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Original Article

A Study on Dimensional Stability and Thermal Performance of Superheated Steam Treated and Thermal Compressed Wood[1]

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ABSTRACT

Recently, wood is attracting attention as green building interior decoration material. When wood is used as building interior decoration material, excellent dimensional stability and thermal performance is required. In this study, superheated steam treatment process and thermal compression process were applied to flat sawn *Pinus koraiensis* wood panel in order to improve dimensional stability and thermal performance. According to results of this study, superheated steam treatment process and thermal compression process improve thermal performance and dimensional stability of wood, especially in tangential direction. The spring back in radial direction reduces the effect of thermal compression on dimensional stability of wood in radial direction.

Keywords : superheated steam treatment, thermal compression, equilibrium moisture content, dimensional stability, thermal conductivity, *Pinus koraiensis*

1. INTRODUCTION

Recently, the interest in wood as green building material is increasing. Especially in building interior decoration materials, the ratio of wooden windows system is increasing. According to Elder *et al*. (2000), the heat loss in building mostly takes place in opening, such as window. The deformation of wood caused by improper moisture control inhibits the air tightness of windows. Also, poor heat insulation property of windows results in an increase in the heating energy.

According to Kamke and Rathi (2011), Kutnar *et al*. (2008, 2009), Standfest *et al*. (2013) and Unsal *et al*. (2009, 2011), the principle of thermal compression of wood is viscous buckling of cell walls without fracture, and density profile of thermal compressed wood varied with the degree of densification as a consequence of different temperature and moisture gradients formed before and during wood

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Fig. 1. Wood specimens before thermal compression.

Fig. 2. Wood specimens after thermal compression.

compression. And according to Hwang *et al*. (2011, 2011, 2012, 2014), the hardness and various mechanical properties of wood are improved by thermal compression.

According to Kim *et al*. (2009, 2010), Lim *et al*. (2014), Park *et al*. (2012, 2014), and Yoon *et al*. (2008, 2009), the superheated steam treatment on wood decreases the content of hemicellulose. And superheated steam treated wood have improved dimensional stability and decay resistance.

In this study, the effect of superheated steam treatment process and thermal compression process on dimensional stability and thermal performance of wood, used as building interior decoration material were investigated.

2. MATERIALS and METHODS

2.1. Specimen preparation

By processing flat sawn air-dried *Pinus koraiensis* wood (initial MC 10%), 4 different types of specimens : control, thermal compressed specimens, superheated steam treated specimens, superheated steam treated and thermal compressed specimens were prepared. And all types of specimens were conditioned at 25℃ and 60% RH condition.

2.2. Thermal compression process (TC)

The specimens were compressed in radial direction with hot press machine heated to 140℃ until its thickness became to be half (Fig. 1, Fig. 2). The compression pressure was 35 kgf/cm^2 and compression time was 30 minutes.

2.3. Superheated steam treatment process (SST)

The specimens were superheated steam treated using superheated steam treatment machine (Fig. 3) in 5 atm, 220℃ during 6 hours.

2.4. Measurement of equilibrium moisture content (EMC)

The equilibrium moisture content of specimens was evaluated in 25℃, 45%, 65%, 85%

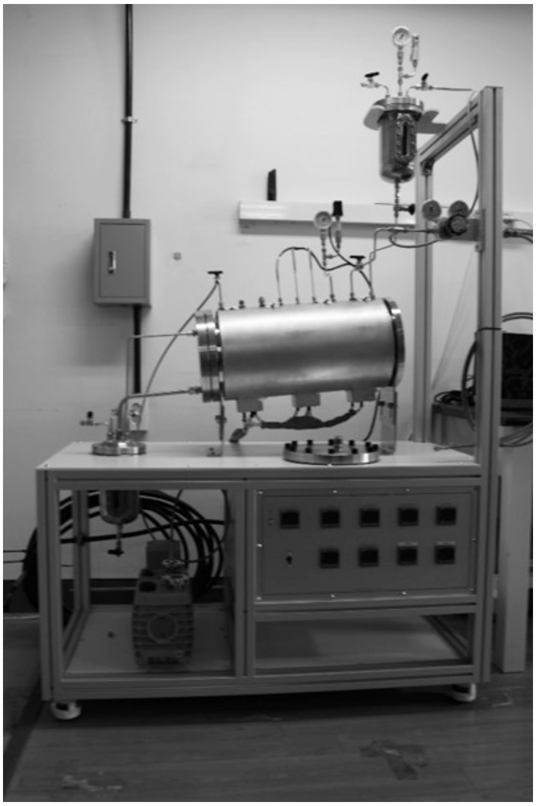

Fig. 3. Superheated steam treatment machine.

