

# Evaluation of Formaldehyde Emissions and Combustion Behaviors of Wood-Based Composites Subjected to Different Surface Finishing Methods

Chang-Young Park,<sup>a</sup> Chang-Ho Choi,<sup>a</sup> Jeong-Hun Lee,<sup>b</sup> Sumin Kim,<sup>b,\*</sup>  
Kyung-Won Park,<sup>c</sup> and Jeong Ho Cho<sup>d</sup>

To use wood-based panels as a final product, they must undergo surface finishing via various processes, such as low pressure laminate (LPL), polyvinyl chloride (PVC), coating paper (CP), direct coating (DC), or veneer overlay/UV coating (VO-UVC). Tests were conducted to look for any reduction of formaldehyde emissions and in combustion behaviors with the use of five different surface finishing methods. To determine formaldehyde emissions, the desiccator method was used according to the Korean Standard KS M 1998. The combustion behaviors of wood-based panels were investigated using a cone calorimeter. The formaldehyde emissions of VO-UVC were lower than those of the other methods. In the burning tests, the heat release rate (HRR) with DC was higher than that with the other methods. The mass loss rate (MLR) when the product with DC was burned was higher than that for the other finishing materials.

*Keywords:* Surface finishing method; Wood composite material; Burning behavior; Cone calorimeter; Formaldehyde; Desiccator

*Contact information:* a: Department of Architecture Engineering, Kwangwoon University, Seoul 139-701, Korea; b: School of Architecture, Soongsil University, Seoul 156-743, Korea; c: Department of Chemical Engineering, Soongsil University, Seoul 156-743, Korea; d: SKKU Advanced Institute of Nanotechnology (SAINT) and Center for Human Interface Nano Technology (HINT), School of Chemical Engineering, Sungkyunkwan University, Suwon 440-746, Korea; \*Corresponding author: skim@ssu.ac.kr

## INTRODUCTION

People spend almost 90% of their time indoors, which presents a higher risk from the inhalation of pollutants than outdoor time does. In recent years many people have been complaining of symptoms of illness such as headaches, irritation of the nose, nausea, skin disorders, and fatigue after spending some time in new buildings or newly renovated housing in recent years (Menzies and Bourbeau 1997; Jang *et al.* 2004; Jo and Sohn 2009). Sick building syndrome (SBS) is a serious problem, with poor air quality caused by indoor contaminants in the home and the workplace (Menzies and Bourbeau 1997; Hodgson 2002; Kim and Kim 2006). SBS symptoms that are experienced by a building's occupants may be caused by volatile organic compounds and formaldehyde (Franck 1986; Kjærgaard *et al.* 1990; Andersson *et al.* 1997; Choi *et al.* 2009), which are known to be emitted from building materials and furnishings (Zhang and Xu 2003; James and Yang 2005).

Wood-based panels are widely used in the manufacture of furniture, flooring, housing, and in other industrial products. These consumer products contain formaldehyde-based resin that emits formaldehyde, which is toxic and is associated with possible

health hazards, such as irritation of the eyes and upper respiratory tract. This problem can be an obstacle to the acceptance of these wood-based panels by the public, given the prevailing climate of environmental awareness and concern. As a result, the European and Northern American governments have imposed regulations limiting the emission of formaldehyde from building materials and from materials used in the manufacture of furniture and fittings (Kawouras *et al.* 1998; Kim *et al.* 2010; Yu and Kim 2012).

Before they can be used as furnishing materials, wood-based panels have to be treated to match the specific requirements of their final use. Therefore, finishing-treatment methods that produce an overlay or coating, such as paints, prints, varnishes, veneers, laminates, impregnated papers, and finishing foils, are used to reduce the absorption of water and humidity and to resist release of harmful gases (Vansteenkiste 1981). Interior fittings and furniture manufacturers commonly use surfacing materials for decorating fiberboard. These materials are manufactured as uniform, flat panels that provide excellent surfaces for the application of coating materials (Nemli and Çolakoğlu 2005; Kim and Kim 2006). These surface materials, such as decorative vinyl film and melamine-impregnated paper, can lower the formaldehyde emission concentration from wood-based panels (Grigoriou 1987; Kim 2010; An *et al.* 2011).

