Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Polymer Testing 25 (2006) 904–911
POLYMER TESTING
www.elsevier.com/locate/polytest

Test Method

# The effects of edge sealing treatment applied to wood-based composites on formaldehyde emission by desiccator test method

Sumin Kim[a], Jin-A Kim[a], Hyun-Joong Kim[a,*], Hwa Hyoung Lee[b], Dong-Won Yoon[c]

[a]*Laboratory of Adhesion and Bio-Composites, Program in Environmental Materials Science, Seoul National University, Seoul 151-921, South Korea*
[b]*Department of Forest Products, Chungnam National University, Daejeon 305-764, South Korea*
[c]*Department of Building Equipment and System Engineering, Kyungwon University, Seongnam 467-701, South Korea*

Received 2 April 2006; accepted 16 May 2006

**Abstract**

Formaldehyde emissions were measured with the Japanese industrial standard desiccator (JIS A 1460) method for particleboard (PB) and medium density fiberboard (MDF) as furniture materials, 8 mm laminate flooring, and engineered flooring as flooring materials. To measure the formaldehyde surface emissions, the edge of each sample was sealed with either parafilm, polyethylene wax or aluminum foil. To determine the effect of thickness, emissions from PB and MDF of 9, 12, 15, 18 and 20 mm thicknesses were measured. The difference between sealing methods was relatively small but the difference from unsealed was large, confirming the need for a test procedure incorporating edge sealing. The reduction rate of formaldehyde emission from PB and MDF was 50–80% for flooring materials and about 30% for furniture materials. The greater core porosity in PB than in MDF may have caused the large reduction of formaldehyde emission from the edge sealed samples. The amount of formaldehyde emitted from the edge was significantly higher in PB than in MDF. These results need to be considered when using the desiccator test to measure formaldehyde emission from flooring and furniture materials.


*Keywords:* Formaldehyde emission; Desiccator method; Edge sealing; Wood-based composite

## 1. Introduction

Formaldehyde release from incompletely cured, urea–formaldehyde resin bonded, wood-based panels, such as particleboard (PB) and medium density fiberboard (MDF), is a well-established, potential cause of indoor air contamination [1]. Emission of formaldehyde from wood-based panels into the air of buildings constructed with these products has been a concern of industry and environmental scientists for several years [2].

The traditional flooring has been replaced by wood flooring materials in modern Korean houses, especially in new apartments. There are three types of wood flooring: laminate, engineered and solid wood. The laminate flooring consists of HDF as the core material, while the engineered flooring consists of plywood with a thin fancy veneer bonded onto

*Corresponding author. Tel.: +82 2 880 4784; fax: +82 2 873 2318.
*E-mail address:* hjokim@snu.ac.kr (H.-J. Kim).

0142-9418/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.polymertesting.2006.05.010

the face of the plywood using urea–formaldehyde and melamine–formaldehyde (MF) resins as hot-press adhesives [3]. Engineered flooring can produce formaldehyde emission because the different wood layers are normally glued together with formaldehyde-based adhesive. The top layer usually consists of hardwood, the middle layer of softwood and the bottom layer of a veneer. The top layer is most often treated with a formaldehyde-free UV-lacquer or an oil to protect the surface [4]. Two types of laminate flooring are commonly available. One is produced by bonding a decorative plastic laminate onto the substrate by means of a wet bonding agent. The other consists of several layers of specially saturated papers directly thermofused onto the substrate. The substrates are high density fiberboard (HDF). Some laminate flooring emits small quantities of formaldehyde and volatile organic compounds (VOCs) [5].

