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THE EFFECT OF PLY COMBINATION ON MECHANICAL AND PHYSICAL PROPERTIES IN LAMINATED VENEER LUMBER (LVL) MANUFACTURED FROM ALDER AND POPLAR

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ABSTRACT: Laminated veneer lumber (LVL) is an engineering product material used as girders, beams, joist, headers, panels, etc. in construction. In this study, the effect of ply combination on oven-dry specific gravity, equilibrium moisture content, thickness swelling and water absorption, tensile-shear strength, modulus of rupture, modulus of elasticity and compression strength parallel to grain of LVL manufactured from alder and poplar was investigated. Alder veneer, poplar veneer and urea formaldehyde glue were used in LVL production. LVLs were produced in a total of 10 different combinations. Oven-dry specific gravity, equilibrium moisture content, thickness swelling and water absorption, tensile-shear strength, modulus of rupture, modulus of elasticity and compression strength parallel to grain of test samples were determined according to TS 2472, TS 2471, TS EN 317, EN 314-1, TS 2474 and TS 2595, respectively. Based on this study, the highest modulus of rupture, modulus of elasticity, compression strength and oven dry specific gravity values were obtained with alder veneers used in all plies. On the other hand, the highest tensile-shear strength values were obtained with poplar veneers used in all plies. With the rising in the use of poplar veneer in LVL production, an increase in the amount of thickness swelling and water absorption was observed. It was also observed that as contribution rate of alder veneer in lamination increases, oven dry specific gravity, modulus of rupture, modulus of elasticity and compression strength values were increased.

Keywords: Laminated veneer lumber (LVL), alder, poplar, ply combination, mechanical and physical properties.

KIZILAĞAÇ VE KAVAKTAN ÜRETİLEN TABAKALI KAPLAMA KERESTELERİN MEKANİK VE FİZİKSEL ÖZELLİKLERİ ÜZERİNE TABAKA KOMBİNASYONUNUN ETKİSİ

ÖZET: Lamine kaplama kereste (LVL) inşaat yapılarında kiriş, döşeme kirişi, başlıklar ve paneller olarak kullanılan bir mühendislik ürünü ağaç malzemedir. Bu çalışmada kızılağaç ve kavak'tan üretilen LVL'lerin fırın kurusu yoğunluk, denge rutubet miktarı, kalınlığına şişme ve su alma, çekme-makaslama direnci eğilme direnci, eğilmede elastikiyet modülü ve liflere paralel basınç direnci özellikleri üzerine tabaka kombinasyonunun etkisi incelenmiştir. LVL üretiminde kızılağaç kaplamaları, kavak kaplamaları ve üre formaldehit tutkalı kullanılmıştır. 10 faklı kombinasyonda LVL üretimi gerçekleştirilmiştir. LVL'lerin fırın kurusu yoğunluğu, denge rutubet miktarı, kalınlığına şişme ve su alma, çekme-makaslama direnci, eğilme direnci, eğilmede elastikiyet modülü ve liflere paralel basınç direnci değerleri sırasıyla TS 2472, TS 2471, TS EN 317, EN 314-1, TS 2474 and TS 2595 standartlarına göre belirlenmiştir. Bu çalışma sonucunda en yüksek eğilme direnci, eğilmede elastikiyet modülü, liflere paralel basınç direnci ve yoğunluk değerleri tüm tabakalarda kızılağaç kullanılan LVL'ler de elde edilmiştir. En yüksek çekme-makaslama direnci tüm tabakalarda kavak kullanılan LVL'lerde bulunmuştur. LVL üretiminde kavak kaplama kullanımının artması ile kalınlığına şişme ve su alma miktarında artış gözlemlenmiştir. Ayrıca laminasyonda kızılağaç kaplama kullanımının artması eğilme direnci, eğilmede elastikiyet modülü, liflere paralel basınç direnci ve yoğunluk değerlerini artırdığı gözlenmiştir.

