Comparison of the Radon Absorption Capacity of Carbonized Boards from Different Wood-based Panels

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The radon absorption performance was determined and compared for different types of carbonized boards to establish effective carbonized boards. Moreover, the absorption mechanism of carbonized boards was investigated by specific surface area and pore size in each of the carbonized boards. The radon absorption performance was ranked in the following order: ash (87%), medium-density fiberboard (MDF, 83%), oriented strand board (OSB, 82%), particleboard (PB, 77%), and plywood (PW, 67%). The correlation between radon absorption capacity and surface area or pore volume showed that a higher surface area or pore volume had higher radon absorption performance. However, the highest surface area and pore volume was detected on carbonized MDF, which had a radon absorption performance that was 5% less than carbonized ash board. Therefore, the surface area and pore volume as well as other factors affected the absorption performance.

Keywords: Carbonized board; Wood-based panel; Carbonization; Radon absorption; Surface area

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INTRODUCTION

Environmental pollution is an everlasting issue and is a threat to mankind. Among the pollutants, radon has been known to be a cancer-causing radioactive gas, according to the World Health Organization (WHO 2009). Also, radon is ubiquitous, being commonly found in all air, including outdoor and indoor. The average concentration of radon in outdoor air is usually very low, between 5 Bq/m^3 and 15 Bq/m^3 (below 0.4 pCi/L) (Porstendörfer 1984; Bodansky *et al.* 1987; WHO 2009). However, radon is a cancer-causing gas to humans through inhalation of aerosols, dust, and other particles that radioactive alpha particles attach to (Keller and Folkerts 1984; Darby *et al.* 1998; Steck *et al.* 1999; Field *et al.* 2001; US EPA 2016). These particles containing radioactive alpha particles can damage DNA and potentially cause lung cancer (Porstendörfer 1984; Bodansky *et al.* 1987; Darby *et al.* 1998; Field *et al.* 2001). According to the United States Environmental Protection Agency (US EPA 2016), approximately 20,000 lung cancer deaths each year in the US are radon related. Exposure to radon for most humans occurs at home, due to highly concentrated radon from construction materials and lack of ventilation (Porstendörfer 1984; WHO 2009). For this reason, the US EPA recommends that when the radon level is between 2 pCi/L and 4 pCi/L, the home needs to be monitored (Bodansky *et al.* 1987). Furthermore, there is an increased chance of exposure to radon from building, subway, and underground shopping centers when they are not well ventilated and are built with concrete and gypsum board (Park *et al.* 1989). For this reason, a determination of radon emission levels and lower radon emitting construction methods need to be developed for indoor air quality.

Charcoal has been known as an excellent environmentally-friendly material when it comes to its absorption of mercury or pernicious components, fireproof characteristic, sound-absorbing ability, and electromagnetic shielding (Novicio *et al.* 2001). Cho and Lee (2011) reported that activated carbon or charcoal could be used as a radon-blocking material because 71% to 85% of radon in their experimental condition was reduced by activated carbon or charcoal. Therefore, the manufacturing of composite boards from charcoal powder is underway, and interest in carbonized material is increasing. Recently, authors have been conducting research to develop new carbonized boards with a similar performance to activated carbon boards and manufacturing simply by using a vacuum furnace without cracking and opening (Kwon *et al.* 2012). Carbonized board could be transformed into other shapes due to its machinability, and it could be used in the electronic and construction industries (Kercher and Nagle 2002). In the authors' preliminary study, carbonized medium-density fiberboard (MDF) had significant performance on absorbing toxic materials, such as formaldehyde, benzene, and volatile organic compounds. In addition, the radon absorption performance of carbonized MDF at different temperatures was measured and it was concluded that the carbonization at 600 °C showed a higher radon absorption performance (Kwon *et al.* 2012).

To compare each carbonized board, the BET surface area and pore size should be assessed. It has been explained that an absorbent's surface area, pore size, pore distribution, and type of pore are critical factors in the performance of absorption (Iimoto *et al.* 2005). An absorbent with uniform pore size yields faster diffusion of particles and better absorption performance (Ebie *et al.* 2001; Wanping *et al.* 2003). An absorption phenomenon by interrelation among pore structure, surface area, and characteristic of adsorbate molecule is affected by the selectivity of adsorbent to adsorbate (Lee *et al.* 2006). In other words, absorption is influenced by pore structure, which is located on the surface and inside of activated carbon, thus, information on the construction of the pore is very important to the design absorption mechanism (Gregg and Sing 1967; Ruthcven 1984). In the previous study, carbonized MDF at 600 °C was found to have a higher BET surface area and its pores were micro-pore size. These characteristics may affect higher radon absorption performance. Therefore, the objectives of this study were: a) to compare the radon absorption performance of different types of carbonized boards, and b) to investigate the correlation between the radon absorption and specific surface area and pore size in each of the carbonized boards.

