Available online at www.sciencedirect.com
ScienceDirect
Construction and Building Materials 21 (2007) 894–900
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Nail and screw withdrawal strength of laminated veneer lumber made up hardwood and softwood layers

Gülser Celebi [a,*], Murat Kilic [b]

[a] *Gazi University, Faculty of Engineering and Architecture, Department of Architecture, 06570 Ankara, Turkey*
[b] *Hacettepe University, Department of Wood Products Industrial Engineering, 06532 Ankara, Turkey*

Received 13 January 2005; received in revised form 5 December 2005; accepted 10 December 2005
Available online 15 February 2006

Abstract

The objective of this research was to evaluate screw and nail withdrawal strength properties of veneer laminated lumber manufactured from poplar (*Populus nigra*) and beech (*Fagus orientalis* L.) in transverse, radial, and tangential directions. Ten and 13 layer laminated samples were produced in different thickness veneers of both species using two types of resins, namely polyvinylacetate (PVAc) and polyurethane (PU). Based on the results of this study it was found that layer thickness did not influence the withdrawal strength in transverse direction but strength values increased with increasing specific gravity of the samples in this direction. Overall strength properties in radial direction were found to be higher than that of tangential direction. Based on the statistical analyses resin type did not significantly effect withdrawal strength of both species.

Keywords: Construction material; Laminated wood; Veneer; Poplar; Beech; Glue; Nail; Screw; Withdrawal strength

1. Introduction

The stability of any building system, composed of interconnected components, is directly related to the performance of the fastening elements. The most widely used fastening elements that are found in the connections of solid wood materials are nails and screws. Therefore, knowledge of the withdrawal strength of nail and screw for wooden building elements will provide useful information about the durability and stability of the whole system. Besides, it is significant to have information about withdrawal strength of nail and screw so as to achieve the efficient use of materials in the building system. In this study, which has evaluated the findings of a research project, building materials – having two distinct layer organizations – were produced by the use of softwood (poplar) and hardwood (beech) layers which were glued to each other with PVAc (polyvinylacetate) and PU (polyurethane) [1]. Findings about the withdrawal strength of nail and screw for the produced materials constituted the subject of this study. In this respect, the overall objectives of the study were as follows:

- To determine the withdrawal strength of nail and screw for laminated materials with different compositions with the condition of their having the same dimension and to compare their withdrawal resistances of nail and screw relative to each other.
- To reveal how changes in the composition of both glue type and layer type affect resistance properties.
- To make direct comparisons with solid specimens and to offer possibilities and locations of usage in the building system for the produced laminated samples as alternative building materials.

* Corresponding author. Tel.: +90 312 2317400/2659; fax: +90 312 2310183.
E-mail addresses: gulser@gazi.edu.tr (G. Celebi), kilicm@hacettepe.edu.tr (M. Kilic).
URL: http://w3.gazi.edu.tr/web/gulser/ (G. Celebi).

0950-0618/$ - see front matter
doi:10.1016/j.conbuildmat.2005.12.015

2. Literature review on withdrawal strength

Withdrawal strength changes according to tree type of which materials are produced, moisture content, the orientations of grains and section, specific gravity, duration of rising, method of nailing, dimensions and surface smoothness [2].

According to an experimental study that was conducted for a group of trees found in Turkey, the highest withdrawal strength of nail was recorded for oak. This was followed by beech, cedar, calabrian pine, black pine and scotch pine and the lowest value was found for fir [3].

In another study conducted for a different group of trees, the withdrawal strengths of nail for the woods of the trees of beech, alder, chestnut, spruce and scotch pine were determined in a decreasing order. In the same research withdrawal strength of nail and screw for a wood section with 30% moisture content was found to be smaller than that of a section with a moisture of 12%. In differing sections, following results were obtained: the highest resistance was achieved with radial section, this was followed by tangential section with approximate values, whereas lowest resistance values were determined in transverse section [4].