One of the main limitations for the use of wood-based panels is its flammability. The lowered flammability of wood-based panels enables them to be used in high-performance applications. Therefore, restrictions have increasingly been placed on the burning of wood materials. The chemical treatment of wood with flame retardants (FR) is the most common way to improve its fire performance (Grexa *et al.* 2003). The combustion behaviors of wood-based panels are evaluated using a cone calorimeter. The cone calorimeter is a newly developed instrument for measuring the heat release and smoke emission behavior from a burning surface and analyzing the combustion products when a constant flow of air is provided to a confined space (Bin 2003; Yimin *et al.* 2005).

In this study, formaldehyde emissions were evaluated while seeking a low-emission method among the various possible surface finishing methods. In addition, the cone calorimeter test was conducted to examine the fire resistance performance of various surface finishing methods.

## EXPERIMENTAL

### Materials

Medium density fiberboard (MDF) and particleboard (PB) panels, which are commonly used as furniture materials in residential buildings in Korea, were chosen for this study. The panels were purchased at a panel retailer. The panel samples were 18 mm thick and were cut to proper size for each experiment. The detailed specifications of the samples are shown in Table 1, and the values are the averages.

To determine the variations in formaldehyde emissions and combustion behaviors depending on the surface finishing method, we investigated low pressure laminates (LPL), polyvinyl chloride (PVC), coating paper (CP), direct coating (DC), and veneer overlay & UV coating (VO-UVC) for wood-based panels. These five are representative of the methods usually used for furnishing materials in Korea. The characteristics of the various surface finishing methods are described in Table 2.

**Table 1.** Detailed Specifications of the Samples

Classification	Size (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Moisture Content (%)
MDF specimens	15×5×18 (for desiccator)	99 (for desiccator) 132 (for cone calorimeter)	73.3	6
PB specimens	10×10×18 (for cone calorimeter)	90 (for desiccator) 120 (for cone calorimeter)	66.7	7

**Table 2.** Characteristics of Various Surface Finishing Methods

Classification	Method	Curing time	Curing temperature	Coating thickness
Reference panel	Untreated	-	-	-
Low Pressure Laminates (LPL)	Saturating papers are cured on panel surface using hot press process at 25 bar	30 s	180 °C	0.1 mm
Poly Vinyl Chloride (PVC)	PVC films are cured on panel surface at room temperature using EVA(Ethylene Vinyl Acetate) resin	24 h	Room temperature	0.1 to 0.3 mm
Coating Paper (CP)	The paper with resin coating cured on panel surface at room temperature using PVAC resin	24 h	Room temperature	0.1 mm
Direct Coating (DC)	Polyester resin cured on panel surface using hot process	20 min	180 °C	120 µm
Veneer Overlay & UV Coating (VO-UVC)	Veneer overlay(0.2~0.6mm) glued on panel surface with PVAC or urea resin and cured using irradiation of UV	Instant hardening	-	45~60 µm

### Formaldehyde Emissions Measured by Desiccator Methods

Formaldehyde emissions from the MDF and PB were determined using a desiccator method according to the Korean standard KS M 1998. The desiccator test was used to determine the quantity of formaldehyde emitted from the building boards and was carried out using a 10-L glass desiccator. The quantity of formaldehyde emitted was determined from the concentration of formaldehyde absorbed in the distilled or deionized water when the test pieces of the specified surface area were placed in a desiccator filled with a specified amount of distilled or deionized water after 24 h had elapsed. The sample surface areas were 1800 mm<sup>2</sup>, as specified by the Korean standard KS M 1998. Throughout the 24 h, the temperature of the dry oven containing the desiccators was set to 20 °C.

