Evaluation of Hygroscopic Property of Thermally Treated Yellow Poplar (*Liriodendron tulipifera*) Wood

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Abstract

For modern people who spend most of their time indoor temperature and humidity to be controlled by electrical appliances have a great effect on the emotion and health of human. However, inappropriate operation of the artificial facilities frequently creates substances to be harmful to our body and causes asthma, allergic rhinitis. Because of those, the importance of natural humidity control performance of interior materials is being emphasized. This study was carried out for quantifying the hygroscopic property of some interior finishing wooden materials. Dried and heat treated yellow poplar (*Liriodendron tulipifera*) lumbers, OSB, and plywood were selected for this experiment. Moisture adsorption and desorption rates of wooden materials were measured (ISO 24353). Also, effects of morphological, physical and chemical factors, like surface microstructure, density, and functional groups, on the hygroscopicity were analyzed. It is expected that the results from this study can contribute to establish a system for evaluating and controlling the hygroscopic property of wooden building.

***Keywords*:** Hygroscopic, Heat-treated wood, FE-SEM, FT-IR, Roughness

Introduction

As indoor environments of building comprise a large proportion of those living in modern people, there are many efforts to improve it. Because of indoor environments of building are affected not only people but also energy efficiency, it needed a multilateral effort into indoor environmental improvement. Especially, one of factors with influenced indoor environments in building, indoor relative humidity (RH) is reported the primary cause of condensation and biological pollutions such as mold. (Cho and Kim, 1990). However, inappropriate operation of the artificial facilities frequently creates substances to be harmful to our body and causes asthma, allergic rhinitis. Because of those, the importance of natural humidity control performance of interior materials is being emphasized. Wood, controlled humidity in residential space by moisture ad/desorption as humidity of the atmosphere; is used to interior materials in buildings. Humidity change of indoor buildings which is composed wood is low deviation than other materials. Therefore, the more wood exposure, the less humidity changes in indoor building.

These hygroscopic properties of wood are affected by changing moisture content and morphological difference. The anatomical structures were examined the heat treatment process by using scanning electron microscope (SEM) (Awoyemi and Jones 2011). And ^{2}H NMR relaxation measurements methods are used to measure the response of liquid confined in porous materials. These methods were used to study on moisture transfer and changes in structure of thermally modified Scots pine wood (Hietala et al 2002). The relation between surface roughness values and drying speed was searched using correlation analysis. It was determined that there was no effect of surface roughness on drying speed wood veneer in radial cut (Gungor et al 2010). Also, to evaluate the interior decorative value of small diameter larch which has low utilization, the study methods of timber are evaluated by the physical characters of it are evaluated by density, swelling, hygroscopicity, hardness, surface roughness, etc. (Park et al. 2010). This study was carried out for quantifying the hygroscopic property of some interior finishing wooden materials. And it is expected that the results from this study could contribute to improve the supplying wooden building.

Materials and Methods

Materials Yellow poplar (*Liriodendron tulipifera*) logs from 25-30 year-old trees, Seoul national university forest, Suwon-si, Gyungki-do, Korea were obtained for this study. Sawn dimensional stock of 50mm (T) x 150mm (W) x 1000 mm (L) were prepared for air-drying(AD), kiln-drying(KD) and high temperature heat-treatment(HT).

AD from green condition (with initial moisture content at an average of 68%) was conducted for three months. And KD was conducted by FPL scheduled which is drying condition runs at initial dry bulb temperature (DBT) 60°C, relative humidity (RH) 87% and final DBT 82°C, RH 26%. And, using high temperature oven, HT runs at DBT 200°C condition for six hours.

Ad/Desorption on wood Yellow poplar sawn lumbers thickness of 10mm, 30mm and vertical, width of 100mm x 100mm, 150mm x 150mm for air-drying(AD), kiln-drying(KD) and high temperature heat-treatment(HT). Except for surface area of measurement, all the section was sealed by aluminum tape. Using temperature & humidity chamber, the mass of wood at each state measured to mass change for 24hr less than 0.01g. Since then, to raise the RH, adsorption process for 12hr was calculated mass of specimen and dropped the RH, desorption process for 12hr was same way.

