0.25 ± 0.09
	AC	101.00 ± 0.17	204.00 ± 0.13	6.51 ± 0.04	28.29 ± 0.07	133.86 ± 0.21	0.21 ± 0.04
	SP (%)	22.90 ± 0.11	22.14 ± 0.15	49.85 ± 0.07	74.16 ± 0.13	70.02 ± 0.19	13.79 ± 0.11
MDF	BC	130.00 ± 0.18	262.00 ± 0.11	11.90 ± 0.12	240.16 ± 0.19	404.78 ± 0.18	0.59 ± 0.16
	AC	100.00 ± 0.20	204.00 ± 0.18	7.06 ± 0.08	63.93 ± 0.21	143.78 ± 0.13	0.44 ± 0.12
	SP (%)	23.08 ± 0.12	22.14 ± 0.10	40.67 ± 0.06	73.38 ± 0.18	64.48 ± 0.05	25.06 ± 0.08
HDF	BC	131.00 ± 0.15	260.00 ± 00.19	7.62 ± 0.02	237.15 ± 0.23	258.82 ± 0.21	0.92 ± 0.05
	AC	100.00 ± 0.22	198.00 ± 0.23	4.32 ± 0.03	60.80 ± 0.11	85.44 ± 0.16	0.71 ± 0.07
	SP (%)	23.66 ± 0.13	23.85 ± 0.07	43.31 ± 0.12	74.36 ± 0.17	66.99 ± 0.11	22.34 ± 0.03

Note: BC-before carbonization, AC-after carbonization, SP-shrinkage percentage

compared in dimension, weight, thickness, and volume, and the results are shown in Table 2. Vertical (width) direction shrinkage on LDF, MDF, and HDF was 22.9%, 23.1%, and 23.7%, respectively, while horizontal (length) direction shrinkage was 22.1% (LDF and MDF) and 23.9% (HDF). Shrinkage of thickness was 49.9% (LDF), 40.7% (MDF), and 43.3% (HDF). More shrinkage of thickness than other directions may be caused by weight of graphite plate during carbonization process, while no weight stress on vertical and horizontal direction. Higher thickness shrinkage of LDF was observed than MDF and HDF, it was possibly caused by original density of fiberboard. LDF may have more space between wood fiber compares to the MDF and HDF.

About 74.2%, 73.4%, and 70.0% of the initial weight was reduced in LDF, MDF, and HDF respectively. Final density of carbonized LDF, MDF, and HDF were reduced to be 13.8%, 25.1%, and 22.3% respectively.

Based on shrinkage results by carbonization, shrinkage in vertical direction in all fiberboards was not significantly changed by carbonization, while shrinkage in horizontal direction, thickness, and weight were significantly changed in all samples. After carbonization of all fiberboards, final volumes and weight of all fiberboards were dramatically decreased around 70% and 50%, respectively, but final densities were reduced 13.79%, 25%, and 22.34% in LDF, MDF, and HDF, respectively. These reduction characteristics by carbonization may be merit to apply for insulation materials between wall, floors, and ceilings.

3.2. Morphological Characteristics

Deformation, irregular arrangement, and strong aggregation of resin and fiber were observed on the surface area of original boards by SEM (Fig. 2).

