

THE EFFECT OF GRAIN DIRECTION ON LATERAL NAIL STRENGTH AND THERMAL CONDUCTIVITY OF STRUCTURAL PLYWOOD PANELS

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ABSTRACT

The aim of study was to determine the effects of grain direction on the lateral nail strength and thermal conductivity of structural plywood panels. Experiment were made with plywood manufactured from Scots pine, maritime pine and black pine. A rotary peeler with a maximum horizontal holding capacity of 80 cm was used for veneer manufacturing. The highest values of max load (2,17 kN), stiffness (2,52 kN/mm) and displacement at ultimate load (36,8 mm) were obtained from C1PR group panels manufactured from black pine. Also, it was determined the mechanical properties in perpendicular to grain were higher than those in parallel to grain. The black pine panels gave highest average thermal conductivity value (0,168 W/mK), while that of Scots pine was lowest (0,145 W/mK). Thermal conductivity of panels in perpendicular to the grain of main axis of plywood was always found to be higher than the values obtained from measurements parallel to the grain.

Keywords: Grain direction, lateral nail strength, structural plywood panels, thermal conductivity.

INTRODUCTION

Plywood, one of the most common wood based panels, has many usage areas varied from furniture (indoor) to construction (outdoor) and superior advantages compared to solid wood (Bal and Bektas 2014). Demirkir *et al.* (2013a), stated that plywood shows one the best performance on building exposed to earthquake loads due to its ability for tolerating the biggest amount of displacement before failure. Scholten (1965), pointed out that the strength, stability and structure life are sensitive to strength, rigidity, and joint durability. When walls are covered with structural wood boards, fasteners represent the most important part of strength of the structure (McCormick 2005). As plywood attached with nails in the frame, the lateral nail resistance test are carried out in order to investigate nail performance on strength and stiffness of wood-frame (Bott 2005). Although there were some studies on lateral nail resistance of plywood panels manufactured from different wood species, the effect of grain direction on lateral nail strength of plywood is not clear. Potter (1976), determined that lateral nail strength in perpendicular to the grain direction was higher than that of parallel to the grain direction, the opposite results was achieved by Hunt and Bryant (1984). Some studies also showed that the grain direction had no effect on the lateral nail strength values of plywood panels (Stewart 1987, Morris 1968, Pirvu 2008).

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Received: 05.03.2014 Accepted: 16.09.2014

An excellent insulation property is another advantage of wood materials (Ngohe-Ekam *et al.* 2006). Thermal insulation is one of the most desirable parameters for structural materials. Demirkir *et al.* (2013b), also emphasized that wood composite materials are superior to other building materials in terms of thermal conductivity due to their porous structure. Thermal conductivity of wood and wood composite materials such as plywood are influenced based on wood specie, direction of wood grain, proportion of early and late wood, density, moisture content (MC), resin type and additives, temperature, and heat's flow direction in former (Bader *et al.* 2007; Sonderegger and Niemz 2009; Kol *et al.* 2008). Grain direction is one of the most important factors influencing the thermal conductivity of wood. In literature, it was reported that the thermal conductivity in parallel to grain was 2,25 – 2,75 times higher than that of perpendicular to grain in wood (Gu and Zink-Sharp 2005).

It is seen from the literature that the grain direction plays an important role on some technological properties of structural plywood panels. However the studies determining the effect of the grain direction on the lateral nail strength and thermal conductivity of wood materials showed different results. The aim of this study is to present and discuss the results of an investigation concerning the determination of the lateral nail strength and thermal conductivity of plywood panels manufactured from Scots pine, maritime pine and black pine. Further aim of this paper is to determine the effect of grain direction on the technological properties of plywood panels.

MATERIAL AND METHODS

Wood Material and Manufacturing of Plywood

Three different wood species were used in this study as Scots pine (*Pinus sylvestris*), maritime pine (*Pinus pinaster*) and black pine (*Pinus nigra*) from Turkey. Pine logs have an average diameter at breast height of 40 cm. A rotary peeler with a maximum horizontal holding capacity of 80 cm was used for veneer manufacturing. The logs were subjected to steaming phase, later peeled, and then veneers were sized to 550×550×2 mm at two different peeling temperatures as 32°C and 50°C. The vertical opening was 0,5 mm and horizontal opening was 85% of the veneer thickness in the veneer manufacturing process. After rotary peeling, veneers were dried at 140°C in a dryer to a final moisture content of 4-6 %.

