Determination of Some Physical Attributes for Wooden Construction Elements Strengthened with Woven Wire Fiberglass

Abdullah Togay [a,*] and Emre Ergin [b]

This study designed composite wooden construction elements strengthened with woven wire fiberglass netting and determined the technical attributes. Scots pine (*Pinus sylvestris* L.) was used in wooden layers, and woven wire fiberglass netting was used in intermediate layers. Layers were pressed with polyvinyl acetate (PVAc) D_3 and Desmodur-VTKA adhesives to form 7 solid 13-layer laminated composite specimens. Experiments on 95 specimens determined density, bonding strength, bending resistance, and compression strength; solid and solid laminated wooden materials were tested and compared. BS EN 204 and BS EN 205 standards were complied with for bonding strength tests, TS 5497 EN 408 was used for densities, and TS 549 EN 408 was followed for bending resistance and compressive strength. Most factors, except for intermediate layer material in compressive strength and bending resistance tests perpendicular to the glue line, did not cause significant differences. Variables (adhesive, intermediate layer material) used for determining bending strength parallel to the glue line were effective. Polyurethane adhesive increased resistance to bending parallel to the glue line. These composite wooden construction elements supported with woven wire fiberglass netting could be advantageous for applications that require high bending resistance perpendicular to the glue line. However, these composites do not hold a compressive strength advantage.

Keywords: Composite materials; Strengthened wood; Laminated wood; Wooden construction elements

Contact information: a: Department of Industrial Product Design, Faculty of Architecture, Gazi University, 06570 Ankara, Turkey; b: Ministry of Education, Ankara, Turkey;
** Corresponding author: atogay@gazi.edu.tr*

INTRODUCTION

The demand for wooden materials has increased continually due to their ease of processing, their insulation against heat and sound, their texture, stemming from the natural structure, and their color and aesthetic attributes. It is necessary to manage forests by complying with scientific standards and to use the trees cut productively to meet this demand (Keskin 2001).

The lamination technique confers the ability to use wooden materials productively, to purify them of defects, and to avoid constituting diagonal fibers with a bent form in manufacturing. Thus, laminated solid wooden material can be produced with high quality and in the desired shape from wooden materials with small dimensions. The quality attributes of the produced materials are better than those of the solid wooden material (Keskin and Togay 2006).

At present, processed wooden products that will better fulfill the developing production technologies and design requirements are being manufactured (Cowan 1991). Considering the results of recent studies for strengthening of wood, which is an important construction product, effective results have been achieved when some materials were added to lamination other than wood and suitable adhesives. The use of fiber-added polymers for strengthening structural elements in the past 20 years has been effective with respect to both structural performance and economics (Taheri *et al*. 2009). The use of materials other than wood in wood lamination applications has been continuously increasing and constitutes a significant search for better results by using economical products in lamination that increase the technical characteristics of wood (Ergin 2011).

Recent studies have demonstrated that wooden and wood-based materials can be strengthened with fiber-reinforced polymer (FRP) composites in construction applications, especially for structural elements, and that the resulting composite materials have promise for the future (Pirvu *et al*. 2004).

In the study of Cao and associates (2013), wood fiber and flax fiber were used to reinforce high-density polyethylene (HDPE) formed by extrusion. The flexural, tensile, and impact resistance properties of the resulting flax fiber / wood fiber / HDPE (F/W/HDPE) composites were measured and modeled as a function of the volume fraction of flax fiber. Finally, the correctness of the modified model was verified. Based on the measurement data, the volume fraction of flax fiber was shown to play an important role in determining the mechanical properties of these composites. Adding flax fiber to a wood fiber/HDPE composite influenced the mechanical properties of the resulting flax fiber/wood fiber/HDPE composite. This influence was most significant on impact strength in comparison to the other properties. The volume fraction of flax fiber almost did not affect flexural strength (Cao e*t al.* 2013).

In a study by Corinaldesi and Moriconi, many wood types strengthened with local composite materials were tested. Encouraging results were obtained, especially for the elasticity behavior of carbon fiber-reinforced polymer (CFRP) layer fastenings and the cutting behavior of CFRP rod connections (Corinaldesi and Moriconi 2006). The objective of a study by Gezer and Aydemir (2010) was to observe the resistance changes of wooden materials. It was determined that there was an increase in compression and three-point bending resistance for wooden materials covered with CFRP. Borri, Corradi, and Grazini studied the use of FRP materials with the objective of strengthening the wooden construction elements under bending load. As a result of the study, it was stated that the CFRP bars have a strengthening effect (Borri *et al*. 2005).

A study by Yahyaei-Moayyed and Taheri (2011), defined the elasticity performance of Southern Scots pine and Douglas fir lumber beams strengthened with one-sided aramid fiber-reinforced polymer (AFRP) boards with short-term experimental and numerical research. The effect of the strengthening on the resistance of elasticity for the strengthened beams was also explained. An increase in AFRP-strengthened wood beams increased both the resistance and the hardness and effectively decreased the elastic deterioration of wooden beams (Yahyaei-Moyayyed and Taheri 2011). The bonding performance of FRP rods to GLULAM elements with epoxy was examined with the tensile test. Pull-out the tests of CFRP rods epoxied into glulam elements were carried out to investigate the bond performance. Their test variables included the bonded length, surface configuration of the rod, and the direction of wood fibres with respect to the longitudinal axis of the joint. They developed a local bond-slip model based on the test results of the joints (De Lorenzis *et al*. 2005).