The formaldehyde concentrations were evaluated as the average values of two set of specimens. The differences of each result should not be more than 20% of the average values of two set of specimens. Otherwise, the test should be repeated again from the beginning. In the formaldehyde emission tests, the reference boards with three types of grade were tested. Various wood-based panels were selected by different emission rates, and various surface finishing methods were applied. The results were analyzed compared to reference board. The grades according to the results of desiccator method are as follows: E0 grade (< 0.5 mg/L), E1 grade (0.5 to 1.5mg/L), and E2 grade (> 1.5 mg/L).

## Cone Calorimeter

The cone calorimeter is recognized worldwide as one of the most acceptable devices for fire testing. To confirm the combustion behavior of the panels, specimens of dimensions 100 mm × 100 mm × 18 mm thickness were fabricated. The experimental results were calculated based on the average of the results of three experiments for each test.

All the experiments were conducted by placing the specimens in the same holder in a horizontal position under the cone heater with 50 kWm<sup>-2</sup> of heat flux. In the cone calorimeter test, the heat release rate (HRR), total heat rate (THR), mass loss rate (MLR), ignition time, and flame-out time were investigated. The cone calorimeter test was conducted according to the ISO-5660-1 standard. Figure 1 shows the appearances of the specimens and the cone calorimeter test.

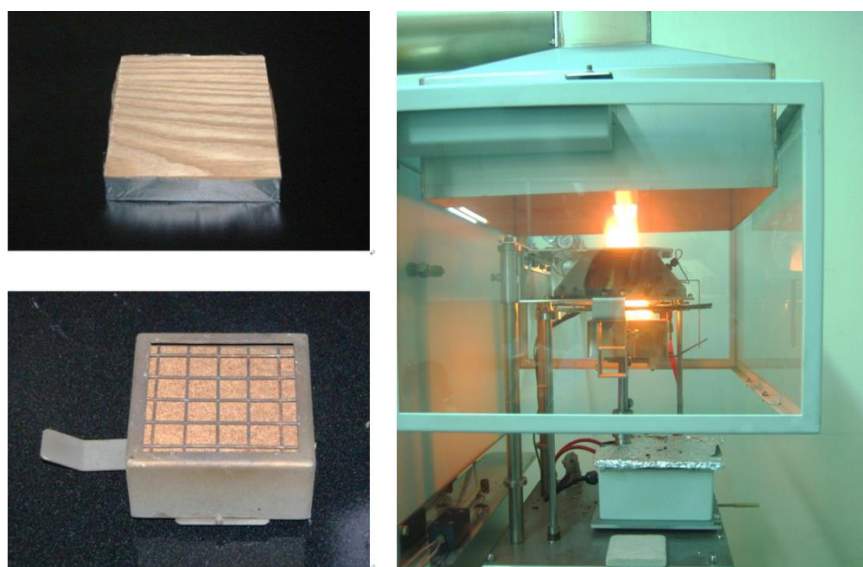


Fig. 1. The appearance of the specimens and the cone calorimeter test

## RESULTS AND DISCUSSION

### Formaldehyde Emissions

To confirm the formaldehyde emissions of the five surface finishing methods and the untreated panels, the panels were tested using the simple and inexpensive desiccator method. Figure 2 shows the formaldehyde emissions of the MDF specimens. For the MDF panels, the emissions of the E0 grade (< 0.5 mg/L) specimens did not vary significantly among the six trials. The LPL and VO-UVC emissions at 0.30 mg/L were lower than those of the other samples, including the reference sample value of 0.36 mg/L. However, the PVC and CP results were higher than the reference values. For the E1 grade (0.5 to 1.5 mg/L), all five surface finishing treatment specimens showed lower emission values than the reference sample. For the E2 grade (> 1.5 mg/L), there was clear variation among the six specimens. The DC and VO-UVC emissions were lower than the reference value, by approximately 20% for the latter. Figure 2 shows the formaldehyde emissions of the MDF specimens.

