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Hygroscopicity and Surface Hardness of Domestic Wood Heat-Treated at 220℃[1]

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ABSTRACT

In a previous study, it was revealed that three major softwoods, Japanese pine, Korean pine and Japanese larch, heat-treated at 220℃, could produce high quality dark-colored boards. It is known that heat treatment decreases the hygroscopicity of wood. The hygroscopicity of major domestic softwoods and hardwoods heat-treated at 220℃ was investigated by a saturated salt solution method and compared with that of black and white charcoals. Equilibrium moisture contents of wood decreased with the increase of heat treatment time. Isotherm shapes of wood species were different from those of charcoals. Heat treatment decreases the equilibrium moisture contents of black locust more than those of Korean pine and Japanese larch. It was found that surface hardness of wood is improved by heat treatment to a certain extent, but a longer heat treatment causes thermal degradation, resulting in the decrease of the surface hardness.

Key words: Heat treatment, *Pinus densiflora*, *Pinus Koraiensis*, *Larix kaempferi*, *Betula platyphylla*, *Robinia pseudoacacia*, discoloration, hardness.

INTRODUCTION

Three major softwoods, Japanese pine, Korean pine and larch, were heat-treated at 220℃, producing high quality dark-colored boards (Kang 2008). They can be substituted for tropical hardwoods. Heat treatment reduces the growing stress of wood, increases the crystallinity of cellulose, decreases equilibrium moisture content, and improves the dimensional stability (Tejada et al. 1997). It has been reported that the crystallinity of wood heat-treated at high moisture content was increased as twice as that at oven-dry condition (Bhuiyan et al. 2000).

Heat treatment decreases the hygroscopicity of wood, which, however, is recovered by steaming at 100℃. It proves that heat treatment does not increase the crystallinity of cellulose, but makes amorphous material changed chemically (Obataya et al. 2000).

If wood is exposed to high temperature its surface is definitely hardened, which makes a deviation from normal wood. Tensile and compression strengths of wood are influenced by the surface hardness. The effect of heat treatment time on the surface hardness was investigated in this study.

The color of heat-treated softwoods turns into noble dark, so they can substitute expensive hardwoods. Furthermore they are highly stable in dimension and thus can be used in severe conditions, such as floor-heating room and sauna.

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The stability of wood is evaluated by measuring the dimensional change due to the change of the environmental conditions. Alternatively equilibrium moisture content would be a predictor of the dimensional stability since the hygroscopicity of wood is linearly related to it. Saturated salt solution method has been used to obtain a sorption isotherm by measuring equilibrium moisture contents at various relative humidities (Lee et al. 2008).

The object of this study is to compare the hygroscopicity of major domestic softwoods and hardwoods heat-treated at 220℃.

MATERIALS AND METHODS

Three major domestic softwoods, Korean red pine (*Pinus densiflora* S. et Z), Korean pine (*Pinus Koraiensis* S. et Z) and Japanese larch (*Larix kaempferi*), and domestic hardwoods, birch (*Betula platyphylla* Var. japonica) and black locust (*Robinia pseudoacacia* L.) were chosen for this study. Birch trees were harvested at University Forest of Chungnam National University, while the logs of the other species were obtained from local sawmills.

All logs were sawn into 3cm-thick boards and they were cut 800mm long. All boards were end-coated with PVAc glue and air-dried in shed for 3 months. Heat treatments were conducted at 220 ℃ with the equipment recently made (Kang 2008).

Two heat-treatment experiments were conducted. The purpose of a first experiment was to investigate the effect of heat treatment temperature on the equilibrium moisture contents of boards. Three softwoods were used and the treatment times were 2, 4, 6, 8, 10, 12 hours. The purpose of a second experiment was to compare the hygroscopicity of heat-treated boards with the controls, which were air-dried. Black locust, Korean pine and Japanese larch were used for this experiment. For further comparison, black and white charcoals were added. They were made from domestic oak and obtained from market.