When reinforcement by non-woody materials is evaluated within the scope of the literature, it can be noted that the approach has been targeted to have positive developments in the properties of wood by supporting it with different materials. This study, which has been designed in view of the cited work, aimed to produce wooden composite materials strengthened by support from woven wire fiberglass netting, to determine some of the technical attributes of these materials, and to make suggestions for the use of these products.

EXPERIMENTAL

Material

Wooden material

Scots pine (*Pinus sylvestris* L.), which is used extensively in the wood construction sector, was used as the wooden material. In the selection of the wooden material, which was randomly obtained from lumber enterprises, care was taken that the wood was healthy, with smooth fibers, without knots, showing normal growth without reactions, and had not been affected by fungi and insects.

After the lumber was cut into various length and widths with a thickness of 15 mm and stacked, it was kept in an aerated environment that did not receive direct sunlight at a temperature of 20 ± 2 ºC and a relative equilibrium moisture content of 65±5% until it reached an equilibrium moisture content of 12% and until it reached a stable weight.

Woven wire fiberglass netting

The woven wire fiberglass netting, which was used as an intermediate layer material in the preparation of the test specimens, was a black woven wire structure containing 35% fiber and 65% plastic, with a minimum density of 125 g/m², and 0.28-mm wire thickness with an 18 x 16 mm pore distance (SGT 1991). It was measured in accordance with the solid material of the experiment by purchasing it in a width of 1 m and a length of 30 m. Product information is given for the typical properties of fibers experimental in Table 1. (SGT 2011).

Table 1. Typical Properties of Fibers Used in Experiments (Product Information)

Property	E-Glass	S-Glass	Aramid	Carbon
Density lbs/in^3	.094	.090	.053	.064
Tensile Strength (psi)	500,000	665,000	400,000	275,000 - 450,000
Tensile Modulus (10^6 psi)	10.5	9.0	9.0	33 - 55
Elongation at Break (%)	4.8	2.3	2.3	0.6 - 1.2

Adhesives

In this study, two different adhesive types were evaluated, each of which is used extensively in the sector. Polyvinyl acetate (PVAc) was preferred due to its favorable properties, such as cold application, facility of spreading, rapid hardening, odorlessness, and fireproof nature. In addition, Desmodur-VTKA adhesive was preferred, since it can be used with materials, such as wood, metal, polyester, stone, ceramics, and PVC.

Polyvinyl acetate (PVAc): Polyvinyl acetate is a thermoplastic polymer with a chemical formula of ($C_4H_6O_2$). And, PVAc adhesives, sometimes referred to as “white glue” are made by polymerisation of the vinyl acetate monomer and then stabilised with other polymers into a copolymer (Kim and Kim 2006).

The single-component polyvinyl acetate (PVAc-D_3) adhesive called Klebit 303 by the German Kleiberit Company was used in this study. Klebit 303 is marketed as being ready for use for the D_3 service class as a single component according to BS EN 204 standards. With the addition of a hardener in the ratio of 5% to the adhesive solution during use, its resistance against humidity is increased even more and it can be brought to D_4 adhesive quality (Keskin 2001). The technical specifications of the adhesive are as follows: density of ~1.12 g/cm^3, 13,000 ± 2000 mPa viscosity at 20 °C, white in color, 120 to 200 g/m^2 amount of usage, 6 to 10 min open time, 0.1 to 1 N/mm^2 compression pressure, period of pressure 15 min at 20 °C, and period of complete hardening 7 days (Söğütlü and Döngel 2007).

Desmodur-VTKA: Polyurethane adhesive is produced from double-bonded alcohol and from suitable isocyanide (Özalp *at al.* 2008). Desmodur-VTKA is a single-component polyurethane-based adhesive that is resistant to water and humidity and does not contain a solvent. According to the information given by the manufacturer, it can be used with confidence in bathrooms and kitchens of houses, in sea and lake vehicles, on the exterior façades of buildings, in the assembly and repair of metal and wooden parts, and in workshops and factories that operate in steam environments. It has a density of 1.11 ± 0.02 g/cm^3 at 20 ºC, 3300 to 4000 cps viscosity at 25 °C, and hardens in 30 min at a temperature of 20 ºC and a relative humidity of 65%. The manufacturer suggests spreading it on surfaces that have a high absorbency at the package viscosity ratio and to slightly moisten the dried surfaces (Döngel 1999).

Method

Preparation of the test specimens

The woven wire fiberglass netting specimens prepared as intermediate layer materials were sized in a manner so that they would be similar to the wooden material.

After reaching standard humidity values, the solid lumber was used by cutting to the required measurements for the solid control specimens and prepared in a manner with a smooth surface suitable for bonding in thicknesses of 14 mm. The lengths of the lumber were 2000 mm and 700 m, with widths of various dimensions. Subsequently, after the lamination process, the dimensions were altered to 1900 x 100 x 100 mm and 600 x 100 x 100 mm, in conformance with TS 5497 EN 408 standards.

