High Temp. Mater. Proc., Vol. **30** (2011), pp. 31–37 DOI 10.1515/HTMP.2011.004

Effects of Density Profile and Hot Press Diagram on the Some Technological Properties of Particleboard Composite

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Abstract. In this study, the effects of density profile and hot press diagram on the technological properties of particleboard were analyzed. Physical and mechanical properties of particleboards were evaluated. Density profile was found a main parameter affecting quality properties of particleboard. While increasing entrance pressure improved the modulus of rupture and elasticity, and thickness swelling of the panels, increasing exit pressure was found to be effective on the bonding strength and thickness swelling. Exit pressure did not statistically affect the bending properties. Decreasing feeding speed of the hot press significantly improved all of the properties. While high surface density improved the modulus of rupture and elasticity, and thickness swelling, high core density caused better internal bond strength and thickness swelling. Entrance pressure was found to be effective on the surface density of particleboard. Exit pressure did not statistically affect the surface density, however, increased the core density.

Keywords. Particleboard, hot press diagram, mechanical properties, density profile, physical properties.

1 Introduction

Particleboard is an engineered wood composite manufactured from particles, such as wood chips, sawmill shavings, or even saw dust, and a synthetic resin or other suitable binder. It is ideal for applications such as wardrobes, millwork, construction, interior decoration, sliding doors, floor underlayment, pool tables, construction, cabinets, shelving, toys, cupboards, and stair treads, joinery, furniture, and wall linings. Particleboard is the most commonly used substrate for applying laminates in bench top applications, and provides the most economical option for general indoor building requirements [1].

In recent years, particleboard panels have been increasingly substituted to solid wood lumber. Particleboard is cheaper and denser than solid wood, but is not very strong or resistant to moisture. It is substituted for them when appearance and strength are less important than cost. However, particleboard can be made more attractive by painting or the use of wood veneers or decorative papers that are glued onto surfaces that will be visible. Particleboard's selling points compared to solid timber are its price, its availability in large flat sheets and its ability to be decorated with melamine based overlays. It has several other advantages, one of which is its stability. Solid wood is prone to warping and splitting with changes in humidity, whereas particleboard is not. This stability enables new design possibilities, without having to take into account seasonal variations [2].

The physical and mechanical properties of particleboard depend on how it is manufactured. Therefore, many researchers have tried to improve the physical and mechanical properties of particleboard composite by studying various processing variables, the most of them being density [3], surface coatings [4], moisture content and temperature of particleboard [5], shelling ratio [6], wood species [7], bark usage [8], wood extractives [9], adhesive type and amount [10], moisture content of raw materials [11], particle dimensions [12], dust usage [13], and additives [14].

The formation of density profile during the manufacturing process of particleboard is dependent on interaction among the moisture, pressure, and heat in the mat during hot pressing [15,16]. The density profile resembles the lowest density in the core of the board, and the peak density near the board surfaces [17]. Kelly [18] stated that vertical density profile resulted in higher bending strength and lower internal bond. According to Kawai and Sasaki [19], a step density profile in particleboard causes shear failure to occur before the specimen in bending. In earlier researches, conclusions were drawn regarding the general qualitative effects of mat moisture content, press closing speed, distribution, configuration and compressibility on the density profile in particleboards [20–23]. This study investigates

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Received: July 14, 2010. Accepted: July 23, 2010.

the effects of density profile and hot press diagram (entrance and exit pressures, and feeding speed of the hot press) on the physical (thickness swelling and water absorption) and mechanical properties (modulus of rupture, modulus of elasticity and internal bond strength) of particleboard composite.

2 Materials and Methods

2.1 Materials

Pine (*Pinus sylvestries* L.), beech (*Fagus orientealis* Lipsky.) and poplar (*Populus tremula* L.) woods were used in the production of particleboard panels. A commercial E_1 grade urea formaldehyde resin (65% solid content) was used as binder at a resin content of 9% and 11% based on the oven dry weight of the particles for core and outer layers, respectively. Based on urea formaldehyde resin, 4% and 5% of paraffin as hydrophobic substance, and 2.5% and 0.80% of ammonium sulphate as hardener were added to urea formaldehyde resin for core and outer layers, respectively.

