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Moisture Content, Vertical Density Profile and Janka Hardness of Thermally Compressed Pine Wood Panels as a Function of Press Pressure and Temperature

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The objective of this study was to investigate the effects of press pressure and temperature on the moisture content (MC), vertical density profile (VDP), and Janka hardness of solid wood panels (SWP) made of *Pinus sylvestris*. Panels with dimensions of 250 mm (width) by 500 mm (length) by 18 mm (thickness) were compressed at temperatures of 120 and 150°C using pressures of 50 and 70 bar for 60 min in a hot press.

Thermal compression at different pressures reduced final MC, increased density, and improved Janka hardness of wood specimens when compared to control specimens. This study indicated that VDP could affect SWP properties by manipulating some production parameters of wood-composite panels and thereby expand the range of applications of SWP.

Keywords Janka hardness; Moisture content; Solid wood panels; Thermally compressing; Vertical density profile

INTRODUCTION

Thermal compressing of wood is used to improve physical and mechanical properties. Thermally compressed wood is known as staypak,[1,2] while compressed wood with phenol formaldehyde (PF) resin pretreatment is called compreg.[2,3] Further studies[4] were carried out by studying surface densification of wood. After 1980, compressed wood products using low-density and cheaper wood species were produced especially for utilization in some fast growing markets in Asia.[5–7]

Compression in wood is generally considered to be analogous to hot-pressing wood composites panels, except that it takes longer to achieve solid wood compression set without bonding effect of resins. In previous studies,[8,9] researchers have investigated the effects of hot-press closing rate, wood initial MC, and sample size on the VDP of compressed fir wood (18 mm thick) and the influences of grain orientation and surface plasticizing methods on the VDP of compressed balsam fir. In the studies on the wood composite pressing, it was reported that wood species and mixture ratios also have some effects on the VDP, performance properties of medium density fiberboard (MDF) panels,[10] and other wood composites. Bending creep behavior of wood treated with hot-pressing during cyclic moisture changes[11] and influences of oil-heat treatment process on swelling properties of densified and thermally modified spruce wood have also been studied.[12]

Density distribution through the thickness of wood composite panels such as particleboard, fiberboard, and oriented strandboard typically shows higher surface density and lower core density. Density gradient is affected by the combined influences of pressure, MC, temperature, resin curing, and other factors during pressing, which in turn affect physical and mechanical properties of the wood composites.[13–16]

Effects of production parameters such as press pressure, mat MC, and pressing time on VDP, physical, and mechanical properties of MDF have been studied. It was reported that the formation of the VDP was affected by press pressure. MOR and MOE values increased with decreasing press pressure.[16] Because of differences in material properties and hot-pressing parameters compared to wood composite panel production, densified SWP showed a different density profile. Hot-pressing treatment under high temperature and pressure can affect drying, physical, and mechanical properties of SWP such as drying speed, equilibrium moisture content (EMC), dimensional stability, durability, surface quality, modulus of rupture, modulus of elasticity, Janka hardness, surface abrasion

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strength, nail/screw withdrawal strength, and shear modulus.[9,12,17–23] The hygroscopicity of wood was influenced by temperature and resulted in a decrease in EMC.[18]

Balsam fir wood with different initial moisture contents 5.8, 11.3, and 14.6% were employed thermal compression procedure including press temperature of 180°C, hot-pressing time of one hour, and press pressure of 5–8 MPa. After hot-pressing, equilibrium moisture content was measured as 6%.[8] White spruce wood specimens, which have 15% MC, were subjected to hot-pressing with press temperature from 20 to 200°C. MC of final products was 7.3–8.9% for 150°C and 6–7.7% for 200°C. In this case, MC of hot-pressed wood specimens was decreased with increasing press temperature.[19]

In this research, the effects of hot-pressing of pine wood boards under high temperatures and press pressures on final MC, VDP, and Janka hardness were evaluated. By thermally compressing low-cost wood species (low market value), it is expected that the improvements in properties and therefore performance can assist producers in developing new markets and applications.

MATERIALS AND METHODS

Materials

Commercial Scotch pine (*Pinus sylvestris* L.) boards with dimensions of 250 mm (width) by 500 mm (length) by 18 mm (thickness) were used in this research. A total of 10 experimental boards, two for each treatment (five groups: four treatments plus one control), were investigated. Larger specimens (500 × 250 × 18 mm) were cut into 50 mm (width) by 50 mm (length) for the tests.

Thermal Compressing of Wood Boards

A laboratory hot-press with hot platen surface dimensions of 500 mm by 500 mm was used to compress the test samples (Fig. 1). Pine wood boards were compressed at temperatures of 120 and 150°C, under press pressures of 5 and 7 MPa for 60 min (Fig. 2).

Test Procedure

Before preparing the test samples, the experimental pine wood boards were conditioned at 20 ± 2°C and 65 ± 5% relative humidity for about 3 weeks. All samples with grain angles of around 0 degree (tangential) were chosen to evaluate VDPs and Janka hardness. The VDPs of the thermally compressed and untreated control specimens were determined by using an X-ray density profiler (GreCon Measurement Systems, Germany; Fig. 3). Peak density (PD) refers to the mean of the highest densities measured within each half of the profile. Core density (CD) indicates the average density of the central region of the panel thickness.[24] Janka hardness of the specimens was evaluated

FIG. 1. Laboratory hot press.