Phenol formaldehyde adhesive with 47% solid content was used as resin type for manufacturing of five-ply-plywood panels with 10 mm thick. Veneer sheets were conditioned until their moisture content reaches to approximately 6-7% in a conditioning chamber prior to gluing. The glue was applied at a rate of 160 g/m² to the single surface of veneer with a four-roller spreader. Production process is schematically shown in figure 1. Assembled samples were pressed in a hot press at a pressure of 8 kg/cm² (785 kPa) and at 140 °C for 10 minutes. Two replicate plywood panels were produced for each group. The test groups are shown in table 1.

Table 1. Test Groups.

Peeling Temperature (°C)	Grain Direction	Wood Species		
		<i>Pinus sylvestris</i>	<i>Pinus pinaster</i>	<i>Pinus nigra</i>
32	Parallel	A1PP	B1PP	C1PP
	Perpendicular	A1PR	B1PR	C1PR
50	Parallel	A2PP	B2PP	C2PP
	Perpendicular	A2PR	B2PR	C2PR

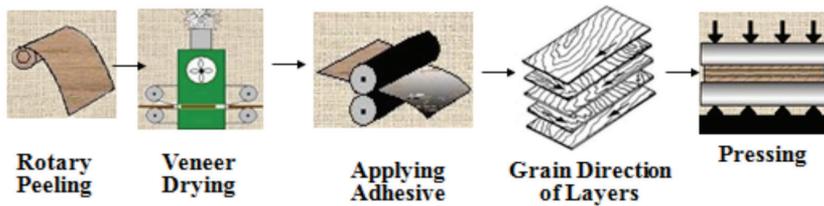


Figure 1. Schematic Diagram of Production Process.

Lateral Nail Strength Test

This test was performed according to ASTM D1761 (ASTM 2006). Lateral nail connection specimens were made with nails driven flush at a distance of 51 mm from the edge of the sheathing material. The nail size was 63,5 mm × 3,3 mm. The nails were driven pneumatically to connect the framing member and the sheathing material. SPF (spruce-pine-fir) was used as the main member. The size of sheathing member was 250mm × 76mm. Test specimen, grain directions and nailing connections are shown in Figure 2. All wooden materials were conditioned at 20°C and 65% relative humidity prior to testing. The specimens were oriented so that the load was applied parallel and perpendicular to the grain of the main axis of plywood panel during the test as shown in figure 2a and 2b. The specimen move was limited to one direction. The loading was set to a loading rate of 12,7 in a minute. A 22,4 kN load cell, attached to a 222 kN universal testing machine, was used to measure the applied load. The test was carried out at FPInnovations (previously called Forintek) Building Systems Department Laboratory in Vancouver, Canada. For each group of test, 6 replications were performed. The followings were determined from this test.

- Initial stiffness
- Ultimate load
- Displacement at ultimate load

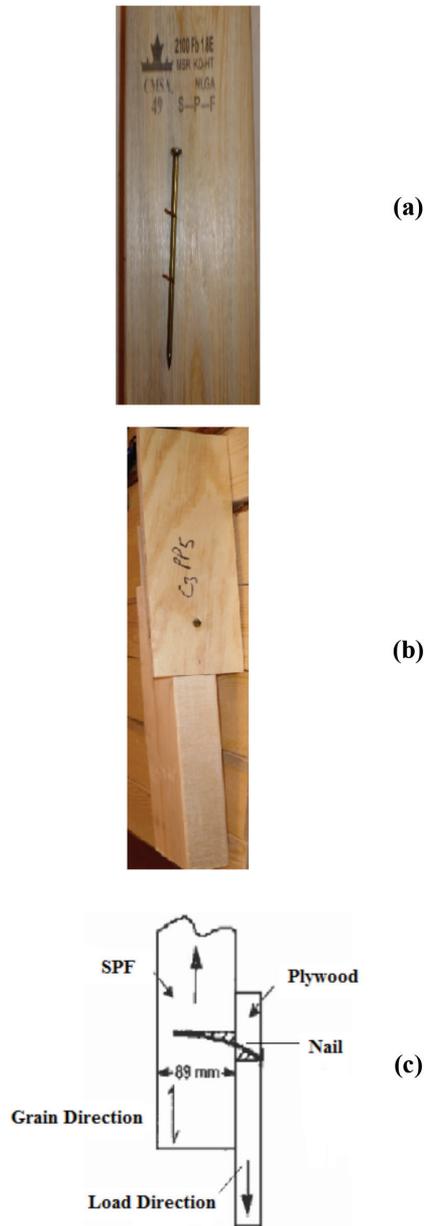


Figure 2. Test Specimens, Grain Directions (a: loading perpendicular to grain of panel; b: loading parallel to grain of panel) and c: Nailing Connections

