Bekir Cihad Bal[1]

SCREW AND NAIL HOLDING PROPERTIES OF PLYWOOD PANELS REINFORCED WITH GLASS FIBER FABRIC

Keywords:
Reinforcement
Glass fiber
Screw withdrawal
Plywood

ABSTRACT: In this study, plywood and reinforced plywood with glass fiber fabric were produced with rotary peeled poplar veneers using phenol formaldehyde adhesive. Screw and nail holding tests were conducted to obtain the characteristics of the plywood and reinforced plywood boards. One control group and three different test groups were used. The effects of glass fiber fabric on the screw direct withdrawal, screw-head pull-through, and lateral nail resistance were determined. The results of the tests indicated that the reinforced plywood's resistances to direct withdrawal of the screw, screw-head pull-through, and lateral nail resistance were significantly higher than those of the unreinforced plywood. In addition, reinforcement of the plywood boards provided longer displacement at maximum load.

Histórico:
Recebido 01/08/2016
Aceito 06/02/2017

PROPRIEDADES DE FIXAÇÃO DE PARAFUSOS E PREGOS EM PAINÉIS COMPENSADOS DE MADEIRA REFORÇADOS COM TECIDO DE FIBRA DE VIDRO

Palavras chave:
Reforço
Fibra de vidro
Arrancamento de parafuso
Compensado

RESUMO: Neste estudo, painéis compensados e painéis compensados reforçados com tecido de fibra de vidro foram produzidos com lâminas do desenrolamento do álamo usando adesivo de fenol-formaldeído. Testes de fixação de parafusos e pregos foram realizados para obter as características dos painéis compensados e painéis compensados reforçados com tecido de fibra de vidro. Os efeitos do tecido de fibra de vidro sobre o arrancamento direto do parafuso, puxado pela sua cabeça, e resistência lateral do prego foram determinados. Os resultados dos testes indicaram que a resistência do painel reforçado ao arrancamento direto do parafuso, puxado pela sua cabeça, e resistência lateral do prego foram significativamente superiores em relação aos valores encontrados para compensados não reforçados. Além disso, o reforço em painéis compensados resultou em maior elongação na carga máxima.

Correspondência:
bcbal@hotmail.com

DOI:
10.1590/01047760201723012210

[1] Kahramanmaraş Sütçü İmam University - Kahramanmaraş, Akdeniz, Turkey

INTRODUCTION

Solid wood and wood-based composite boards are used in constructing buildings because they have some superior advantages, such as easy processability, low price, good aesthetic appearance, and light weight. But, in addition to those positive features, these materials have some negative features, such as low load-carrying capacity and other low mechanical properties (DEMIRKIR et al., 2013; GAFF et al., 2015). Different fibers, such as natural fibers and synthetic fibers, are used to reinforce wood-based composite boards (XU et al., 1998a; CAI, 2006; MOHEBBY et al, 2011; GÜNTEKIN and AYDIN, 2015) and load-carrying structural wooden elements (BORRI et al, 2013; BASTERRA et al, 2012). The main aim of these reinforcement related studies was to obtain a new composite material with high mechanical performance. For this, many researchers have investigated reinforced materials using different types of fibers. For example, Wangaard (1964) and Biblis (1965) were the pioneers of reinforcing wood using fiberglass in their experiments. Xu et al. (1998a) investigated the effects of the length of the fibers and their orientation on the elasticity of fiber-reinforced plywood. Xu et al. (1998b) studied the mechanical properties of plywood reinforced by bamboo or jute and reported some positive results. Basterra et al. (2012) studied reinforced duo beams with flax fibers, glass fibers, and carbon fibers. Borri et al. (2013) reinforced timber beams with hemp fibers, flax fibers, basalt fibers, and bamboo fibers. Bal (2014a-b) investigated some of the mechanical properties of reinforced laminated veneer lumber with glass fiber fabric using phenol formaldehyde resin. Bal et al. (2015) investigated some of the technological properties of poplar plywood reinforced with glass fiber fabric and reported some favorable results.