In a different study, it was found that there was a linear relationship between withdrawal strength of nail and the specific gravity, and increases in withdrawal strength of nail were determined for increased specific gravity values [5]. In the study which was aimed to investigate the effects of moisture content on resistances, nails and screws were first drawn in a wooden section of 60% moisture and the resistances were measured at certain intervals as the moisture content of the section dropped to the ratio of 0%. According to various studies, it was proved that at the point where moisture content fell below the grain saturation point, considerable decreases in the withdrawal strength of nail and screw were observed [5–7].

In the studies in which the effects of static withdrawal strength, nailing method and its duration were investigated, the withdrawal strengths for static and dynamic conditions were determined. It was seen that withdrawal strengths in static conditions were higher than those in dynamic conditions. It was also emphasized that there were decreases in the withdrawal strength as the time period were increased and the specific weight were decreased [5,8–10].

According to a study investigating the effects of the shapes of screw and nail; it was found that annularly threated nail and helically threated nail represented considerably higher withdrawal resistances as compared to smooth nails [7]. A kind of linear relationship was determined between nail and screw diameter and the withdrawal strength in various investigations. Within this context, it was found that increments in nail and screw diameters yielded increases in the resultant withdrawal strengths. In addition, it was also found that there was no relationship between screw length and withdrawal strength while the diameter of screw had a linear relationship [11–14].

In addition to the effective factors mentioned above, some other factors such as glue type and layer thickness are known to be influential on the withdrawal strength of nail and screw and some contradictory findings about this effect were encountered in various studies. For instance, for laminated specimens that were prepared with beech layers of 2 and 4 mm thickness by the use of Polyurethane (PU) and Polyvinylacetate (PVAc) glues, the resultant experiments on radial sections showed that the layer thickness had no effect on the withdrawal strength of nail, whereas the type of glue used was found to be influential. According to this, the withdrawal strengths of nail for the specimens prepared with the use of PU glue was found to be higher than those of the ones prepared with PVAc glue [15].

3. Materials and test method

Beech (*Fagus orientalis Lipsky*) and poplar (*Populus nigra*) were used as wood materials in the test specimens. Beech was provided from the Research Forest of Bolu-Mengen Yaylacık and poplar was from Hacettepe-Beytepe.

Beech and poplar used in the test specimens were cut to dimensions of 70 mm × 600 mm complying the standards of TS 4176 [16] and ISO 4471 [17], and the lumbers cut were dried to the moisture of 12% in dehumidification furnaces, this was followed by cutting them into panels of 6 mm thickness by the use of a circular saw. The panels were then sanded till the thicknesses of 4 and 5 mm were achieved. Finally, these panels were used in the preparation of test specimens.

In the preparation of test specimens two different types of glues were used. These were the glues of Polyvinylacetate (PVA) (Kleiberit 303) [18], which was suitable for applications in interiors and dry spaces and Polyurethane (PU) (Bizon Timber PU Max Express) [19], which was suitable for applications in open (exposed to outdoor conditions) and humid spaces. PVAc (Kleiberit 303) is a glue type which has D3 grade for adhesion according to BS EN 204 [20] whereas Polyurethane-PU (Bizon timber max express) has the grade of D4 for adhesion according to BS EN 204.

The test specimens were prepared using the layers which were obtained from the woods of beech and poplar by 'slicing method' and which were glued to each other in two different compositions by the use of PVAc (Kleiberit 303) and PU (Bizon timber PU-max express) glues. Apart from these test specimens, some control specimens were prepared from solid beech and poplar wood. After the preparation of layers with 4 and 5 mm thicknesses, they were glued by the use of Kleiberit 303 (PAVc) and Bizon (timber express PU-max express) (PU) in such a way that 4 mm thick layers have 13 layers and 5 mm ones have 10 with grains being parallel to each other. After that 25 specimens were prepared having the dimensions of 50 × 50 × 150 mm for each group (as shown in Fig. 1) according to ASTM D 1761 [21], 5 of these

