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Formaldehyde Emissions and Moisture Content Change of Wood Composites during Bake-out*1

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ABSTRACT

Wood composites are a hygroscopic material and have ability to exchange its moisture content with air. This study investigated the formaldehyde emission and moisture content change of four wood composites (particleboard (PB), medium density fiberboard (MDF), high density fiberboard (HDF), laminated HDF (L-HDF)) as a function of bake-out temperature and time. The composites were baked out for 1, 3, 5, 7, 10, 14, 21, and 28 days at temperatures of 20 ± 2, 35 ± 2, and 50 ± 2°C in a dry oven. The moisture content change was used to determine the emission bake-out of the composites. Best bake-out time results were obtained with after 7 days all composites. Formaldehyde emission values of composites decreased with decreasing moisture content for both temperatures. The formaldehyde emission results of bake-out temperature 35 and 50°C showed a similar tendency.

Keywords : formaldehyde emission, moisture content, bake-out, wood composites, desiccator method

1. INTRODUCTION

Building materials play an important role in determining the indoor air quality owing to their large surface areas and permanent exposure to indoor air. Building materials can release wide range of pollutants, particularly the volatile organic compounds (VOCs), which can cause indoor air related health problems. Since building materials are important sources of VOCs in indoor environments, their emission characteristics should be studied.

Wood-based panels, such as particleboard (PB), medium density fiberboard (MDF) and veneer, are used widely in the manufacture of furniture, flooring, housing and other industrial products. However, wood-based panels bonded with urea-formaldehyde (UF) resin emit formaldehyde, which is toxic and is associated with possible health hazards, such as irritation of the eyes and the upper respiratory tract[1-3].

The formaldehyde emission rate of wood

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composites bounded with UF resins is a strong function of temperature, humidity, and formaldehyde vapor concentration in the atmosphere surrounding the board[4,5]. Increased formaldehyde emission rates at elevated temperature and humidity levels are consistent with the anticipated chemical kinetics of a resin hydrolysis mechanism[6,7]. Increases in formaldehyde vapor concentration with increased product loading and / or decreased ventilation generally suppress the formaldehyde emission rate of wood composites. This is consistent with a physical diffusion mechanism whose driving force is the difference in formaldehyde concentration between the board and surrounding vapor phases[8].

Previous studies have investigated the effect of bake-out. Offerman *et al*.[9] reported that the VOC concentration immediately reduced after the bake-out in an office building with air heating system but subsequently rebounded to the level before the bake-out. They hypothesized that the bake-out only affects surface materials, and does not affect the primary sources that are separated from direct contact with indoor air, such as paints, caulks, and adhesives. In addition they hypothesized that after the bake-out, cleaned surface materials can act as an indoor sink until primary sources re-contaminate the surfaces. To confirm the effect of the bake-out, all of the previous researchers have suggested that further studies are required[9-11].

In the building field, there has been considerable research into methods to reduce TVOCs (total volatile organic compounds), such as ventilation equipment, the application eco-friendly materials and bake-out treatments. 'Bake-out' has been used to reduce the emissions of VOCs from newly installed materials, products and furnishings. This procedure is normally used to prevent building-associated illnesses caused by the out-gassing of VOCs and formaldehyde from residual solvents in new building materials and furnishings. In this procedure, the air temperature in an unoccupied but fully furnished building is elevated while some ventilation is maintained[11-13]. The principle of this process is to drive the VOCs out of the construction materials by increasing the temperature in the building to 32～40°C, while increasing the outdoor air exchange so that hazardous gases are emitted from the building. The procedure generally takes several days to 2 weeks, and is performed prior to occupancy. According to the results of a few pilot studies, a 60～94% decrease in the total VOC levels was achieved using a bake-out treatment[14].

Wood is a hygroscopic material and exchanges its moisture content with air; the amount and direction of the exchange (gain or loss) depend on the relative humidity and temperature of the air and the current amount of water in the wood. This moisture relationship has an important influence on wood properties and performance[4,7,8].