Generally, when wood is used for construction, the covering materials, such as plywood and oriented strand board (OSB), are fastened to the main wooden members, such as solid lumber, laminated veneer lumber, and parallel strand lumber. Different types of screws and nails are used to fasten the members to each other. The durability of construction is dependent on fastening the members at the connection points between the main wooden members and the covering members. In some cases, such as seismic activity and strong winds, failures can occur at the connection points even though the wooden members have very high mechanical performance (HERZOG; YEH, 2006). In these cases, screws and nails may be withdrawn or the cover materials may break away from the head of the fastener. There are limited studies concerned with screw tests of plywood that have been reinforced by various methods. Candan and Akbulut (2014) investigated the flexural properties and resistance to the withdrawal of screws of reinforced plywood using nanomaterials at different loading levels, and some positive results were reported.

In accordance to the previous studies mentioned above, it can be said that the researchers reported some increases of mechanical properties. Generally, previous studies have investigated the flexural properties and performance of the connection points of reinforced materials, such as lumber that has been sawn and structural composite lumbers. There have been no investigations of the screw and nail holding performance of plywood reinforced with glass fibers. Thus, the main aim of this study is to investigate the screw and nail holding performance of plywood reinforced with different combinations of glass fiber fabric.

MATERIAL AND METHODS

Material

In this study, plywood panels (control group) were produced with poplar rotary veneers using phenol formaldehyde adhesive. In addition, reinforced plywood panels (test groups) were produced with poplar veneers and glass fiber fabric using the same adhesive. Poplar veneers (*Populus deltoides* Bartr. I-77/51) were obtained from a plywood factory. The dimension of the veneers were 2.7 x 650 x 2000 mm (thickness x width x length). The moisture content of the veneers was 7±1 %. Phenol formaldehyde (PF) adhesive was obtained from Polisan A.Ş. Some properties of the PF adhesive are described as follows: specific gravity at temperature 20 °C of 1.2 g/cm^3; solid content is 47±1%, pH is 10.5-13, viscosity at temperature 20 °C is 250-500 Cp. PF adhesive was used in its pure form. Glass fiber fabric was bought from Fibroteks A.Ş. The weight of the woven glass fiber was 500 g·m^{-2}, and the knitting type of fabric was 'plain-weave'. Glass fiber fabric was obtained as a roll, and was divided into small sheets (600 x 600 mm).

Plywood production

For plywood production, rotary peeled veneers were cut to the dimensions of 2.7 x 600 x 600 mm. Veneers were glued manually using a roller. No additives or fillers were used with the PF adhesive. Adhesive in the amount of 220 g·m^{-2} was applied on the surfaces of the veneer. Five-ply veneers were used for each panel. The adhesive was applied to the loose side of the veneers. The veneers were piled on each other crosswise. Plywood panels were pressed in a laboratory using an electrically-heated press. The press pressure was 7 kg·cm^{-2}, the press time was 18 minutes, and the press temperature was 140 °C. The 'A' group of plywood panels was produced using only veneer sheets. The B, C, and D groups of plywood panels were produced with veneers and glass fiber sheets, as shown in Figure 1 and Figure 2.

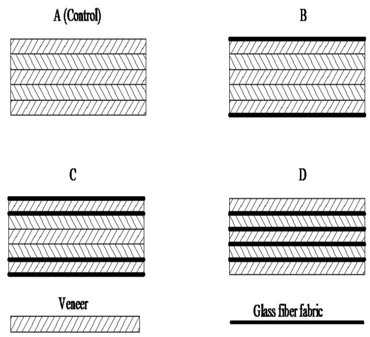

FIGURE 1 Schematic representation of the plywood groups.

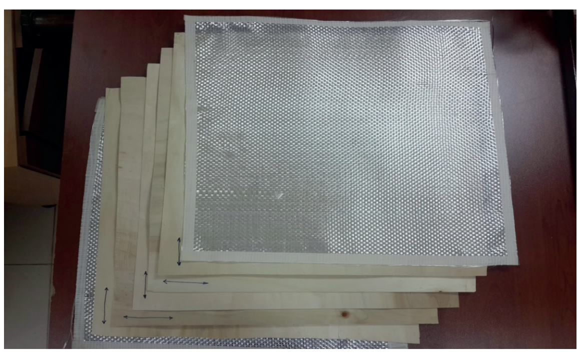

FIGURE 2 Poplar veneers and glass fiber sheets for B group.

Method

The direct withdrawal of the screw, the screw-head pull-through, and the lateral nail resistance tests were conducted according to ASTM D1761-12 with the exception of the dimensions of the samples.