Good laboratory methods are most important, in order to control the emission of formaldehyde from the exposed area of the final product. Of the many different methods employed for formaldehyde emission measurement, Roffael first introduced the very simple Wilhelm-Klauditz Institute (WKI) method featuring a special climate chamber to measure the formaldehyde concentration in the air [6]. The perforator method has also been applied, although it requires special apparatus [7]. The European particleboard association originally developed this test procedure in the late 1970s and it was established in 1984 as European standard EN 120. In North America, Australia and Asia, however, the desiccator method was adopted. The desiccator test was developed in the mid-1970s in Japan and standardized in the US in 1983. The Japanese industrial standard (JIS) desiccator method and similar procedures use a closed vessel in which the test material and a water reservoir are enclosed. Released formaldehyde from the material is captured in the water and the level of formaldehyde in the water is determined after a standard time interval such as 24 h [8].

A 20 L small chamber was developed in Japan and has been standardized in Korea. The air control system consisted of an air supply unit, a humidifier and pumps. The 20 L chamber was set up in a temperature-controlled climate chamber. Purified air was used for ventilation. The stainless steel seal box was used to prevent the cut edge effect, which allowed chemical emission only from one side surface of the test piece. When two seal boxes were used, the total surface area was $0.044\,m^2$ and the loading was $2.2\,m^2/m^3$ [9].

Furniture and flooring products come in different shapes and compositions depending on their use and type, with consequent variations in their contribution to air pollution. Despite different surfaces from raw board to treated surfaces through such processes as painting and overlay, the test for evaluating air pollutants in the home is the same for wood-based furniture and flooring products. There is therefore a need for different tests for measuring harmful substances in the air according to the surface treatment, different from the criteria used to measure pollutants in the raw material, and an urgent need to develop a systematic and independent pollutant emission test according to usage and application depending on paints and adhesives used on the surface of each product [10,11]. Currently, the testing method used to test formaldehyde emission in the furniture and flooring industries is the most basic method, the desiccator method defined in KS F 3104 and KS F 3200, which is similar to JIS A 1460 (Building Boards Determination of Formaldehyde Emission-Desiccator Method). This method is inexpensive and simple to carry out. When we consider the small-scale nature of the building, flooring and furniture-related businesses in Korea, we need to develop practical testing methods and establish the correlation among them. There should be different formaldehyde emission tests for different composite wood products. Sample pretreatment and test procedure should be adjusted to suit the different products. Furthermore, formaldehyde emitted from the surface should be analyzed in order to establish a correlation with the 20 L chamber defined as the process testing method.

Although the use of edge sealing treatment for the desiccator method is described in the ASTM test method [12], no attention has been focused on the variation of formaldehyde emission according to the thickness and structure of the panels. Thus, in this study the formaldehyde emission characteristics were analyzed by the desiccator method in composite wood products by sealing the edge of each product sample. Furthermore, the effects of the flooring structure and thickness of wood-based panels on the determination of formaldehyde emission by desiccator method were studied.

## 2. Experimental

### 2.1. Materials

The materials used in this study were 15 mm-thick PB and MDF as furniture materials, 8 mm laminate flooring and engineered flooring as flooring materials obtained from Dongwha Enterprise Co. Ltd. The MDF and PB raw materials were Korean pine (*Pinus densiflora*) and urea–formaldehyde resin was used as the adhesive. Laminate flooring was manufactured with HDF made by Korean pine and melamine–urea–formaldehyde co-polymerization resin to reduce formaldehyde emission. In the case of engineered flooring, we used plywood made by Oceania timber veneers and bonded by phenol–formaldehyde resin. One surface of the plywood was coated with a fancy veneer and UV-curable coating.

### 2.2. Edge sealing treatment

To analyze the formaldehyde emitted from the surface, the edge of each sample was sealed with parafilm, polyethylene wax or aluminum foil. As defined in the JIS and KS desiccator methods, a 5 cm × 15 cm (L × W) sample, with the thickness not taken into account, was treated with polyethylene wax. After polyethylene wax was melted at 60 °C, the edge was sealed. Unlike polyethylene wax, bonding parafilm and aluminum foil directly onto the surface was difficult so a 6 cm × 16 cm sample was prepared and 0.5 cm of its edge was covered (Fig. 1). Despite the different sample sizes, 12 samples were used in one desiccator in order to meet the surface size of 1800 mm$^2$ as defined by JIS and KS. To determine of the effect of thickness, PB and MDF of 9, 12, 15, 18 and 20 mm thicknesses were measured.

