

SHORT NOTE**EFFECT OF HOT-PRESSING PARAMETERS ON
SELECTED PROPERTIES OF FLAKEBOARD**

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ABSTRACT

Physical and mechanical properties of flakeboards produced from radiata pine flakes under different hot-pressing conditions were investigated in this study. The flakeboard mats were hot-pressed at 2.8 MPa with two different temperatures (170 and 190°C) and three different durations (7, 10, and 15 min). At the 170°C of hot-pressing temperature, the highest bending strength was found in the flakeboards pressed for 7 min while the highest modulus of elasticity was found in the flakeboards pressed for 15 min. The highest internal bond strength was found to be 0.13 MPa for the flakeboards pressed at 190°C for 15 min. The thickness swelling and water absorption of flakeboards pressed at 190°C were lower than those of the flakeboards pressed at 170°C. The control of hot press temperature and duration appears an effective method to enhance serviceability of flakeboard.

KEYWORDS: Flakeboard, structural board; hot-pressing; wood; water resistance, mechanical properties; building material.

INTRODUCTION

Hot pressing plays an important role in over all performance of structural wood-based panels such as flakeboard, particleboard, and plywood. It provides thermal energy and mechanical force of compression to consolidate the mat (Elaieb et al. 2015). This process is complex and involves

heat and mass transfer inside the mat of the panels. The rate of temperature increase has a significant effect on the rate of adhesive cure. This is a critical factor not only for total press time but also in the development of the vertical density gradient (Rofii et al. 2014). Vertical density profile significantly affects the physical and mechanical properties of wood-based panels.

The main purpose for the thermal-treatment between approximately 150 and 220°C is to achieve new material properties such as increased biological durability and weather resistance, enhanced dimensional stability, reduced extractive contents, increased heat insulating capacity, lower equilibrium moisture content, which might prolong the service life of wood products (Hill 2006, Dos Santos et al. 2014, Elaieb et al. 2015). Wood is a complex polymeric material constituted mainly of cellulose, hemicelluloses and lignin, with a minor proportion of extractives. The exposure of wood to elevated temperatures causes the thermal degradation of its structure, i.e., changes in composition, often accompanied by loss of thermal mass, and thus the properties of wood are somewhat modified (Borrega and Kärenlampi 2008, Ayilimis 2010).

Somewhat is manufactured by applying relatively small amounts of adhesive to wood flakes, forming these constituents into a loose mat structure, and then consolidating the mat under heat and pressure to form an integrated board. Flakeboard generally has poorer dimensional stability than plywood or solidwood. This precludes the use of flakeboards where they are exposed to high relative moisture content (Youngquist et al. 1986). The objective of this research was to determine the effect hot-pressing conditions (temperature and duration) on the selected physical and mechanical properties of flakeboard. Our opinion is that enhanced serviceability of the flakeboard produced with urea-formaldehyde (UF) adhesive could be achieved in the hot-press through extended cycles to create controlled thermal-treatment process.

MATERIAL AND METHODS

Wood flakes and adhesive

The average length, width, and thickness of Radiata pine (*Pinus radiata* D. Don) flakes used in the experiments were 75-100, 8.5-10, and 0.4 mm, respectively. The moisture content of the flakes was 4-5 % based on the oven-dry weight of the flake.

A commercial liquid UF adhesive (E1 class) with 61.1 wt % solid content was supplied from a wood-based panel manufacturer in South Korea. The viscosity and acidity of the adhesive were 191 cPs and 7.8, respectively. Ammoniumchloride (NH₄Cl) solution with 20 % solid content was used as hardener for the UF adhesive. No wax or other hydrophobic substance was used in the flakeboard manufacture.

Production of flakeboards

The flakes were sprayed with a 61.1 wt % aqueous solution of UF adhesive to give a 10 % adhesive content based on the oven-dry weight of wood in the blender. As a hardener, 1 % of ammoniumchloride solution based on the adhesive solid content was added. The flakes were hand-formed in randomly oriented mats with dimensions of 290 x 290 x 10 mm. The flakeboard mats were hot-pressed at 2.8 MPa pressure with two different temperatures (170 and 190°C) and three different durations (7, 10, and 15 min). A total of 18 flakeboards, 3 flakeboards for 6 series of flakeboards (from type A to type F), were produced under laboratory conditions (Fig. 1). Prior to testing, the specimens were conditioned to constant mass at a temperature of 20°C and a relative humidity of 65 %.



Fig. 1: Production line of flakeboards at the laboratory.

