PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD LAMINATED WITH THERMALLY COMPRESSED VENEER

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The aim of this study was to investigate the effects of thermally compressed veneer laminating on some of the physical and mechanical properties of particleboard. Oriental beech (*Fagus orientalis* Lipsky) veneers were compressed under various press conditions. Commercially produced particleboard samples were laminated with such compressed veneer sheets. The density, 2-h and 24-h water absorption (WA) and thickness swelling (TS), bending strength (MOR), and modulus of elasticity (MOE) in the parallel and perpendicular directions to grain orientation were measured. The results showed that all of the particleboards laminated with compressed veneer had higher MOR and MOE values compared to unlaminated particleboard and particleboard laminated with non-compressed veneer. In the sandwiched panels, particleboards laminated with veneer sheets and compressed at a pressure of 4 MPa and a temperature of 150 ^{o}C had the highest MOR and MOE values. The MOR and MOE values decreased with increasing temperatures higher than 150 ^{o}C. The TS value for 2-h and 24-h immersion times decreased with increasing press temperature. The findings of this work could provide some insight in producing sandwich-type panels with improved properties. It appears that compressed veneer using different press temperatures and pressures could be considered as an alternative way of developing sandwich-type products with satisfactory structural properties.

Keywords: Particleboard; Lamination; Thermal compression; Thickness swelling; Water absorption; Modulus of elasticity; Bending strength

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INTRODUCTION

Thermal compression processes have been used for many years in different applications (Bekhta et al. 2009; Unsal and Candan 2008; Candan et al. 2010). It is well known that compression of wood can have a positive effect on the overall strength properties of wood products; this is important with respect to structural applications in which higher mechanical properties are desired (Wood Handbook 1999). A prior study attempted to evaluate the strength properties of plywood produced from non-compressed and compressed veneer (Bekhta et al. 2009). These authors stated that all the measured strength properties increased with increasing compression degree from 5% to 15%. Increases in compression degree caused the bending strength to decrease. In another study, compressing Japanese cedar (*Cyrotomeria japonica*) samples was shown to have an influence on strength characteristics (Adachi et al. 2009). Kamke (2006) investigated the bending properties of LVL produced from compressed and non-compressed veneers of the radiata pine. He found that the LVL produced with compressed veneer had higher modulus of elasticity (MOE) value compared to LVL produced with non-compressed veneer. Kutnar et al. (2008) reported the respective modulus of rupture (MOR) and MOE values of 3-layered composites to be 64.0 MPa and 8.2 GPa for uncompressed composites and 87.0 MPa and 12.1 GPa for compressed composites.

In addition to the enhancement of mechanical properties of wood products, surface quality can also be improved as a result of compression processes. Densifying wood causes compression of any irregularities on a substrate, resulting in a smoother surface. Faust and Rice (1986) determined that the use of rougher veneer in LVL manufacture reduced the bending strength by an average of 33% compared to LVL made from smoother veneer sheets. In particular, veneer sheets with a smoother surface used in plywood and laminated veneer lumber (LVL) reduce the consumption of adhesive pickup so that the overall production cost is reduced.

Particleboard is one of the most widely used interior wood composite substrates and it is commonly used for cabinetry and furniture manufacture. Solid veneer is also used as a prime overlay for particleboard in manufacturing expensive furniture. Beech wood is widely used to laminate substrate for wood based panels in many European countries. Compressed veneer laminated particleboards can be used for various structural applications. The aim of this study was to evaluated MOR, MOE, thickness swelling (TS), and water absorption (WA) of experimentally manufactured panels employing such structures.