### 2.3. Formaldehyde emission by desiccator method

The formaldehyde emissions from the laminate flooring, plywood flooring, MDF and PB were determined according to the JIS method (JIS A 1460) using a glass desiccator. The 24-h desiccator method uses a common glass desiccator with a volume of 10 L. The emission test lasted 24 h in the covered desiccator at a temperature of 20 °C. Samples of the non-edge sealed and edge sealed by three sealing methods all underwent testing. The emitted quantity of formaldehyde was obtained from the concentration of formaldehyde absorbed in a Petri dish filled with a specified amount of distilled or deionized water. The absorbed formaldehyde was analyzed by means of the chromotropic acid method [13]. The principle for determining the concentration of formaldehyde absorbed in the distilled or deionized water is based on the Hantzsch reaction in which the formaldehyde reacts with ammonium ions and acetylacetone to yield diacetyldihydrolutidine (DDL) (JIS, 2001).

## 3. Results and discussion

As shown in Fig. 2, the amount of formaldehyde emitted differed according to the edge treatment. The

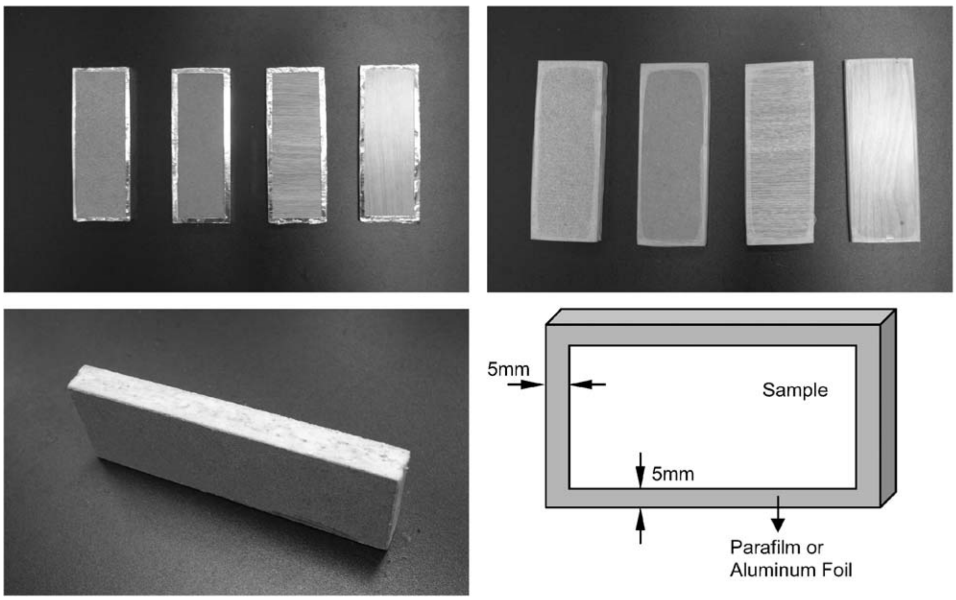


Fig. 1. Edge sealing treatment of wood-based panel sample for desiccator test by parafilm, aluminum foil and polyethylene wax.

difference between sealing methods was relatively small but the difference from unsealed was large, confirming the need for a test procedure incorporating edge sealing. Fig. 2 conclusively shows these differences. Fig. 3 shows the reduced formaldehyde by edge treatment in each sample. Although the level of reduction was different, laminate flooring and engineered flooring products that showed an emission of less than 1.5 mg/L (E1) even before treatment showed a significant reduction of 50–80%. Each surface of laminate flooring was treated with low pressure melamine (LPM) to prevent formaldehyde emission from the surface of the raw material. Only one surface of engineered flooring was UV treated and the other side was mostly wood composite, despite back grooving. Thus, the amount of formaldehyde emitted from the edge portion of the engineered flooring was also high.