Determination of selected physical and mechanical properties

Physical and mechanical properties of the flakeboards were determined according to Korean Standard (KS) F 3104 (2002). One day thickness swelling (TS) and water absorption (WA) tests were performed on the ten specimens with dimensions of 50 x 50 x 10 mm. The moisture content and density tests were performed on the ten specimens with dimensions of 100 x 100 x 10 mm. A total of ten specimens with dimensions of 200 x 50 x 10 mm (5 // and 5 \perp to the flakeboard surface) were tested for each type of flakeboard to determine the bending strength (MOR) and modulus of elasticity (MOE). Internal bond (IB) tests were performed on the ten specimens with dimensions of 50 x 50 x 10 mm.

Statistical analysis

An analysis of variance, ANOVA, was conducted ($p < 0.05$) to evaluate the effect of the hot-pressing temperature and duration on the selected physical and mechanical properties of the flakeboard. Significant differences among the average values of the flakeboards were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

The results of physical and mechanical properties of the flakeboards are presented in Tab. 1. A slight increment in the density of the flakeboards was determined. The moisture content of the flakeboards conditioned at 20°C and a relative humidity of 65 % decreased from 5.57 to 3.94 % with increasing severity of the hot-pressing conditions. This reduction is an advantageous and it means that the flakeboard is more stable in variable environmental conditions. The decrease in the moisture content of the flakeboard produced at higher temperature and longer duration in the hot press could happen because of the hemicelluloses, which are the most heat sensitive polymers of wood components are hydrolysed during heat the treatment (Gündüz et al. 2009). The TS and WA of the specimens significantly decreased with increasing pressing temperature and duration. For example, the average TS and WA values of the flakeboards decreased from 90.1 to 64.2 % and 77.8 to 59.3 %, respectively, as the hot-pressing duration increased from 7 to 15 min at 170°C.

The TS and WA values significantly decreased as the hot-pressing temperature increased from 170 to 190°C (Tab. 1). This was mainly attributed to the destruction of hemicelluloses, which reduced the hygroscopic sites of wood. As hemicelluloses are very hydrophilic compounds, their

alteration could affect the dimensional stability of wood (Korkut and Budakci 2010). Exposure duration and temperature are two important factors affecting hemicelluloses degradation. Cumulative thermal exposure in the hot-press alters the hemicelluloses structure because arabinan and galactan, each a side-chain component of the hemicelluloses, tend to be more degraded as both temperature and duration increase (Winandy and Krzysik 2007). These changes in the chemistry of hemicelluloses result in the reduction of the hygroscopicity of the flakes.

Tab. 1: Selected physical and mechanical properties of flakeboards produced at different hot-pressing conditions.

Board code	Hot-pressing conditions		Physical properties				Mechanical properties		
	Temperature (°C)	Duration (min)	Density (g·cm ⁻³)	MC (%)	TS (%)	WA (%)	MOR (N·mm ⁻²)	MOE (N·mm ⁻²)	IB (N·mm ⁻²)
A	170	7	0.87 a (0.10)	5.57 a (0.47)	90.1 a (6.9)	77.8 a (3.4)	36.0 a (9.3)	3228 a (345)	0.12 a (0.04)
B	170	10	0.89 ab (0.07)	5.53 a (0.20)	75.7 b (9.8)	64.4 b (4.7)	35.1 a (11.4)	2685 b (295)	0.12 a (0.06)
C	170	15	0.90 ab (0.06)	4.95 a (0.17)	64.2 c (7.9)	59.3 c (4.1)	31.9 b (11.3)	3929 c (310)	0.11 a (0.03)
D	190	7	0.90 ab (0.04)	5.02 a (0.23)	94.6 d (7.1)	75.2 a (7.1)	30.5 bc (10.5)	3197 a (225)	0.10 a (0.02)
E	190	10	0.94 b (0.04)	4.23 b (0.26)	68.6 e (6.7)	61.1 c (7.7)	30.0 c (10.5)	3587 d (349)	0.11 a (0.05)
F	190	15	0.93 b (0.07)	3.94 b (0.25)	52.9 f (5.4)	59.7 c (8.6)	31.0 bc (5.4)	1758 e(176)	0.13 a (0.04)

MC: moisture content. TS: thickness swelling. WA: water absorption. MOR: bending strength. MOE: modulus of elasticity. IB: internal bond strength. The values in the parentheses are standard deviations.

Groups with same letters in column indicate that there is no statistical difference ($p < 0.05$) between the specimens according to Duncan's multiply range test.