The PVAc and Desmodur-VTKA adhesives, which were used to bond the layers to each other, were taken, prepared, and used in accordance with the directives of the manufacturers. The figure below shows the placement of the layers as realized by placing an adhesive solvent and woven wire fiberglass netting between two wood (Scots pine) layers and pressing. The control specimens were also obtained with the same method by putting liquid adhesive solution between the wooden layers and pressing.

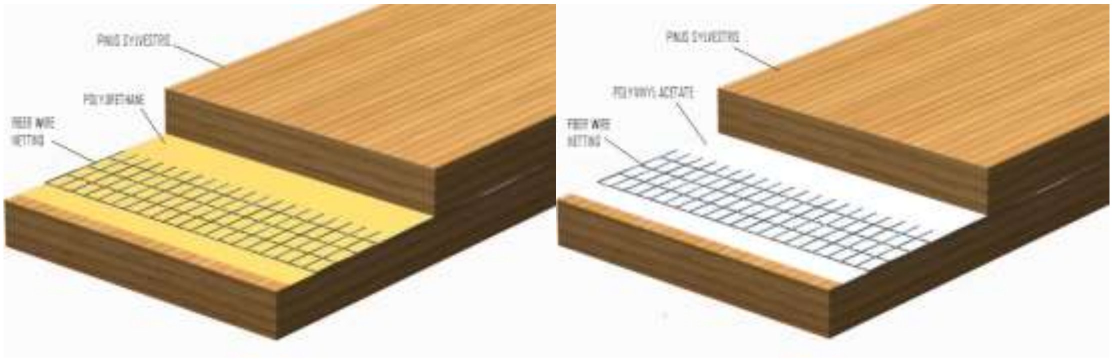

Fig. 1. The placement of the layers

The test specimens were glued and pressed for a total of seven wooden layers and six layers of support materials with a sufficient amount of adhesive solvent. Figure 2 below shows the test specimen configuration.

Fig. 2. The test specimen configuration

From the solid lumber, 2 specimens with dimensions of 100 x 100 x 100 mm were prepared for the solid control specimens, and 2 specimens for each adhesive with dimensions of 100 x 100 x 100 mm were prepared for the plain lamination specimens, for a total of 4 specimens, and 2 specimens for each adhesive with dimensions of 100 x 100 x 100 mm were prepared for the composite laminations, for a total of 4. The densities were thus determined for a total of 10 specimens.

In the bonding strength tests made in accordance with BS EN 204 and BS EN 205 standards, 10 specimens for each adhesive with measurements of 28 x 20 x 150 mm for the plain lamination specimens, for a total of 20, and 10 for each adhesive with measurements of 28 x 20 x 150 mm for the composite lamination specimens, for a total of 20, were prepared.

The TS 5497 EN 408 standards were complied with for the preparation of the bending resistance test specimens. A total of 30 test specimens, including the solid control specimens, were prepared with dimensions of 100 x 100 x 1900 mm for each adhesive and intermediate layer material, for a total of 24 specimens tested both perpendicular and parallel to the glue line (TS 5497 EN 408 1998).

TS 5497 EN 408 standards were complied with for the preparation of the compressive strength test specimens. Accordingly, a total of 15 test specimens were prepared, together with the solid control specimens, with dimensions of 100 x 100 x 600 mm, for a total of 12, using different adhesive and intermediate layer materials (TS 5497 EN 408 1998). Experiment numbers of samples are given in Table 2.

Table 2. Experiment Numbers for the Samples

	Control			Composite		Total
	Massive	PVAc	Desmodur-VTKA	PVAc	Desmodur-VTKA	
Density	2	2	2	2	2	10
Bonding	-	10	10	10	10	40
Bending Strength Perpendicular to Glue Line	3	3	3	3	3	15
Bending Strength Parallel to Glue Line	3	3	3	3	3	15
Compressive Strength	3	3	3	3	3	15
Total	11	21	21	21	21	95

Test methods

Density

The specimens used in the determination of density are shown in Fig. 3. The dimensions of all three sides of the test specimens were measured with a micrometric digital compass with a sensitivity of ± 0.01 mm, the densities were measured with a digital scale with a sensitivity of ± 0.01 g, and the volumes were determined with the stereometric method.

Bonding strength

BS EN 204 and BS EN 205 standards were complied with for the bonding strength tests, and Fig. 3 shows the test specimens. The two end parts of the test specimens were placed in the tension mechanism of the universal test equipment and tensile force was applied in an opposite direction with a loading speed of 1.6 mm/min. It was attempted to break the sample from the glue line with force applied regularly and in stages, and the bonding resistance was calculated by determining the maximum force (F_{max}) at the moment of breaking.