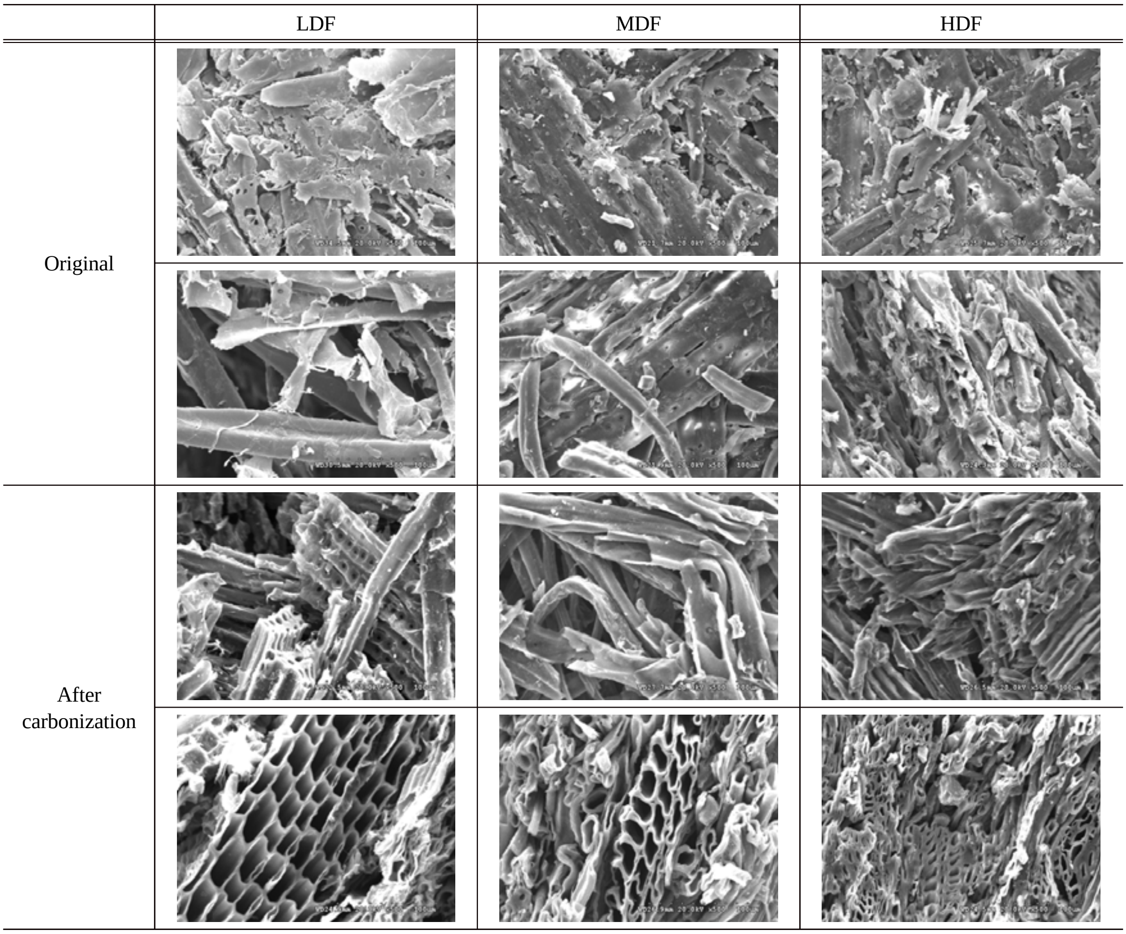


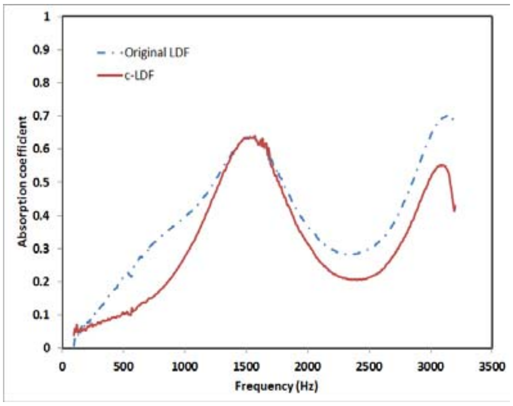
Fig. 2. SEM images of original- and carbonized- LDF, MDF, and HDF (× 500).

After carbonization, more porous and hairy fiber prominently appeared on the surface area of all fiberboards. Wood cell lumen in MDF and HDF was significantly collapsed, which may be due to hot pressing, while there was no damage in LDF. The cell lumen damage also may be related with density because lower densities may provide enough space for cell lumen to be compressed between wood fibers. Therefore, the lumen of wood fiber on LDF was not damaged.

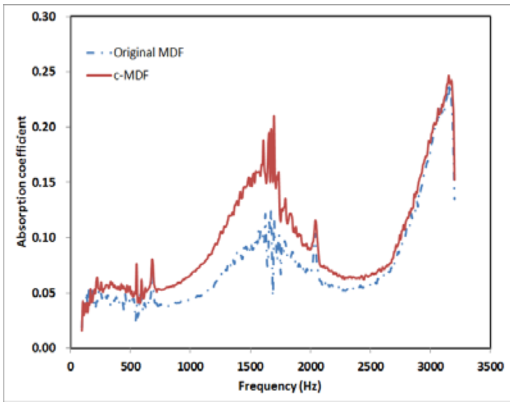
The carbonization process did not affect the morphological characteristics of wood fiber, because wood fiber's form was the same as before. Moreover, most resin was removed by carbonization process. Less porous and more closely bonded fibers were observed on c-HDF, compared to c-MDF and c-LDF. On the other hand, c-LDF had higher porosity than others. The porosity of all carbonized fiberboards was originated from their original characteristics.