The procedure for measuring the equilibrium moisture contents of boards were as followed. Twelve 6mm-long specimens were cut in the middle of each 800mm-long board. Six different salt solutions were prepared and poured in sex desiccators. Two 6mm-long specimens of each board were placed in the salt solution desiccators avoiding wetting. The desiccators were place in a room at 20℃ for 3 months until the specimens were equilibrated. The relative humidities of the salt solutions used for this study are listed in Table 1 (Hoadley 1980).

Table 1. Relative humidities of saturated salt solutions at 20℃

Saturated salt solution	RH (%)
$CaCl_2 \cdot 2H_2O$	32.0
NaBr	58.0
$(NH_4)_2SO_4$	80.5
$ZnSO_4 \ 7H_2O$	90.0
$NaSO_4$	95.0
H_2O (distilled water)	100.0

Two hardness specimen of 100mm width and 200mm length was cut from each 800mm-long board. Rock Well Hardness Tester DTR-300 was used for measuring the surface hardness of boards.

The diameter of a tester ball was 1/2 inch and a weight of 30kgf was loaded. Five measurement points were selected on a hardness specimen as Fig. 1.

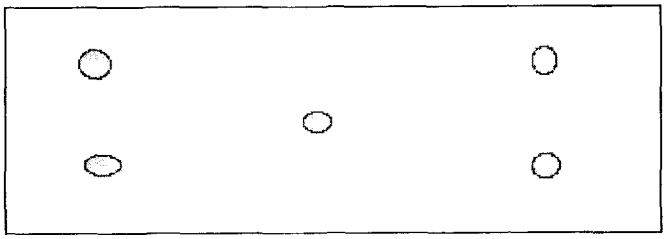

Fig.1. Diagram of five test points for measuring the surface hardness of wood specimens.

RESULTS AND DISCUSSION

Heat treatment time and equilibrium moisture content

The sorption isotherms of four species boards heat-treated at 220℃ and six treatment time levels are plotted in Fig. 2. It was revealed that the equilibrium moisture contents of all relative humidities decreased with the increase of heat treatment time for all species. The equilibrium moisture content of 12 hour-treated boards was compared with that of the 2 hour-treated. The differences are -3.0%, -3.2%, -5.8% and -5.5%, respectively, for Korean red pine, Korean pine, Japanese larch and black locust. These values were the averages of the equilibrium moisture contents measured at six relative humidities except 100%. As relative humidity approaches 100% moisture condenses in a capillary, causing rapid increase of moisture content of wood. But it does not influence the dimensional change of wood.

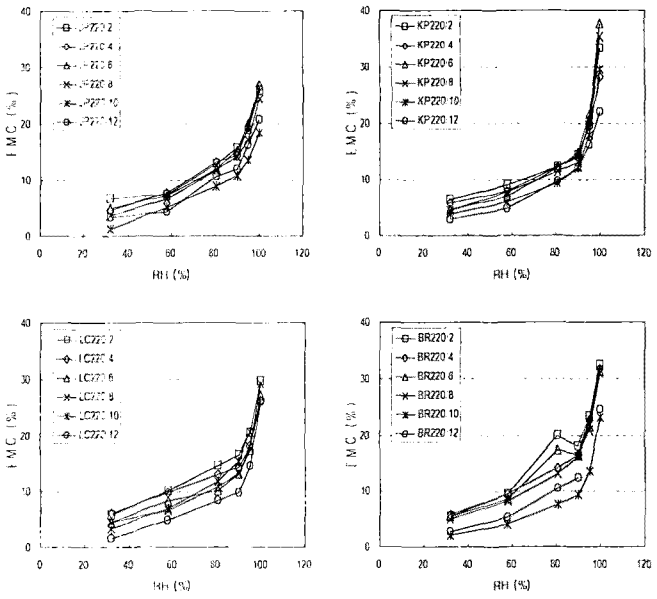

Fig. 2. Sorption isotherms of Japanese pine (JP), Korean pine (KP), Japanese larch (LC) and birch (BR) boards heat-treated at 220℃ and six different treatment times.