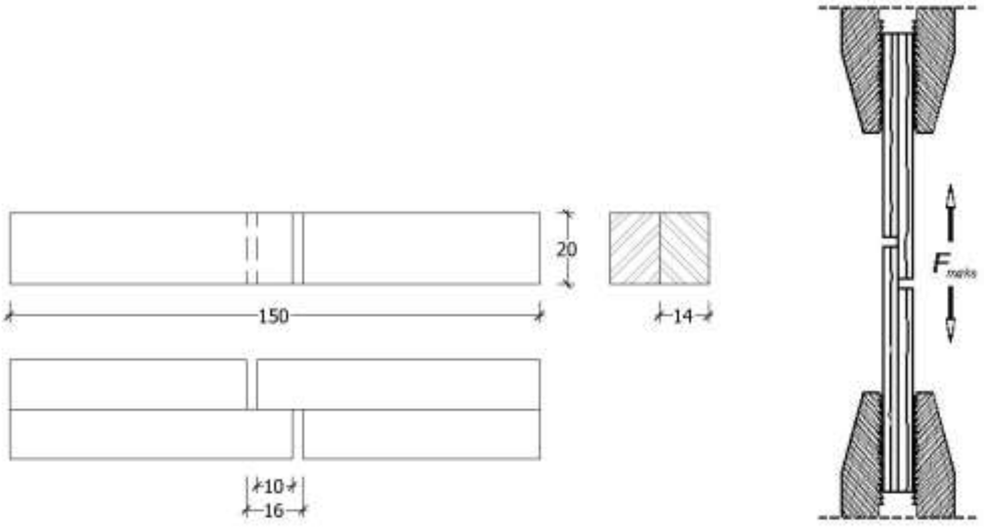

Fig. 3. Bonding strength test specimen and test mechanism (measurements in mm)

Equation 1 was used in the calculation of the bonding strength,

$$\sigma = \frac{F_Y}{A} = \frac{F_Y}{b_2 \cdot \ell_1} \tag{1}$$

where σ is the bonding strength (N/mm^2), F_Y is the force at the moment of breaking (N), b_2 is the width of the bonding surface (mm), and ℓ_1 is the length of the bonding surface (mm)

Bending resistance

The TS 5497 EN 408 standards were complied with for the bending resistance and modulus of elasticity tests (TS 5497 EN 408 1998). The force was applied from two symmetrical points about the center of the material. The reason for this is to provide for breakage at the weakest place between these points of the material without forming shearing tension between the points. The test specimen configurations are shown in Figs. 4, 5, and 6 for testing perpendicular to the glue line and parallel to the glue line, respectively. The capacity of the Universal Testing Equipment was 2000 kN. The speed of the test machine was adjusted to 0.083 mm/sec with a fixed speed. The loading was realized symmetrically in a manner in which the greatest load at the two bending points would be reached between 3 and 7 min. The experiments made in the universal test machine were realized in a manner so that the load applied to the specimens could be measured with an accuracy of 1 %.

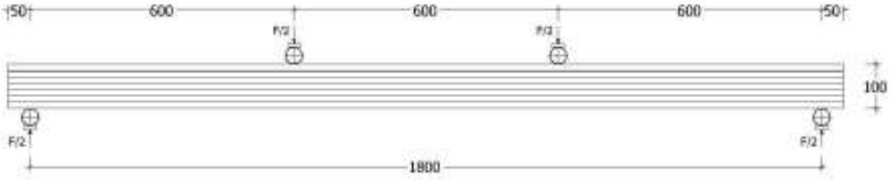

Fig. 4. Test specimen perpendicular to the glue line (measurements in mm)

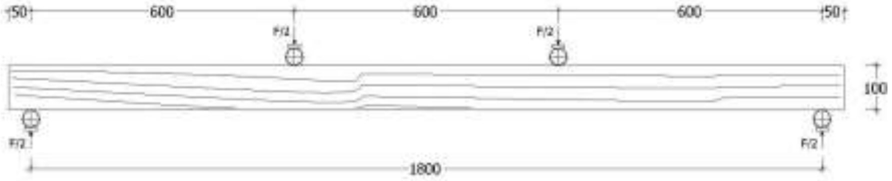

Fig. 5. Test specimen parallel to the glue line (measurements in mm)

The bending resistance in this case is given by,

$$\sigma_E = \frac{3}{2} \cdot \frac{F\left(L_s - L\right)}{b.h^2} \tag{2}$$

where σ_E is the bending resistance (N/mm²), F is the same as $2F/2$ (N), L_s is the distance between supports (mm), L is the distance (mm) between *F/2* forces applied, b is the width of a piece (mm), and h is the height of a piece (mm).

Fig. 6. Four points bending test

Compressive strength

TS 5497 EN 408 standards were complied with for the compressive strength tests (TS 5497 EN 408 1998). Figures 7 and 8 show the test specimen and arrangement. Accordingly, it was provided that the end surfaces of the test pieces were smooth, parallel to each other, and perpendicular to the axis of the test piece. The application for the bending resistance experiment was made the same, but was realized in the form of loading from a single point.

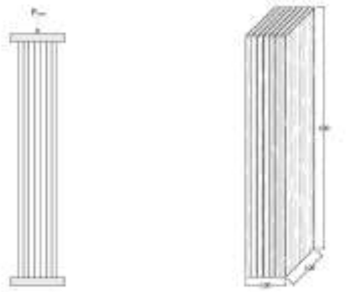

Fig. 7. Compressive strength test specimen

Fig. 8. Compressive strength test arrangement

Evaluation of the Data

The statistical results for the data obtained in the experiments were calculated with the arithmetical average, standard deviation, and percentage coefficient of variation. Multivariate analysis of variance (MANOVA) was conducted with the objective of determining the effect of adhesives and support material on the values obtained for all the groups. If the differences among groups were statistically significant according to a difference of $p < 0.05$, then the differences among groups were determined with the least significant difference (LSD) test. Thus, the success listings according to the lamination types from the factors in the experiment were determined by separating them into homogeneous groups according to the LSD critical values.