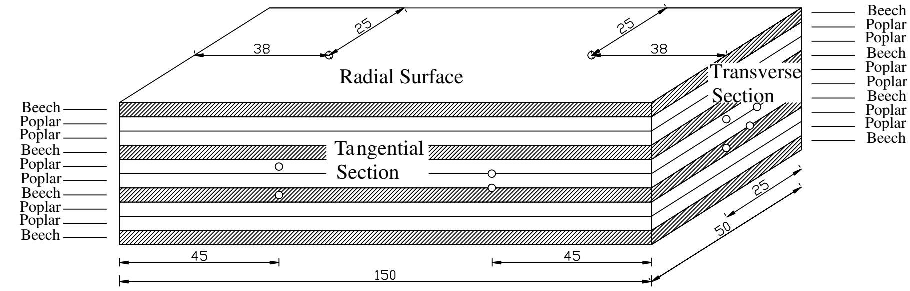

Fig. 1. PU5 and PVAc5 (5 mm layer thickness-10 layers) driving points of screws and nails.

specimens were selected as options and 20 of them were used for each different test conducted in the study.

The points where the nails and screws were drawn in were marked 25 mm away from the sides and 38 mm away from the corners of the surfaces perpendicular to the glue-line. Lead holes with the diameter of 70/100 of screw root diameter and 13 mm depth were opened to the screw points of screw withdrawal specimens. There were no lead holes opened to the nail withdrawal specimens. ASTM 1761 were also compared with EN 1382 [22] and determined similar statements with the dimensions of the specimens.

4. Testing procedures

Universal test machine with capacity of 4 tons was used in the experiments. In Figs. 1 and 2 the experiment set-ups and configuration of specimens were shown.

4.1. Tests for screw withdrawal

A total of 6 screws (22×50) were located to each specimen prepared according to the standard of ASTM D 1761 in such a way the screws were perpendicular to the driving surface with a portion of 35 mm being inside. Each pair of these 6 screws were screwed to previously opened lead holes in such a way that every single pair would be in touch with the tangential, radial and transverse sections, respectively. The screwing arrangement was kept same for the specimens of solid poplar and beech woods. For laminated elements screws were drawn to penetrate each layer through the glue-line. Screwing points were shown in Figs. 1 and 2 and the experiment set-ups were given in Figs. 3 and 4.

Tests were conducted by locating specimens into the testing machine according to the standard of ASTM D 1761. During these tests a pulling speed of 2.5 mm/min was applied until the screws were completely separated from specimens. For each of the test results belonging to 20 different specimens were recorded. Although withdrawal parameter is declared as a parameter in EN 1382 (TS EN

Fig. 3. Experiment set-up of PVAc5 tangential surface and test of poplar–poplar intersection in transverse surface.

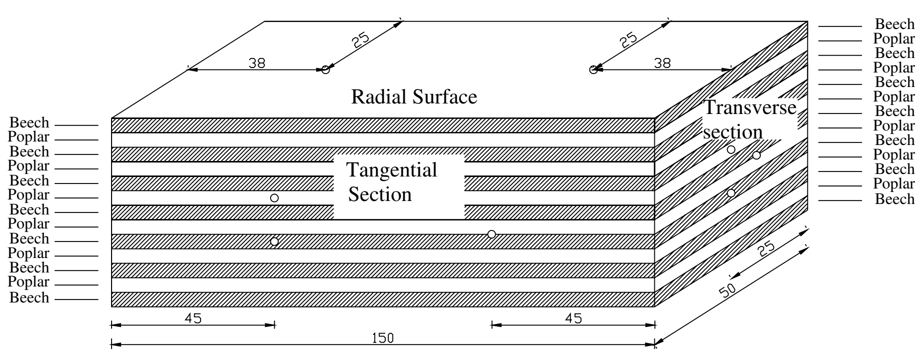

Fig. 2. PU4 and PVAc4 (4 mm layer thickness-13 layers) driving points of screws and nails.

Fig. 4. Experiment set-up for radial surface.

1382), surface area of nail and screw-exposed the friction is realized more expressive for this study and withdrawal strength of screws for the related surfaces of test specimens was computed according to the equation given below (see Figs. 5 and 6):

$$\sigma_s = \frac{P_{max}}{2\pi rh},$$

where σ_s is the withdrawal strength of screw (N/mm^2), P_{max} is the maximum load (N), $2\pi rh$ the surface area of screw-exposed to friction (mm^2).

