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Effect of Heat Treatment on the Bending Strength and Hardness of Wood*1

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ABSTRACT

Heat treatment improves dimensional stability and sound absorption properties of wood. However, mechanical properties of wood can be deteriorated during the heat treatment. The effect of heat treatment on the bending strength and hardness of wood for *Korean paulownia, Pinus densiflora, Lidiodendron tulipifera* and *Betula costata* were measured. The heat treatment temperature has been investigated at 175°C and 200°C, respectively. The results showed that the weight and density of wood decreased after heat treatment. It was found that the density by heat treatment was lower at 200°C than that at 175°C. And, MOE increased with the reduced density. On the contrary, MOR and hardness decreased. In all conditions, It was found that there was a high correlation of 1% level between bending modulus of elasticity and modulus of rupture.

Keywords : heat treatment, density, bending MOE and MOR, hardness

1. INTRODUCTION

The demand of wood has risen sharply because of the necessity for environment friendly fuels with an increase of personal income and economic growth. Until recently, Korea is importing more than 90% of the annual wood consumption (2.60 million m^3) because most of the resources are low-diameter wood or low-quality wood in Korea. It is an inevitable consequence because the timber resources of high quality are reducing and every consumer want to use cheap wood resource of high quality.

Recently, the "ThermoWood" (heat treated wood product) is manufactured to make high value and to accept consumers' preference in Europe. And the thermal treatment of wood is an alternative to the chemical treatment for preservation purposes (Poncsak *et al*., 2006). Also, It has been continuously researching around the world about removing resin from conifer, changing of the material quality for softwood and hardwood, and improving of dimensional stability (Shin *et al*., 2009). And relatively mild thermal treatments of wood according to a two step process which leads to improved dimensional

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stability (Tjeerdsma *et al*., 1998). Hydrothermal processing of lignocellulosic materials (wood or agricultural residues) causes a variety of effects including extractive removal, hemicellulose hydrolysis and alteration of the properties of both cellulose and lignin (Garrote *et al*., 1999). Changes in the chemical structure of wood caused by thermal treatment and modification during heat treatment could be explained by a modification of conformational arrangement of wood biopolymers due to loss of residual water or more probably to plasticization of lignin (Sivonen *et al*., 2002, Hakkou *et al*., 2005). And decrease in hydroxyl groups increases the hydrophobicity of wood and reduces the adoption of water (Kamdem *et al*., 2002, Stamm *et al*., 1946, Pavlo *et al*., 2003). The wood structure changes due to decomposition of hemicelluloses, ramification of lignin, and crystallization of cellulose. These changes improve the dimensional stability of wood, increase its resistance to micro-organisms, darken its color, and modify its hardness (Kocaefe *et al*., 2008). The heat-treated wood is more dimensionally stable in the change of moisture condition and the mechanical properties of heat-treated wood showed relatively higher performance (Kim *et al*., 2009).

It has been suggested that this study takes a subsequent investigation for the research of the sound absorption property of heat-treated wood at a low temperature and vacuum conditions (Byeon *et al*., 2010). In this study, the effect of heat treatment on the bending strength and hardness of *Korean paulownia, Pinus densiflora, Lidiodendron tulipifera* and *Betula costata* was investigated under different conditions.

2. MATERIALS and METHODS

2.1. Material

The species of *Korean paulownia, Pinus densiflora, Lidiodendron tulipifera* and *Betula costata* were used in the dry ingredients. Specimens of each species were made from edge grain 20 (R) × 10 (T) × 100 mm(L) and flat grain 10 (R) × 20 (T) × 100 mm(L) and processed 8 each.

The humidification of specimens was treated over 1 week in the constant temperature and humidity room (20°C ± 1°C, 65% ± 5%), and heated for 6 hours at 120°C in dry oven. The heat treatment of specimens treated at the heating rate 10°C/min heating conditions in the vacuum sintering furnace (KOVACO KSF-100 Type). At this time, maintained for 30 minutes in the maximum temperature of 175°C and 200°C. After heat treatment, the humidification of treated samples were treated again over 1 week in the constant temperature and humidity room (20 ± 1°C, 65 ± 2%). After that, bending strength and hardness test of specimen was conducted.

2.2. Weight and Density Changes

Weight and density were measured before and after heat treatment of each specimen with electronic scale, and used electronic calipers to measure the size.

