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Research Article

THE EFFECTS OF WOOD SPECIES, NAIL SIZE, GRAIN DIRECTION AND LAYER NUMBERS ON LATERAL NAIL STRENGTH OF STRUCTURAL PLYWOOD PANELS

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ABSTRACT

In the use of solid wood and wood-based composite materials in wooden structures, metal elements such as nails, screws and bolts are used as fasteners. The strength of the connection points depends on many factors. In this study, it was aimed to determine effects of wood species, nail size, grain direction and layer numbers on lateral nail strength of structural plywood panels. Scots pine, black pine and spruce were used as wood species for structural plywood production. Five and seven-ply plywood panels, 10 mm and 14 mm thick, were manufactured by using phenol formaldehyde glue resin. Lateral nail strength test was performed according to ASTM D1761. 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. Also, nail size was chosen as 6d and 8d for test. As a result of the study, it was seen that the Scots pine plywood gave the highest lateral nail strength values among other wood species. Lateral nail strength values of seven-ply plywood was found higher than five-ply plywood. Lateral nail strength value of the samples using 8d nails was found to be higher than those using 6d nails. Also, it was determined the lateral nail strength values in perpendicular to grain were higher than those in parallel to grain.
Keywords: Lateral nail strength**,** structural plywood, nail size, grain direction, layer numbers.

1. INTRODUCTION

Solid wood and wood-based composite boards are used in constructing buildings because they have some excellent advantages, such as easy process ability, low price, good aesthetic appearance, and light weight [1]. 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 [2].

Plywood-sheathed shear walls are widely used as bearing elements against horizontal loads such as seismic forces and wind forces [3]. Moreover, when a wood-frame house is properly designed and constructed, plywood sheathing will not decay, and hence, will retain sufficient strength in the long term [4-5]. To achieve the highest performance of a shear wall, it should have

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not only a high load-bearing capacity, but also a high ductility or ultimate deformation. Besides, the performance of a shear wall is affected by the joints between the plywood and timber [3].

The strength and stability of any structure depend heavily on the fastenings that hold its parts together. One prime advantage of wood as a structural material is the ease with which wood structural parts can be joined together with a wide variety of fastenings-nails, spikes, screws, bolts, lag screws, drift pins, staples, and metal connectors of various types [6]. When walls are covered with structural wood boards, fasteners represent the most important part of strength of the structure [7]. As plywood attached with nails in the frame, the lateral nail strength test are carried out in order to investigate nail performance on strength and stiffness of wood-frame [8-9].

Lateral nail strength is affected on many factors such as fastener specification, wood properties, connection types and load application conditions. In this study, it was aimed to determine effects of wood species, nail size, grain direction and layer numbers on lateral nail strength of structural plywood panels.

2. MATERIALS AND METHOD

Scots pine (*Pinus slyvestris*), black pine (*Pinus nigra*) and spruce (*Picea orientalis L.*) were used in this study. The logs were obtained from Trabzon region. The logs were steamed for 12-16 hours before veneer production. A rotary type peeler (Valette&Garreau - Vichy, France) with a maximum horizontal holding capacity of 800 mm was used for veneer manufacturing and rotary cut veneer sheets with dimensions of 1.2x2.4 m by 2 mm were clipped. Vertical opening was 0.5 mm and horizontal opening was 85% of the veneer thickness in veneer manufacturing process. After rotary peeling, the veneer sheets were oven-dried at 110°C, for 5-7% moisture content in a laboratory scale jet veneer dryer (manufactured by Hildebrand Holztechnik GmbH).

Five and seven-ply plywood panels, 10 and 14 mm thick, were manufactured by using phenol formaldehyde (PF) glue resin with 47% solid content. Veneer sheets were conditioned to approximately 6–7% moisture content in a conditioning chamber before gluing. The glue was applied at a rate of 160 g/m^2 to the single surface of veneer by using a four-roller spreader. The assembled samples were pressed in a hot press at a pressure of 8 kg/cm^2 and at 140°C for 10 and 14 min.

Density of plywood panels manufactured in industrial plant were determined according to EN 323 [10] before the lateral nail strength test. Twenty samples were used for the evaluation of plywood density. The density results of plywood panels are given Table 1.

Table 1. Test results of density of plywood panels

Wood Species	Layer Numbers	Density (g/cm^3)
Scots pine	5	0.585
	7	0.663
Spruce	5	0.510
	7	0.487
Black pine	5	0.566
	7	0.613

The lateral nail strength test was performed according to ASTM D1761 [11]. 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 chosen as 6d (63 mm × 2.5 mm) and 8d (76 mm × 2.8 mm). The nails were driven pneumatically to connect the framing member and the sheathing material. Spruce timber was used as the primary member. The size of sheathing member was 250mm × 76mm. 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. The step by step show of the prepared examples is given in Figure 1.