Because the moisture content of wood composites affects the formaldehyde release of final products, the objective of this study was to investigate the influence of moisture content change of composites on formaldehyde emission during bake-out.

2. MATERIALS and METHOD

2.1. Materials

After investigation of product information

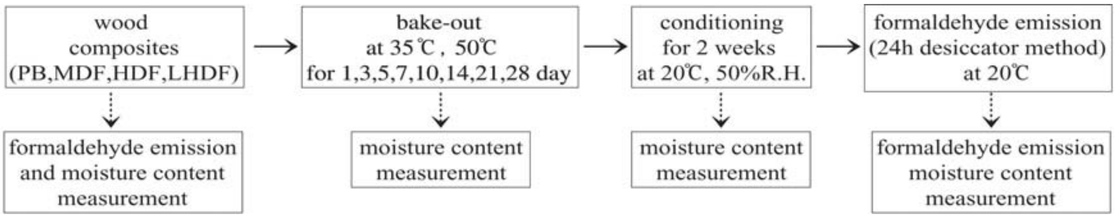

Fig 1. Schemes of the measurement process of moisture content and formaldehyde emission from wood composites.

and the use of pressed wood products indoors, four different composite wood products were selected; PB, MDF, HDF, and L-HDF.

PB: The PB product is a combination of fine wood particles and UF-resin pressed into panels. The thickness was 15 mm, specific gravity was 0.63, and moisture content was 9.04%. PB is suitable for interior use in a wide variety of furniture and joinery assemblies and particularly as shelving, in cupboards, wardrobes and wall units.

MDF: UF resin is used to bond the wood fiber. The thickness was 15 mm, specific gravity was 0.61, and moisture content was 7.51%. Fiberboard is commonly used as decorative panelling, and has further decorative uses in furniture and structural uses in joinery.

HDF: UF resin is used to bond the wood fiber. The thickness was 8 mm, specific gravity was 1.0, and moisture content was 7.26%. HDF is used as flooring.

L-HDF: HDF is decoratively surfaced on both sides with low-pressure, melamine-impregnated paper. The thickness was 8 mm, specific gravity was 1.11, and moisture content was 5.88%.

2.2. Methods

2.2.1. Bake-out Procedure

The composites were formaldehyde emission tested before, during, and after the bake-out. The composites were baked out for 1, 3, 5, 7, 10, 14, 21, and 28 days at temperatures of 20 ± 2, 35 ± 2, and 50 ± 2°C in a dry oven. After bake-out processing, the specimens were conditioned for 2 weeks at 20 ± 2°C and 50 ± 3% relative humidity. After the bake-out, the specimens were measured for moisture content. Then the formaldehyde emission was tested by desiccator method. After formaldehyde emission test, the specimens were measured for moisture content.

2.2.2. Determination of Formaldehyde Emission (Desiccator method, JIS A 1460)

Emission of formaldehyde is determined by placing test pieces of known surface area in a desiccator at a controlled temperature and measuring the quantity of emitted formaldehyde absorbed in a specified volume of water during 24 h[15].

The interior volume of the desiccator was about 10 ℓ and 5 × 15 cm specimens were used for each desiccator test. The specimens were cut from the sample panel of panel segments to obtain adequate representation of area within the panel or panel segment. The sample total surface area was 1,800 cm^2. The released formaldehyde was caught in the distilled water