2.3. Bending Strength and Hardness Test

Bending strength test was conducted using a span (80 mm) by central method of three points, and carried out test load speed of 1 mm/min. In this condition, bending MOE and MOR was determined. TAESIN Precision Machinery TSU-2 Universal Mechanical Testing Machine was used for the measurement.

Hardness test was conducted using the universal strength tester by Brinell hardness test method. When the load in the 0.32 mm indentation hardness was measured using steel balls of 10mm diameter by loading rate of 0.5 mm/min.

Table 1. Mass and density properties of heat-treated woods

Species	Heat treatment condition		Mass		Density	
			(g)	R_M (%)	(g/cm^3)	$R\rho$ (%)
Korean Paulownia	solid	Mean	5.730	0	0.299	0
		S.D	0.483		0.023	
	175	Mean	4.310	-24.78	0.224	-25.08
		S.D	0.280		0.013	
	200	Mean	3.705	-35.34	0.194	-35.12
		S.D	0.275		0.011	
Pinus densiflora	solid	Mean	10.960	0	0.546	0
		S.D	0.695		0.034	
	175	Mean	9.40	-14.23	0.497	-9.64
		S.D	0.40		0.021	
	200	Mean	8.053	-26.52	0.452	-17.82
		S.D	0.462		0.031	
Lidiodend-ron tulipifera	solid	Mean	10.550	0	0.548	0
		S.D	0.653		0.039	
	175	Mean	7.729	-26.73	0.440	-20.00
		S.D	0.357		0.023	
	200	Mean	6.331	-39.99	0.374	-32.00
		S.D	0.586		0.045	
Betula costata	solid	Mean	13.440	0	0.694	0
		S.D	0.275		0.023	
	175	Mean	11.755	-12.53	0.648	-6.67
		S.D	0.774		0.037	
	200	Mean	9.174	-31.74	0.572	-11.01
		S.D	0.371		0.021	

Notes; R_M: Ratio change in mass after heat treatment,
ρ: Density,
$R\rho$: Ratio change in density after heat treatment,
S.D: Standard deviation.

3. RESULTS and DISCUSSION

3.1. The Weight and Density of Species According to the Heat Treatment

Table 1 shows weight of each species after heat treatment. The weight of wood after heat treatment decreased according to increase of temperature. Especially, *Korean paulownia* and *Lidiodendron tulipifera* showed very high decreasing rate. The decreasing rate at temperature between 175°C and 200°C for *Korean paulow-*

Table 2. Bending strength and hardness properties of heat-treated woods

Species	Heat treatment condition		MOE (kgf/cm^2)	R_{MOE} (%)	MOR (kgf/cm^2)	R_{MOR} (%)	Hardness (kgf/mm^2)	R_{HB} (%)
Korean Paulownia	Solid	mean	57,374	0	433	0	3.35	0
		S.D	8,229		14		0.38	
	175°C	mean	55,010	-4.12	264	-39.03	3.12	-6.87
		S.D	6,608		39		0.72	
	200°C	mean	51,396	-10.42	145	-66.51	2.26	-32.54
		S.D	7,449		28		0.51	
Pinus densiflora	Solid	mean	95,299	0	876	0	10.37	0
		S.D	18,045		61		0.21	
	175°C	mean	104,778	+9.95	875	-0.11	8.65	-16.59
		S.D	16,162		102		1.81	
	200°C	mean	113,342	+18.93	660	-24.66	8.58	-17.26
		S.D	17,050		126		1.23	
Lidiodend-ron tulipifera	Solid	mean	105,984	0	830	0	8.54	0
		S.D	24,611		103		0.46	
	175°C	mean	109,300	+3.13	583	-29.76	8.35	-2.22
		S.D	21,720		77		1.54	
	200°C	mean	111,624	+5.32	334	-59.76	6.33	-25.88
		S.D	24,458		160		1.29	
Betula costata	Solid	mean	125,461	0	1236	0	10.39	0
		S.D	31,463		104		0.58	
	175°C	mean	125,007	-0.36	1002	-18.93	12.11	+16.55
		S.D	9,226		162		1.69	
	200°C	mean	139,683	+11.34	665	-46.20	9.76	-6.06
		S.D	29,467		136		1.69	

Notes; R_{MOE}: Ratio of change in MOE after heat treatment,
R_{MOR}: Ratio of change in MOR after heat treatment,
R_{HB}: Ratio of change in Hardness after heat treatment,
S.D: Standard deviation. RF : Resonance frequency.

nia, Pinus densiflora, Lidiodendron tulipifera and *Betula costata* showed -24.78%, -35.34% and -14.23%, -26.52% and -26.73%, -39.99% and -12.53%, -31.74%, respectively. It was acted commonly as well not only moisture desorption of wood fiber at the over 100°C but also different composition of each species. Borrega and Kärenlamopi (2008) reported that the weight loss of spruce at the same moisture content increased at the high temperature.