Figure 3 shows the formaldehyde emissions of the PB specimens. The emission results for the E0 grade were slightly different from those for MDF, as all treated specimens showed higher emissions than the reference values. In particular, the PVC method increase was approximately 56%, but the absolute increase of 0.18 mg/L was not excessive. All E1-grade tested samples showed lower emissions than the reference, with DC having the lowest. The E2-grade samples showed clearly different emission behavior that was similar to the trend for MDF. Again, the DC specimen showed the lowest emission, with a reduction rate of approximately 27%. The VO-UVC sample also showed lower emission than the reference value. However, the formaldehyde emissions were increased for the other three methods. Figure 3 shows the formaldehyde emissions of the PB specimens.

To summarize these formaldehyde emission test results, the PVC and CP methods showed higher emission levels compared with natural boards because of the influences from the EVA and PVAc resins used for bonding of the surface finishing material and from the curing at room temperature. On the other hand, the DC and VO-UVC methods showed the lowest emission levels regardless of the natural emission grade of the product. This was attributed to the following: unlike the other methods involving room temperature curing, the DC method includes hot or infrared curing, and the VO-UVC method includes UV irradiation curing. This can be explained by the decomposition and reduction of free formaldehyde that occurs during the thermal curing process of the DC and VO-UVC methods. However, the LPL method, which includes a hot pressing process for curing, showed different behavior. The formaldehyde reduction rates that were investigated were higher in the E2 grade. With the E2-grade wood-based panels that are the ones mainly used in Korean industry, the DC and VO-UVC methods are considered efficient ways to reduce formaldehyde emissions. The difference of formaldehyde emission results was attributed to the use of a thermal curing process. It was considered that the free formaldehyde in the wood based panel was decomposed during hot curing process or radiation of UV. Therefore, further studies on thermal curing process are considered necessary.