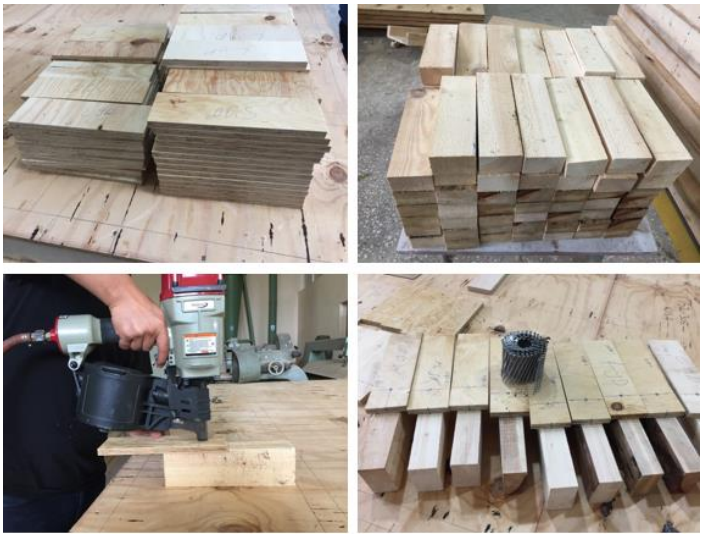

Figure 1. Preparation of specimens for lateral nail strength test

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 10 kN universal testing machine, was used to measure the applied load. The test was carried out at Forest Industry Engineering Department Laboratory in Trabzon, Turkey. For each group of test, 4 replications were performed. Figure 2 shows the test setup for the lateral nail strength and the changes that occur as a result of the test.

Figure 2. Lateral nail strength test setup and changes at the end of the test

The following properties were calculated from this test, as illustrated in Figure 3:

• Initial stiffness, by selecting the points closest to 10% and 40% of the maximum load and fitting a straight line to the intervening points;

• Ultimate load, as 80% of the maximum load;

• Displacement at ultimate load; was identified based on the calculated ultimate load.

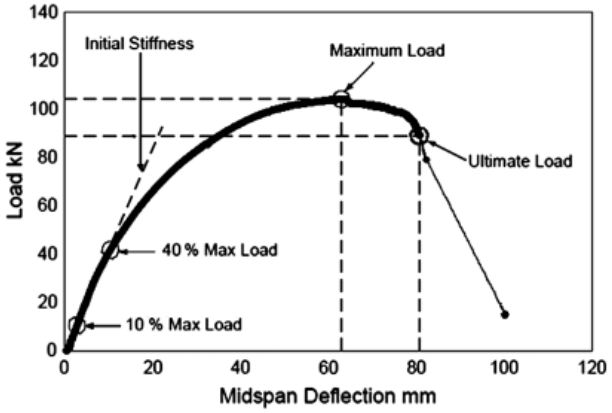

Figure 3. Analysis of a load-displacement curve [12].

3. RESULTS AND DISCUSSION

It was showed in Table 2 that lateral nail strength test results of plywood specimens according to wood species, layer numbers, nail size and grain direction.

Table 2. Results of Lateral nail strength of plywood panels

Wood Species	Layer Numbers	Nail Size	Grain Direction	Lateral Nail Strength (kN)	
				X	S
Scots pine	5	8d	Parallel	2.08	0.01
			Perpendicular	2.12	0.06
		6d	Parallel	1.64	0.09
			Perpendicular	1.69	0.12
	7	8d	Parallel	2.85	0.03
			Perpendicular	2.96	0.03
		6d	Parallel	1.65	0.03
			Perpendicular	1.86	0.02
Spruce	5	8d	Parallel	1.29	0.12
			Perpendicular	1.56	0.07
		6d	Parallel	1.20	0.04
			Perpendicular	1.24	0.10
	7	8d	Parallel	2.25	0.02
			Perpendicular	2.32	0.04
		6d	Parallel	1.70	0.06
			Perpendicular	1.72	0.03
Black pine	5	8d	Parallel	1.57	0.06
			Perpendicular	1.86	0.05
		6d	Parallel	1.33	0.01
			Perpendicular	1.42	0.06
	7	8d	Parallel	2.03	0.05
			Perpendicular	2.10	0.03
		6d	Parallel	1.78	0.04
			Perpendicular	1.82	0.04

X: Arithmetic mean values S: Standard Deviation

In order to determine the effect of wood species, layer numbers, nail size and grain direction on the lateral nail strength values of plywood panels, multiple variance analysis was performed and Student-Newman-Keuls test results used to compare the mean values of variance sources were given in Table 3.

Table 3. Student-Newman-Keuls test results of the samples ($p<0.05$).

Variance Sources	N	Lateral Nail Strength (kN)
Wood Species		
Scots pine	32	2,18 c
Black pine	32	1,74 b
Spruce	32	1,66 a
Layer Numbers		
5	48	1,58 a
7	48	2,09 b
Grain Direction		
Perpendicular	48	1,89 b
Parallel	48	1,78 a
Nail Size		
6d	48	1,59 a
8d	48	2,08 b

* Different letters indicate the statistically significant difference

As can be seen Table 2, scots pine plywood gave the highest lateral nail strength values among other wood species. The mechanical properties of plywood produced from the veneers of high-density wood are higher [13]. In Table 1, it is seen that scots pine plywood gave the highest density values among other wood species. It is stated in a study by Nanami et al. [4] that there is a linear relationship between plywood density and lateral nail strength. Nanami et al. [4] determined that the nail resistance (1.71 kN) of plywood panels with 9 mm thick and density of 0.63 g/cm^3 was higher than the resistance (1.36 kN) of same thickness panels with density of 0.59 g/cm^3. The primary impact on the density of the plywood is wood specie [14]. In the literature, the density of the Scots pine wood is determined as 0.49 g/cm^3, and the density of spruce wood is determined as 0.43 g/cm^3 [15]. Similarly, laminated materials obtained from wood species with high density have high nail or screw holding resistance [16]. Former studies also showed that lateral nail strength is affected by wood species [17-18].