RH conditions. The size of specimens were 20 × 20 × 20 mm^3 (Fig. 4).

2.5. Measurement of dimensional stability

The deformation of all types of specimens in radial direction and tangential direction was measured using Vernier calipers in oven dried, air dried (25℃, 60%RH), and water-soaked state. For water soaked state, the specimens were soaked in water for 72 hours (Korean Standard Association, 2004, 2004).

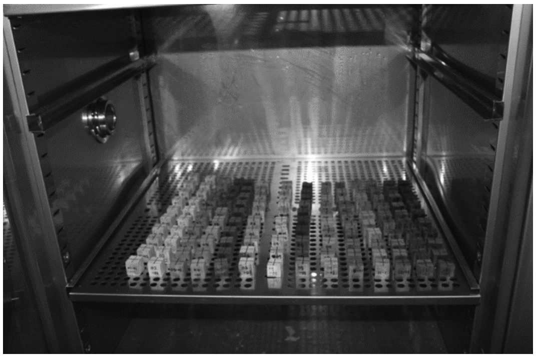

Fig. 4. Measurement of EMC of treated specimens in thermohygrostat.

2.6. Measurement of thermal conductivity

The thermal conductivity of specimens was measured with hot plate machine heated to 100℃ and copper plate shown in Fig. 5 The temperature of each interfaces were measured by using thermocouple. The thermal conductivity was calculated by putting the measured temperature into following equation (1) and equation (2) (Kang *et al.*, 2008).

$$Q = C_{copper} \times m_{copper} \times \Delta T_{copper} \quad \cdots\cdots (1)$$

where Q = heat (kcal); C = specific heat (kcal/℃); m = mass (kg); ⊿T = temperature difference (℃),

$$\frac{Q}{t} = k_{wood}\left(\frac{A_{top} \times \Delta T_{wood,top}}{L_{top}} + \frac{A_{bottom} \times \Delta T_{wood,bottom}}{L_{bottom}}\right) \quad \cdots\cdots (2)$$

where Q = heat (kcal); t = time (sec); A = area (m^2); L = length (thickness) (m); k = thermal conductivity (cal/m · sec · ℃); ⊿T = temperature difference (℃).

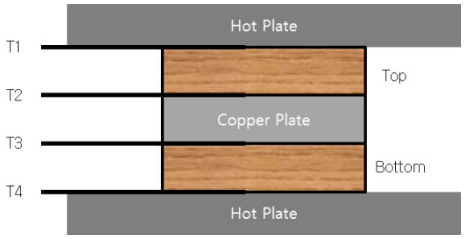

Fig. 5. Measurement of thermal conductivity of treated specimens using copper plate and hot press machine.

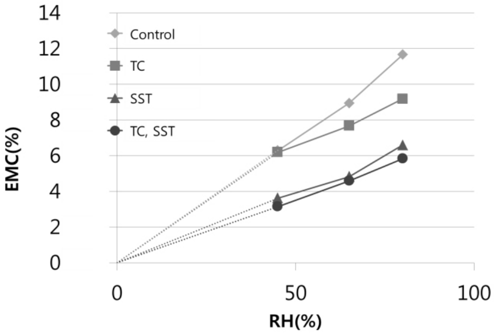

Fig. 6. EMC of treated specimens measured at 25℃ with 45%RH, 65%RH and 85% RH conditions.

3. RESULTS and DISCUSSION

3.1. Equilibrium moisture content

The Equilibrium moisture content of each type of specimen is represented in Fig. 6 Due to the increase in hydrophobicity by superheated steam treatment process, equilibrium moisture content decreased by 44% in only superheated steam treated specimens, and 49% in superheated steam treated and thermal compressed specimens. And, only thermal compressed specimens presented 14% decreased equilibrium moisture content. These results show that equilibrium moisture content reducing effect of superheated steam treatment process is very high. According to Park *et al*. (2012, 2014), superheated steam treatment process decreases hydroxyl group of wood. The decrease of equilibrium moisture content is due to the reduction of hydroxyl group.