For the screw direct withdrawal (Figure 3A) and the screw-head pull-through (Figure 3B), the tests were conducted on samples with the dimensions of 13 x 75 x 75 mm (thickness x width x length). The dimensions of the flathead screw were as follows, total length of 45 mm, length of the threaded portion of 30 mm, diameter of the shank of 4 mm, diameter of the head of 8.5 mm, and diameter of the threaded portion of 4.5 mm. Fourteen test samples were prepared for each group. No pilot holes were drilled for screw-test samples. The test speed was 3 mm·min^{-1} for the screw direct withdrawal and screw-head pull-through tests. The tests were performed on a Losenhausen testing machine.

Lateral nail resistance was tested on samples with the dimensions of 13 x 50 x 250 mm (thickness x width x length). The lateral nail resistance test was performed as shown in Figure 3C. The plywood test samples were nailed to solid beech wood. No pilot hole was drilled for the nail test samples. The nails were driven into the plywood until the head of the nail was flush with the surface of the plywood. The dimensions of the plywood were 13 x 50 x 300 mm, and the dimensions of the main member (beech wood) were 50 x 50 x 200 mm (thickness x width x length). The samples used to test lateral nail resistance were prepared for both the parallel and perpendicular directions to the grain of the surface layers. Twelve test samples were prepared for each group. Common nails that had dimensions of 3 x 60 mm were used in the tests. The nails were hammered manually into the test samples. The nails were driven as nearly perpendicular to the surface of the specimen as possible. The speed of the lateral nail resistance tests was 8 mm·min^{-1}.

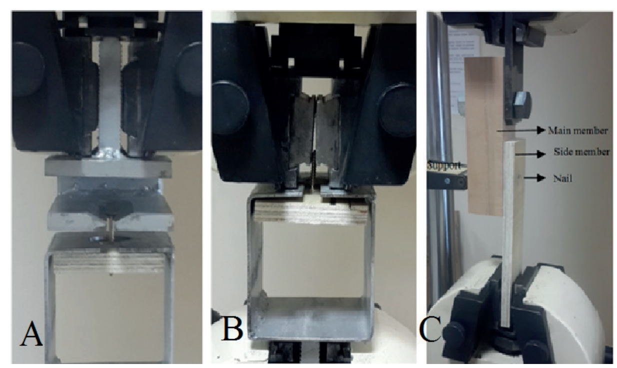

FIGURE 3 A) Screw direct withdrawal, B) screw-head pull-through, C) lateral nail resistance test.

RESULTS AND DISCUSSION

Density, maximum load, and displacement at maximum load at the end of tests of the screw direct withdrawal, screw-head pull-through, and lateral nail resistance tests are shown in Table 1. In addition, significance levels of the ANOVA and Tukey test results (shown in lower case) are given in the same table. When the data in Table 1 were analyzed, it was apparent that the density values of the test groups were significantly higher than those of the control group. These results were expected because of the greater density of the glass fiber. Solid wood and wood-based composite materials have higher strength/density ratios (specific strength properties) than other engineering materials, such as concrete, metals, glass, and marble. Many researchers have reported the specific mechanical properties of engineered wood products in their studies (TANK; PU, 1997; LEE et al., 1999; BAO et al., 2001; BAL; BEKTAŞ, 2012; BAL; BEKTAŞ, 2014). Therefore, the density increase is the undesirable result of present study.

Table 1 provides the results of the maximum load and displacement at maximum load of the screw direct withdrawal tests. The maximum loads of the B, C, and D groups were higher than for the A group, but the C and D groups had values that were significantly higher than those of the A and B groups ($P < 0.001$). The increase in the values of the C and D groups was approximately 14% compared to the A group. In addition, displacement at maximum load of the test groups was higher than the control group, but the differences among the groups were not significant (NS). It can be said that the glass fiber fabric and adhesive used to bond glass fiber enhanced the screw withdrawal strength of the C and D groups. In previous studies, it was determined that many factors affect the screw withdrawal strength of materials, such as the density of the wood, the direction of the grain, the moisture content of the wood, and the type of screws used (WANG et al., 2007; TAJ et al., 2009; ÖZÇIFTÇI, 2009; BAL et al., 2013, ESHAGHI et al., 2013)