The formaldehyde emission was decreased more in PB than in MDF (Fig. 3). The composition of PB and MDF differed in that the former was composed of particles and the latter of fibers. Especially, the edge shape was different. Formaldehyde emission was higher from the edge of PB than from the surface, and was affected by PB construction variables such as particle geometry, porosity and density. In the case of MDF, same-sized fibers were tangled and distributed in the edge. However, in the case of PB, different-sized particles were present in the core and surface so that there were fewer pores amongst the particles (Fig. 4). The larger porosity of the core in PB than in MDF may have caused the large reduction of formaldehyde emission from the edge sealed samples.

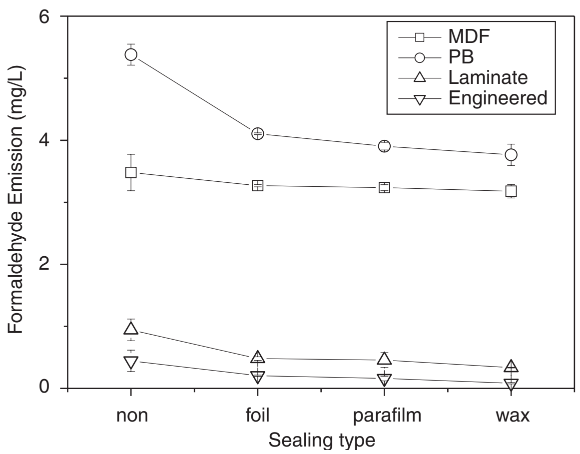


Fig. 2. Difference of formaldehyde emission for various edge sealing treatments.

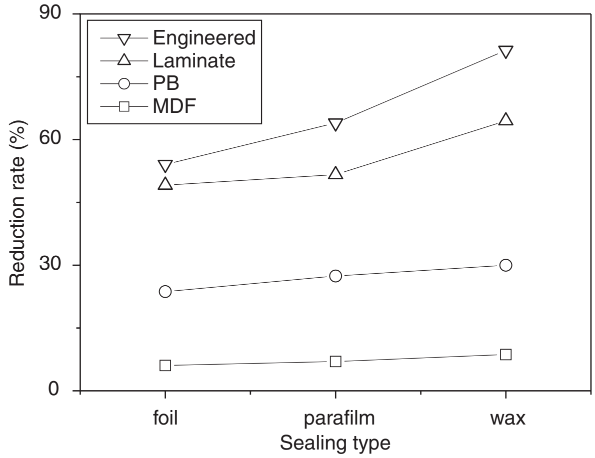


Fig. 3. Reduction rate of formaldehyde emission for various edge sealing treatments.

As for sealing type, the reduction rate of formaldehyde emission was in the order: polypropylene wax > parafilm > aluminum foil. In the case of aluminum foil, there was only a small difference between board sample and aluminum foil. On the other hand, polypropylene wax provided a proper seal for the edge of the sample board. Although it takes longer to seal the edge with melted polypropylene wax than with parafilm and aluminum foil, it is the most suitable material for edge sealing in terms of formaldehyde emission reduction.