EXPERIMENTAL

Oriental beech (*Fagus orientalis* Lipsky) veneer sheets with a thickness of 1.5 mm produced by a rotary peeling technique and commercially manufactured particleboard panels with a thickness of 18 mm were cut into 500 mm by 500 mm squares. The veneers having 12% moisture and 0.630 g/cm^3 density were compressed using a laboratory type hot-press. A total of 4 veneer samples were compressed for each trial. The thickness of each veneer was measured at the four corners with an accuracy of 0.01 mm before and after compression to determine the reduction of thickness as function of pressure and temperature. Particleboards were laminated with control (non-compressed) and compressed veneer sheets using a urea formaldehyde adhesive at 160 g/m^2. Ammonium chloride (NH_4Cl) was also added to the adhesive mix at a level of 1% based on the dry weight of the wood. Sandwiched panels with the two sheets of veneer were compressed in a computer-controlled hot press. Specimens were conditioned in a climate chamber at a temperature of 20 ^{o}C and a relative humidity of 65% for three weeks before tests were carried out.

Density tests (based on the EN 323), water absorption, and thickness swelling tests (based on the EN 317), and bending tests (based on the EN 310 on a Universal Testing Machine equipped with a load cell having capacity of 1,000 kg) were carried out. Laminated and unlaminated bending test samples are shown in Fig. 1.

Fig. 1. Laminated and non-laminated bending test samples

A total of 20 samples were used for each test. Experimental design, veneer compression, and sandwich panel production parameters are shown in Table 1. The obtained data were statistically analyzed using the analysis of variance (ANOVA) and Duncan's mean separation tests.

Table 1. Experimental Design, Veneer Compression, and Sandwich Panel Production Parameters

Panel Type	Process	Veneer Compression			Sandwiched Panels			No of Test Samples	
		Pressure (MPa)	Temp. (^oC)	Time (min.)	Pressure (MPa)	Temp. (^oC)	Time (min)	MOE MOR	TS WA
A	PB Control	-	-	-	-	-	-	20	20
B	Laminated	-	-	-	2.6	110	4	20	20
C	Laminated	4	150	8				20	20
D	Laminated	6	150	8				20	20
E	Laminated	4	180	8				20	20
F	Laminated	6	180	8				20	20
G	Laminated	4	200	8				20	20
H	Laminated	6	200	8				20	20

RESULTS AND DISCUSSION

The amounts of reduction in the thickness of the veneers after pressing are shown in Table 2. Group H had the greatest reduction, while group C had the lowest. The thickness reduction increased with an increasing press pressure and temperature. Similar findings have been observed by several researchers (Unsal et al. 2009, 2011; Welzbacher et al. 2008; Tabarsa and Chui 1997; Rautkari et al. 2010). Unsal et al. (2009) found that a decrease in thickness of pinewood compressed at 150 ºC was 4.7% at a press pressure of 5 MPa and 38.8% at 7 MPa. Rautkari et al. (2010) found that the compression ratio (decreasing of thickness) increased with an increasing press pressure in beech and spruce woods. Compression ratios of spruce wood in a tangential direction were 2.7% under low pressure and 7.1% under high pressure. Welzbacher et al. (2008) and Tabarsa and Chui (1997) found that the thickness of wood samples decreased with an increasing densification temperature. This phenomenon can be explained as being a consequence of softening of the solid wood with the increasing temperature.

Table 2. Decreasing in Thickness of Veneers

Type of Board	Decreasing of Thickness (%)
A	Unlaminated
B	Not compressed
C	13.31 (1.52)
D	22.78 (1.02
E	15.36 (1.00)
F	28.19 (1.52)
G	22.10 (0.97)
H	40.43 (1.60)

The results of the ANOVA and Duncan’s mean separation tests for density, WA, and TS of the panels are given in Table 3. The density of the sandwiched panels was higher than that of the unlaminated particleboard panels. Except for groups G and H, panels laminated with non-compressed veneers had lower densities compared to panels laminated with compressed veneers. Lower densities in group G and H can be due to mass loss. Increasing temperatures above 150 ºC gradually decrease the physical and chemical properties of wood (Syrjanen and Oy 2001; Mitchell 1988).