In the usage areas, the failure of screws occurred due to the threads and due to the failure of the heads of the screws. Therefore, we conducted tests to determine these characteristics of the screws. One of the tests was the screw-head pull-through test. Maximum load and displacement at maximum load of screw-head pull-through test of the B, C, and D groups were greater than those in the control group. The values of the C and D groups were greater than those for the A and B groups, and differences were significant ($p < 0.001$).The increase of maximum load and displacement at maximum load of the D group were approximately 32 and 50%, respectively. The increase that was obtained was more remarkable than the other test results presented here. Another remarkable result was that the results of the screw-head pull-through tests were greater than those of the tests of the direct withdrawal tests. The reason for this difference was that the diameter of the screw head (8.5 mm) was greater than that of the threads of the screw (4.5 mm). Another reason was the resistance of the glass fiber. Glass fiber is drilled with a diameter of 4.5 mm when the screw is screwed. The screw is pulled from the same hole with a diameter of 4.5 mm when the screw direct withdrawal test is conducted. But, when the screw head is pulled, the head (8.5 mm) of the screw is forced through the 4.5 mm-diameter hole.

TABLE 1 Screw and Nail test data and ANOVA and Tukey results

			SDW		SHPT		LNR Perpendicular		LNR Parallel	
		D	Lmax	Dmax	Lmax	Dmax	Lmax	Dmax	Lmax	Dmax
	Units	$g \cdot cm^{-3}$	N	mm	N	mm	N	mm	N	mm
A (Control)	x	0.443 a	1765 a	1.94	2282 a	6.2 a	2004 a	21.5	2115 a	18.3 a
	ss	0.022	137	0.28	290	1.98	214	5.2	220	2.6
	cov	4.86	7.8	14.9	12.7	31.9	10.7	24.0	10.4	14.1
B	x	0.528 b	1799 a	2.20	2509 a	7.5 ab	2153 ab	23.4	2282 ab	22.1 a
	ss	0.013	106	0.56	233	1.43	215	2.8	274	5.2
	cov	2.50	5.9	25.8	9.3	18.8	10.0	12.1	12.0	23.3
C	x	0.574 c	2006 b	2.33	2995 b	8.5 b	2371 b	24.3	2411 b	27.7 b
	ss	0.016	183	0.33	403	2.24	257	3.2	200	4.2
	cov	2.78	9.1	14.3	13.4	26.3	10.8	13.3	8.3	15.1
D	x	0.579c	2014 b	2.25	3009 b	9.3 b	2372b	24.1	2531 b	27.9 b
	ss	0.04	269	0.35	382	2.33	202	4.0	266	3.6
	cov	6.91	13.3	15.8	12.7	25.0	8.5	16.6	10.5	12.8
ANOVA		***	***	NS	***	**	***	NS	**	***

SDW: screw direct withdrawal, SHPT: screw-head pull-through, LNR: lateral nail resistance, D: density, Lmax: maximum load, Dmax: displacement at maximum load. x: arithmetic mean, ss: standard error, cov: coefficient of variation.

Lateral nail resistance is a very important issue for wooden construction and buildings. It can occur at many connection points, but in some connection points at which the sheathing materials (plywood or OSB) are fastened to solid wood or structural composite lumber, the nail's head can be pulled through the sheathing material. This is one of the three major types of failures. The other two types are the nail being withdrawn from the main member and the splitting of the main member. In addition, Rammer (2010) showed that there were some different possibilities of wood bearing and nail bending at the end of lateral nail resistance, such as Modes I-IV. In the present study, Mode III type was observed at the end of the test.

Table 1 provides the lateral nail resistances in the perpendicular and parallel directions. The maximum loads of the B, C, and D groups in both the parallel and perpendicular groups were greater than that of the A group. The differences were significant, as indicated in the bottom line of Table 1. The increases of the perpendicular samples in the C and D groups were approximately 18% greater than the increases in the A group. For the parallel samples, this value was approximately 19%. The most remarkable increase was the displacement at maximum load of the C and D groups for the parallel samples (52%).