The number of test specimens that can be placed in the desiccator differs according the thickness of the board sample. The total surface area must be close to 1800 $cm^2$ but, again, this differs with the thickness of the board sample. From the above results showing that for PB and MDF more formaldehyde was emitted from the edge than from the surface, the importance of the ratio of the edge to the total surface area was confirmed (Table 1). For the 9 mm-thick board, the edge/total ratio was 19.35%, while for the 20 mm-thick board it was 34.78%. The edge ratio was positively correlated with the level of formaldehyde emission. To determine the effect of board thickness on formaldehyde emission, we tested PB and MDF at 9, 12, 15, 18 and 20 mm thicknesses. Three kinds of sealing methods were also used in comparison with the non-sealed sample. The reduction rate of emission for PB and MDF according to board thickness by edge sealing type is shown in Fig. 5. With increasing sample board thickness, the reduction rate increased in both cases. On the whole, the reduction rates were larger for PB than for MDF at the sample

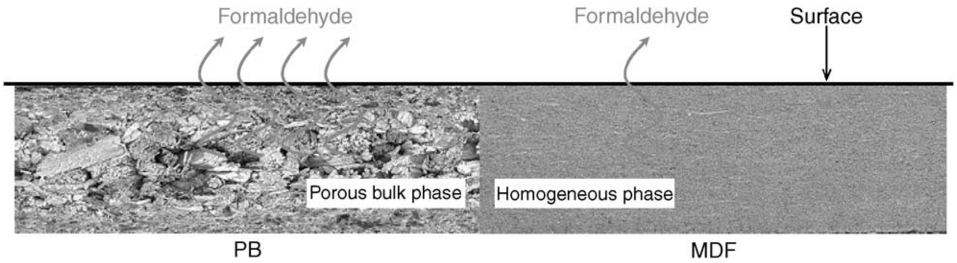


Fig. 4. A section of PB and MDF; porosity of PB core and formaldehyde emission.

Table 1
Edge ratio and sample number according to sample board thickness

| Sample boards | Width (cm) | Length (cm) | Thickness (cm) | Total surface area of a sample ($cm^2$) | Sample number (ea) | Total surface area for desiccator test ($cm^2$) | Edge ($cm^2$) | Surface ($cm^2$) | Edge/Total (Edge + surface) (%) |
|---|---|---|---|---|---|---|---|---|---|
| 9 mm MDF/PB | 5 | 15 | 0.9 | 186 | 10 | 1860 | 36 | 150 | 19.4 |
| 12 mm MDF/PB | 5 | 15 | 1.2 | 198 | 9 | 1782 | 48 | 150 | 24.2 |
| 15 mm MDF/PB | 5 | 15 | 1.5 | 210 | 9 | 1890 | 60 | 150 | 28.6 |
| 18 mm MDF/PB | 5 | 15 | 1.8 | 222 | 8 | 1776 | 72 | 150 | 32.4 |
| 20 mm MDF/PB | 5 | 15 | 2.0 | 230 | 8 | 1840 | 80 | 150 | 34.8 |