EXPERIMENTAL

Materials

Five different types of wood-based boards, ash (*Fraxinus* sp.) board, oriented strand board (OSB, Georgia-Pacific LLC, Atlanta, GA, USA), particleboard (PB, Donghwa Enterprise, Incheon, Korea), plywood (PW, Sunchang Corporation, Incheon, Korea), and MDF (Sunchang Corporation, Incheon, Korea), were used in this study. Each board was mainly made of the following wood species: OSB (Southern yellow pine), PB (construction waste wood), PW and MDF (Radiata pine). All boards were commercially available in market and purchased. Each board was cut into 260 mm × 130 mm pieces and then wrapped with aluminum foil.

The carbonization of boards was conducted by stacking the boards between two graphite sheets (10-mm thickness) to prevent distortion and cracking by a vacuum furnace under nitrogen gas flow (200 mL/min) (Fig. 1). The temperature in the vacuum furnace was raised 50 °C/h, until its temperature reached 600 °C, maintaining that temperature continuously for 2 h.

Methods

The concrete board, used as the source of radon emission, was cut into 150 mm × 50 mm pieces, and then 10 pieces of that were placed in a desiccator (11-L). Each prepared carbonized board (100 mm × 200 mm) was additionally added into the desiccator containing concrete boards (Fig. 1). The desiccators were fully sealed and temperature-controlled between 25 °C and 27 °C to prevent sampling error.

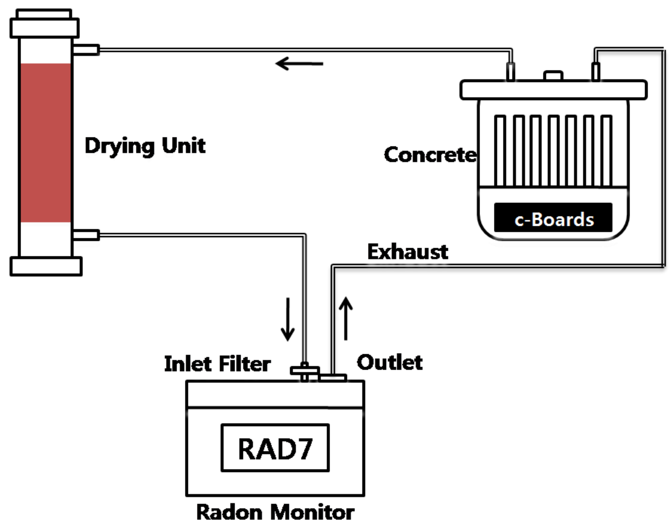

Fig. 1. Schematic of radon determination system

Determination of radon (^{222}Rn and ^{220}Rn)

The air in the desiccator was collected at 30 min cycles and the radon concentration was analyzed. The concentration of radon from concrete boards in a desiccator was determined using RAD7, which mainly detected radon-222 and radon-220 (Durridge Company Inc., Billerica, MA, USA). The RAD7 has a detection range between 0.1 pCi/L to 10,000 pCi/L (4-400,000 Bq/m^3). Three measurements were taken at days 7, 35, and 50, with 3 replicates.

BET surface area and pore volume

The specific surface area and pore volume of carbonized boards was investigated with an automated chemisorption apparatus (Autosorb-1, Quantachrome Instruments, Boynton beach, FL, USA) using nitrogen as the adsorbate at liquid nitrogen temperature (77 K). Each carbonized board was ground down to powder with a mortar and sieved through a 150-µm screen. Approximately 10 mg to 30 mg of each sample powder was used for analysis. The sample powders were degassed at 300 °C for at least 12 h until the outgas pressure test passed 30 micron per min. After the degassing procedure, sample tubes (6-mm without rod) were backfilled with helium and then analyzed.

RESULTS AND DISCUSSION

Determination of Radon

The radon emission and absorption rates for each carbonized board are listed in Table 1. An excess amount of concrete boards was added as the control to determine the radon absorption capacity, because the capacity of the carbonized boards was unknown. The desiccator contained only concrete boards (1800 cm^2) that emitted 62.2 Bq/m^3, 84.1 Bq/m^3, and 98.8 Bq/m^3 on days 7, 35, and 50, respectively. The amount of radon emission increased by accumulation due to no ventilation overtime.