The maximum loads of the C and D groups were similar in both directions. The reason for this likely was that four glass fiber sheets were used for the C and D groups in different places. It can be inferred that the placement of the glass fiber sheets had no effect on the lateral resistance if the nails. However, when the related data were analyzed, it was apparent that the maximum load of parallel samples was greater than that of the perpendicular samples. It is well known that solid wood and wood-based composite materials, such as structural composite lumbers, plywood, and OSB, have different properties in the parallel and perpendicular grain directions (POTTER, 1976; ÖZEN, 1981; BIBLIS; CARINO, 2000; BEKHTA et al., 2009; DAOUI et al., 2011; CHANS et al., 2014; BAL; BEKTAŞ, 2014; IWAKIRI et al., 2015; DEMIRKIR; ÇOLAKOĞLU, 2015) because wood is a natural anisotropic material. Related to the plywood, some results were reported by Demirkir and Çolakoğlu (2015); they studied the effect of grain direction on lateral nail strength of structural plywood, and they stated the maximum load of perpendicular samples was significantly greater than that of parallel samples. In the same study, they noted that Potter (1976) determined that the lateral nail resistance was greater for the perpendicular samples than for parallel samples, while Hunt and Bryant (1984) determined opposite results, and Pirvu (2008) reported that the grain direction had no effect on the lateral nail strength of plywood. In previous studies of these discrepancies, some variables may have greater effects, such as the ply number of the plywood and the thickness of the veneer. It is known that as the number of ply increases in plywood, the discrepancy between parallel and perpendicular samples decreases (ÖZEN, 1981). But, in the present study, there was the effect of the glass fibers on the lateral nail resistance. The difference between the A group's perpendicular and parallel samples differed from the C and D groups. In a previous study it was reported that the support of the glass fiber fabric decreased the inequality in the modulus of elasticity and the modulus of rupture tests between the parallel and perpendicular samples (BAL et al., 2015).

At the end of tests, the C and D groups provided significant improvements. Therefore, the discussion was focused on the comparison of the A and D groups. The load-deformation curves of screw-head pull-through test samples of the A and D groups are given in Figure 4. The differences between the two groups are evident. The load-deformation curves of the D group were wavy after the elastic zone. It can be said that the effective factor for fluctuation was the glass fiber fabric. Figure 5 shows the load-deformation curves of the screw direct withdrawal test samples of groups A and D. In Figure 5, the fluctuation is lower than in Figure 4. This result was expected due to the dimensions of the screw head. Figure 6 shows the load-deformation curves of the lateral nail resistance test of the perpendicular samples, and Figure 7 shows the load-deformation curves of the lateral nail resistance test of the parallel samples. Another result that can be inferred from the figures is that the plastic region of test groups (B, C, D) was greater than that of the control group.

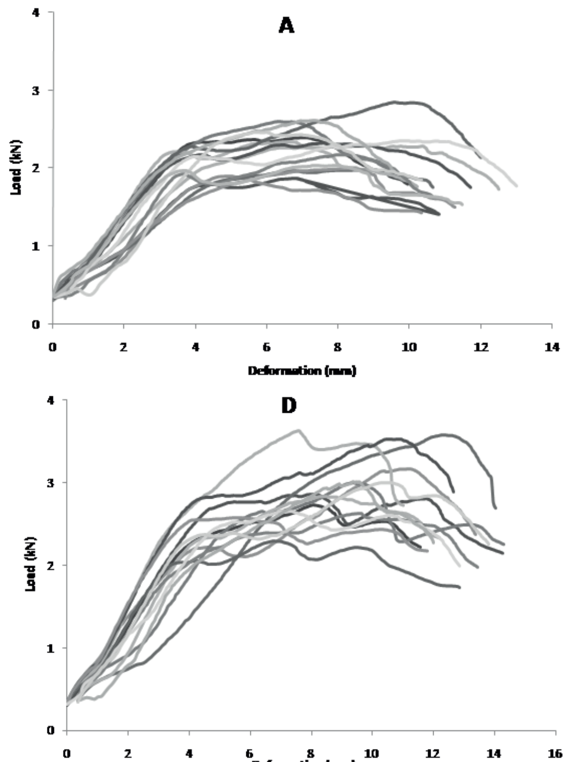

FIGURE 4 Load-deformation curves of screw-head pull-trough test samples.