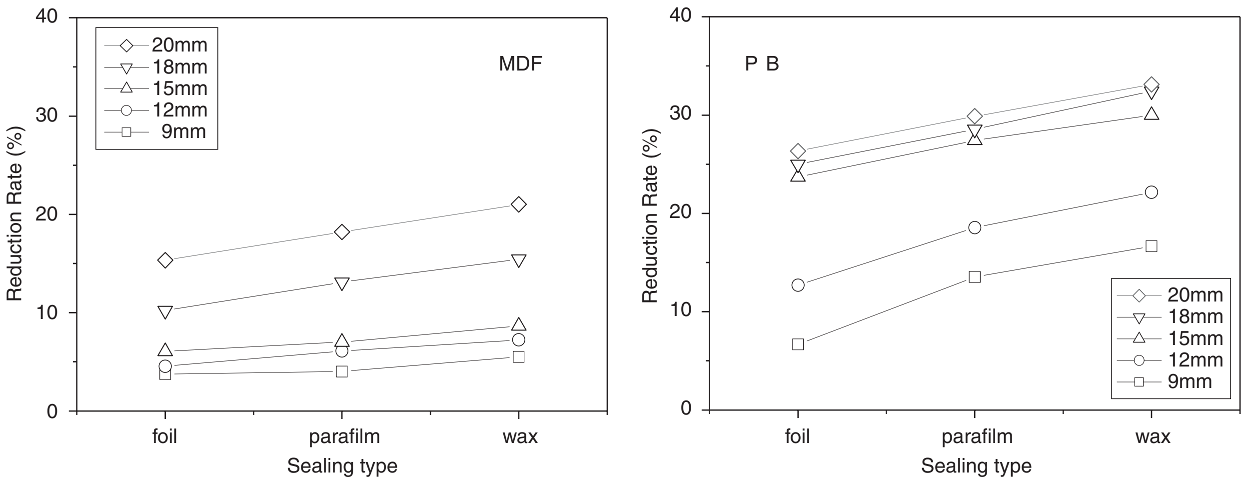


Fig. 5. Reduction rate of formaldehyde emission of PB and MDF for various board thicknesses according to edge sealing type.

board thickness. Although only a small difference in reduction rate was evident with sample board thicknesses ranging from 9 to 15 mm, the difference was large for thicknesses ranging from 15 to 20 mm. On the other hand, the opposite trend was evident for PB. In the case of PB, between thick boards like 18 and 20 mm, there was little difference in reduction rate. On discovering this tendency, we doubted that it was related to the number of test specimens and the ratio of edge to the total surface area in the desiccator. We therefore checked this trend with the results of Fig. 6. When the whole surface of the sample boards was sealed, the measured formaldehyde emission level was reduced to almost zero (Fig. 6). Hence, this result confirmed the large effect of surface sealing on the reduction of formaldehyde emission and also the necessity of determining the proper formaldehyde emission result from furniture materials which feature surfaces and edges treated with sealing materials such as deco paper, fancy veneer and UV coating.

Generally, for the same board thickness and density, the density of MDF was a little higher in the core and surface than that of PB, as shown in Fig. 7 [14,15]. When the board is hot-pressed during its manufacturing process, the thermal heat of the hot plate is delivered to the core more easily for MDF than for PB because of MDF's higher core density. Accordingly, the proportion of surviving, non-reacted, free formaldehyde is greater in the PB core than in the MDF core (Fig. 8), which explains the lower reduction rate of MDF. The 9–15 mm-thick sample boards were too thin to show this tendency because they were cured by direct heat from the hot plate. Furthermore, due to the high density profile, free formaldehyde in the MDF core could not easily diffuse out. Because of its lower core density, the diffusion rate of free formaldehyde from the core to the surface was higher in the PB boards. This tendency was evident in the thick MDF boards. On the other hand, the greater PB core porosity was more important than the heating delivery and diffusion rate in determining the high formaldehyde emission rate from the edge. Hence, there was a limit to the reduction rate by edge sealing for PB boards above 15 mm of about 30%.

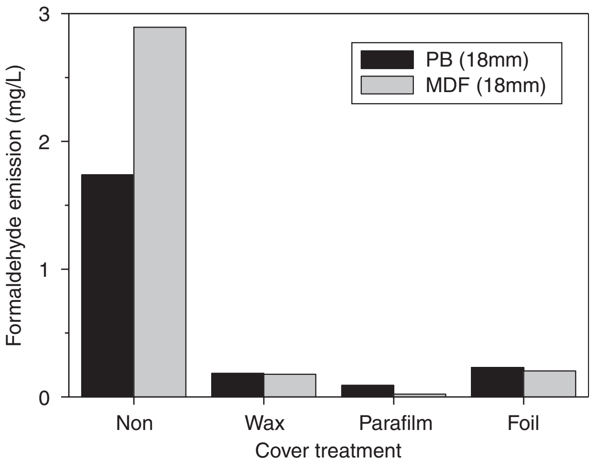


Fig. 6. Formaldehyde emission data from whole covered sample boards with polypropylene wax, parafilm and aluminum foil.

The reduction rates in formaldehyde emission by desiccator method of 50–80% for flooring materials and about 30% for furniture materials following edge sealing treatment are very significant and should not be ignored. These reductions need to be considered when performing the desiccator test to measure formaldehyde emission from flooring and furniture materials, because when these materials are used in human living environments, only the surfaces appear while the edges are sealed.