And following formula, moisture ad/desorption contents and rates of moisture ad/desorption after 12hr were calculated at each state. Except for moisture ad/desorption by humidity condition, surface roughness, microstructure and functional group were conducted by medium humidity condition.

$$\rho_{A,a} = \frac{w_a - w_o}{A} \qquad \rho_{A,d} = \frac{w_a - w_d}{A} \qquad G_n = \frac{w_n - w_{n-1}}{A \cdot \Delta t} \qquad \text{(Eq.1)}$$

$\rho_{A,a}$ = Moisture adsorption content(kg/m^2), $\rho_{A,d}$ = Moisture desorption content(kg/m^2), G_n = Rate of ad/desorption at state(kg/(m^2·h)), w_0 = Weight of final state at equilibrium(kg), w_a = Weight of final state at absorption(kg, after 12hr), w_d = Weight of final state at desorption(kg, after 12hr), A = Surface area(m^2), t = Time(hr)

Table 1. Humidity conditions for testing specimens

Humidity Conditions (Temp. 23℃)	Relative Humidity(%)	
	Adsorption(12hr)	Desorption(12hr)
Low (Equilibrated at 30%RH)	55	30
Medium (Equilibrated at 50%RH)	75	50
High (Equilibrated at 70%RH)	95	70

Functional group FT-IR spectrum analysis on wood was conducted for changing functional group by heat-treatment. Using ball miller (pulverisette 23, Fritsch), specimens were milling of the 100mesh. The FT-IR spectra were recorded on a FT-IR-6100 spectrometer, operating in the spectral range 650-4000 cm^{-1} with a resolution of 8 cm^{-1}.

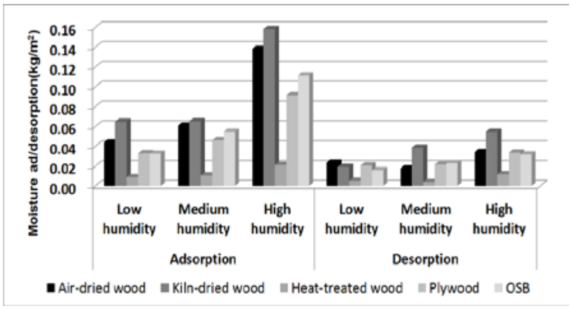
Microstructure Field-emission scanning electron microscopy (FE-SEM, SUPRA 55VP, Carl Zeiss, Germany) was used to image the changing microstructure of wood by heat treatment. The cross, radial, tangential section of wood were prepared using a microtome with 100㎛ in thickness.

Roughness The surface section of KD wood was ground by 180, 1000 grit sandpaper and measured rate of adsorption. The quantitative analysis of surface roughness of wood was conducted by using surface roughness measurement device (TR-200, Time High Tech.)

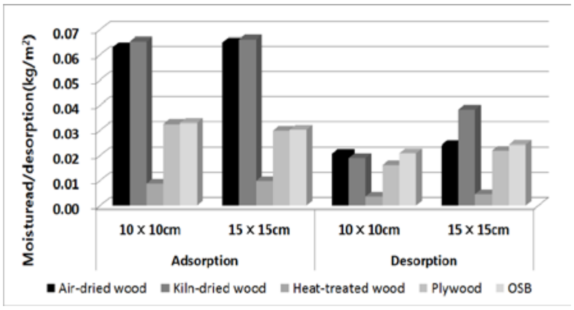
Results and Discussions

Ad/Desorption Figure 1 shows that moisture ad/desorption contents after 12hr was calculated at each condition. In case of relative humidity, high moisture ad/desorption contents on high humidity condition than others, it related to sorption property of bound water on wood by multilayer adsorption on high relative humidity. And then moisture ad/desorption contents weren't a distinct difference by surface area and thickness