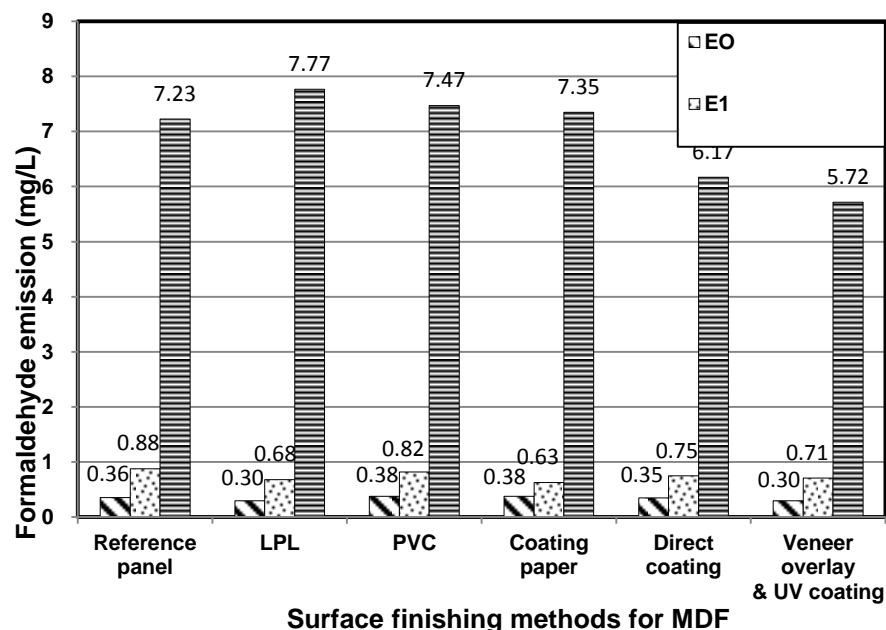


Fig. 2. Formaldehyde emissions of MDF for the six surface finishing methods

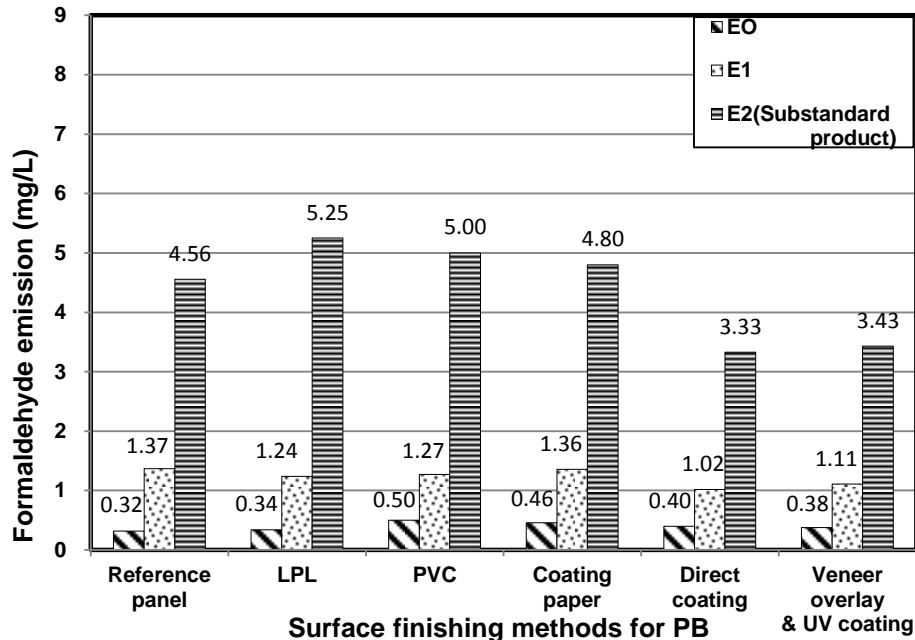


Fig. 3. Formaldehyde emissions of PB for the six surface finishing methods

**Combustion Behaviors**

Only E2-grade specimens were used in the cone calorimeter test. The cone calorimeter is a performance-based, bench-scale, fire-testing apparatus that provides comprehensive insight into not only fire risks such as HRR, total heat release (THR), and time to ignition, but also fire hazards such as smoke release and CO production. However, in this study, the cone calorimeter was used to test and confirm the fire risks of the surface finishing methods.