Thermal conductivity and Density

Thermal conductivity was measured according to the hot-wire method described in ASTM C 1113-99 (2009). Instrument was a quick thermal conductivity meter (QTM 500, Kyoto Electronics Manufacturing, Japan) with PD-11 probe of the same manufacturer. Measurement was ranked from 0,0116 to 6 W/mK. Measurement precision and reproducibility were F5% of reading and F3% of reading value per reference plate, respectively. Measurement temperature was ranked between -100 to 1000°C (external bath or electric furnace for temperature other than room). In the measurement, upper and lower plates were constantly heated at 40°C and cooled at 20°C, respectively. Sizes of the test specimens are 10×50×100 mm³. Measuring time was 100–120 s. Five specimens were used for each group. Density of the panels was determined in accordance with EN 323 (1993).

RESULTS AND DISCUSSION

Average values of lateral nail strength, thermal conductivity and density of plywood panels based on panel groups are listed in table 2. It was found the effects of wood species, peeling temperature and grain direction on max load and thermal conductivity were statistically significant at the $\alpha=0,05$ level (Table 3). Multifactor analysis of variance was performed for statistical evaluation of the changes in lateral nail strength and thermal conductivity of the panels depending on wood species, veneer peeling temperature and grain direction. Student–Newman–Keuls test with 99% confidence level was conducted to see the comparison of the mean values of variance sources and the results for statistical evaluation presented in table 4.

Table 2. Lateral nail strength and thermal conductivity values of test groups.

Panel Groups	Density (g/cm ³)	Thermal Conductivity (W/mK)	Lateral Nail Strength				
			Max Load (kN)	Displacement At Max Load (mm)	Stiffness (kN/mm)	Ultimate Load (kN)	Displacement At Ultimate Load (mm)
A1PP	0,51	0,127	1,77	10,17	1,36	1,28	17,45
A1PR	(0,02)	0,143	1,85	11,97	1,51	1,45	18,81
A2PP	0,58	0,145	1,87	16,16	1,32	1,49	24,65
A2PR	(0,03)	0,166	2,02	9,67	1,84	1,72	16,84
B1PP	0,53	0,152	2	13,11	1,91	1,58	24,87
B1PR	(0,02)	0,194	1,86	13,25	1,99	1,74	29,85
B2PP	0,54	0,137	1,88	21,32	1,68	1,49	31,97
B2PR	(0,04)	0,154	2,09	18,96	1,96	1,52	27,59
C1PP	0,63	0,157	1,80	16,55	1,90	1,45	29
C1PR	(0,02)	0,187	2,17	14,66	2,52	1,76	36,8
C2PP	0,59	0,151	2,01	17,1	1,73	1,55	29,84
C2PR	(0,02)	0,176	2,17	21,47	1,95	1,73	29,9

Note. Each value is the average of six replicates for lateral nail strength results

Table 3. Anova table related to the effects of wood species, peeling temperature and grain direction on maximum load, thermal conductivity of the plywood panels

	Source of Variation	Sig. Level
Max Load	Wood Species	**
	Peeling Temperature	*
	Grain Direction	***
Thermal Conductivity	Wood Species	***
	Peeling Temperature	**
	Grain Direction	***

N.S: Non-significant

*Significant at the $0,01 < \alpha \leq 0,05$ level** Significant at the $0,001 < \alpha \leq 0,01$ level*** Significant at the $\alpha=0,001$ level**Table 4.** Results of Student-Newman-Keuls test at 99% confidence level.