The sorption isotherms of the controls and charcoals

The isotherms of air-dried black locust, Korean pine and Japanese larch boards were compared those of black and white charcoals in Fig. 3. It is clearly shown that the formers have a sigmoidal shape representing a multimolecular adsorption layer, while the latters have a Langmuir shape representing a monomolecular adsorption layer (Lee et al. 1989). It proves that wood adsorbs moisture more than charcoal.

The sorption isotherms of the controls and heat-treated

The isotherms of the air-dried and heat-treated at 220℃ for 12 hours of black locust, Korean pine and Japanese larch were compared in Fig. 3. The equilibrium moisture contents of the black locust control were higher than those of the other species. However, after heat treatment, the formers were lower than the latters in all RH ranges. It can be concluded that heat treatment decreases the equilibrium moisture contents of black locust more than those of Korean pine and Japanese larch. In other words, the hygroscopicity of a denser species is lost more than that of a less dense species. It was confirmed by the first experiment. The denser species, Japanese larch and birch, showed higher discrepancy in equilibrium moisture contents between 2- and 12-hour heat treatments than less dense species, Korean red pine and Korean pine (Fig. 2).

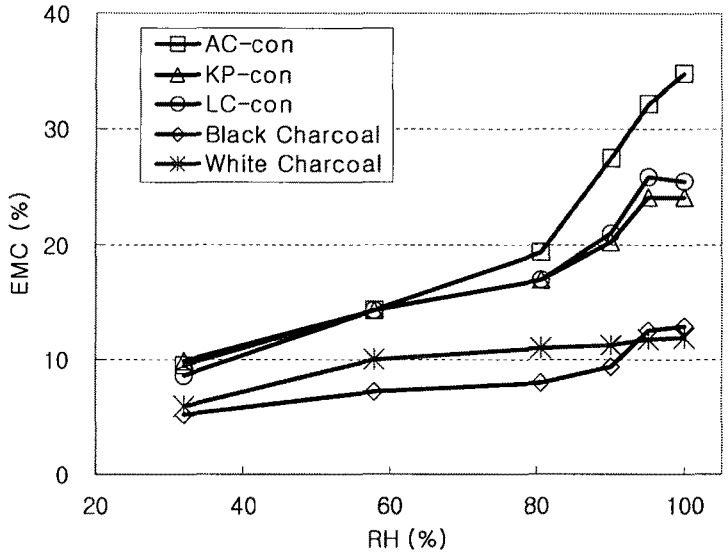

Fig.3. Comparison of the sorption isotherms of the air-dried black locust, Korean pine and Japanese larch specimens with the black and white charcoals. It shows definitely low hygroscopicity of the charcoals.

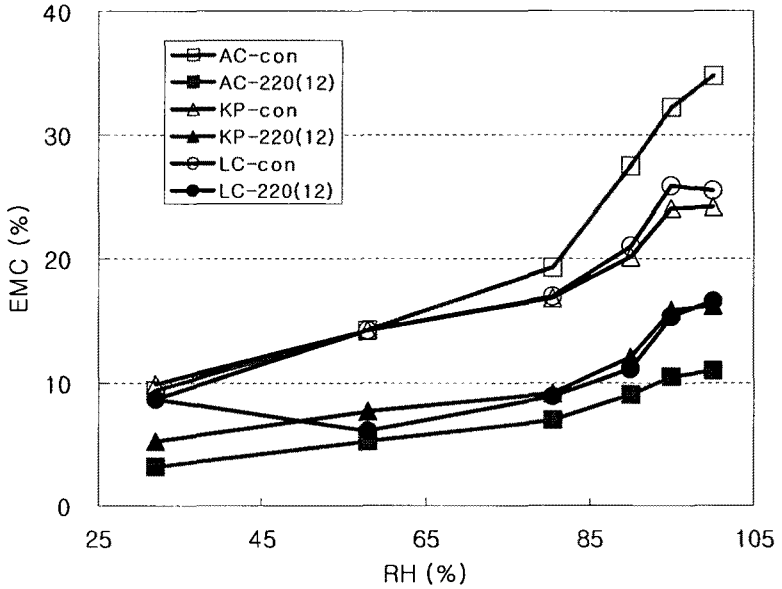

Fig.4. The isotherms of the air-dried and heat-treated at 220℃ for 12 hours of black locust, Korean pine and Japanese larch.