The core layer density of wood-based panels increases with increasing pressing temperature and duration (Candan and Akbulut 2015). This results in the lower internal void volume might obstruct the migration of moisture and diminish the convective effect. The improvement in the water absorption of the flakeboards pressed at elevated temperatures and durations could be due to the decreased porosity in the board. In addition, the elevated temperatures and duration decrease the internal stress and spring back in the core layer of the flakeboard. The internal stress is a significant factor on the thickness swelling of the wood-based panels. The lower thickness swelling of the flakeboards can also explained by the decreased internal stress.

The MOR of the specimens decreased with increasing hot-pressing durations at 170°C stress in the board. There was no significant difference between the MOR values of flakeboards pressed for 7 and 10 min. As the hot-pressing duration was increased to 15 min, the MOR significantly decreased (35.1 to 31.9 MPa). However, the MOR was slightly increased by elevated hot-pressing durations at 190°C. In general, the MOR and MOE of the specimens pressed at 170°C for 7-15 min were better than those of the specimens 190°C for 7-15 min (Tab. 1). The significant differences ($p < 0.05$) among the flakeboards pressed at different hot-pressing conditions for the mechanical properties are presented in Tab. 1 as letters. The highest MOE with a value of 3929 MPa was found in the specimens pressed at 170°C for 15 min.

At 190°C, the highest MOE with a value of 3587 MPa was observed for the specimens pressed for 10 min. As for the MOR, the highest MOR was found in the specimens pressed at 170°C for 7 min. As the hot-pressing duration was increased to 190°C, the highest MOR with a value of 31 MPa was found in the specimens pressed at 190°C for 15 min. It is clear that appreciable loss in all mechanical properties eventually occurs from any extended hot-pressing scenario, with modulus of elasticity being the most affected property.

The primary modulus reason for the lower bending properties of the wood-based panels pressed at elevated temperatures and durations is the degradation of hemicelluloses, which are less stable to heat than cellulose and lignin (Winandy and Krzysik 2007). The chemical composition of some of the constituents of wood used to manufacture flakeboard is considerably altered by elevated temperatures and extended thermal durations. Cumulative thermal exposure in the hot-press alters the hemicellulose structure, especially arabinan and galactan. These changes in hemicellulose leads to additional loss in mechanical properties (Winandy and Krzysik 2007).

The IB strength of the specimens improved with increasing treatment temperature as compared to the control specimens. Nemli (2002) reported that the increase in the hot-pressing temperature and duration was significantly able to improve the IB of the particleboard. The IB strength of the flakeboard specimens slightly increased as the hot pressing duration increased from 7 to 15 min at 190°C. However, this was not observed for the specimens pressed at 170°C. The results of the IB strength showed that the best bonding between the flakes was found in the specimens pressed at 190°C. This could be related to the decrement in the weight loss of the flakes and thereby increment in the compression ratio in the flakeboard mat during the hot pressing. A higher compaction ratio could increase the magnitude of the bonding area between the flakes and subsequently enhanced bond strength (Song and Ellis 1997). The amount of the heat transferred to the core layer of wood-based panels increases at the elevated hot pressing temperature and duration. Consequently, the flakes become more soft and compact due to the increase in the heat transfer rate, and subsequently, become the IB strength increases (Candan and Akbulut 2015).

The gas pressure caused by the moisture inside mat during hot pressing is also a significant factor on the mechanical properties of the wood-based panels. The gas pressure in the board is reduced by increased pressing time (Kamke 2004), which can affect bond performance between the flakes. Temperature facilitates the liquid accessed in wood, followed by acceleration diffusion of adhesive molecule in wood lumen. At low temperature, adhesive diffusion in wood becomes lower that it causes the decrease in mechanical interlocking (Iswanto et al. 2014).

CONCLUSIONS

The results of the present study showed that cumulative thermal exposure in the hot-press altered the hemicellulose structure of the flakes. This was because the TS and WA of the flakeboard specimens significantly decreased with hot-pressing temperature and duration. The changes in hemicellulose seem to reduce the hygroscopicity of the wood. In general, the bending properties of flakeboards decreased with increasing severity of the hot-pressing conditions. This was mainly due to the thermal degradation of the hemicellulose. However, the results showed that the water resistance and IB strength of the flakeboard were improved by the elevated temperatures and durations in the hot press while the bending properties decreased. According to the obtained results, it can be said that the optimum pressing conditions for the flakeboards were 190°C for 10 min. The control of hot-press temperature and duration appears an effective method to enhance serviceability of flakeboard.

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