FINDINGS

Density

The average values for the air-dried densities of the laminated wood, laminated layered composite materials, and solid wood are given in Table 3.

Table 3. Average Air-Dried Density

Adhesive	Support Material	Density
PVAc	Control	0.47
	Woven wire fiber-glass netting	0.45
Desmodur-VTKA	Control	0.50
	Woven wire fiber-glass netting	0.49
Solid wood		0.54

Bonding Strength

The statistical values for the bonding strengths of the laminated wood, laminated layered composite materials, and solid wood are given in Table 4.

Table 4. Bonding Strength (N/mm²)

Adhesive	Support Material	Xmin	Xmax	Xav	SD	V (%)
PVA	Control	4.10	4.65	4.36	0.1724	3.954128
	Woven wire fiber-glass netting	3.85	4.36	4.07	0.2175	5.343980
Desmodur-VTKA	Control	4.75	5.32	4.98	0.2170	4.417671
	Woven wire fiber-glass netting	4.11	4.72	4.38	0.1983	4.566210

Xmin = minimum value; Xav = arithmetical average; Xmax = maximum value; SD = standard deviation; V = coefficient of variation (coefficient of change)

The results of the analysis of variance for the effects of the type of adhesive and type of support material on the bonding strength values are given in Table 5.

Table 5. Analysis of Variance for the Effects of Adhesive and Support Material on Bonding Strength

Source of Variance	DF	Sum of Squares	Mean Square	F Value	P Value
Adhesive Type (A)	1	2.162	2.362	52.7922	0.0001
Support Material (B)	1	1.998	1.998	48.7922	0.0001
AB	1	0.234	0.234	5.7154	0.0222
Error	36	1.474	0.041		
Total	39	11.107			

DF = degrees of freedom

The adhesive type and support material, as well as their interaction, had statistically significant (α = 0.05) effects on the bonding strength. The comparative Duncan test results for the adhesive type for determining the degree of significance of differences among groups are given in Table 6.

Table 6. Comparative Duncan Test Results for the Effect of Adhesive Type on Bonding Strength

Adhesive Type	$\overline{X}$	HG
PVAc	4.214	B**
Desmodur-VTKA	4.679	A*

LSD = 0.1295; * = maximum value; ** = minimum value; HG = homogeneity group

The comparative Duncan test results for the support material for determining the degree of significance of differences among groups are given in Table 7.

Table 7. Comparative Duncan Test Results for the Effect of Support Material on Bonding Strength

Support Material	$\overline{X}$	HG
Control	4.670	A*
Woven wire fiber-glass netting	4.223	B**

LSD = 0.1290; * = maximum value; ** = minimum value; HG = homogeneity group

The comparative Duncan test results for both the type of adhesive used and the type of support material are given in Table 8.

Table 8. Comparative Duncan Test Results for the Effects of Both Adhesive and Support Material on Bonding Strength

Adhesive Type	Support Material	$\overline{X}$	HG
PVA	Control	4.361	B
	Woven wire fiber-glass netting	4.067	C**
Desmodur-VTKA	Control	4.979	A*
	Woven wire fiber-glass netting	4.379	B

LSD = 0.1832; * = maximum value; ** = minimum value; HG = homogeneity group

When the bonding strengths between two different adhesive types were examined, it was observed that the chemical bond formed by the solid materials, both among themselves and with the woven wire fiber-glass netting, was stronger with the Desmodur-VTKA adhesive compared to the PVAc adhesive.

Bending Resistance

Bending resistance perpendicular to the glue line

The statistical values for the bending resistances perpendicular to the glue line of laminated wood, laminated layered composite materials, and solid wood are given in Table 9.

Table 9. Bending Resistance Perpendicular to the Glue Line (N/mm²)

Adhesive	Support Material	Xmin	Xmax	Xav	SD	V (%)
PVA	Control	36.58	42.35	39.47	2.887745	7.3163035
	Woven wire fiber-glass netting	43.68	49.29	46.48	2.803937	6.0335667
Desmodur-VTKA	Control	43.11	44.03	43.57	0.458669	1.0527175
	Woven wire fiber-glass netting	44.71	50.80	47.76	3.044758	6.3751214
Solid wood		34.24	41.79	38.02	3.77797899	9.936820

Xmin = minimum value; Xav = arithmetical average; Xmax = maximum value; SD = standard deviation; V = coefficient of variation (coefficient of change)

The results of the analysis of variance for the effects of the type of adhesive and type of support material on the bending resistance values perpendicular to the glue line are given in Table 10.