2.2 Manufacture of Particleboard

Pine (*Pinus sylvestries* L.), beech (*Fagus orientealis* Lipsky.) and poplar (*Populus tremula* L.) particles were prepared using a chipper and knife-ring flaker. The particles were dried at 483,15 K in an oven to reach target moisture content (1%). A screening machine with meshes of 1 and 0.25 mm apertures and a pneumatic system were used to separate the core and surface layer particles. The particles were placed in a blender and sprayed with urea formaldehyde, paraffin and ammonium sulphate. Mats were continuously pressed at 498 K. Hot press pressures (entrance and exit) and feeding speeds of continuous press were changed during the pressing of the panels. Panels were sanded using a sequence of 50, 60, 80, 100 and 120 grits. Produced particleboards were conditioned at 293 K and 65% relative humidity. The panels were designed to consist of 35% particles at the face layers and 65% at the core layer. Target board density and thickness were 0.640 Mg/m^3 and 18 mm, respectively. Two replications of each board were made, yielding a total of 18 boards. The experimental design and panel characteristics are shown in Table 1.

2.3 Evaluation of Particleboard Properties

Values for modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), and thickness swelling (TS) were determined according to procedures defined in the European Union standards EN 310 (1993), EN 319 (1993) and EN 317 (1993), respectively [24–26]. Twenty samples were randomly taken from each type of the panel.

A 50 mm wide sample strip, the full width of the panel, was cut from the middle of each panel. The strip was cut into 50 mm $\times$ 50 mm specimens and a commercial X-ray densitometry (DP 200 Density Profile System) was used to measure the vertical density profile of each sample. 10 measurements were reported for density profile.

The determination of the thickness (T) of the particleboard panels was conducted according to TS EN 323/1 (1999) standard [27]. Twenty specimens were used for each type panel. Five different measuring points were determined for each specimen.

3 Statistical Analysis

Data for each test were statistically analyzed. The analysis of variance (ANOVA) was used to evaluate the significance in the difference between factors and levels. Comparison of the means was done employing Newman Keuls test to identify which groups were significantly different from other groups at 95% confidence level.

4 Results and Discussion

The density profile and thickness values of the particleboard panels and the results of analysis of variance own to effects of entrance and exit pressures, and feeding speed of the continuous press on the density profile and panel thickness are summarized in Table 2 and Table 3.

It can be seen that increasing entrance pressure significantly decreased the panel thickness and increased the surface density. This may be due to decreasing of surface layer's thickness and closely pressing of surface layers. The pressure applied in the entrance of hot press is effective on the surface layers of particleboard [28]. The results showed that increasing entrance pressure statistically did not affect the core density. This result shows that entrance pressure affects only surface layer of the particleboard. The similar result was reported by [11]. Figure 1 illustrates the effects of pressures and feeding speed on the surface and core densities of the test panels.

While increasing exit pressure significantly decreased the panel thickness and increased the core density, it did not statistically affect the surface layer density. Exit pressure is more effective on the pressing of core layer particles [29]. For this reason, increasing exit pressure decreased the thickness of the core layer. Decreasing core layer thickness caused more compact and tighter structure and an increasing on the core density.

Increasing entrance and exit pressures together statistically decreased the panel thickness and increased the surface and core density of the test panels. This may have been due to decreasing of core and surface layer's thickness and related to this, increasing core and surface layer's

board type	entrance pressure of continuous press (kg/m^2)	exit pressure of continuous press (kg/m^2)	feeding speed of continuous press (mm/sec)
A	30×10^{-4}	10×10^{-4}	235
B	35×10^{-4}	10×10^{-4}	235
C	25×10^{-4}	10×10^{-4}	235
D	30×10^{-4}	7.5×10^{-4}	235
E	30×10^{-4}	12.5×10^{-4}	235
F	35×10^{-4}	12.5×10^{-4}	235
G	25×10^{-4}	7.5×10^{-4}	235
H	30×10^{-4}	10×10^{-4}	205
I	30×10^{-4}	10×10^{-4}	265

Table 1. The experimental design and panel characteristics.