Surface hardness

Fig. 5 shows the surface hardness of Korean red pine, Korean pine, Japanese larch and birch at various treatment times. The depth of a hall made by the ball was expressed as a negative value. The point with higher value represents harder surface and is plotted in the upper part in Fig. 5. Thus the surface hardness of birch is the highest among four species in all heat-treatment time ranges while those of three softwoods are not distinguishable.

In general the surface hardness has a peak between 4 and 8 treatment hours and lowest value at 2 and 12 hours. Specially three out of four species have a peak at 8 treatment hours. It can be concluded that heat treatment improves the surface hardness to a certain level, but a longer heat treatment causes thermal degradation, resulting in the decrease of the surface hardness. Heat treatment is sometimes used for improving the acoustic performance of a musical instrument. For this goal it is very important to find out a optimum heat-treatment time.

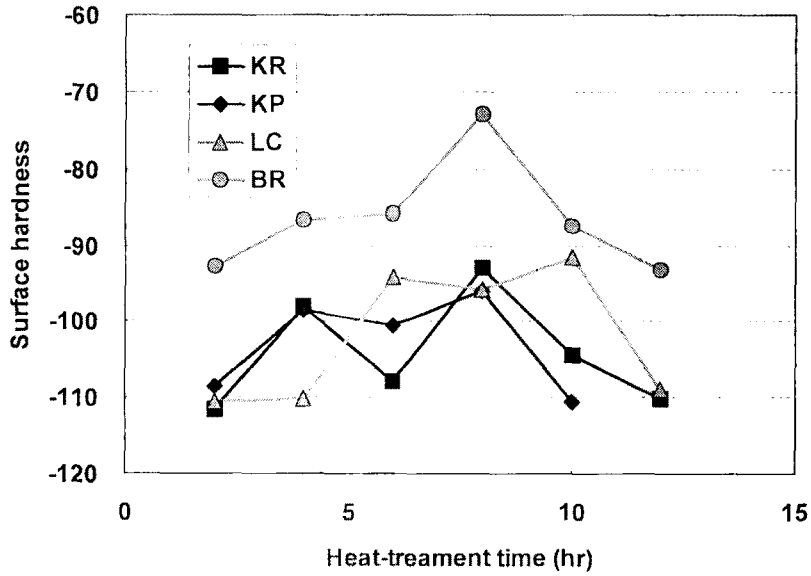

Fig.5. The surface hardnesses of Korean red pine, Korean pine, Japanese larch and birch at various treatment times.

CONCLUSIONS

The hygroscopicity of major domestic softwoods and hardwoods heat-treated at 220℃was investigated by a saturated salt solution method and compared with black and white charcoals. The conclusions obtained from this study are as followed:

1. Equilibrium moisture contents of wood at all relative humidities decreased with the increase of heat treatment time.

2. The sorption isotherms of all wood species showed sigmoidal shapes of multimolecular adsorption layers whether they were heat-treated or not, while those of black and white charcoals Langmuir shapes of monomolecular adsorption layers.

3. Heat treatment decreased the equilibrium moisture contents of black locust more than those of Korean pine and Japanese larch. In other words, the hygroscopicity of a denser species was lost more than that of a less dense species by heat treatment.

4. Heat treatment improved the surface hardness to a certain level, but a longer heat treatment causes thermal degradation, resulting in the decrease of the surface hardness.

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