Table 10. Analysis of Variance for the Effects of Adhesive and Support Material on the Bending Resistance Perpendicular to the Glue Line

Source of Variance	DF	Sum of Squares	Mean Square	F Value	P Value
Adhesive Type (A)	1	14.454	14.454	1.6008	N.S.*
Support Material (B)	2	253.022	126.511	14.0111	0.0007
AB	2	13.234	6.617	0.7328	N.S.*
Error	12	108.352	9.029		
Total	17	389.062			

*N.S. = Not significant

The support material had a statistically significant (α =0.05) effect on the bending resistance perpendicular to the glue line. The comparative Duncan test results for the support material are given in Table 11.

Table 11. Comparative Duncan Test Results for the Effect of Support Material on Bending Resistance Perpendicular to the Glue Line

Support Material	$\overline{X}$	HG
Control	41.52	B**
Woven wire fiber-glass netting	47.12	A*
Solid wood	38.02	B**

LSD = 3.660; * = maximum value; ** = minimum value; HG = homogeneity group

The highest bending resistance value perpendicular to the glue line was obtained with the woven wire fiberglass netting. It provided an increase in the bending resistance perpendicular to the glue line of ~24% compared to the solid wood and ~13.5% compared to the laminated wood. This situation may stem from an increase in the elasticity between layers when woven wire fiberglass materials are placed between the layers. Examples of experimental results are given in Fig. 9.

PVAC / Woven wire fiber-glass netting

Desmodur-VTKA / Woven wire fiber-glass netting

Fig. 9. Examples of experimental results of bending resistance perpendicular to the glue line

Bending resistance parallel to the glue line

The bending resistances parallel to the glue line in the laminated wood, laminated layered composite material, and solid wood are given in Table 12.

Table 12. Bending Resistance Parallel to the Glue Line (N/mm²)

Adhesive	Support Material	Xmin	Xmax	Xav	SD	V (%)
PVA	Control	45.17	47.06	46.11	0.941104	2.0401
	Woven wire fiber-glass netting	46.28	52.20	49.24	2.958062	6.00744
Desmodur-VTKA	Control	49.69	57.02	53.35	3.664984	6.8697
	Woven wire fiber-glass netting	48.60	52.20	50.40	1.799932	3.57129
Solid wood		25.81	31.62	28.72	2.90411	10.1118

Xmin = minimum value; Xav = arithmetical average; Xmax = maximum value; SD = standard deviation; V = coefficient of variation (coefficient of change)

The analysis of variance results for the effects of adhesive and support material on the bending resistance values parallel to the glue line are given in Table 13.

Table 13. Analysis of Variance for the Effects of Adhesive and Support Material on the Bending Resistance Values Parallel to the Glue Line

Source of Variance	DF	Sum of Squares	Mean Square	F Value	P Value
Adhesive Type (A)	1	35.280	35.280	4.8994	0.0470
Support Material (B)	2	1774.117	887.058	123.1884	0.0001
AB	2	45.365	22.682	3.1500	0.0795
Error	12	86.410	7.201		
Total	17	1941.172			

Both the type of adhesive and the support material had statistically significant (α =0.05) effects on the bending resistance parallel to the glue line. The comparative Duncan test results for the type of adhesive for determining the degree of significance of the difference among groups are given in Table 14.

Table 14. Comparative Duncan Test Results for the Effect of Adhesive on Bending Resistance Parallel to the Glue Line

Adhesive Type	$\overline{X}$	HG
PVAc	41.36	B**
Desmodur-VTKA	44.16	A*

LSD = 2.669; * = maximum value; ** = minimum value; HG = homogeneity group

The Desmodur-VTKA adhesive showed an ~7% better resistance compared to the PVAc adhesive in the determination of bending resistance parallel to the glue line. The comparative Duncan test results for the support material for determining the degree of significance of the differences among groups are given in Table 15.

Table 15. Comparative Duncan Test Results for the Effect of Support Material on Bending Resistance Parallel to the Glue Line

Support Material	$\overline{X}$	HG
Control	49.73	A*
Woven wire fiber-glass netting	49.82	A*
Solid wood	28.72	B**

LSD = 3.269; * = maximum value; ** = minimum value; HG = homogeneity group

The highest bending resistance parallel to the glue line independent of adhesive was realized for the woven wire fiberglass netting and laminated wood. This value was determined to be ~73% higher than that of the solid wood.

The layered composite wood structured elements strengthened with woven wire fiberglass did not have any negative effects on the load parallel to the glue line, and it is thought that it would be suitable to use this material, especially in construction elements that would be subjected to loads parallel to the glue line. Examples of experimental results are given in Fig. 10.

PVAC / Woven wire fiber-glass netting

Desmodur-VTKA / Woven wire fiber-glass netting

Fig. 10. Examples of experimental results of bending resistance parallel to the glue line

Compressive Strength

The compressive strengths of the laminated wood, laminated layered composite materials, and solid wood are given in Table 16.

Table 16. Compressive Strength (N/mm²)

Adhesive	Support Material	Xmin	Xmax	Xav	SD	V (%)
PVA	Control	37.84	38.75	38.30	0.450531	1.17632
	Woven wire fiber-glass netting	34.18	37.11	35.65	1.46614	4.11259
Desmodur-VTKA	Control	35.87	40.31	38.09	2.22289	5.83589
	Woven wire fiber-glass netting	35.09	38.57	36.83	1.742989	4.73253
Solid wood		34.65	34.99	34.77	0.172434	0.495928

Xmin = minimum value; Xav = arithmetical average; Xmax = maximum value; SD = standard deviation; V = coefficient of variation (coefficient of change)

The analysis of variance results for the effects of adhesive and support material on the compressive strength are given in Table 17.