## 4. Conclusions

Wood-based composites such as plywood, PB, MDF and wood-based flooring come in various shapes, thicknesses and sizes. Hence, the shapes and composition of the flooring and furniture products

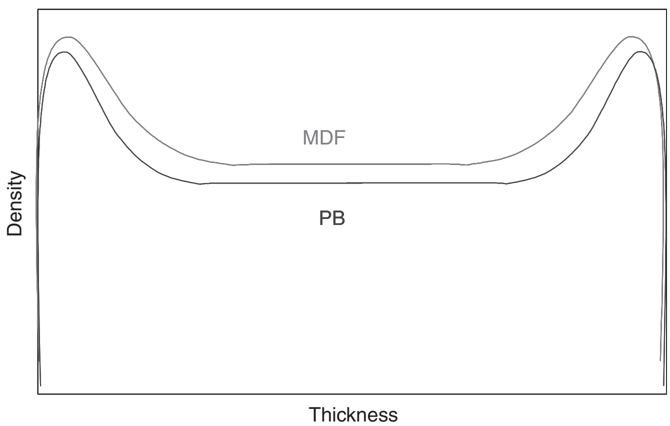


Fig. 7. General density profiles of PB and MDF for the same board thickness and density.

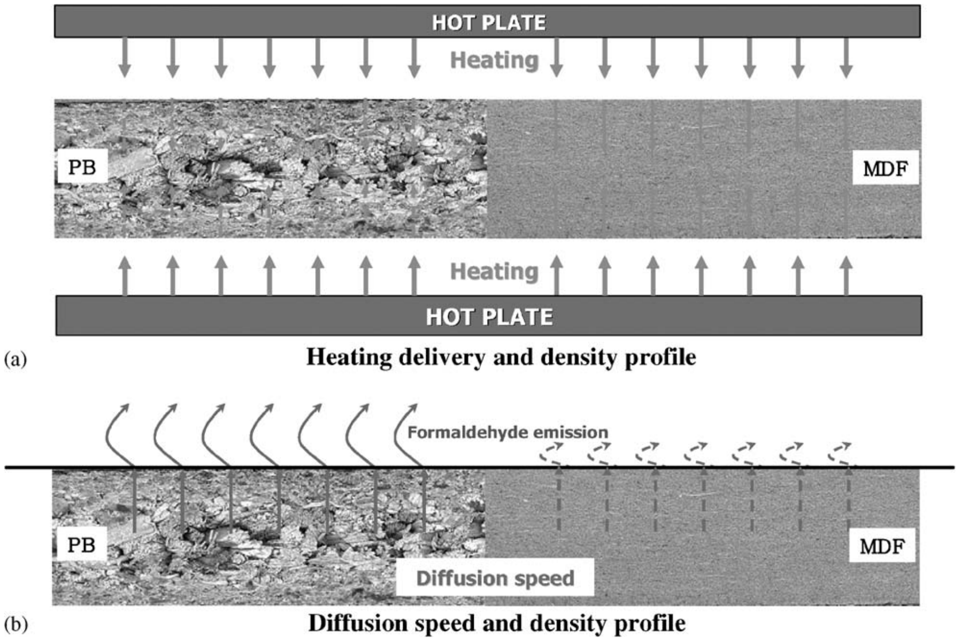


Fig. 8. Schematic model of different formaldehyde emissions from edge sealed PB and MDF.

processed from these composite wood products also vary widely. It is therefore important to confirm the consistency of the results when using the desiccator method to test for formaldehyde emission levels of such products, as they show large variation in shape and properties due to different pretreatments and manufacturing methods. One form of pretreatment involves edge sealing of the sample board. Three kinds of sealing methods were also used in comparison with the non-sealed sample. As for sealing type, the reduction rate of formaldehyde emission was in the order: polypropylene wax > parafilm > aluminum foil. The reduction rate of emission for PB and MDF according to board thickness by edge sealing type was increased in both cases with increasing sample board thickness. Because difference of structure in boards and shape of core of boards effected the reduction rate of formaldehyde emission, it is necessary to consider board structure and core shape in the formaldehyde emission test.