4.2. Tests for nail withdrawal

A total number of six steel nails, having circular sections with 2.67 mm diameter and 50 mm length and surface of which was not covered with any kind of substance [23], were drawn in the conditioned specimens to the point

Fig. 5. Experiment set-up for nail withdrawal.

Fig. 6. Experiment in transverse surface and set-up of radial surface.

where 35 mm of the total length was completely penetrated the surface from the points indicated in Figs. 1 and 2. The nailing set-up was prepared similar to the one used for screws, and a pulling force with a constant speed of 2.5 mm/min was applied until the nails were completely separated from the specimens. Maximum applied force at the point of separation was recorded from the indicator of the test machine. Current equation was used to calculate the withdrawal strength of nails:

$$\sigma_n = \frac{P_{max}}{2\pi rh},$$

where σ_n is the withdrawal strength of nail (N/mm^2), P_{max} is the maximum load (N), $2\pi rh$ the surface area of nail-exposed to friction (mm^2).

5. Test results

An F-test was used to determine the effects of two different glues (PVAc and PU) and two different layer thicknesses (4 and 5 mm) investigated in this study. In cases where variations between different groups appeared to be significant, comparisons were made with Duncan test with ($\alpha = 0.05$) level of confidence. Calculations for analysis of variance (ANOVA), arithmetic means, standard deviations and minimum and maximum values were computed using the software of SPPS 11.5 (Statistical Package for Social Science) [24].

5.1. Test results of withdrawal strength of screws

According to the F-test applied to the results of screw withdrawal tests for transverse, radial and tangential surfaces, a difference with a level of significance of $\alpha = 0.05$ and level of confidence of 95% was found among the investigated materials ($P < 0.05$). According to the results of Duncan test, the highest withdrawal strength of screw was detected for solid beech, this was followed by PU5 beech, PVAc5 beech, PU4 beech and PVAc4 beech, respectively [1]. Below were given the test results for which statistically proved differences could not be found with relevant analyses:

- Between layers of PU5 beech, PVAc5 beech, PU4 beech, PVAc4 beech.
- Between interfaces of PU5 poplar–beech, PVAc5 poplar–beech, PU4 poplar–beech and PVAc4 poplar–beech.
- Between layers of PU5 poplar, PVAc5 poplar, PU4 poplar and PVAc4 poplar.
- Between interfaces of PU5 poplar–poplar and PVAc5 poplar–poplar.

In Table 1 statistical values of the average withdrawal strength of screw for transverse and tangential surfaces of composite laminated materials and solid wood materials are given. Average values for radial section are given in Table 2.

Table 1
Transverse and tangential surface-statistical average values of screw withdrawal

Materials	Statistical screw values	
	Transverse surface average values (N/mm^2)	Tangential surface average values (N/mm^2)
Solid beech	12,763	22,605
Solid poplar	9434	11,649
PU5 poplar layer	8544	11,937
PU5 beech layer	11,775	21,878
PU5 poplar–poplar intersection	7039	9521
PU5 poplar–beech intersection	10,761	15,383
PVAc5 poplar layer	8449	11,677
PVAc5 beech layer	11,626	21,622
PVAc5 poplar–poplar intersection	6770	9404
PVAc5 poplar–beech intersection	10,571	15,210
PU4 poplar layer	8251	11,420
PU4 beech layer	11,473	21,403
PU4 poplar–beech intersection	10,393	14,903
PVAc4 poplar layer	8110	11,244
PVAc4 beech layer	11,373	21,221
PVAc4 poplar–beech intersection	10,306	14,754

Table 2
Radial surface-statistical average values of screw withdrawal

Materials	Statistical value
	Radial surface average value (N/mm^2)
Solid beech	22.222
Solid poplar	10.691
PU5	13.805
PVAc5	14.645
PU4	17.693
PVAc4	17.582