Table 17. Analysis of Variance for the Effects of Adhesive and Support Material on the Compressive Strength

Source of Variance	DF	Sum of Squares	Mean Square	F Value	P Value
Adhesive Type (A)	1	0.476	0.476	0.2765	N.S.*
Support Material (B)	2	35.312	17.656	10.2534	0.0025
AB	2	1.680	0.840	0.4878	N.S.*
Error	12	20.664	1.722		
Total	17	58.132			

*N.S. = Not significant

The support material had a statistically significant (α =0.05) effect on the compressive strength. The comparative Duncan test results for the type of support material for determining the degree of significance of the difference between the groups are given in Table 18.

Table 18. Comparative Duncan Test Results for the Effect of Support Material on Compressive Strength

Support Material	$\overline{X}$	HG
Control	38.19	A*
Woven wire fiber-glass netting	36.24	B**
Solid wood	34.77	B**

LSD = 1.598; * = maximum value; ** = minimum value; HG = homogeneity group

According to the Duncan tests results applied, the highest compressive strength value among the types of support materials was obtained in the control specimens without support elements, and the lowest compressive strength value was obtained in the woven wire fiber-glass netting and solid material specimens. Examples of experimental results are given in Fig. 11.

PVAC / Woven wire fiber-glass netting

Desmodur-VTKA / Woven wire fiber-glass netting

Control

Fig. 11. Examples of experimental results of compressive strength

DISCUSSION

In this study, the aim was to obtain different and strong composite lamination products that could be used as construction materials by adding non-wood materials to the lamination process. With this objective, solid specimens were compared with solid lamination specimens prepared by adding woven wire fiberglass netting, which is an industrial construction product, to the intermediate layers of laminated wood. The numerical data obtained was evaluated.

When the bonding strengths between two different adhesive types were examined, it was observed that the chemical bond formed by the solid materials, both among themselves and with the woven wire fiber-glass netting, was stronger with the Desmodur-VTKA adhesive compared to the PVAc adhesive.

The highest bending resistance value perpendicular to the glue line among the solid and solid lamination with the support material was obtained from the woven wire fiberglass netting. It provided an increase in the bending resistance perpendicular to the glue line of ~24% compared to the solid material and ~13.5% compared to the solid lamination. It can be thought that this situation stems from an increase in the elasticity between layers when woven wire fiberglass materials are placed between layers.

The Desmodur-VTKA adhesive showed an ~7% better resistance compared to the PVAc adhesive as a type of adhesive in the determination of bending resistance parallel to the glue line. The highest bending resistance value parallel to the glue line independent of adhesive was realized very close to each other for the woven wire fiberglass netting and solid lamination materials. This value was determined to be ~73% higher than the solid materials. It can be stated that the reason for this can be connected to the effect of the parallel to the glue line constraining to separate the layers in lamination and even if slight, of the support materials negatively affecting the bonding.

The layered composite wood structured elements strengthened with woven wire fiber-glass did not result in any negative effects against the parallel to the glue line loads and it is thought that it would be suitable to use them especially in construction elements that would be subjected to perpendicular to the glue line loads.

On the other hand, the highest compressive strength was obtained with the laminated wood. There was not a significant difference in compressive strength between the woven wire fiberglass netting and the solid wood. This situation can negatively affect the compressive strength of the composite specimens used in the experiments, leading to the conclusion that the use of this material in cases where compressive strength is desired would not be suitable and that the intermediate support materials negatively affect the bonding line.

There was a significant difference in the level of compressive strength on the support material, control, and solid material, and the highest compressive strength was found in the control, followed by the fiber specimens. However, the degree of significance of the difference appears to be rather low. Results for all of the experiments are given in Table 19.

Table 19. Results for All of the Experiments

	Solid wood	Control	Fiber
Bending Resistance **(Perpendicular to the glue line)**	*38.02***	41.52	**47.12***
Bending Resistance **(Parallel to the glue line)**	*28.72***	49.73	**49.82***
Compressive	*34.77***	**38.19***	36.24

* = maximum value; **bold =** positive attribute; ** = minimum value; *italic* = negative attribute

When the results obtained with the 4 different experiments from the 5 different material types were evaluated, it was observed that the intermediate layer materials from the variables used for all the experiments and specimens were effective factors. In this context, it was observed that the intermediate layer material in the specimens tested parallel to the glue line did not have a significant strengthening effect and, despite the fact that it also did not have a weakening effect, the most significant result was that the intermediate layer materials provided a high ratio of resistance against bending perpendicular to the glue line. When the compressive strength is considered, the intermediate layer materials in the control specimens had a weakening effect, even if the ratio was slight. However, it was found that they showed a greater resistance against compression compared to solid wood.

The polyurethane (Desmodur-VTKA) adhesive increased the resistance for the bonding experiments, and the intermediate layer materials had a weakening effect on bonding.