The lateral nail strength values of seven-ply plywood was found higher than five-ply plywood. The reason for this can be shown that the density of seven-ply plywood is higher than that of five-ply plywood (Table 1). In previous studies, it was determined that there is a linear relationship between density and lateral s nail strength [19].

Lateral nail strength value of the samples using 8d nails was found to be higher than those using 6d nails. The value given by APA for 6d straight nails is 180 lbf (0.80 kN) and the limit value given for 8d straight nails is 220 lbf (0.98 kN) [20]. Considering these limit values, the values obtained in this study are generally higher. These high values are due to the density of the materials used [21]. Also, it was determined the lateral nail strength values in perpendicular to grain were higher than those in parallel to grain. It is stated in the literature that the lateral nail strength of perpendicular to the grain is higher than the lateral nail strength of parallel to the grain [4, 14, 22].

For the lateral nail strength, the displacement at maximum load, stiffness, ultimate load and displacement values at the ultimate load using graphs showing the relationship between

displacements under the effect of applied load, while determining the maximum load are given in Table 4.

Table 4. Results of displacement at maximum load, stiffness, ultimate load and displacement values at the ultimate load according to the lateral nail strength

Wood Species	Layer Numbers	Nail Size	Grain Direction	Displacement at maximum load (mm)	Stiffness (kN/mm)	Ultimate load (kN)	Displacement at ultimate load (mm)
Scots pine	5	8d	Parallel	16.27	0.72	1.66	23.67
			Perpendicular	11.9	0.76	1.7	19.62
		6d	Parallel	16.48	0.76	1.31	25.31
			Perpendicular	14.15	0.69	1.35	20.65
	7	8d	Parallel	16.58	0.83	2.28	24.14
			Perpendicular	16.95	1.15	2.36	23.55
		6d	Parallel	17.15	0.6	1.32	19.04
			Perpendicular	16.21	0.66	1.49	21.84
Spruce	5	8d	Parallel	14.54	0.47	1.03	21.62
			Perpendicular	17.39	0.55	1.25	24.55
		6d	Parallel	12.76	0.35	0.96	20.7
			Perpendicular	14.7	0.41	0.99	22.76
	7	8d	Parallel	16.27	0.6	1.8	22.37
			Perpendicular	11.91	1.08	1.85	19.62
		6d	Parallel	17.48	0.79	1.36	23.98
			Perpendicular	13.18	0.59	1.37	21.99
Black pine	5	8d	Parallel	15.5	0.89	1.26	24.44
			Perpendicular	20.2	0.7	1.49	29.83
		6d	Parallel	14.56	0.63	1.06	24.13
			Perpendicular	14.78	0.54	1.14	22.17
	7	8d	Parallel	18.39	0.48	1.62	25.43
			Perpendicular	15.6	0.67	1.68	28.51
		6d	Parallel	14.72	0.57	1.42	29.88
			Perpendicular	17.23	0.8	1.46	28.77

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 4, stiffness values in perpendicular to grain of plywood panels are generally higher than those of parallel to grain of the panels for all wood species. Moreover, 8d nails and 7-ply plywood panels gave the highest stiffness values among the groups. In literature, the results of some studies on the effect of grain direction on stiffness supported these findings [9, 19], while Pirvu [12], determined that there was no effect of grain direction on stiffness of panels. Some of the groups gave similar results. 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 scots pine and black pine are more convenient for structural aims, since they have higher stiffness, max load and displacement at ultimate load (Table 4). Displacement quantities at ultimate load of all groups exceed the value (15.6 mm) described in ISO 16670 [23]. In Ekwueme and Hart [24], the maximum load and stiffness values of 8d common nails in 9.5-mm plywood were determined to be 1.22 kN and 1.59 kN/mm, respectively.

The results also exceed the standards in the National Design Specifications for Wood Construction (NDS) [25] and ISO 16670 [23], and met the values described in American Plywood Association (APA) standards L350G and L350A [26-27].

4. CONCLUSIONS

The effects of wood species, nail size, grain direction and layer numbers on lateral nail strength of structural plywood panels was investigated in this study. The highest lateral nail strength values were obtained in scots pine plywood among the all groups. The seven-ply plywood panels gave higher strength values than five-ply plywood panels. 8d nails resulted in increased lateral nail strength according to 6d nails. The strength values of perpendicular to grain were higher than those of parallel to grain. Stiffness and displacement values at the ultimate load of plywood have been determined to be suitable according to the literature and standards and it has been proved that domestic resources can be especially resistant to earthquake risk.

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