Table 3. Density, Thickness Swelling, and Water Absorption Values of Boards

Board Type	Density of Board (g/cm^3)	2-h		24-h	
		WA (%)	TS (%)	WA (%)	TS (%)
A	0.619 (0.006) a	64.78 (5.91) a	10.12 (0.64) a	77.08 (1.50) a	13.90 (0.61) a
B	0.657 (0.007) b	58.61 (1.57) b	10.97 (0.62) b	71.41 (1.09) b	14.73 (0.54) b
C	0.667 (0.007) cd	53.22 (1.24) ce	11.89 (0.57) c	74.29 (0.63) c	15.91 (0.53) c
D	0.670 (0.011) d	56.65 (1.67) d	12.13 (0.53) c	74.33 (1.49) c	15.79 (0.62) c
E	0.659 (0.008) b	56.36 (1.75) d	10.15 (0.42) a	74.73 (2.46) c	14.65 (0.48) b
F	0.664 (0.009) c	53.98 (1.52) e	10.56 (0.56) d	73.00 (1.84) d	14.50 (0.62) b
G	0.650 (0.006) e	51.75 (1.01) c	9.31 (0.53) e	74.93 (0.73) c	13.57 (0.64) a
H	0.655 (0.005) be	48.93 (1.54) f	8.62 (0.30) f	67.72 (2.69) e	12.53 (0.47) d

Values in parentheses are standard deviations.
[a,b,c,d,e,f] Values having the same letter are not significantly different (Duncan test).

Panel density increased with increasing press pressure and decreased with increasing press temperature. This negative influence of temperature (Yildiz 2002; Unsal et al. 2003; Korkut et al. 2008) and positive influence of press pressure (Unsal et al. 2009; 2011) on the density of wood have been observed by several researchers.

Sandwiched panels with 2-h and 24-h immersion times had lower WA values than the unlaminated control group. For the sandwiched panels, particleboards laminated with compressed veneer had a lower WA value for the 2-h immersion time and a higher WA value for the 24-h immersion time compared to particleboard laminated with non-compressed veneer. For both the 2-h and 24-h immersion times, the WA value decreased with an increasing press pressure at 180 ºC and 200 ºC and increased with press pressure at 150 ºC. For 24-h immersion time, increase of the WA value with increasing pressure at 150 ºC was not statistically significant. Decreases in the WA value at 180 ºC and 200 ºC can be related to the densification of the surface and decreasing porosity of the veneers; when the material is immersed, water fills void volume. This finding is similar to the results of previous studies carried out related to wood composite panels (Winandy and Krzysik 2007; Ayrilmis et al. 2009; Vernois 2007). Vernois (2007) reported that the WA of wood increased with increasing porosity, and when the wood was soaked in water it could absorb more than 20% water.

For 2-h and 24-h immersion times, except for groups G and H, the sandwiched panels had higher TS values compared to the unlaminated particleboard. The compressed veneer laminated panels at temperatures of 180 ^{o}C and 200 ^{o}C had lower TS values compared to panels laminated with veneer sheets without any compression applied. In the compressed panels, the TS values for 2-h and 24-h immersion times decreased with an increase in press temperature at both press pressures. Similar results were observed by Unsal et al. (2011). They concluded that improvement in TS with an increasing press temperature is explained by the changes in chemical composition of the wood.

The results of the ANOVA and Duncan's mean separation tests for the MOR and MOE of the panels are illustrated in Table 4. Parallel to the grain orientation, the non-laminated particleboard had a lower MOR value compared to the laminated particleboards.

Table 4. Modulus of Rupture and Modulus of Elasticity Values of the Samples Parallel and Perpendicular to Grain Orientations

Panel Type	Modulus of Rupture (MOR)-MPa		Modulus of Elasticity (MOE) GPa	
	//	⊥	//	⊥
A	11.3 (0.3) a	11.3 (0.3) a	1.897 (0.06) a	1.897 (0.06) a
B	47.3 (1.6) b	14.3 (1.1) bc	4.869 (0.11) b	1.982 (0.05) b
C	51.8 (1.9) c	11.7 (1.0) a	5.641 (0.15) c	1.593 (0.07) c
D	51.2 (2.3) c	13.4 (0.9) c	5.574 (0.32) c	2.076 (0.07) d
E	50.2 (3.0) c	8.6 (1.6) d	5.490 (0.23) c	1.719 (0.03) e
F	48.0 (1.4) b	12.2 (1.1) a	5.154 (0.11) d	2.046 (0.04) d
G	48.2 (1.4) b	8.5 (1.2) d	5.556 (0.09) c	1.714 (0.04) e
H	47.9 (1.1) b	14.6 (0.4) b	5.150 (0.08) d	2.189 (0.08) f

Values in parentheses are standard deviations
[a,b,c,d,e,f] Values having the same letter are not significantly different (Duncan test).