board type	density in the bottom surface (Mg/m^3)	density in the top surface (Mg/m^3)	density in the core (Mg/m^3)	T (mm)
A	0.978 (0.009)	0.960 (0.004)	0.514 (0.007)	18.05 (0.05)
B	0.987 (0.004)	0.962 (0.002)	0.515 (0.005)	17.83 (0.04)
C	0.970 (0.011)	0.937 (0.005)	0.509 (0.006)	18.25 (0.02)
D	0.973 (0.010)	0.956 (0.003)	0.505 (0.009)	18.28 (0.09)
E	0.979 (0.002)	0.961 (0.006)	0.525 (0.004)	17.75 (0.03)
F	1.016 (0.012)	0.992 (0.012)	0.532 (0.007)	17.60 (0.04)
G	0.935 (0.007)	0.912 (0.010)	0.500 (0.005)	18.42 (0.06)
H	1.009 (0.004)	0.965 (0.006)	0.529 (0.003)	17.62 (0.07)
I	0.942 (0.013)	0.915 (0.011)	0.505 (0.009)	18.35 (0.02)

Note: Numbers in the parenthesis are standard deviations.

Table 2. The average density profile and thickness values of the test panels.

factors	board type	surface density (Mg/m^3)	core density (Mg/m^3)	T (mm)
entrance pressure	25×10^{-4} kg/m^2	0.953 a	0.509 a	17.84 a
	30×10^{-4} kg/m^2	0.969 b	0.514 a	18.05 b
	35×10^{-4} kg/m^2	0.974 c	0.515 a	18.25 c
exit pressure	7.5×10^{-4} kg/m^2	0.964 a	0.505 a	18.28 a
	10×10^{-4} kg/m^2	0.969 a	0.514 b	18.05 b
	12.5×10^{-4} kg/m^2	0.970 a	0.525 c	17.75 c
entrance-exit pressures	$25 - 7.5 \times 10^{-4}$ kg/m^2	0.923 a	0.500 a	18.42 a
	$30 - 10 \times 10^{-4}$ kg/m^2	0.969 b	0.514 b	18.05 b
	$35 - 12.5 \times 10^{-4}$ kg/m^2	1.004 c	0.532 c	17.60 c
feeding speed	265 mm/sec	0.929 a	0.505 a	18.35 a
	235 mm/sec	0.969 b	0.514 b	18.05 b
	205 mm/sec	0.987 c	0.529 c	17.62 c

Note: While the different letters in the same column represent statistical differences at 95% confidence level, values having the same letter are not significantly different (Newman Keuls tests).

Table 3. Results of statistical analysis own to effects of entrance and exit pressures, and feeding speed of the continuous press on the density profile and thickness of the test panels.

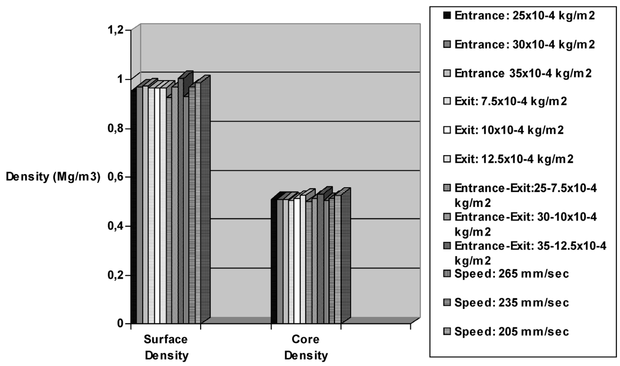

Figure 1. Effects of entrance and exit pressures, and feeding speed on the surface and core densities.

density. Similar reduction in panel thickness related to the increasing of pressure was reported by Hata [30] and Maloney [31].

According to the results of analysis of variance and Newman Keuls tests, decreasing feeding speed of hot press significantly increased the surface and core density and decreased the panel thickness. Decreasing feeding speed of the press causes longer press time. For this reason, mats spend more time in the press. Increasing press time causes a decreasing in panel thickness and related to this, increases the panel density [32].