CONCLUSIONS

1. Composites using Desmodur-VTKA adhesive with the woven wire fiberglass netting had the highest bonding strengths. The reason for this stems from the fact that the Desmodur-VTKA adhesive provides a much better adaptation among the solid materials and netted structure fiberglass, and from the fact that it could form a stronger chemical bond.
2. The woven wire fiberglass netting increased the bending resistance perpendicular to the glue line, and the use of this material would be beneficial in cases where bending resistance perpendicular to the glue line is desired. This material and the process should be tried with different adhesives.
3. Adverse effects of support materials in adhesion should not be neglected during the lamination process. The reason for this can be connected to the effect of the parallel to the glue line constraining to separate the layers by the slight support materials negatively affecting the bonding. For this aim many different materials can be used, and different solutions with these materials should be tried.
4. In specimens subjected to bending perpendicular to the glue line, materials with support layers should be preferred. Despite the fact that there were no negative aspects in cases where specimens were subjected to bending parallel to the glue line,

it would be more suitable to used laminated wood materials for economic and production advantages. In materials subjected to compressive strength, the most effective results would still involve the control specimens.

5. Different intermediate support materials and the use of adhesives will show a positive effect on bending resistance perpendicular to the glue line. Some physical and chemical attributes in wood lamination could be improved with different adhesives and intermediate support materials. A hypothesis can be made that positive results could be obtained with intermediate support elements with a netting structure and different intermediate layer symmetries.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Scientific Research Department of Gazi University, Grant. No. 25.2010.4.

REFERENCES CITED

Borri, A., Corradi, M., and Grazini, A. (2005). “A method for flexural reinforcement of old wood beams with CFRP materials,” *Composites: Part B* 36(2), 143-153.

BS EN 204 (2001). “Classification of thermoplastic wood adhesives for non-structural applications,” (British Standard).

BS EN 205 (2003). “Adhesives. Wood adhesives for non-structural applications. Determination of tensile shear strength of lap joints,” (British Standard).

Cao, Y., Wang, W., Wang, Q., and Wang, H. (2013). “Application of mechanical models to flax fiber/wood fiber/plastic composites,” *BioResources* 8(3), 3276-3288.

Corinaldesi, V., and Moriconi, G. (2006). “Local reinforcement of wood elements by means of composite materials,” *Università Politecnica*.

Cowan, H. J. (1991). *Handbook of Architectural Technology, 18th Ed.*, Van Nostrand Reinhold, New York.

De Lorenzis, L., Scialpi, V., and La Tegola, A. (2005). “Analytical and experimental study on bonded-ın CFRP bars ın glulam timber,” *Composites: Part B* 36, 279-289.

Döngel, N. (1999). “The effects of bending strength of wood and adhesive type and the number of layers,” M.S. thesis, Gazi University, Science Institute, Ankara, Turkey.

Ergin, E. (2011). “Reinforced wood building element design and characterization of some technical specifications,” M.S. thesis, Gazi University, Science Institute, Ankara, Turkey.

Gezer, H., and Aydemir, B. (2010). “The effect of the wrapped carbon fiber reinforced polymer material on fir and pine woods,” *Materials and Design* 31, 3564-3567.

Keskin, H. (2001). “Technological properties of laminated wood materials and use of facilities of wood processing industry,” Ph.D. thesis, Gazi University, Science Institute, Ankara, Turkey.

Keskin, H., and Togay, A. (2006). “Impacts of impregnation with Imersol Aqua on the compression strength of laminated wood materials” *Materials Science* 2, 6-18.

Kim, S., and Kim, H.- J. (2006). "Thermal stability and viscoelastic properties of MF/PVAc hybrid resins on the adhesion for engineered flooring in under heating system; ONDOL," *Thermochim. Acta* 444 (2), 134-140.

Özalp, M., Atılgan, A., Esen, Z., and Kaya, S., (2008). "Comparing the resistance and bending in the plywoods which each made with different glues," *Dumlupınar University, Journal of Science* 18, 99 -104, ISSN – 1302 -3055.

Pirvu, A., Gardner, D. J., and Lopez-Anido, R. (2004). "Carbon fiber-vinyl ester composite reinforcement of wood using the VARTM/SCRIMP fabrication process," *Composites: Part A* 35, 1257-1265.

SGT (2011). Sanayii ve Ticari Ürünler Dış Ticaret Ltd. Şti. "Products Catalog".

Söğütlü, C., and Döngel, N. (2007). "Tensile shear strengths of some native trees glued with polivinilasetat (PVAc) and poliüretan (PU)," *G.Ü. Faculty of Technical Education, Journal of Polytechnic* 10(3), 287-293.

Taheri, F., Nagaraj, M., and Khosravi, P. (2009). "Buckling response of glue-laminated columns reinforced with fiber-reinforced plastic sheets," *Composite Structures* 88, 481-490.

TS 5497 EN 408 (1998). "Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties," Ankara.

Yahyaei-Moayyed, M., and Taheri, F. (2011). "Experimental and computational investigations into creep response of AFRP reinforced timber beams," *Composite Structures* 93, 616-628.

Article submitted: November 12, 2013; Peer review completed: March 4, 2014; Revised version received and accepted: April 28, 2014; Published: May 12, 2014.