Anahtar kelimeler: Tabakalı kaplama kereste (LVL), kızılağaç, kavak, tabaka kombinasyonu, mekanik ve fiziksel özellikler.

INTRODUCTION

Laminated veneer lumber (LVL), a timber-like product, is an engineered wood material usually obtained by bonding rotary-peeled veneers with their fibers aligned in the same direction. Compared to LVL solid wood, more efficient use of wood, better strength, better dimensional stability and better workability performance can provide. LVL is used as floor beam, main beam, pillar, column and panel in building construction (Nelson, 1997). In addition, some furniture factories produce especially for the purpose of obtaining bent furniture pieces (Dallı, 2005).

The type of wood used in production, its density, physical and mechanical properties, different combinations of wood species, veneer thickness, glue type and adhesion performance of veneers have a significant effect on the quality properties of LVL (Bal and Bektaş, 2013; Cırrık et al., 2017; Kılıç et al., 2006).

In LVL manufacturing, phenolic adhesives such as phenol formaldehyde (PF) and phenol resorcinol formaldehyde (PRF) are generally used for structural applications in outdoor environments, while urea formaldehyde (UF) adhesives are recommended for semi-structural and non-structural applications in indoor environments (Pizzi, A., 1983; Nemli, G. and Çolak, S. 2002).

LVL can be produced with one wood type veneer or with combinations of different wood type veneers. In previous studies, LVL productions in different combinations were made by using veneers obtained from tree species with different resistance properties (Burdurlu, 2007; Demir et al., 2017). Since LVLs are mostly used as load bearing elements, bending strength must be high.

The quality of the wood used in the production of laminated wood materials affects the bending strength (Tichy and Bodig, 1978). The increase in the amount and size of knots decreases the mechanical properties of the laminated wood material (Strickler and Pellerin, 1971). The width of veneers used in production does not affect the modulus of rupture and modulus of elasticity of laminated wood materials (Marx and Moody, 1982; Youngquist et all., 1984). As the thickness of veneers used in lamination increases, the modulus of rupture decreases and the modulus of elasticity varies according to the wood species (Youngquist et all., 1984; Baş, 1995; Senay, 1996; Kilic, 1997). The wood species and glue type affect the mechanical properties of laminated materials (Marx and Moody, 1982; Baş, 1995; Senay, 1996; Kilic, 1997;Döngel, 1999; Altinok, 2002; Celebi and Kilic, 2006; Celebi and Kilic, 2004; Aydin et al., 2004).

Alder and poplar are fast growing tree species in Turkey. Alder has higher mechanical properties than poplar while poplar is less expensive than alder. It is aimed to determine the effects of ply combinations on oven-dry specific gravity, equilibrium moisture content, thickness swelling and water absorption, tensile-shear strength, modulus of rupture, modulus of elasticity and compression strength parallel to grain in two wood species.

MATERIALS AND METHODS

Materials

In the production of LVL, rotary-peeled veneer of 50x50cm, 1.5mm thick alder and 2.2mm thick poplar were used at a moisture content of 6-8%. The veneers were purchased from the Petek Plywood factory in Gaziantep. Urea formaldehyde (UF) glue was used as the adhesive. UF was provided from Adana Kastamonu Integrated Factory (Table 1). For the production of LVL, 200 gr/m² of glue was applied to each glue line (ASTM D899, 1994). Ammonium chloride as a hardener 1.5% was used according to the dry glue amount.

Table 1. Properties of Urea Formaldehyde

Properties	**Values**
Appearance	Transparent
Solids content (%)	65,21±2
Density (20 ºC) gr/cm^3	1,275
Viscosity (20ºC) cP	236,7
Flow time (20ºC, FC4) sn.	74
pH (20ºC)	8,38
Free folmaldehyde (%)	0,23
Gel time (100ºC) sn.	32
Storage time (20ºC) gün	30

Laminated Veneer Lumber Production

9-ply LVLs were produced using alder and poplar rotary peeled veneers in 10 different combinations (Table 2).