The thickness tolerance of the particleboard is ± 0.30 mm according to TS EN 312 (2005) standard [33]. Except for F, G, H and I types of the panels, the other groups met the required level of the thickness tolerance. Although, having positive or negative effects of entrance and exit pressures and feeding speed on the properties of the particleboard panels, the higher or lower entrance and exit pressures, and feeding speeds than required levels should not be applied due to acceptable thickness tolerance.

The physical and mechanical properties and required values to meet EN 312 (2005) standard [34], and the results of ANOVA and Newman Keuls tests for modulus of rupture, modulus of elasticity, internal bond strength and thickness swelling are shown in Table 4 and Table 5.

As shown in Table 3, panels A, B, D, E, F and H satisfied the minimum MOR and MOE requirements for general purpose use and interior fitments including furniture manufacture stated in the EN 312 (2005) standard. Average MOR and MOE values of the panel types B, F and H met the minimum requirement for load bearing applications in dry conditions.

IB values of the experimental panels ranged from 0.272 to 0.516 $\mathrm{N/mm^2}$. The highest IB value was observed for F type panel while the lowest was observed for G type panel. All of the produced panels met the IB requirement for general purpose end use while A, B, E, F and H type particleboards satisfied the minimum requirement for interior fitments and load bearing applications (in dry conditions) stated in EN 312 standard.

Panel types B, E, F and H were found to comply with particleboard maximum thickness swelling requirement of 15% for use in load bearing applications in dry conditions. The other particleboard types did not meet the TS requirement of the EN 312 (2005) standard.

With the increasing entrance pressure, MOR and MOE values of the test panels significantly increased, and TS decreased. These results could be attributed to decreasing panel thickness in the surface layers and, related to this, increasing surface density as shown in Table 3. High surface density improves the modulus of rupture and modulus of elasticity of the particleboards. The diffusion of the water is difficult to inside of particleboard due to more compact and tighter structure at high density. Efficient compaction reduces interparticle porosity resulting in decreased water entry into the specimens [35]. Several researchers have mentioned the positive effect of the density on the bending properties and thickness swelling [36, 37]. The results of ANOVA and Newman Keuls tests showed that increasing entrance pressure did not statistically affect the internal bond strength. This result may be related to the unchanging of core density. Core layer of the particleboard affects the internal bond strength. The internal bond is the bonding strength between the core layer particles [11]. The effects of pressures and feeding speeds on the MOR, MOE, IB and TS are indicated in Figures 2–5.

Statistical analysis found significant differences ($p < 0.05$) between different exit pressures for internal bond strength and thickness swelling values. Increasing exit pressure of the hot press statistically improved the internal bond and thickness swelling of the test panels. These results may be related to the increasing core density of the particleboards as shown in Table 3. The diffusion of the water to the core layer of particleboard is difficult due to more compact and tighter structure of core layer. The positive influence of the high core density on the internal bond strength was mentioned by May [38]. However, high exit pressures did not significantly affect the MOR and MOE of the test panels. This is due to insignificant differences between the surface density values of the test panels pressed under different exit pressures as shown in Table 3. The main factor affecting modulus of the rupture and modulus of elasticity of particleboard is surface density [39].

As shown in Table 5 and Figures 2–5, MOR, MOE, IB and TS significantly were improved when entrance and exit pressures were increased together. This can be due to increasing of surface and core density of the test panels. While increasing core density improved the internal bond strength, high surface density caused higher MOR and MOE values.

Decreasing feeding speed of the hot press significantly improved all of the properties of particleboard. This result is attributed to having longer pressing time of the test pan-