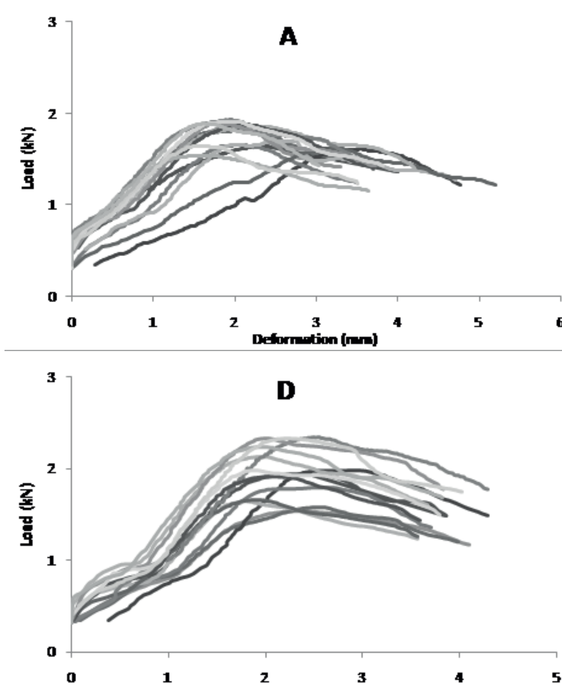

FIGURE 5 Load-deformation curves of screw direct withdrawal test samples.

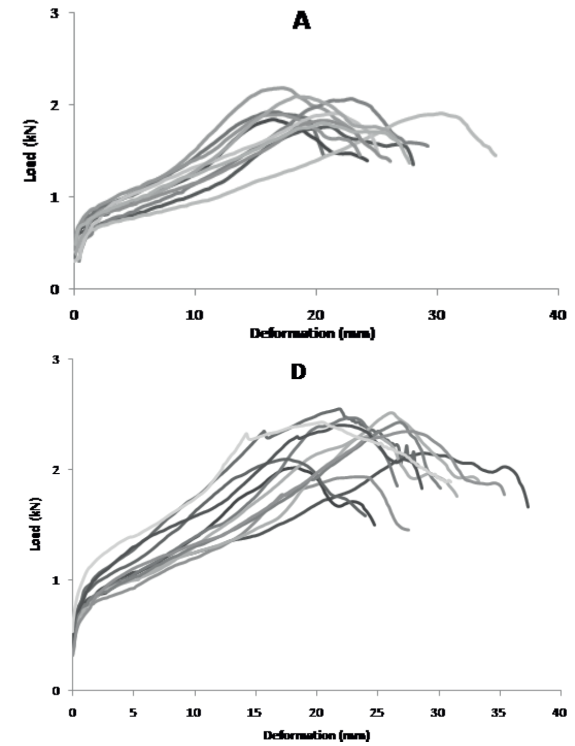

FIGURE 6 Load-deformation curves of lateral nail resistance test of perpendicular samples

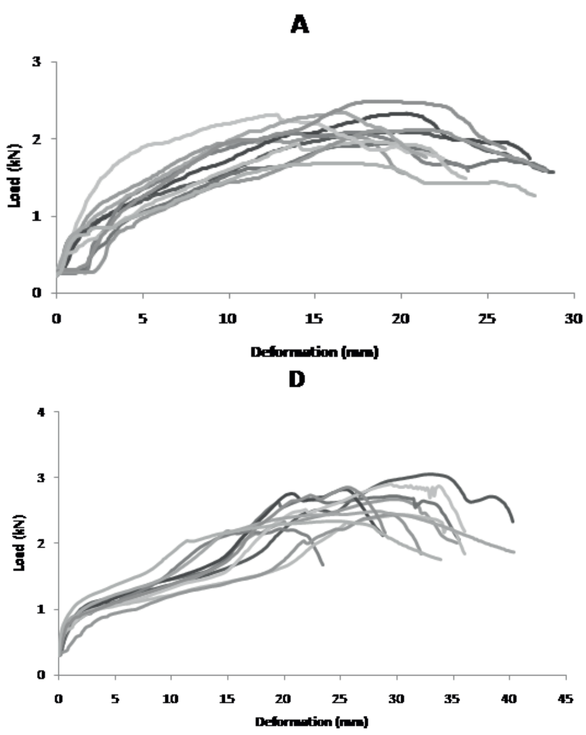

FIGURE 7 Load-deformation curves of lateral nail resistance test of parallel samples

CONCLUSIONS

In this study, the effects of glass fiber fabric on the screw direct withdrawal, screw-head pull-through, and lateral nail resistance were determined. According to the data that were obtained, we reached the following conclusions. The maximum load of the C and D groups was significantly greater than that of control groups for all of the tests. The differences between the C and D groups were not significant. The maximum loads of lateral nail resistance of the parallel groups were greater than those of the perpendicular groups. Displacements at maximum load of screw direct withdrawal and lateral nail resistance in the perpendicular samples were insignificant compared to the control samples. The property tested here that showed the greatest increase in the reinforced plywood panels was the screw head pull-through in both the maximum load and displacement at maximum load.