5.2. Test results of withdrawal strength of nails

According to the *F*-test conducted for withdrawal strength of nails, a difference with a level of significance of $\alpha = 0.05$ and level of confidence of 95% was found among the investigated materials ($P < 0.05$). According to the results of Duncan test, the highest withdrawal strength of nails for transverse, radial and tangential surfaces was obtained from solid beech, this was followed by PU5 beech, PVAc5 beech, PU4beech and PVAc4 beech and other materials, respectively. Test results for which statistically proved differences could not be found with relevant analyses [1], were as follows:

- Between layers of PU5 beech, PVAc5 beech, PU4 beech and PVAc4 beech.
- Between interfaces of PU5 poplar–beech, PVAc5 poplar–beech, PU4 poplar–beech and PVAc4 poplar–beech.
- Between layers of solid poplar, PU4 poplar and PVAc5 poplar.
- Between layers of PU4 poplar, PVAc4 poplar and layers of PU5 poplar–poplar and PVAc5 poplar–poplar.

In Table 3 transverse and tangential surface-statistical average values of nail withdrawal for solid and composite laminated wooden materials and for points at the interface of two different layers are given. Radial surface-statistical average values of nail withdrawal for solid and composite laminated wooden materials were given in Table 4.

Table 3
Transverse and tangential surface-statistical average values of nail withdrawal

Materials	Statistical nail values	
	Transverse surface average values (N/mm^2)	Tangential surface average values (N/mm^2)
Solid beech	2998	4246
Solid poplar	1274	2000
PU5 poplar layer	1237	1877
PU5 beech layer	2215	2736
PU5 poplar–poplar intersection	1025	1363
PU5 poplar–beech intersection	1448	2375
PVAc5 poplar layer	1247	1850
PVAc5 beech layer	2174	2651
PVAc5 poplar–poplar intersection	1046	1308
PVAc5 poplar–beech intersection	1482	2324
PU4 poplar layer	1131	1615
PU4 beech layer	2112	2634
PU4 poplar–beech intersection	1465	2245
PVAc4 poplar layer	1059	1567
PVAc4 beech layer	2099	2576
PVAc4 poplar–beech intersection	1414	2221

Table 4
Radial surface-statistical average values of nail withdrawal

Materials	Statistical nail values
	Radial surface (average values N/mm^2)
Solid beech	4931
Solid poplar	1976
PU5	3578
PVAc5	3493
PU4	3915
VAc4	3813

6. Conclusion

Based on six specimen types the withdrawal strength of nails and screws are evaluated in this study. The experimental results justify the following conclusions:

- In all tests the withdrawal strength of screw was found higher than that of nail.
- In tangential surface; solid beech materials showed the best nail and screw holding strength and this result was followed by PU5 beech layer, PVAc5 beech layer, PU4 beech layer and PVAc4 beech layer, respectively.
- For tangential and transverse surfaces, nails and screws that were drawn in beech layers showed better withdrawal strength than other layers and interfaces.
- The lowest values were detected for transverse surface. The reason for this was that nails and screws drawn perpendicularly in the surfaces were also in the direction of grain configuration of tested materials. Therefore, it was concluded that it would be useful to take into consideration of the effects grain direction on withdrawal strengths.
- In radial surface the type of glue used was found to be influential. In this respect, higher resistances were determined for the specimens in which Polyurethane glue was used.
- For radial surfaces, nails and screws drawn perpendicularly to the surface showed better results for 4 mm thick layer and 13 layers specimens. The ratio of beech being higher in such specimens played a significant role in resultant strengths.
- For tangential and transverse surfaces the effect of glue type on withdrawal strength of nails and screws could not be determined.
- In both transverse and radial surfaces, the withdrawal strength measured for poplar–poplar interface was found smaller that the one measured for solid poplar samples. It was seen that resistances in the glue-line had a tendency to decrease. For this reason, it was conclude that better results could be achieved if the driving line of nail and screw did not coincide with the glue-line in laminated specimens.
- The type of glue used did not have considerable effects on withdrawal strength of nails and screws which were located at the interface of two different layers.
- Although it was considered that the values measured for the interface of poplar–beech would be the mean of those measured for solid beech–poplar, some values below this mean were recorded during the experiments. In other words, it was seen that two different tree types did not affect the resistances equally.