board type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS* (%)	TS** (%)
A	13.84 (1.37)	1944.09 (111.61)	0.385 (0.011)	7.35 (2.04)	17.34 (1.57)
B	15.12 (0.93)	2343.78 (117.47)	0.391 (0.008)	5.54 (1.05)	14.79 (1.35)
C	12.51 (1.02)	1582.05 (89.09)	0.343 (0.010)	9.47 (2.10)	19.56 (2.17)
D	13.53 (0.99)	1914.20 (112.98)	0.307 (0.006)	9.86 (1.39)	20.08 (2.00)
E	13.98 (1.16)	1958.41 (115.72)	0.478 (0.009)	5.42 (1.30)	14.30 (2.02)
F	15.55 (0.72)	2355.32 (119.41)	0.516 (0.012)	5.30 (1.27)	14.14 (1.46)
G	11.82 (0.49)	1573.29 (98.97)	0.272 (0.017)	10.77 (0.84)	21.13 (1.24)
H	15.28 (0.74)	2348.64 (107.66)	0.494 (0.013)	5.35 (1.01)	14.23 (2.38)
I	12.40 (0.65)	1577.86 (108.74)	0.299 (0.014)	10.11 (1.64)	20.78 (1.03)
GUR	min. 11.50	–	min. 0.240	–	–
IFR	min. 13.00	min. 1600.00	min. 0.350	–	–
LBR	min. 15.00	min. 2300.00	min. 0.350	–	max. 15

Note: Numbers in the parenthesis are standard deviations, *– after 2 h immersion, **– after 24 h immersion, GUR – General Use Requirements, IFR – Interior Fitment Requirements, LBR – Load Bearing (in dry conditions) requirements.

Table 4. The average MOR, MOE, IB, and TS values of the test panels and required values to meet EN 312 standard.

factors	board type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
entrance pressure	25×10^{-4} kg/m^2 30×10^{-4} kg/m^2 35×10^{-4} kg/m^2	12.51 a 13.84 b 15.12 c	1582.05 a 1944.09 b 2343.78 c	0.343 a 0.385 a 0.391 a	14.50 a 12.34 b 9.99 c
exit pressure	7.5×10^{-4} kg/m^2 10×10^{-4} kg/m^2 12.5×10^{-4} kg/m^2	13.53 a 13.84 a 13.98 a	1914.20 a 1944.09 a 1958.41 a	0.307 a 0.385 b 0.478 c	14.96 a 12.34 b 9.86 c
entrance-exit pressures	$25 - 7.5\times 10^{-4}$ kg/m^2 $30 - 10\times 10^{-4}$ kg/m^2 $35 - 12.5\times 10^{-4}$ kg/m^2	11.82 a 13.84 b 15.55 c	1573.29 a 1944.09 b 2355.32 c	0.272 a 0.385 b 0.516 c	15.94 a 12.34 b 9.71 c
feeding speed	265 mm/sec 235 mm/sec 205 mm/sec	12.40 a 13.84 b 15.28 c	1577.86 a 1944.09 b 2348.64 c	0.299 a 0.385 b 0.494 c	15.45 a 12.34 b 9.79 c

Note: While the different letters in the same column represent statistical differences at 95% confidence level, values having the same letter are not significantly different (Newman Keuls tests).

Table 5. Results of statistical analysis own to effects of entrance and exit pressures, and feeding speed of the continuous press on the physical and mechanical properties

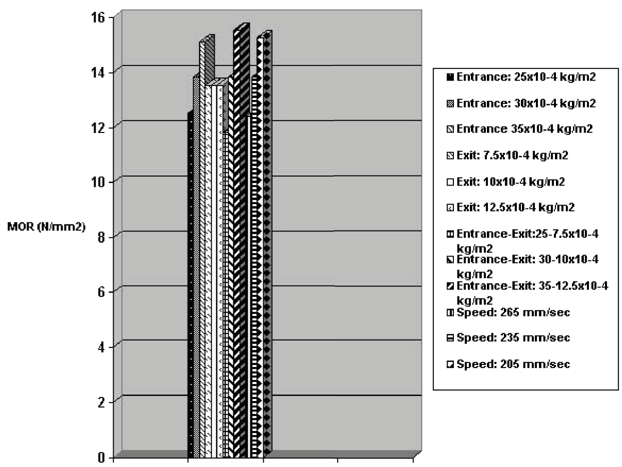

Figure 2. Effects of entrance and exit pressures, and feeding speed on the modulus of rupture.