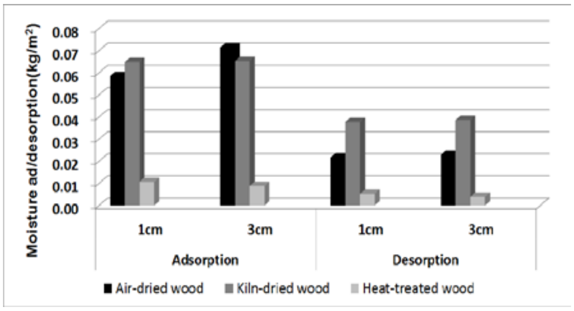
These results were similarly changing humidity conditions in indoor building during the day. It is used base data to calculated appropriate area and thickness of wooden interior materials with concerning size of space and changing humidity conditions in indoor building.



(a)



(b)



(c)

Fig 1. Quantity of Moisture in wood after 12hr adsorption and desorption at different conditions ((a): Relative Humidity, (b): surface area, (c): thickness)

But, these data which calculated by a cycle of 12hr weren`t knew when and how much to attain moisture ad/desorption contents, it was needed to measure those per hour. The results of rates of moisture ad/desorption at each material, all specimen were high ad/desorption rates for 2hr and gradually convergent trend. The rates of moisture ad/desorption is a degree of moisture ad/desorption of materials per unit surface area and time, its high value means efficiently responds to rapid change in humidity. As compared with other specimens, HT wood was certainly lower in those. It is due to hydrophobicity of wood surface that hard to adsorption of water molecule. Also, rates of moisture ad/desorption on KD wood is higher than that of AD wood. Vapor and moisture transfer on KD wood easier than that of AD wood because KD wood increase of inner opening on wood with volatilization of wood extractives by heat treatment.

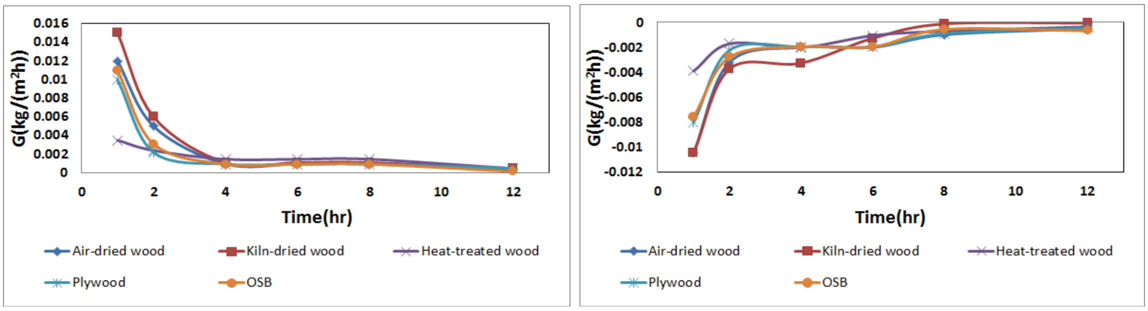


Fig 2. Moisture adsorption and desorption rate of air-dried, kiln-dried and heat-treated *Liriodendron tulipifera* wood

FT-IR Figure 3 shows FT-IR spectra at AD/KD/HT yellow poplar wood. Moisture adsorption point of wood is OH group from cellulose and hemicellulose. It was related to hygroscopic property of wood. And the more high temperature treatment, the lower peaks at around 3400 cm^{-1} represents OH group and 2900 cm^{-1} represents the C-H group a symmetric stretching in aliphatic methyl. It means that combinations of alkyl group, aromatic compound, carboxylic acid were broken on the dehydration by heat treatment.