Table 1. Reduction rates of Radon Emission from Containers of Concrete Boards and Different Carbonized Boards on Days 7, 35, and 49

Sample ID	Reduction Rates of Radon Emission (%)		
	Day 7	Day 35	Day 49
Control	0	0	0
Ash board	69.94	73.96	87.04
Medium density fiberboard (MDF)	70.58	64.09	83.00
Oriented strand board (OSB)	68.97	70.04	81.98
Particleboard (PB)	67.04	70.99	77.02
Plywood (PW)	50.00	51.96	67.00

The carbonized boards absorbed between 67% and 87% radon form concrete boards at day 49. The highest absorption capacity for radon was observed on ash board (87%), and MDF (83%), OSB (82%), and PB (77%) had a lower radon absorption capacity. Based on the results, the carbonized boards had an excellent radon absorption ability, comparable to that of activated carbon or black charcoal, thus it can be used as a radon absorbing material for indoor finishing materials. Moreover, carbonized natural wood showed better radon absorption performance than composite wood panels, but there were no differences between carbonized ash, MDF, and OSB. Among the carbonized boards, MDF is recommended as a radon absorbing material due to its high radon absorption ability and quality assurance from carbonization. After carbonization, cracks or other minor defects were observed on carbonized boards, except for carbonized MDF. Carbonizing ash had technical limitations for industrialization because it was difficult to supply bigger sizes and carbonize without defects. The carbonized plywood had a lower radon absorption performance, which was 50% to 67% at day 7 and 49, respectively. Even plywood, which maintains more wood characteristics, had a lower radon absorption performance after carbonization. Therefore, the authors assumed that the radon absorption performance could depend on specific surface area and pore volume and its distribution of char, as a result of the wood species.

BET Surface Area and Pore Volume of Carbonized Boards

Table 2 displays the BET surface area of the five different types of carbonized boards used in this study. The carbonized MDF board (853 m^2/g) had more surface area than ash (732 m^2/g), OSB (723 m^2/g), PB (497 m^2/g), and PW (360 m^2/g). Based on the pore volume results, MDF also had a higher pore volume than other carbonized boards.

Table 2. BET Surface Area of Carbonized Boards with Respect to Ash, MDF, OSB, PB, and PW

Sample ID	Surface Area (m^2/g)	Pore Volume (cm^3/g)
Ash board	732 ± 85	0.110
Medium density fiberboard (MDF)	853 ± 98	0.128
Oriented strand board (OSB)	723 ± 74	0.092
Particleboard (PB)	498 ± 65	0.020
Plywood (PW)	360 ± 81	0.018

The correlation between the radon absorption performance and the surface area and pore volume of carbonized boards indicated that the radon absorption performance could be influenced by the surface area and pore volume. The surface area of five different carbonized boards was lower than currently developed or used activated carbon (over 1200 m^2/g), but ash, MDF, and OSB were higher than activated carbon from waste material by pyrolysis (Tamai *et al.* 1996; Nagano *et al.* 2000; Ariyadejwanich *et al.* 2003; Kim *et al.* 2012). However, each carbonized board had different absorption and desorption characteristics, based on nitrogen isotherm data. Carbonized ash board had more meso-pore content than carbonized MDF, OSB, PB, and PW. In the authors' instrumental condition, micro-pore material was difficult to analyze completely; thus an adsorbate could be changed to argon gas to look at more detailed micro-pore and pore size distribution. Furthermore, the surface area and pore volume correlated with the absorption ability of the radon. Although, further study is needed due to the lack of information about the characteristics of the carbonized board's particles and ambiguous mechanism for the carbonization of wood-based panels. The aforementioned pore structures were observed as shown in Fig. 2.

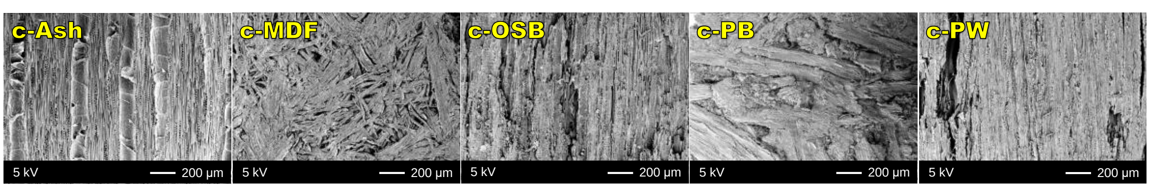

Fig. 2. SEM images of carbonized boards with respect to Ash board, MDF, OSB, PB and PW

CONCLUSIONS

1. Carbonized boards, except carbonized PW, had a high radon absorption performance, similar to the ability of activated carbon.
2. When considering the effect of absorption due to the pore size distribution, even carbonized ash board had a lower surface area than carbonized MDF, but it showed a higher radon absorption capacity (87%).
3. Based on the results, non-cracked carbonized MDF could be recommended for use as a radon absorbing material in indoor applications.

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