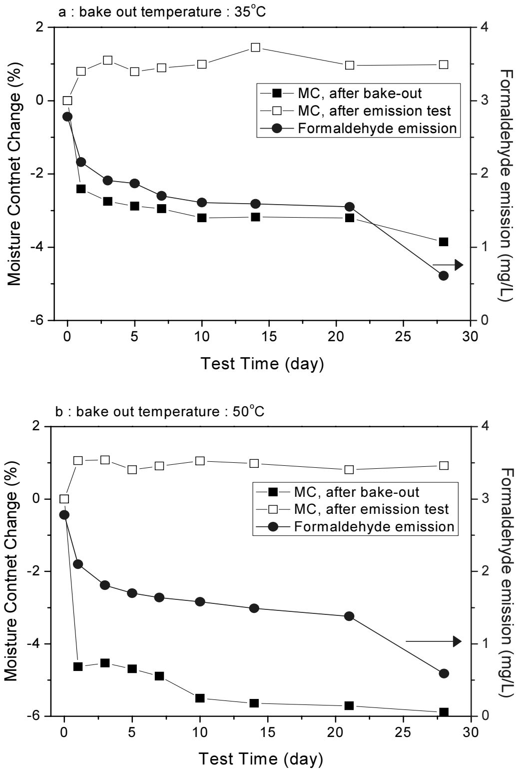

Fig 2. Formaldehyde emission and moisture content change for PB under bake-out (a : bake-out temperature 35°C, b : bake-out temperature 50°C).

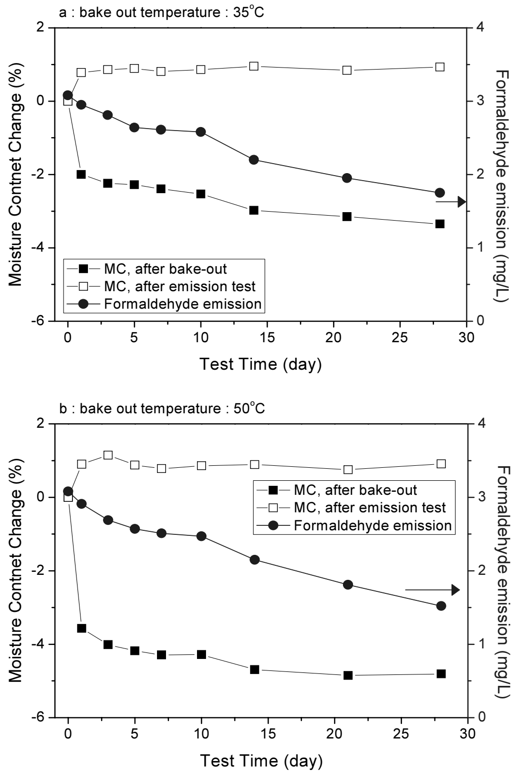

Fig 3. Formaldehyde emission and moisture content change for MDF under bake-out (a : bake-out temperature 35°C, b : bake-out temperature 50°C).

which was analyzed using a UV spectrophotometer, after treatment with acetyl acetone and acetyl acid ammonium. After the formaldehyde emission test, the specimens were measured for moisture content (Fig. 1).

3. RESULTS and DISCUSSION

The formaldehyde emission and moisture content change for PB under bake-out is shown in Fig. 2. The initial formaldehyde emission of PB was 2.7 mg/ℓ, which rapidly decreased over the bake-out time. After 5 days it stabilized at 1.7 mg/ℓ. At 28 days emission was about 6-fold lower at bake-out temperature 35°C. The formaldehyde emission results of bake-out temperature 35 and 50°C showed a similar tendency. And Fig. 2 shows the change in moisture contents at different bake-out temperatures and after desiccators test, respectively. The moisture contents change two matching factors were tested. The first one was calculated from the relation between water desorption as determined by bake-out temperature and time. The moisture content change rate so calculated was -2.41～-3.86%. The second matching factors were