A band at approximately 1650 cm-1 is characteristic to C=C stretching vibration in aromatic skeletal of lignin. This peak`s decrease occurred in wood with volatilization of wood extractives by heat treatment. In a KD wood, beside AD wood, was lower peaks at around 3400 cm^{-1} because it occurred water molecule loss and combination between the cellulose, which ester linkages simultaneously by heat treatment and decreased the ratio of hemicellulose which has many OH groups. But, rates of moisture ad/desorption of KD wood higher than AD wood, vapor and moisture transfer were easier because KD wood increase of micro pore on wood cell wall with volatilization of wood extractive by heat treatment.

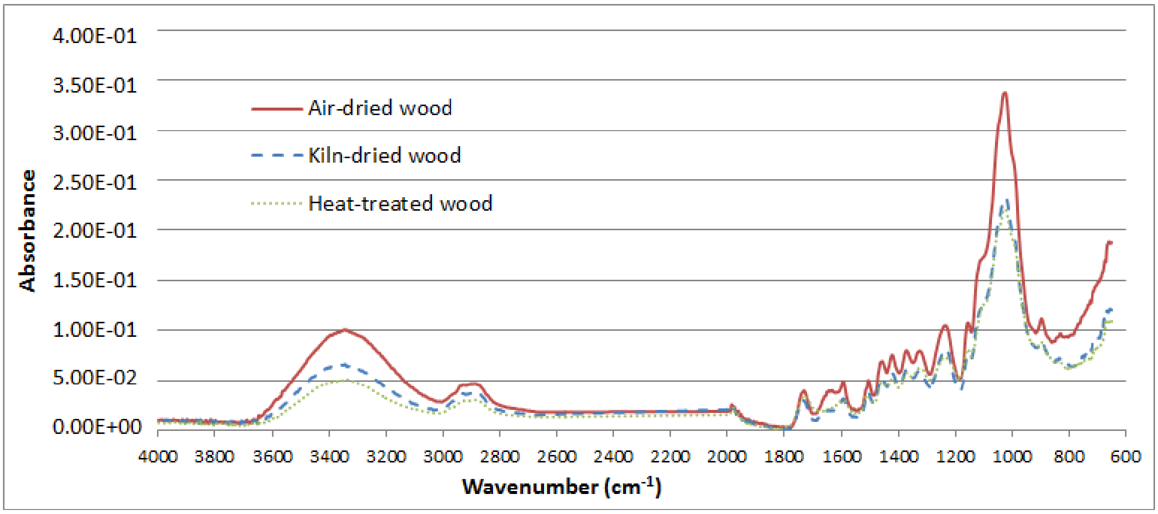


Fig 3. FT-IR spectrum of air-dried, kiln-dried and heat-treated *Liriodendron tulipifera* wood

FE-SEM In a HT wood, many micro cracks, shrinkage of cell wall and collapsed wood cell as sharply water loss were found on the cross section of wood. And rise of surface roughness and expansion of micro movement path were increased the speed of ad/desorption by reduced the vapor diffusion resistance. But these effects of structure change lesser than those of chemical change such as hydrophobicity, rates of moisture ad/desorption were lower than others.