Consequently, it can be said that the effects of reinforcement with glass fiber fabric on the screw and nail strength of plywood are not very high. But, this finding should be evaluated and compared with the results of previous studies of reinforced plywood. In future experiments, the screw or nail strength and the strength of the reinforced connection points should be investigated completely.

ACKNOWLEDGEMENT

The author thanks Research Fund of Kahramanmaraş Sütçü İmam University for financial support of this study (Project No: 2014/1-17M).

REFERENCES

ASTM D 1761-12. Standard test methods for mechanical fasteners in wood, **American Society of Testing and Materials**. 2006.

BAL, B.C.; BEKTAŞ, I. The effects of some factors on the impact bending strength of laminated veneer lumber. **BioResources v.**7, n.4, p. 5855–5863. 2012.

BAL, B. C.; ÖZDEMİR, F.; ALTUNTAŞ, E.Masif ağaç malzeme ve tabakalı kaplama kerestenin vida tutma direnci üzerine karşılaştırmalı bir çalışma,**Düzce Üniversitesi Ormancılık Dergisi,**v.9, n.2, p. 14-22. 2013.

BAL, B.C.; BEKTAŞ, I. Some mechanical properties of plywood produced from eucalyptus, beech, and poplar veneer. **Maderas. Ciencia y Tecnol.** 16: 99–108. 2014.

BAL, B.C. Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber. **Construction Building Material,**v.51, n.2014, p. 9–14, 2014a.

BAL, B.C. Some physical and mechanical properties of reinforced laminated veneer lumber. **Construction Building Material**,v.68, n.2014, p. 120–126. 2014b.

BAL, B.C.; BEKTAŞ, İ.; MENGELOĞLU. F.; KARAKUŞ, K.; DEMİR, H.Ö.;Some technological properties of poplar plywood panels reinforced with glass fiber fabric, **Construction Building Material**, v.101, n.1, p. 952-957, 2015.

BAO, F.; FU, F.; CHOONG, E. T.; HSE, C. Contribution factor of wood properties of three poplar clones to strength of laminated veneer lumber, **Wood and Fiber Science**,v.33 n.3, p. 345-352, 2001.

BASTERRA, LA, ACUNA, L, CASADO, M, LOPEZ, G, BUENO, A. Strength testing of Poplar duo beams, Populus x euramericana (Done) Guinier cv. I-214, with fiber reinforcement, **Construction Building Material**.v.36, n.2012, p. 90-96, 2012.

BEKHTA, P.; HIZIROGLU, S.; SHEPELYUK, O. Properties of plywood manufactured from compressed veneer as building material. **Materials & Design**, v.30, n.4, p. 947-953, 2009.

BIBLIS, E.J. Analysis of wood-fiberglass composite beams within and beyond the elastic region, **Forest Product Journal**,v.15, n.2, p. 81-89, 1965.

BIBLIS, E. J.; CARINO, H. F. Flexural properties of southern pine plywood overlaid with fiberglass-reinforced plastic. **Forest Product Journal,**v.50, n.4, p. 34-36, 2000.

BORRI. A.; CORRADI, M.; SPERANZINI, E. Reinforcement of wood with natural fibers, **Composites: Part B**. 53 (2013): 1-8. 2013.

CAI Z. Selected properties of MDF and flakeboard overlaid with fiberglass mats. **Forest Product Journal**,v.56, n.11/12, p.142-146, 2006.

CANDAN, Z.; AKBULUT, T. Nano-engineered plywood panels: Performance properties. **Composites Part B: Engineering**, v.64, n.2014, p.155-161, 2014.

CHANS, D. O.; CIMADEVILA, J. E.; GUTIÉRREZ, E. M. Orientation of bars glued on glued laminated products: Parallel vs. perpendicular. **Composites Part B**: **Engineering**, v.62, n.2014, p. 97-103, 2014.

DAOUI, A.; DESCAMPS, C.; MARCHAL, R.; ZERIZER, A. Influence of veneer quality on beech LVL mechanical properties. **Maderas. Ciencia y Tecnología**, v.13, n.1, p. 69-83, 2011.

DEMIRKIR, C.; COLAK, S.; AYDIN, I. Some technological properties of wood–styrofoam composite panels, **Composites Part B: Engineering**, v.55, n.2013, p.513-517, 2013.