Previous studies showed that coating particleboard surfaces improved the mechanical properties of the panels (Nemli 2003; Nemli et al. 2005). The highest MOR value was found for panel type C laminated with veneer sheets compressed at a pressure of 4 MPa and temperature of 150 ^{o}C. Compressed veneer-laminated particleboards had higher MOR values than particleboards laminated with non-compressed veneer. The MOR values decreased with an increase in temperature higher than 150 ^{o}C. Jämsä and Viitaniemi (2001) stated that strength properties of wood start to weaken at temperatures over 150 ºC due to the wood becoming more brittle at this high temperature. The MOR values decreased with increasing press pressure due to the breaking of cell walls. Unbroken cell walls are a major factor for acceptable properties of the viscoelastic thermal compressed wood (Kutnar et al. 2009).

MOE values parallel to grain orientation of all sandwiched panels laminated with compressed veneers were higher than those of non-laminated particleboard and particleboard laminated with non-compressed veneer. Plywood made from compressed birch and alder wood showed higher MOE values than unpressed samples (Bekhta et al. 2009). The particleboards laminated with compressed veneer at a pressure of 4 MPa and a temperature of 150 ^{o}C had the highest MOE value of 5.641 GPa while the lowest MOE (1.897 GPa) was observed for the non-laminated particleboard. Group C had 197.4% and 15.9% higher MOE values than non-laminated particleboard and particleboard laminated with non-compressed veneer, respectively. The average MOE values of the sandwiched panels decreased as the press pressure increased. The influence of press pressure was more pronounced at temperatures of 180 ºC and 200 ºC. MOE decreased with increasing temperature at more than 150 ^{o}C. Temperature showed no significant effect at a pressure of 4 MPa but had a significant effect at a pressure of 6 MPa.

The MOR and MOE of panels laminated with non-compressed veneer were respectively 318% and 157% higher than unlaminated particleboard. Panels laminated with compressed veneer under a pressure of 4 MPa at 150 ^{o}C had 9.6% and 15.9% higher MOR and MOE values than panels laminated with non-compressed veneer. Similar improvements in the MOR and MOE due to thermal compression have been previously observed by several researchers (Kutnar et al. 2008; Kamke 2006). Kamke (2006) observed an 81% higher MOE of LVL produced with compressed veneers compared with uncompressed veneer. Kutnar et al. (2008) reported the respective MOR and MOE values of 3-layered composites to be 64.0 MPa and 8.2 GPa for uncompressed composites and 87.0 MPa and 12.1 GPa for compressed composites. Testing perpendicular to the grain orientation of veneer sheets showed a significantly lower MOE and MOR than those tested parallel to the grain orientation. This result is expected due to the fact that the bending strength of wood along the grain orientation is 20 to 25 times higher than across the grain orientation (Wood Handbook 1999).

CONCLUSIONS

In this work, some of the mechanical and physical properties of particleboard panels laminated with thermally compressed veneer sheets were investigated. The density of the sandwiched panels increased with increasing press pressure and decreased with increasing press temperature. All the particleboards laminated with compressed veneer had a higher modulus of rupture and modulus of elasticity compared with unlaminated particleboards and particleboards laminated with non-compressed veneer. For the sandwiched panels, particleboards laminated with veneer sheets and compressed under a pressure of 4 MPa and a temperature of 150 ^{o}C had the highest MOR and MOE values. The MOR and MOE decreased with increasing temperature at temperatures higher than 150 ^{o}C. The thickness swellings for 2-h and 24-h immersion times decreased with increasing press temperature. It appears that compressed veneer using different press temperatures and pressures could be considered as an alternative way of developing sandwich-type products with satisfactory structural properties.

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