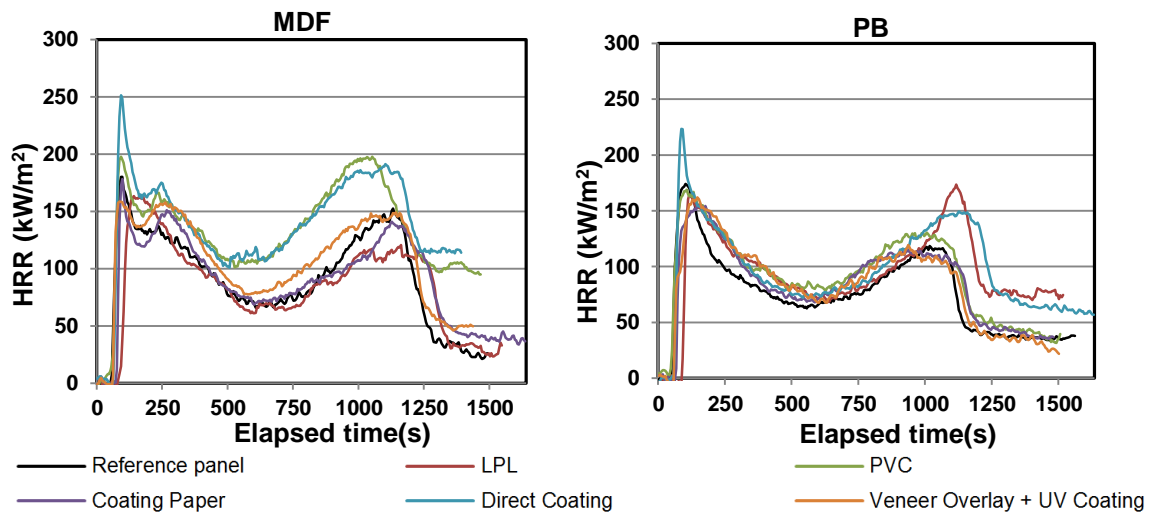
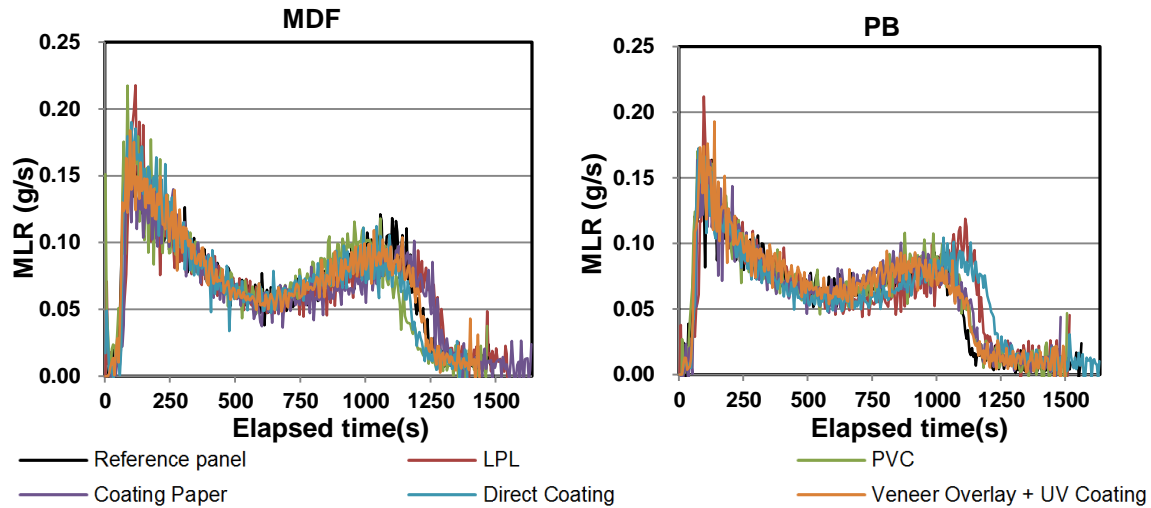


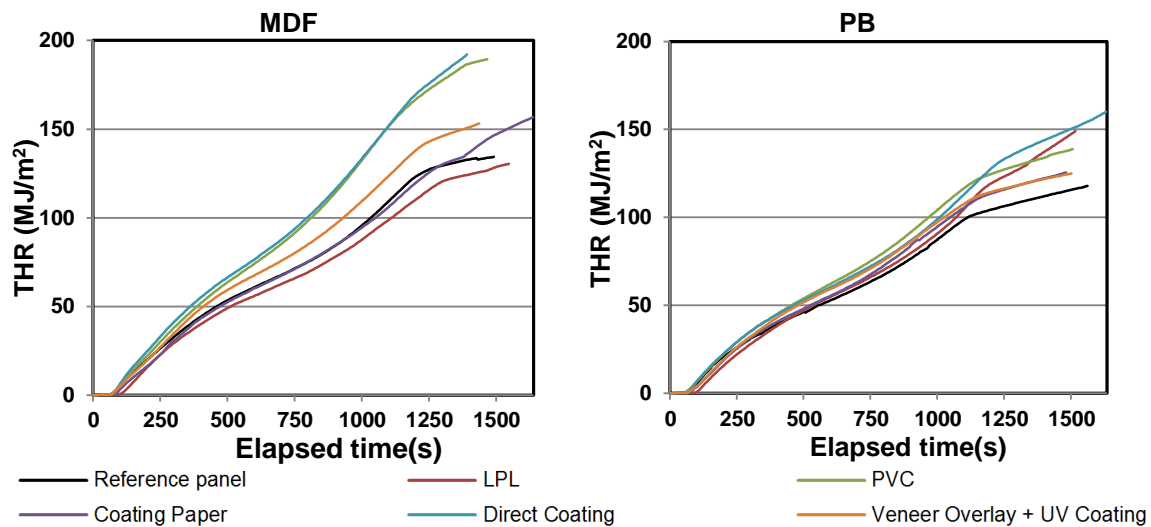
Fig. 4. The HRR of MDF and PB for the six surface finishing methods