Table 1 shows density of each species after heat treatment. Especially, the highest decreas-

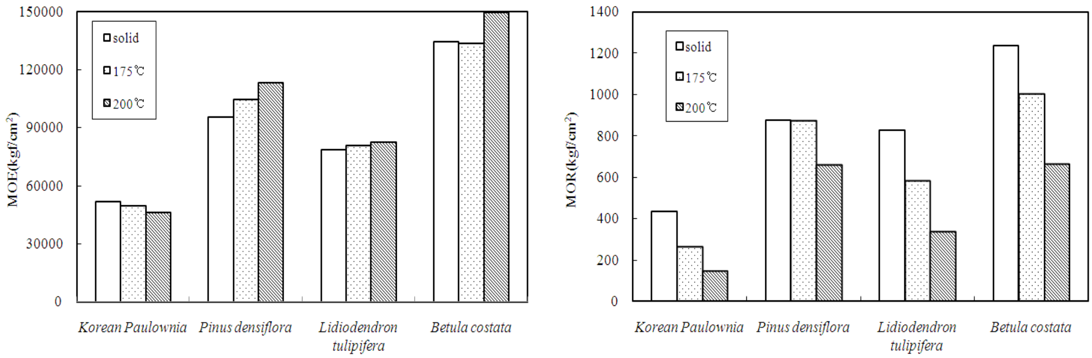

Fig. 1. Bending strength properties of heat-treated woods.

ing rate on the *Korean paulownia* showed -25.08% at the 175°C and -35.12% at the 200 °C. The *Lidiodendron tulipifera* also showed very high decreasing rate of -20% at the 175 °C and -32% at the 200°C. This result is also due to different component of each species. In addition, the density of heat treatment at the high temperature is lower than heat treatment at the low temperature. The reason why the density of heat treatment at the high temperature is low because hemicellulose was degraded as well at the 200°C more than 175°C. Esteves *et al* (2007) reported that wood density decrease because of the removal of wood components by heat treatment and moisture desorption.

In studies of the characteristics of pyrolysis for wood has been reported that cellulose, hemicellulose and lignin consist of each component and differ from decomposition temperature (Shafizadeh and McGinnis, 1971; Bridgwater, 2000; Demirbas, 2002). They said that the decomposition temperature was 275～350°C for cellulose, 150～300°C for hemicellulose and 250～500°C for lignin. It shows in the other studies such as the pyrolysis characteristics of wood (Lee, 2003) and hemicellulose was a variety of heterogeneous materials (Manninen, 2002).

3.2. The Bending Strength of Each Species According to the Heat Treatment

Table 2 and Fig. 1 shows the averages between the modulus of elasticity (MOE) and the modulus of rupture (MOR) of each species after heat treatment. Before and after heat treatment, *Betula costata* showed highest bending modulus followed by *Lidiodendron tulipifera*, *Pinus densiflora* and *Korean paulownia,* respectively. Every species increased the bending modulus except *Korean paulownia*. MOE showed much higher at the 200°C than 175°C. Kocaefe *et al* (2010) reported that there is a significant change in mechanical properties (MOE, MOR, hardness, etc.) due to heat treatment. Mechanical properies of heat-treated jack pine generally were deteriorated at temperatures higher than 200°C compared to those of untreated jack pine.