3.2. Dimensional stability

The swelling ratio of each type of specimen is represented in Fig. 7. Because thermal compression was applied in radial direction, the specimens were tension treated in tangential direction due to the Poisson effect of compression in radial direction. Due to the thermal compression process in radial direction, the swelling ratio of tangential direction decreased by 87% on air dried and 69% on oven dried. And due to the superheated steam treatment process, the swelling ratio of tangential direction decreased by 52% on air dried and 58% on oven dried. The reduction of swelling ratio is due to decrease of equilibrium moisture content of wood. Because thermal compression process and superheated steam treatment process caused reduction of hydroxyl group, hydrophobicity of wood increased, and in result, the swelling ratio decreased. According to Kamke and Rathi (2011), Kutnar *et al*. (2008, 2009), Standfest *et al*. (2013) and Unsal *et al*. (2009, 2011), thermal compression process makes buckling of cell walls. The buckling of cell walls also affected decrease of the swelling ratio. However, the swelling ratio of radial direction increased due to the effect of spring back. According to

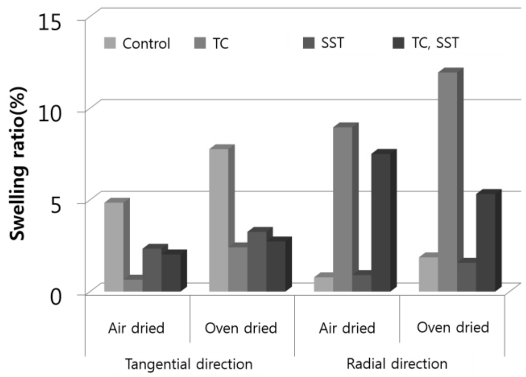

Fig. 7. Tangential and radial swelling ratio of air dried and oven dried specimens.

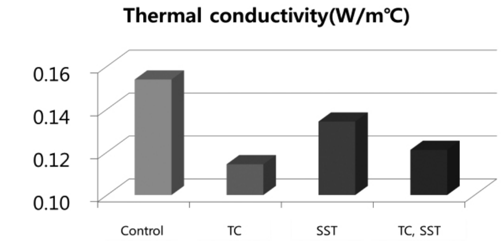

Fig. 8. Thermal conductivity of treated specimens in radial direction.

results, superheated steam treatment reduces the spring back phenomena. It seems that permanent deformation was caused by superheated steam treatment. Also, lignin which is softened by superheated steam treatment increases lignin-cellulose linkage formed during thermal compression.

3.3. Thermal conductivity

The thermal conductivities in radial direction of each type of specimens are represented in Fig. 8. The thermal conductivity of control type specimens was 0.154 W/m℃. In comparison, the thermal conductivity of the specimens that pass through only thermal compression process was 0.114 W/m℃ and the thermal conductivity of the specimens that pass through only superheated steam treatment process was 0.134 W/m℃. And the thermal conductivity of the specimens that pass through both thermal compression and superheated steam treatment was 0.121 W/m℃. These results show that the thermal conductivity of wood can be decreased by thermal compression process and superheated steam treatment process. The reduction of thermal conductivity was caused by decreased equilibrium moisture content and cell wall structure deformation of wood which was thermal treated. In steady state, the thermal conductivity of water is higher than thermal conductivity in radial direction of wood. When the specimens were superheated steam treated, equilibrium moisture content decreases and the effect of water on thermal conductivity decreases. So, superheated steam treated specimens have lower thermal conductivity than control specimens. In case of thermal compression, the ray tissue structures are destroyed by compression in radial direction. Due to destroy of ray tissue structure, the thermal conductivity in radial direction decreased dramatically.

4. CONCLUSION

To evaluate the effect of thermal compression process and superheated steam treatment process on dimensional stability and thermal performance of *Pinus koraiensis* wood, the equilibrium moisture content, swelling ratio, and thermal conductivity were measured for 4 types of specimens (control, thermal compressed specimens, superheated steam treated specimens, superheated steam treated and thermal compressed specimens).

The result of this study shows that equilibrium moisture content and thermal conductivity of *Pinus koraiensis* wood was reduced by superheated steam treatment process and thermal compression process. Also, superheated steam treatment process and thermal compression process improved and changed the dimensional stability of *Pinus koraiensis* wood. Through these results, it was verified that superheated steam treatment process and thermal compression process can control the performance of wood used as building interior decoration material.

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