Acknowledgements

The research Project was funded by The Scientific and Technical Research Council of Turkey (TUBITAK), Project No. 1021022, Ictag-I 671 and Gazi University Project No. 06/2003-72.

References

[1] Celebi G, Kilic M. Determination of performance characteristics of composite laminated construction material produced from beech and poplar. The Scientific and Technical Research Council of Turkey (TUBITAK), Project No. 1021022, Ictag-I 671, Ankara; 2004.
[2] Soltis AL. Fastenings. Wood handbook: wood as an engineering material. General Technical Report FPL-GTR-113. Madison (WI): US Department of Agriculture, Forest Service, Forest Products Laboratory; 1999. p. 7.1–29.
[3] Ferah O. Determination of withdrawal strength of screw and nail in some important trees. Institute of Forest Research Technical Bulletin, No. 252, Ankara; 1991. p. 51–72.
[4] Akyıldız M, Malkocoglu S. Wood screw withdrawal resistance of some important tree species growing in Eastern Blacksea region. J Artvin Forest Facul Kafkas Univ 2001;2(1):54–60.
[5] Bacher F. Nailing of wet wood. Holzforsch Holzverw (Wien) 1964;16(3):6–55.
[6] Kanaomori K, Chino A, Kawarada Y. Studies on the withdrawal resistance of nail effect of changing moisture content in wood and time after nail driving. J Hokkaido Forest Prod Res Institut (Jpn) 1978;67:103–28.
[7] Rammer DR, Winistorfer SG, Bender DA. Withdrawal strength of threaded nails. J Struct Eng 2001;127(4):442–9.
[8] Broker FW, Krause HA. Preliminary investigations on the holding power of dynamically loaded wood screws. Holz Roh Werkst 1991;49(10):381–4.
[9] Kim SC. Studies on the static withdrawal resistance on nail in wood. Wood Indus (Korea) 1979;7(1):8–11.
[10] Noguchi M, Sugihara H. Studies on static withdrawal resistance of nail. Effect Driving Method Time Driving Wood Res (Kyoto) 1961;25:1–13.
[11] Eckelman CA. Predicting withdrawal strength of sheet-metal-type screws in selected hardwoods. Forest Prod J 1978;28(8):25–8.
[12] Kjucukov G, Encev E. The effect of screw dimensions on the withdrawal resistance in fir wood. Holztechnologie 1977;18(1):26–9.
[13] Kjucukov G, Encev E. The effect of screw dimensions on the withdrawal resistance in beech wood. Holztechnologie 1977;18(3):149–51.
[14] Ors Y, Ozen R, Doganay S. Screw holding ability of wood materials used in furniture manufacture. Turk J Agr Forest 1998;22(4):29–34.
[15] Senay A. Technological properties of laminated wood material. Ph.D. thesis. Institute of Science and Technology, Istanbul University; 1996. p. 40–75.
[16] TS 4176. Wood-sampling sample trees and long for determination of physical and mechanical properties of wood in homogeneous stands. TSE Institute of Turkish Standards; 1984.
[17] ISO 4471. Wood-sampling sample tree and logs for determination of physical and mechanical properties of wood in homogeneous stands. ISO; 1982.
[18] Catalog of Kleiberit 303; 2004.
[19] Catalog of Bizon Timber PU Max; 2004.

[20] BS EN 204. Non structural adhesives for jointing of wood and derived timber products. British Standards, England; 1991.
[21] ASTM D 1761. Standard methods of testing mechanical fastener in wood, nail, staple or screw withdrawal test. USA: ASTM International; 2000.
[22] EN 1382 and TS EN 1382 timber structures, test methods, withdrawal capacity of timber fasteners.
[23] TS 155. Nails. TSE Instıtute of Turkish Standards; 1978.
[24] SPSS 11.5. Statistical package for social science, Licence No. 30731 36090 778423 67348.