The 20 L small chamber method, in which only the board surface is exposed, has been defined as the process testing method by the Ministry of the Environment in its brief to collect and measure formaldehyde and VOC surface emission levels [9]. Therefore, to establish a correlation with the desiccator method we need to seal the sample edge in order to ensure that only the formaldehyde emission levels from the surface are being measured.

## Acknowledgements

This work was supported by the research program of Agricultural R&D Promotion Center and the Brain Korea 21 project.

## References

[1] B. Meyer, Formaldehyde exposure from building products, Environ. Int. 12 (1–4) (1986) 283.

[2] S.K. Brown, Chamber assessment of formaldehyde and VOC emissions from wood-based panels, Indoor Air 9 (1999) 209.

[3] S. Kim, H.-J. Kim, Effect of addition of polyvinyl acetate to melamine–formaldehyde resin on the adhesion and formaldehyde emission in engineered flooring, Int. J. Adhes. Adhes. 25 (2005) 456.

[4] M. Risholm-Sundman, N. Wallin, Comparison of different laboratory methods for determining the formaldehyde emission from three-layer parquet floors, Holz Roh Werkst. 57 (1999) 319.

[5] R. Wiglusz, E. Sitko, G. Nikel, I. Jarnuszkiewicz, B. Igielska, The effect of temperature on the emission of formaldehyde and volatile organic compounds (VOCs) from laminate flooring—case study, Build. Environ. 37 (1) (2002) 41.

[6] E. Roffael, Progress in the elimination of formaldehyde liberation from particleboards. In: Proceedings of the International Particleboard Composite Materials Symposium 12th, Washington State University, Pullman, WA, USA, 1978, pp. 233–249.
[7] E. Roffael, L. Mehlhorn, Einfluβ der randbedingungen bei der bestimmung des extrahierbaren formaldehyds in holzspanplatten nach der perforatormethode, Holz Roh Werkst. 38 (1980) 85.
[8] L.C. Griffis, J.A. Pickrell, Effect of sample conditioning and chamber loading on rate of formaldehyde release from wood products in a desiccator test, Environ. Int. 9 (1983) 3.
[9] S. Kim, J.-A Kim, H.-J. Kim, S. D. Kim, Determination of formaldehyde and TVOC emission factor from wood-based composites bonded with formaldehyde-based resins by small chamber, Polym. Test. (2006), in press.
[10] S. Kim, H.-J. Kim, Evaluation of formaldehyde emission of pine and wattle tannin-based adhesives by gas chromatography, Holz Roh Werkst. 62 (2004) 101.
[11] S. Kim, H.-J. Kim, Comparison of formaldehyde emission from building finishing materials at various temperatures in under heating system, ONDOL, Indoor Air 15 (2005) 317.
[12] ASTM, Standard test method for determining formaldehyde levels from wood products using a desiccator, The American Society for Testing and Materials, Philadelphia, 2000.
[13] S. Kim, H.-J. Kim, Comparison of standard methods and gas chromatography method in determination of formaldehyde emission from MDF bonded with formaldehyde-based resins, Bioresource Technol. 96 (2005) 1457.
[14] S. Hiziroglu, S. Jarusombuti, V. Fueangvivat, Surface characteristics of wood composites manufactured in Thailand, Build. Environ. 39 (2004) 1359.
[15] S. Kim, Y.-K. Lee, H.-J. Kim, H.H. Lee, Physico-mechanical properties of particleboards bonded with pine and wattle tannin-based adhesives, J. Adhes. Sci. Technol. 17 (2003) 1863.