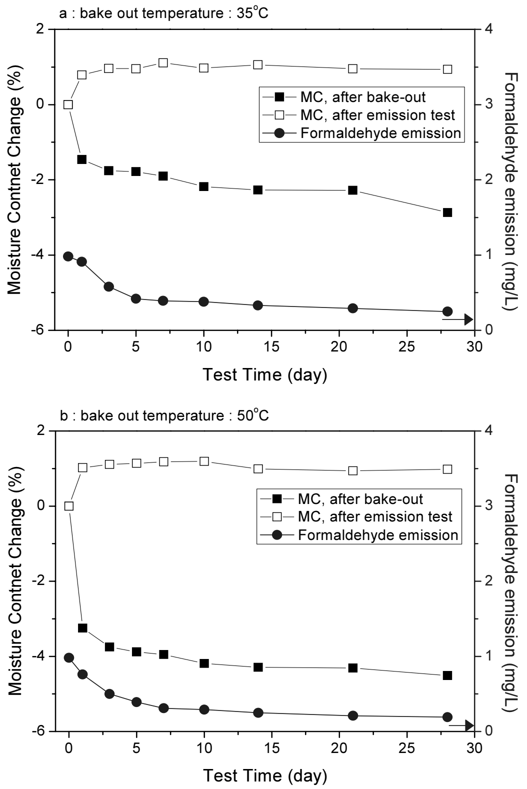

Fig 4. Formaldehyde emission and moisture content change for HDF under bake-out (a : bake-out temperature 35°C, b : bake-out temperature 50°C).

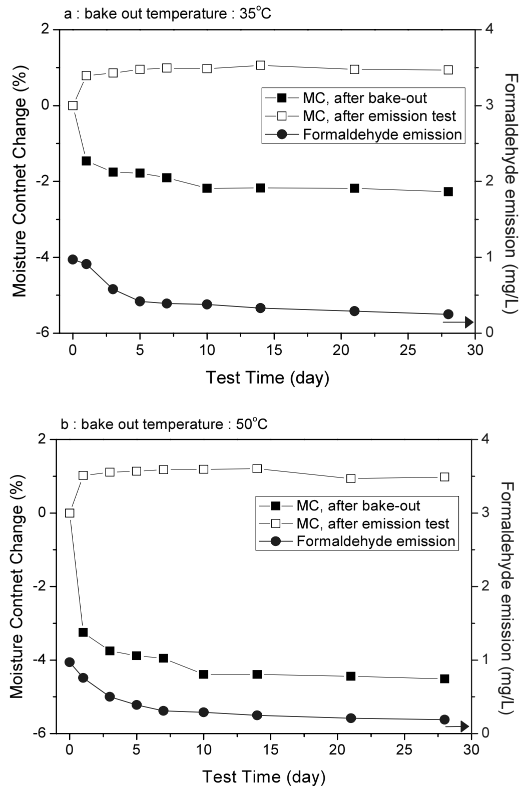

Fig 5. Formaldehyde emission and moisture content change for L-HDF under bake-out (a : bake-out temperature 35°C, b : bake-out temperature 50°C).

calculated from the water adsorption in desiccators, which formaldehyde emission test method, for 24 h. The moisture content change rate range so calculated was from 0.79 to 1.45%. In bake-out temperature 50°C, moisture desorption rate was -4.53～5.89%.

The initial formaldehyde emission of MDF was only slightly affected by bake-out temperature. After 10 days, the formaldehyde emission was rapidly decreased in Fig. 3. On the contrary, the initial formaldehyde emission of MDF was 3.08 mg/ℓ, which decreased over the bake-out time. After 10 days, the formaldehyde emission was rapidly decreased. At 28 days emission was about 1.75 and 1.52 mg/ℓ at bake-out temperature 35 and 50°C, respectively. The formaldehyde emission results of bake-out temperature 35 and 50°C showed a similar tendency.

Figs. 2 and 3 show the formaldehyde emission for the PB and MDF, respectively, as the samples decreased in moisture content due to desorption of water vapor. The moisture content change of the PB and MDF samples was less than 0.4% per day after the first day and 21 days, respectively. After 7 and 21 days the

Table 1. Results of moisture content change and formaldehyde emission.