3.3. Sound Absorption Coefficients

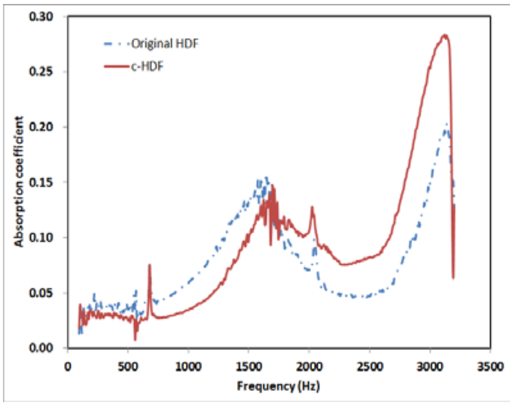
Fig. 3 shows the difference between the sound absorption coefficients (SACs) of the original fiber-



(a) LDF



(b) MDF



(c) HDF

Fig. 3. Sound absorption coefficient of original- and carbonized- LDF, MDF, and HDF.

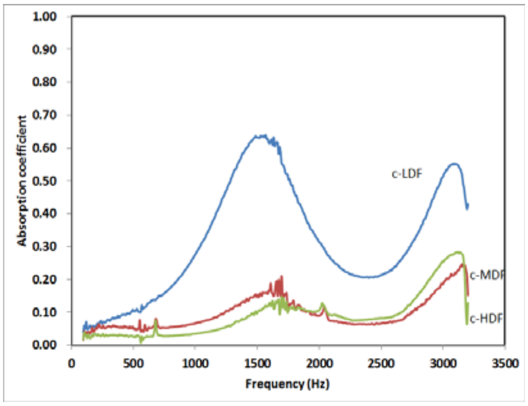


Fig. 4. Comparison of sound absorption coefficient among carbonized- LDF, MDF, and HDF.

boards (o-LDF, o-MDF, and o-HDF) and carbonized fiberboards. In general, for the LDF, the carbonization process reduced SACs on most frequency ranges, except on frequency range around 1500~1600 Hz. For the c-LDF, higher SACs were observed for frequencies between 1400~1700 Hz (63%) and between 3000~3100 Hz (55%), similar to the o-LDF. The MDF showed opposite results compared to the LDF, with c-MDF having higher SACs on most frequencies compared to o-MDF. The SAC pattern of c-MDF was similar to the LDF, with higher SAC on frequencies between 1400~1700 Hz (15%) and between 3000~3100 Hz (25%). For frequencies below 1600 Hz, higher SAC were observed on o-HDF than c-HDF, while lower SAC were observed on o-HDF than c-HDF at frequency range above 1600 Hz. Lower SAC was observed the frequency at 2500 Hz and below 1000 Hz on all samples. These results are confirmed with previous studies, which were found that lower density board had higher SACs (Yang *et al*. 2003, 2004; Kang *et al*. 2010, 2012).

Carbonization process could remove the other components except wood fiber, and SACs were expected to be increased in all samples by carbonization. Based on our results, however, carbonization did not significantly affect on the SACs of LDF, MDF, and HDF, even though resin and other components were removed.

Fig. 4 shows the comparison among the SAC of c-LDF, c-MDF, and c-HDF. The c-LDF had significantly higher SACs than the c-MDF and c-HDF. Thus the SACs are more related to the density of fiberboard than carbonization. In our experiment, comparison between each fiberboard may not be necessary and shows controversial results because each fiberboard manufactured with different source of wood fiber, hot press time and temperature. Moreover, LDF was manufactured for sound absorbing materials, so it should be higher SAC than MDF and HDF. These results will be helpful to confirm that carbonization did not significantly affect the SAC of fiberboards, and the SAC is more related to wood fiber source and density than thickness or other factors.

4. CONCLUSION

Noise pollution has been becoming more issue and a critical parameter to evaluate indoor environment quality. Also, noise control techniques have been developed to keep up with the times. In the market, many types of sound absorbing materials exist and are distributed such as glass wool, rock wool, sponge, wood-based panels, and fabric. However, most of these materials have the potential to cause air pollution. Because the indoor air quality act has been established, air pollutants should be minimized from raw materials. Carbonized fiberboard may be considered as one of the substitute materials for sound absorbing materials because of its abilities such as absorbing toxic substants, controlling moisture, and removing bad smell. In this study, three different densities of fiberboard were carbonized and then physical and morphological properties were determined. In general, carbonization yielded shrinkage on the vertical (22%) and horizontal (22%) directions and thickness (50%), reduction in weight (74%), and density reduction (20%). These shrinkage and reduction could be advantageous for use on ceiling and insulation. Moreover, no damage from carbonization on wood fiber was observed by SEM. The damage of lumen was caused from the manufacturing process of fiberboard such as hot press, and pressure. Based on sound absorption coefficient results, carbonization did not influence the sound absorbing ability of fiberboard. Therefore, carbonized fiberboard (LDF) may be used as a sound absorbing material because it keeps the original sound absorbing ability and carbonization treatment assigns additional functionalities, such as absorbing toxic substants and controlling high humidity.

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