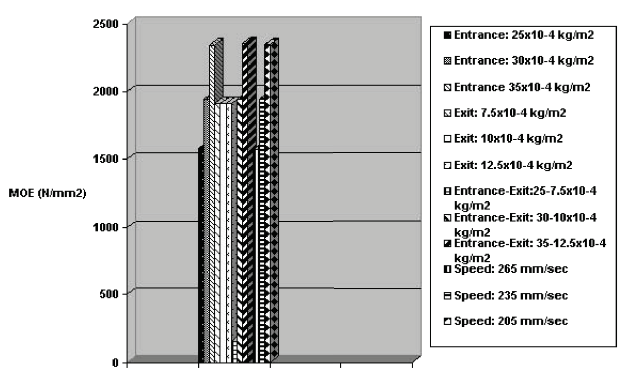

Figure 3. Effects of entrance and exit pressures, and feeding speed on the modulus of elasticity.

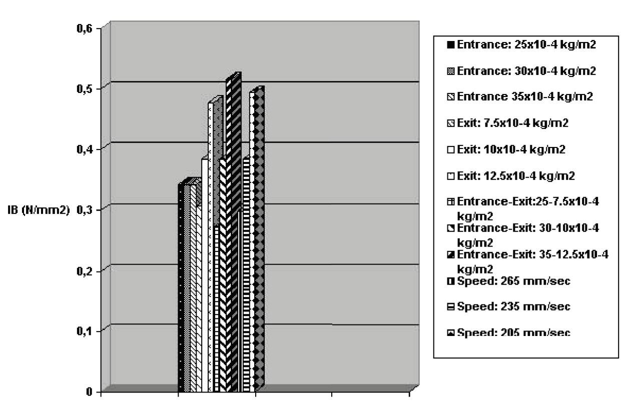

Figure 4. Effects of entrance and exit pressures and feeding speed on the internal bond strength.

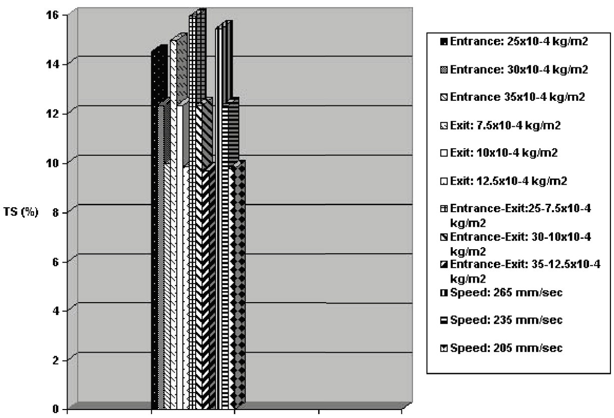

Figure 5. Effects of entrance and exit pressures and feeding speed on the thickness swelling.

els pressed with lower feeding speeds. Longer pressing time positively affects properties of particleboard via compaction and urea formaldehyde polymerization effects. This is due to reduced porosity resulting from efficient compaction accruing from effective politicization of wood particles and full polymerization [35]. The statistical analysis showed that surface and core density of the test panels were increased when the feeding speed was decreased. Lynam [40] reported that increasing of surface and core densities and longer pressing time improved the physical and mechanical properties of the particleboards.

5 Conclusions

This study investigated the effects of density profile and hot pres diagram on the physical and mechanical properties of particleboard. In addition, the fundamental relationships between the density profile and the board properties were basically established. The results can be summarized as follows:

1. Density profile played major role in the physical and mechanical properties of particleboard panels.

2. While increasing entrance pressure improved the MOR, MOE and TS of the panels, IB was not affected.

3. Increasing exit pressure did not statistically affect the MOR and MOE. However, IB was improved related to the increasing exit pressure.

4. Decreasing feeding speed of the hot press significantly improved the physical and mechanical properties of the particleboard panels.

5. While high surface density increased the MOR and MOE, and improved the TS, high core density positively affected IB and TS.

6. Entrance pressure was found to be effective surface density of the particleboard.

7. Exit pressure did not statistically affect the surface density, however, increased the core density of the test panels.

8. Although increasing entrance and exit pressures and decreasing feeding speed of the hot press positively affected all of the properties of particleboard panels, the thickness of the test panels was decreased under the acceptable tolerance. Therefore, pressure and feeding speeds should not exceed the necessary levels.

Acknowledgments

The authors gratefully thank to Mr. Hüseyin Yıldız and Starwood Forest Products Company for manufacturing of the test panels.

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