Properties	Factors	LS	Homogenous
		Mean	Groups*
Max Load	Wood Species		
	<i>Pinus sylvestris</i>	1,88	a
	<i>Pinus pinaster</i>	1,96	b
	<i>Pinus nigra</i>	2,04	c
	Peeling Temperature		
	32°C	1,91	a
	50°C	2	b
	Grain Direction		
	Parallel	1,89	a
Perpendicular	2,03	b	
Thermal Conductivity	Wood Species		
	<i>Pinus sylvestris</i>	0,145	a
	<i>Pinus pinaster</i>	0,159	b
	<i>Pinus nigra</i>	0,168	c
	Peeling Temperature		
	32°C	0,160	a
	50°C	0,155	b
	Grain Direction		
	Parallel	0,145	a
Perpendicular	0,170	b	

* Different letters denote a statistically significant difference

The effect of wood species, peeling temperature and grain direction on max load were significant at the $\alpha=0,01$; $\alpha=0,05$ and $\alpha=0,001$ level, respectively. When the max load values were analyzed with respect to wood species, the highest one (2,17 kN) was found for black pine panels. This may be explained to have their higher density values (Table 2). It was known that there was a positive correlation between plywood density and lateral nail strength (Demirkir *et al.* 2013a). In another study, Nanami *et al.* (2000) determined that the nail resistance (1,71 kN) of plywood panels with 9 mm thick and density of 0,63 g/cm³ was higher than the resistance (1,36 kN) of same thickness panels with density of 0,59 g/cm³. Former studies also showed that lateral nail strength is affected by wood species (Wu 1999, Stieda 1990). Difference in max load was determined to have a small but significant in terms of peeling temperature. Max load values measured in perpendicular to grain of panels were higher than those measured in parallel to grain. This corresponds well to findings Hunt and Bryant (1984) and Nanami *et al.* (2000). Max load values of the test panels compare favorably with those of published studies (Pirvu 2008, Nanami *et al.* 2000). In also Ekwueme and Hart 2000, the max load of 8d common nails in 9,5 mm plywood was found as 1,22 kN. The results also met the max load requirements (0,98 kN) given in APA L350G and L350A (APA 2001 and 2007).

Stiffness is one of the most important parameters for structural panels. If the panels used for sheathing material in a shear wall which have higher stiffness, they will be more resistant to earthquake loads. As shown in table 2, stiffness values in perpendicular to grain of panels are higher than those of parallel to grain of the panels for all wood species. In literature, the results of some studies on the effect of grain direction on stiffness supported these findings (Winistorfer and Soltis 1994), while Pirvu (2008), determined that there was no effect of grain direction on stiffness of panels. Besides the stiffness, higher max load and higher displacement at ultimate load are desired for resisting to lateral loads such as earthquakes. It can be concluded from the study that the plywood panels manufactured from black pine are more convenient for structural aims, since they have higher stiffness, max load and displacement at ultimate load (Table 2). Displacement quantities at ultimate load of all groups exceed the value (15,6 mm) described in ISO 16670 (2003).

The effect of wood species, peeling temperature and grain direction on thermal conductivity values of panels were significant at the $\alpha=0,001$, $\alpha=0,01$ and $\alpha=0,001$ level, respectively. The highest thermal conductivity values were obtained from the panels manufactured from black pine species. This result may be explained with relationship between density of wood materials and thermal conductivity of them. It is stated that thermal conductivity increases as wood density increases (Glass and Zelinka 2010). Some former studies also proved a positive correlation between density and thermal conductivity of wood. (Gu and Zink-Sharp 2005, Sahin Kol and Altun 2009, Sanderegger and Niemz 2009). Thermal conductivity values from this study met the values (between 0,132 and 0,75 W/mK according to wood species) described in Handbook of Finnish Plywood (2002).

When the thermal conductivity values of the test groups were analyzed according to grain direction, thermal conductivity in perpendicular to grain was higher than that in parallel to grain as seen from table 4. In literature, it was stated that on average, thermal conductivity along the grain is about 1,8 times as high as across the grain in wood (Zylkowski 2002). But this situation cannot be expected for wood based products such as plywood, since they are cross-laminate composite materials including wood, resin and other additives. The difference between the thermal conductivity values of panels in perpendicular to grain and parallel to grain may be clarified with cross-laminated layers and additives. It can be concluded from these findings that these properties of plywood panels should not be ignored for structural using to supply the desired insulation in constructions.

CONCLUSIONS

The effect of grain direction on lateral nail strength and thermal conductivity of structural panels were studied. The thermal conductivity in perpendicular to grain of plywood panels was higher than that in parallel to grain of the panels. Black pine panels gave higher stiffness and displacement at ultimate load. It is suggested that the plywood panels manufactured from black pine should be used for structural aims. The properties which are important for building construction in perpendicular to grain of the panels were greater than those in parallel to grain of the plywood panels.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Scientific and Technological Research Council of Turkey (TÜBİTAK).

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