The FR and combustion behaviors were evaluated with a heat flux of  $50 \text{ kWm}^{-2}$  over the total duration from complete installation of the specimen until the flame was turned off. The HRR and MLR of PB and MDF for each surface finishing method are shown in Figs. 4 and 5.



**Fig. 5.** The MLR of MDF and PB for the six surface finishing methods

The DC method showed higher HRR for both MDF and PB than the other specimens. However, the MDF and PB specimens showed similar patterns regardless of the surface finishing method, with only negligible differences. The results for the MLR were consistent with the results for the HRR. The THR results are shown in Fig. 6. The DC method showed the highest values for both MDF and PB. Generally, in the cone calorimeter test, the HRR and THR for MDF were higher than those for PB.



**Fig. 6.** The THR of MDF and PB for the six surface finishing methods

When comparing combustion behaviors, there were no significant noticeable differences among the finishing methods, and the fire risk remained high compared with other indoor finishing materials. In addition, the somewhat higher HRR and THR of MDF, compared with those of PB, were attributed to the higher density of MDF compared with PB.

## CONCLUSIONS

1. The formaldehyde emission tendency of wood-based board is definitely influenced by the surface finishing method. The DC and VO-UVC methods were the most effective overall in reducing formaldehyde emissions. Thus, pollutants emitted by wood-based boards can be reduced by changing the surface finish method. On the other hand, the PVC and CP methods both increased the formaldehyde emissions of wood-based composites.
2. The formaldehyde emissions of the LPL specimens were far from reduced despite the absence of any adhesives and the inclusion of a hot press curing process. This is contrary to the basic concept that formaldehyde emission shielding from the surface of wood-based products significantly decreases the overall emissions.
3. The combustion and fire resistance varied slightly according to the surface finishing method. The initial HRR was slightly higher with DC than with the other surface finishing methods. However, the difference was not significant. In comparison with a previous study and with other interior materials, the panel specimens retained higher initial HRR and THR, indicating that the fire resistance or FR retardant performance cannot be guaranteed for surface treatment only. Thus, for improved FR performance, other methods should be designed and tests conducted to confirm the combustion behaviors.

## ACKNOWLEDGMENTS

This work was supported by the Soongsil University Research Fund of 2011.

## REFERENCES CITED

- An, J., Kim, S., and Kim H. (2011). "Formaldehyde and TVOC emission behavior of laminate flooring by structure of laminate flooring and heating condition," *J. Hazard. Mater.* 187(1-3), 44-51.
- Andersson, K., Bakke, J. V., Bjørseth, O., Bornehag, C., Clausen, G., Hongslo, J. K., Kjellman, M., Kjærgaard, S., Levy, F., Mølhav, L., Skerfving, S., and Sundell, J. (1997). "TVOC and health in non-industrial indoor environments," *Indoor Air* 7(2), 78-91.
- Bin, L. (2003). "Influence of polymer additives on thermal decomposition and smoke emission of poly(vinyl chloride)," *Polym. Degrad. Stab.* 82(3), 467-476.
- Choi, D. W., Moon, K. W., Byeon, S. H., Lee, E. I., Sul, D. G., Lee, J. H., Oh, E. H., and Kim, Y. H. (2009). "Indoor volatile organic compounds in atopy patients' houses in South Korea," *Indoor and Built Environment* 18(2), 144-154.
- Franck, C. (1986). "Eye symptoms and signs in buildings with indoor climate problems ('office eye syndrome')," *Acta Ophthalmol.* 64(3), 306-311.
- Grexa, O., Poutch, F., Manikova, D., Martvonova, H., and Bartekova, A. (2003). "Intumescence in fire retardancy of lignocellulosic panels," *Polym. Degrad. Stab.* 82(2), 373-377.