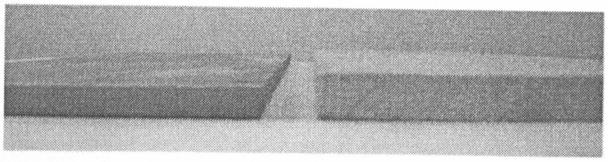

FIG. 2. Treated (left) and untreated (right) boards.

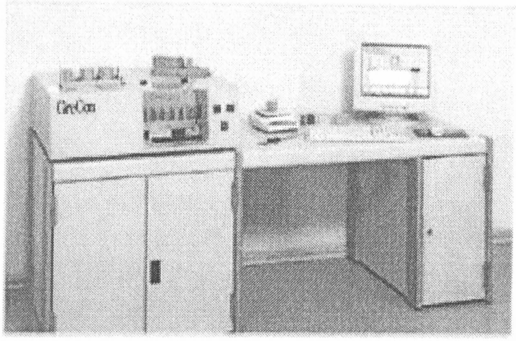

FIG. 3. Vertical density profile meter.

TABLE 1
Processing parameters of experimental groups

Group	Pressure (bar)	Temperature (°C)	Time (h)
A	50	120	1
B	50	150	1
C	70	120	1
D	70	150	1
Control	—	—	—

according to ASTM-D 1037/1999.[25] A universal test machine was used for determining Janka hardness of the specimens. Processing parameters of the experimental groups are shown in Table 1.

RESULTS AND DISCUSSION

Final Moisture Content

In the pre-experiment, the boards were dried by heating under pressure in the hot press from 60 to 13% MC. When the press temperature was 180°C, press pressure was 7 MPa for 60 min. At the end of the drying process, drying defects such as checks and warp were observed. In addition, darkening of the boards was quite noticeable. Based on the drying results, boards were predried to 19% and then hot-pressed. Average moisture content at the end of the hot pressure treatment was 8.6%. The boards subjected to predrying process were finally free of any defects and deformations.

VDP of the Boards

The untreated control boards had an average mean density (MD) of 460 kg/m^3. This result indicates that the lowest MD obtained from control board. The VDP is shown in Fig. 4.

Results for press pressure of 50 bar (120°C) indicated average PD of 560 kg/m^3 and CD of 435 kg/m^3. MD of A group was 470 kg/m^3. These values were higher than those observed for the untreated boards. The VDP is shown in Fig. 5. For boards treated under the same pressure (50 bar) but at a maximum temperature (150°C), average PD was 650 kg/m^3 and average CD was 550 kg/m^3 as shown in Fig. 6. In addition, B group's MD (Table 1) was 580 kg/m^3.

C group (Table 1) solid wood board pressed at a maximum press pressure (70 bar) and minimum temperature

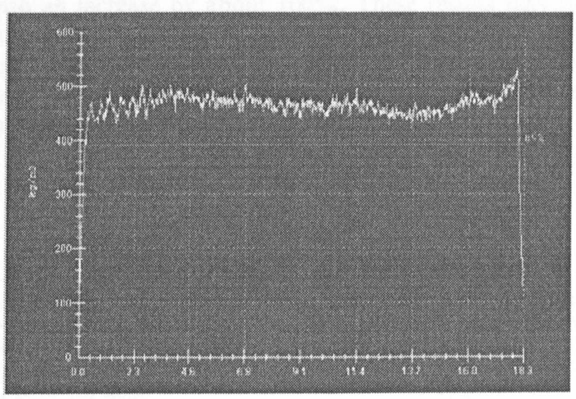

FIG. 4. VDP of control board.

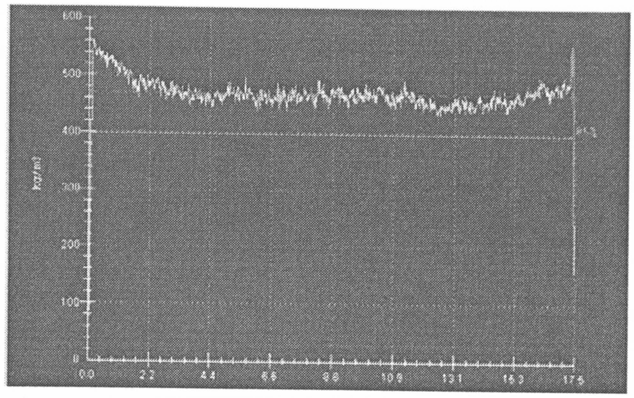

FIG. 5. VDP of A group.