The density is generally proportional to the modulus of elasticity. However, like in this experiment, decreasing density of the heat-treated wood was caused by decomposition of hemicelluloses, ramification of lignin, and crystallization of cellulose. (Kocaefe *et al,* 2008). Thereby increasing the MOE. But, further research is required why unlike other species,

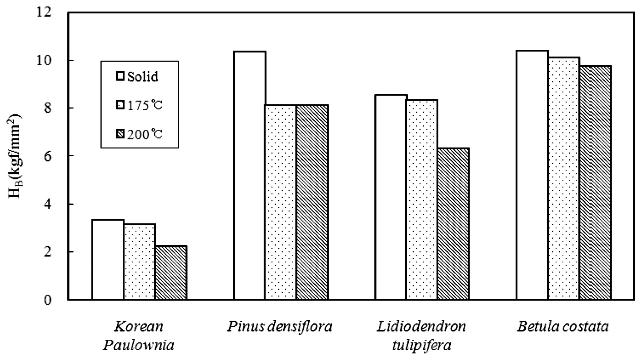

Fig. 2. Hardness property of heat treated woods.

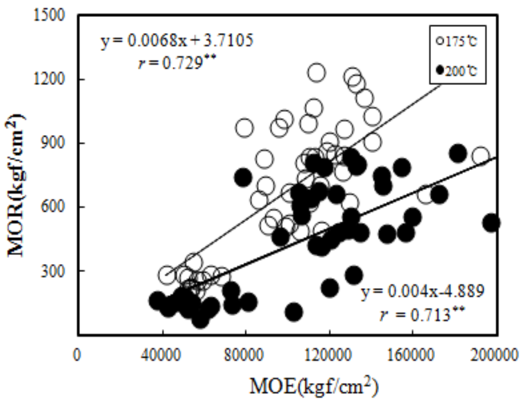

Fig. 3. Relation of bending MOE to MOR of heat treated woods.

MOE of *Korean paulownia* decreased after heat treatment.

The MOR of heat-treated *Betula costata, Lidiodendron tulipifera*, *Pinus densiflora* and *Korean paulownia* were decreased at temperature of 200°C more than those at 175°C. This deterioration might be explained as due to hemicellulose degradation. Yildiz *et al* (2006) reported that the heat treatment and control samples were tested for some mechanical properties; compression strength, bending strength, modulus of elasticity in bending, hardness, impact bending strength and tension strength perpendicular to grain. The results indicated that heat treatment samples had lower mechanical properties compared to the control samples. It was seen that hemicelluloses were the wood-cell components most degraded by the heat treatment.

3.3. The Hardness of Each Species According to the Heat Treatment

Table 2 and Fig. 2 shows the mean value of each species after heat treatment. Before and after heat treatment, the bending solidity and density was measured lower at the 200°C than 175 °C. *Betula costata* showed highest hardness followed by *Lidiodendron tulipifera*, *Pinus den-*

siflora and *Korean paulownia,* respectively.

The bending strength and hardness decreased due to the reduction of density after heat treatment. In this study, the heat treatment of specimens treated at the heating rate 10°C/min heating conditions, and maintained for 30 minutes in the maximum temperature of 175°C and 200°C.

Therefore, the maximum temperature of 200°C was more active degradation of hemicellulose than 175°C. Kocaefe *et al* (2010) reported that there is a significant change in hardness due to heat treatment. The hardness of heat-treated jack pine generally were deteriorated at temperatures higher than 200°C compared to those of untreated jack pine.

3.4. The Bending MOE-Bending MOR, Density-Bending MOE and Density-Hardness Correlation of Heat Treated Wood

Fig. 3 shows the relation of bending MOE to MOR of heat treated woods. The correlation coefficients for the regression bending MOE to MOR were 0.729 at the 175°C and 0.713 at the 200°C. Both were significant at the 1% level, and there were a similar correlations between 175°C and 200°C. Byeon *et al* (2005) reported that a high correlation coefficient between bending MOE and MOR of finger-jointed wood were similar to this results (significant at the 1% level). And Nakai (1984) also reported that solid Japanese cedar showed a high correlation coefficient (0.69-0.78) between bending MOE and MOR.

4. CONCLUSIONS

Heat treatment tests for four species of woods were performed in order to assess the effects on the bending strength performence and hardness. The results showed that there was a significant change in mechanical properties such as MOE, MOR and hardness due to heat treatment. The density of heat treatment at the high temperature was lower than heat treatment at the low temperature. The reason why the density of heat treatment at the high temperature is low because hemicellulose was degraded as well at the 200°C more than 175°C. And MOE showed much higher at the 200°C than 175°C. The hardness decreased due to the reduction of density after heat treatment. And, a high correlation and 1% level of significance were observed in all conditions between bending MOE and bending MOR.

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