	Bake-out temperature (35°C)				Bake-out temperature (50°C)			
	Moisture content change (%)			Formaldehyde emission (mg/L)	Moisture content change (%)			Formaldehyde emission (mg/L)
	Bake-out day	After bake-out	After emission test		Bake-out day	After bake-out	After emission test	
PB	control	0	0	2.78	0	0	0	2.78
	1	-2.41	0.8	2.16	1	-4.63	1.06	2.1
	3	-2.75	1.1	1.91	3	-4.53	1.08	1.81
	5	-2.88	0.79	1.87	5	-4.69	0.81	1.7
	7	-2.95	0.89	1.7	7	-4.89	0.91	1.64
	10	-3.2	0.99	1.61	10	-5.5	1.05	1.58
	14	-3.18	1.45	1.59	14	-5.64	0.98	1.49
	21	-3.2	0.96	1.55	21	-5.71	0.81	1.38
	28	-3.86	0.98	0.61	28	-5.89	0.92	0.59
MDF	0	0	0	3.08	0	0	0	3.08
	1	-2	0.78	2.95	1	-3.57	0.9	2.91
	3	-2.24	0.86	2.81	3	-4.01	1.15	2.69
	5	-2.28	0.89	2.64	5	-4.18	0.88	2.57
	7	-2.39	0.81	2.61	7	-4.29	0.78	2.51
	10	-2.53	0.86	2.58	10	-4.28	0.86	2.47
	14	-2.98	0.95	2.2	14	-4.69	0.89	2.15
	21	-3.15	0.84	1.95	21	-4.85	0.75	1.81
	28	-3.35	0.93	1.75	28	-4.81	0.91	1.52
HDF	0	0	0	0.98	0	0	0	0.98
	1	-1.46	0.79	0.91	1	-3.25	1.02	0.76
	3	-1.76	0.96	0.58	3	-3.75	1.11	0.5
	5	-1.78	0.95	0.42	5	-3.88	1.14	0.39
	7	-1.9	1.11	0.39	7	-3.95	1.18	0.31
	10	-2.18	0.97	0.38	10	-4.19	1.19	0.29
	14	-2.27	1.06	0.33	14	-4.29	0.99	0.25
	21	-2.28	0.95	0.29	21	-4.31	0.94	0.21
	28	-2.87	0.94	0.25	28	-4.51	0.98	0.19
L-HDF	0	0	0	0.97	0	0	0	0.97
	1	-1.46	0.79	0.91	1	-3.25	1.02	0.76
	3	-1.76	0.86	0.58	3	-3.75	1.11	0.5
	5	-1.78	0.95	0.42	5	-3.88	1.14	0.39
	7	-1.9	0.99	0.39	7	-3.95	1.18	0.31
	10	-2.18	0.97	0.38	10	-4.39	1.19	0.29
	14	-2.17	1.06	0.33	14	-4.39	1.21	0.25
	21	-2.18	0.95	0.29	21	-4.44	0.94	0.21
	28	-2.27	0.94	0.25	28	-4.51	0.98	0.19

overall formaldehyde emission from PB can be described using a straight line with a release rate (slope). When observed for several days, the bake-out time in dry oven at approximately equilibrium condition appears to have no major effect on the release rate from PB. The formaldehyde emission from the MDF was for the first day 2.95 and 2.91 mg/ℓ (control MDF was 3.08 mg/ℓ).

Fig. 4 shows the formaldehyde emission and moisture content change for the HDF, respectively. A low formaldehyde emission was observed from HDF at 20°C. The increase of temperature up to 30 and 50°C caused a slight decrease in the formaldehyde emission, which stabled after 7 days. Fig. 5 shows the formaldehyde emission of L-HDF. After 14 days at 35°C, the emission was reduced by 28% compared to that 20°C. After 14 days at 50°C, the emission was decreased by 58% compared to that at 20°C.