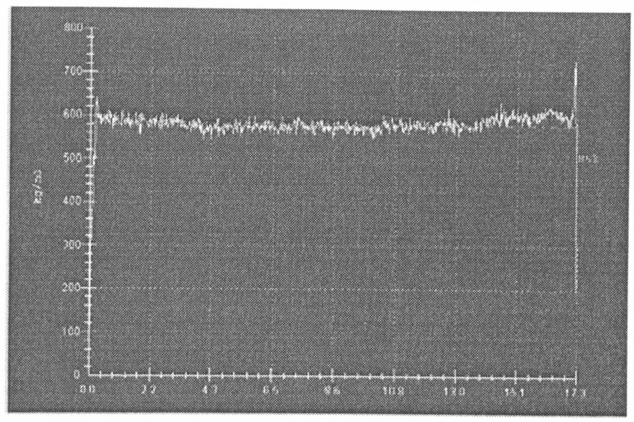

FIG. 6. VDP of B group.

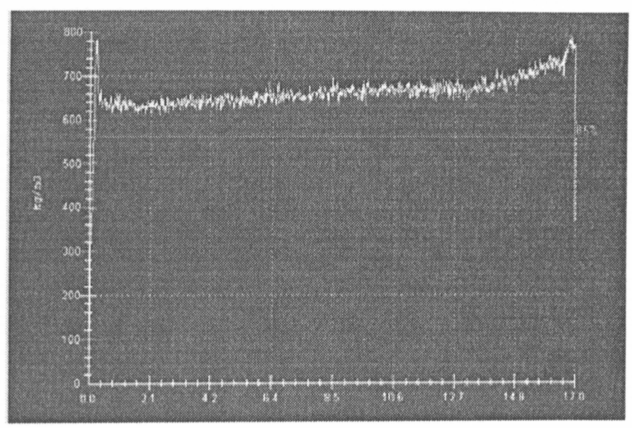

FIG. 7. VDP of C group.

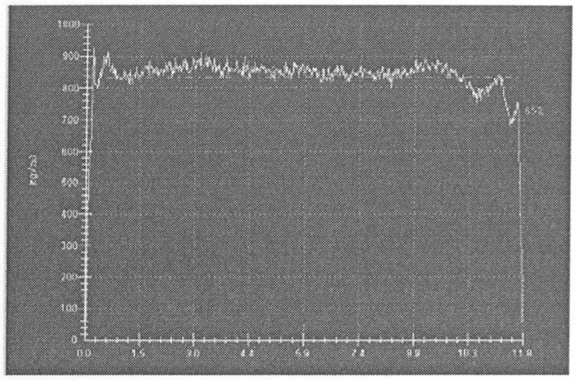

FIG. 8. VDP of D group.

(120°C) had PD of 780 kg/m^3, CD of 610 kg/m^3, and the VDP is shown in Fig. 7. The group's MD was 660 kg/m^3. D group (Table 1) solid wood board pressed at a maximum press pressure (70 bar) and maximum temperature (150°C) had the highest PD and CD, which were 900 kg/m^3 and 800 kg/m^3, respectively, and the VDP is shown in Fig. 8. The group's MD was calculated as 830 kg/m^3.

Janka Hardness

Janka hardness was evaluated for control and all treatment groups as shown in Table 2 The lowest Janka hardness values (193.29 kgf/cm^2) were observed in the untreated board group. The first treatment group (Group A) had a Janka hardness value of 230.11 kgf/cm^2, which was higher than that in the control group. As pressing temperature increased to 150°C, hardness values increased. When pressure increased from 50 to 70 bar, the hardness value was also improved. The board group produced at the maximum press pressure and pressing temperature level (Group D) had the highest hardness value (382.30 kgf/cm^2) with an increase by about 100%. These results may have occurred due to the increase in density (from 460 kg/m^3 to 830 kg/m^3) of the specimens with increasing press pressure and temperature. Janka hardness is approximately proportional to the density of the wood.[26]

TABLE 2
Janka hardness values of wood boards

Treatment	Janka hardness (kgf/cm^2)
Control	193.29
50 bar + 120°C	230.11
50 bar + 150°C	269.96
70 bar + 120°C	274.93
70 bar + 150°C	382.30

CONCLUSIONS

In conventional drying methods, total drying time is in general 24 h for 20-mm-thick pine lumber when the MC is decreased from 19 to 8.6%. However, in the process we used, drying time decreased to 1 h using high pressure and temperature. In this process, the board thickness decreased to 11 mm by using the maximum pressure. Although the thickness reduction was approximately 45%, no drying defects occurred.

It was concluded that the VDP in the solid wood panels was closely related with the press pressure and pressing temperature. Increasing pressure and temperature resulted in increased PD and MD values, which are defining factors VDP.

This research indicated that as increased press pressure and temperature as increased Janka hardness value in solid wood boards and when the pressing parameters used maximum levels hardness value was the highest. Janka hardness values of the SWPs were positively affected by densification on the surface layers. The group D had the highest PD value showing the greatest hardness.

Finally, with some additional findings such as strength, surface roughness, color, and shrinkage-swelling behavior of this type of wood material from preferably cheaper tree species, it can be defined using areas of this wood product that have been dried and hardened in hot press.

Future studies will focus the effect of pressing parameters on the surface roughness and water absorption behavior of solid wood boards.

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