DEMIRKIR, C.; COLAKOGLU, G. The effect of grain direction on lateral nail strength and thermal conductivity of structural plywood panels, **Maderas Ciencia y Tecnologia**, v.17, n.4, p.469-478, 2015.

ESHAGHI, S.; FAEZIPOUR, M.; TAGHIYARI, H.R. Investigation on lateral resistance of joints made with drywall and sheet metal screws in bagasse particleboard and comparison with that of commercial MDF. **Maderas. Ciencia y Tecnología**, v.15, n.2, p. 127-140, 2013.

GAFF, M.; GAŠPARÍK, M.; BORŮVKA, V.; HAVIAROVÁ, E.Stress simulation in layered wood-based materials under mechanical loading. **Materials and Design**, v.87, n.2015, p. 1065-1071, 2015.

GÜNTEKIN, E.; AYDIN, T.Y. Kızılçamdan (*Pinus brutia* Ten.) Üretilen Tabakalı Kerestede Cam Lifi ve Çelik Plaka ile Güçlendirmenin Eğilme Performansına Etkisi. **Kastamonu Üniversitesi Orman Fakültesi Dergisi**, v.15, n.1, p.73-77. 2015.

HERZOG, B.; YEH, B. Nail withdrawal and pull-through strength of structural-use panels. **In Proceedings of the 9 th World Conference on Timber Engineering**, pp: 6-10. 2006.

HUNT, R.D.; BRYANT, A.H. Nailed joints for timber structures, **Proceeding of Pacific Timber Engineering Conference**, Auckland, New Zealand, May. pp. 616-621. 1984.

IWAKİRİ, S., NİELSEN, I. R., & ALBERTİ, R. A. Evaluation of the influence of veneer composition in structural plywood of Pinus elliottii and *Eucalpytus saligna*. **Cerne,** v. *6, n.* 2, p. 019-024. 2015.

LEE, J. N.; TANG, R. C.; KAISERLIK, J. H. Edge static bending properties of yellow-poplar laminated veneer lumber: effect of veneer-joint designs, **Forest Product Journal**, v.49, n.7/8, p. 64-70. 1999.

MOHEBBY. B.; TAVASSOLI, F.; KAZEMI-NAJAFI, S. Mechanical properties of medium density fiberboard reinforced with metal and woven synthetic nets, **European Journal of wood and Wood Products**, v.69, n.2, p.199-206, 2011.

ÖZÇIFÇI, A. The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber. **Materials & Design**, v.30, n.7, 2355-2358. 2009.

PIRVU, C. Structural Performance of Wood Diaphragms with Thick Panels, **Canadian Forest Service** No. 13, Final report. FPInnovations Forintek, March. 2008.

POTTER, F.H. Grain direction and lateral loading, The Wood Engineering Group, **IUFRO**, Division 5, Denmark. 1976.

RAMMER, D.R. Fastenings, **Wood handbook, Wood as Engineering Material.** General Technical Report, FPL, GTR 190, Madison. 2010.

TAJ, M. A.; NAJAFI, S. K.; EBRAHIMI, G. Withdrawal and lateral resistance of wood screw in beech, hornbeam and poplar, **European Journal of wood and Wood Products**, v.67, n.2,p. 135-140. 2009.

TANG, R.C.; PU, J.H. Edgewise bending properties of laminated veneer lumber: Effect of veneer grade and relative humidity, **Forest Product Journal**,v.47, n.5, p. 64-70, 1997.

WANGAARD, F.F. Elastic deflection of wood–fiberglass composite beams. **Forest Product Journal**, v.13, n.6, p. 256-260, 1964.

WANG, X.; SALENIKOVICH, A.; MOHAMMAD, M. Localized density effects on fastener holding capacities in wood-based panels, **Forest Product Journal**, v.57, n.1/2, p.103. 2007.

XU, H.; NAKAO, T.; TANAKA, C.; YOSHINOBU, M.; KATAYAMA, H. Effects of fiber length and orientation on elasticity of fiber-reinforced plywood, **Journal of Wood science**, v.44, n.5, p.343-347, 1998a.

XU, H.; TANAKA, C.; NAKAO, T.; KATAYAMA, H. Mechanical properties of plywood reinforced by bamboo or jute, **Forest Product Journal**, v.48, n.1, p. 81-89. 1998b.