The moisture content change of the HDF and L-HDF samples was less than 0.3% per day after the first day and 21 days, respectively. After 7 days the overall formaldehyde emission from HDF and L-HDF can be described using a straight line with a release rate.

The effect could be expected from a bake-out in relation to the PB. The relatively large decrease of the emission from 20 to 35°C was remarkable, as was the strong increase from 35 to 50°C. After the bake-out at 50°C 28 days, the formaldehyde concentration decreased by 78.8, 60.4, 80.6, 78.5% of the concentration before the bake-out for PB, MDF, HDF and L-HDF, respectively. On one hand, even under the mild conditions of this bake-out, the formaldehyde concentrations were 78.1, 59.4, 74.5, 77.2% lower after the bake-out for PB, MDF, HDF and L-HDF, respectively. According to the results of a few pilot studies, bake-out achieved a decrease of 60～94% in total VOC levels[12, 14].

Table 1 shows the moisture content change, after bake-out and formaldehyde emission test for PB. During bake-out, the moisture content in PB was reduced because the water turned into vapor. During formaldehyde emission testing, the composite adsorbed water, thereby raising the moisture content. As temperature and time were increased during bake-out, the moisture content decreased. The formaldehyde emission showed decreasing result.

Even 4 weeks after a moisture content change, the desorption-sorption did not always become constant or even reach the same value after each cycle. Moreover, upon changing moisture content there may have been an initial sharp change in emission in the opposite direction from the eventual change, as seen for PB upon changing 1%. These transient changes are postulated to be caused by water vapor carrying the formaldehyde with it as it leaves or enters the board under the driving force of a moisture content change.

The importance to formaldehyde emission of the moisture in the wood (with its strong attraction to the polar hydroxyl groups of wood substance as well as its affinity for water) is clearly indicated by measurements of bake-out. As low moisture contents were attained during bake-out, there may be a permanent loss of the available polar hydroxyl groups.

Removing the last bound water from the wood fiber or particle cell wall substance brings the hydroxyl groups of the cellulose chains close enough together to form a strong, mutually satisfying intra molecular bond[16]. This can be seen in the hysteresis effect on moisture sorption and desorption from the atmosphere. In a desorption-sorption cycle, wood equilibrates at a higher moisture content during desorption than during subsequent sorption at the same temperature and relative humidity.

After bake-out processing, the specimen was condition for 2 weeks at 20 ± 2°C and 50 ± 3% relative humidity. The amount of water adsorbed from a dry condition to equilibrium with the condition of relative humidity is always less than the amount retained in the process of drying from a wetter condition to equilibrium with that same relative humidity. The ratio of adsorption equilibrium moisture content to desorption equilibrium moisture content is constant at about 0.85. Furthermore, equilibrium moisture content in the initial desorption (that is, from the original green condition of the tree) is always greater than in any subsequent desorptions.

Formaldehyde emission from composites in service is caused by residual formaldehyde present in the UF resin bonded boards trapped as gas in the structure as well as dissolved in the water in boards. Hydrolysis of weakly bound formaldehyde from N-methylol groups, acetals and hemiacetals and hydrolysis of methylene ether bridges in more severe cases, also increase the content of emittable formaldehyde[17]. The methylol groups are easily split. In the presence of moisture, UF resin is slightly hydrolysed and the hydrolysis is enhanced under elevated temperatures[18].

4. CONCLUSIONS

This study investigated the formaldehyde emission and moisture content change of wood composites as a function of bake-out temperature and time. Best bake-out time results were obtained with after 7 days all composites. Formaldehyde emission values of composites decreased with decreasing moisture content for both temperatures. The formaldehyde emission results of bake-out temperature 35 and 50°C showed a similar tendency. Formaldehyde emission from composites in service is caused by residual formaldehyde present in the UF resin bonded boards trapped as gas in the structure as well as dissolved in the water in boards. Decreasing moisture content of composites about 6% significantly decreased formaldehyde emission.

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