- Grigoriou, A. (1987). "Formaldehyde emission from the edges and faces of various wood based materials," *Holz als Roh und Werkstoff* 45(2), 63-67.
- Hodgson, M. (2002). "Indoor environmental exposures and symptoms," *Environ. Health. Perspect.* 110(Suppl. 4), 663-667.
- James, J. P., and Yang, X. (2005). "Emissions of volatile organic compounds from several green and non-green building materials: A comparison," *Indoor and Built Environment* 14(1), 69-74.
- Jang, S. K., Lee, S. J., Yoo, S. W., Jung, K. M., and Ryu, J. M. (2004). "A survey of indoor air quality in new apartment houses in Korea," *J. Korea Indoor Environ. Tech.* 1(1), 12-24.
- Jo, W., and Sohn, J. (2009). "The effect of environmental and structural factors on indoor air quality of apartments in Korea," *Building and Environment* 44(9), 1794-1802.
- Kawouras, P. K., Koniditsiotis, D., and Petinarakis, J. (1998). "Resistance of cured urea-formaldehyde resins to hydrolysis," *Holzforschung* 52(1), 105-110.
- Kim, S. (2010). "Control of formaldehyde and TVOC emission from wood-based flooring composites at various manufacturing processes by surface finishing," *J. Hazard. Mater.* 176(1-3), 14-19.
- Kim, S., Choi, Y.K., Park, K.W., and Kim, J.T. (2010). "Test methods and reduction of organic pollutant compound emissions from wood-based building and furniture materials," *Bioresource Technology* 101(16), 6562-6568.
- Kim, S., and Kim, H. (2006). "Anti-bacterial performance of colloidal silver-treated laminate wood flooring," *Int. Biodeterior. Biodegrad.* 57(3), 155-162.
- Kjærsgaard, S. K., Pedersen, O. F., Taudorf, E., and Mølhav, L. (1990). "Assessment of changes in eye redness by a photographic method and the relation to sensory eye irritation," *Int. Arch. Occup. Environ. Health* 62(2), 133-137.
- Menzies, D., and Bourbeau, J. (1997). "Building related illnesses," *N. Eng. J. Med.* 337(21), 1524-1531.
- Nemli, G., and Çolakoğlu, G. (2005). "The influence of lamination technique on the properties of particleboard," *Build. Environ.* 40(1), 83-87.
- Vansteenkiste, R. (1981). "Surface treatment of wood based panels," in: *Seminar on Wood Based Panels and Furniture Industries*, 23 March to 7 April, 1981, Beijing, United Nations Industrial Development Organization.
- Yimin, L., Yao, B., and Qin, J. (2005). "Preliminary burning tests on PVC fires with water mist," *Polym. Test.* 24(5), 583-587.
- Yu, C.W.F., and Kim, J.T. (2012). "Long-term impact of formaldehyde and VOC emissions from wood-based products on indoor environments; and issues with recycled products," *Indoor and Built Environment* 21(1), 137-149.
- Zhang, Y., and Xu, Y. (2003). "Characteristics and correlations of VOC emissions from building materials," *Int. J. Heat. Mass. Transfer.* 46(25), 4877-4883.

Article submitted: May 29, 2013; Peer review completed: August 5, 2013; Revised version received: September 5, 2013; Accepted: September 8, 2013; Published: September 13, 2013.