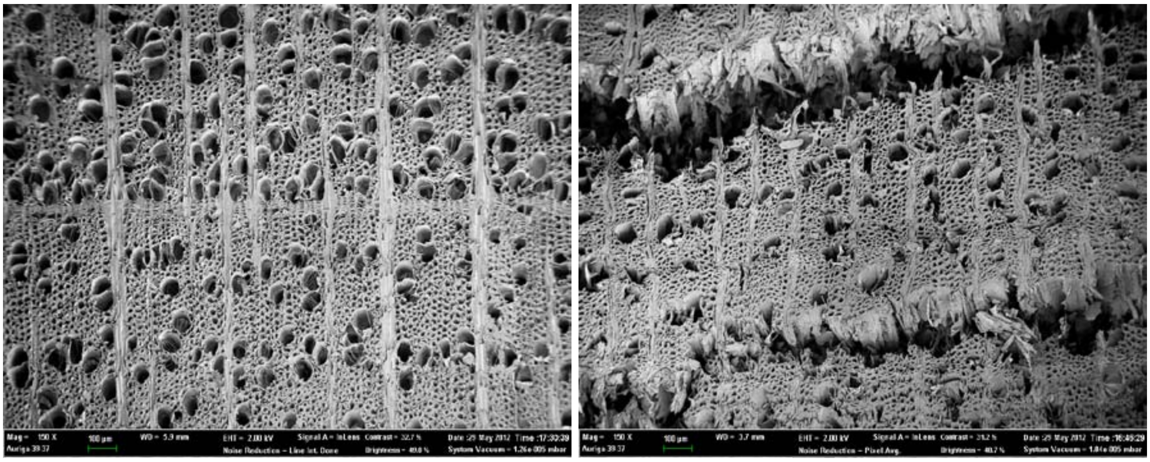


Fig 4. Cross-sectional view of air-dried(left), heat-treated wood(right)

Fig 5. Cell wall of air-dried wood(left) and heat-treated wood(right)

Roughness As the effect of hydrophobicity by heat treatment, AD wood was conducted to measure rate of adsorption by each surface roughness because it wasn`t clearly found the relation between the speed of adsorption and surface roughness. Four main roughness parameters, mean arithmetic deviation of profile (R_a), root mean square roughness (R_q), maximum roughness (R_t) and mean peak-to-valley height (R_z), obtained from the surface of wood were used to evaluate the effect of heat treatment on the surface roughness of the specimens.

Table 2. surface roughnesses of specimens abraded with 180-grit and 1000-grit sandpaper

Material	Roughness(μm)			
	R_a	R_q	R_t	R_z
180grit (air dried wood)	8.09	11.83	45.85	31.95
1000grit (air dried wood)	3.6	5.366	41.1	28.2

In a grinded AD wood by sandpaper, it shows distinctly difference that R_a: 8㎛, R_q: 12 ㎛ at 180-grit and 4㎛, R_q: 5㎛ at 1000-grit. As moisture adsorption rate, 180-grit is higher than 1000-grit and these results were interpreted to high roughness was increased contact surface between water molecule and wood surface. The gap between 180-grit sandpaper's adsorption rate and that of 1000-grit sandpaper was about 5 g/m^2h at initial time, the gap was gradually decreasing. In the initial adsorption, surface roughness was major factor of adsorption because water molecule was absorbed surface of wood. But, it was lesser because water molecule diffused wood cell wall as time went on.

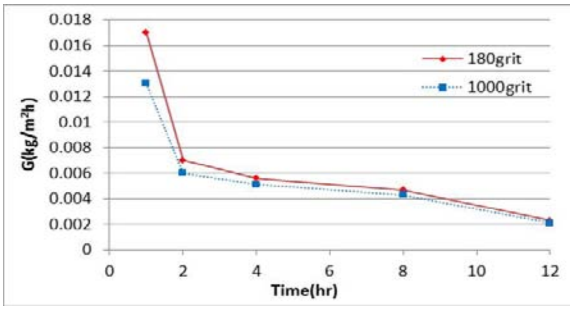


Fig 6. Moisture adsorption rate by surface roughness in wood

Conclusion

This study was carried out for changing the hygroscopic property of yellow poplar by heat treatment. In the moisture ad/desorption contents, KD wood was higher than AD wood. And these results were interpreted by changing microstructure, surface roughness and functional group. Surface roughness was considered major factor of initial ad/desorption. Also, KD wood is highest rate of ad/desorption value, it means that appropriate hygroscopic performance with severe changing humidity condition. And heat treatment with appropriate temperature will contributed to enhanced hygroscopic performance of wood. And, HT wood had a lower hygroscopic property. But, it has an advantage of high dimensional stability and decay resistance which using products.

Therefore, it used to interior material in space of continuous high RH condition. Also, It is possible that substance of outstanding hygroscopic property was injected into extended inner openings of HT wood to enhance hygroscopic performance. This study was expected to base data for quantifying the hygroscopic property of residential space on wooden house.

Acknowledgement

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