Table 2. LVL Production Combination

Sample ID	Ply Combination
A	All layers alder
1A	The first plies on the outside are alder, the middle plies are poplar
2A	The first two plies on the outside are alder, the middle plies are poplar
3A	The first three plies on the outside are alder, the middle plies are poplar
AB	In the form of alder-poplar-alder
BA	In the form of poplar-alder-poplar
B	All layers poplar
1B	The first plies on the outside are poplar, the middle plies are alder
2B	The first two plies on the outside are poplar, the middle plies are alder
3B	The first three plies on the outside are poplar, the middle plies are alder

Press time is adjusted to be 1 minute for 1mm in productions. LVLs were produced at 110°C and 40 bar pressure. The samples coming out of the press were conditioned for a week by placing them on top of each other and then cut to the dimensions specified in the standards. Before testing, the samples were kept in climate cabinet at 20°C and 65% relative humidity for three weeks. Oven-dry specific gravity, equilibrium moisture content, thickness swelling and water absorption, tensile-shear strength, modulus of rupture, modulus of elasticity and compression strength parallel to grain of test samples were determinated according to TS 2472, TS 2471, TS EN 317, EN 314-1, TS 2474 and TS 2595, respectively. The span/depth ratio was adjusted to 16 for bending test samples. In the study, the thickness swelling percentages and water absorption percentages of LVLs at the end of short and long-term (2, 24, 168, 336 and 504 hours) soaking in water were determined. Tensile-shear strength tested from 5/4 glue line of LVLs (Figure 1). 10 samples were prepared for each of the groups.
The obtained data as a result of the tests were analyzed using one-way ANOVA for mechanical and physical properties (p=0,05) from SPSS program. Beside significant differences between groups were determined by Duncan's Multiple range Test (α=0,05).

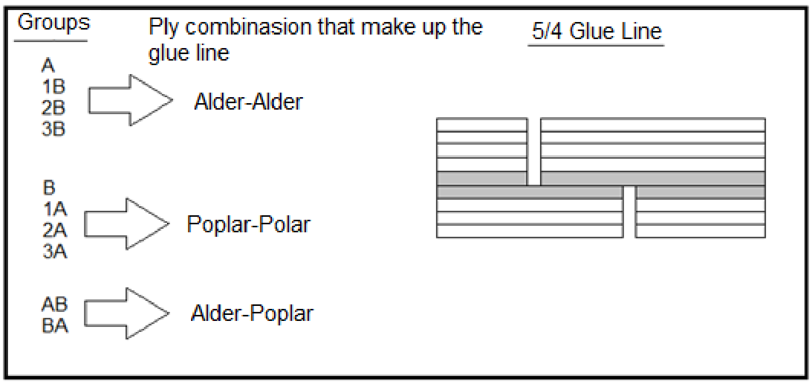

Figure 1. Tensile-shear test sample

RESULTS AND DISCUSSION

Physical Properties

The data that were obtained for oven-dry specific gravity (OD), equilibrium moisture content (EMC), thickness swelling (TS) and water absorption (WA) are given in Table 3. Duncan's multiple range test was used to find out between which groups there are differences. The homogeneity groups found as the result of the test for oven-dry specific gravity, equilibrium moisture content, thickness swelling and water absorption was shown in Table 4, Table 5, Table 6 and Table 7, respectively.

Statistical analysis showed that the ply combination had a significant effect on the oven-dry specific gravity value (P<0,0001). The graph of the oven-dry specific gravity value of LVLs is shown in Figure 2.The highest oven-dry specific gravity value was found in group A (0.564 g/cm^3), and the lowest oven-dry specific gravity value was found in group 3B (0.477 g/cm^3). The oven-dry specific gravity of the samples increased with the increase in the number of alder veneers in the ply combination. This situation is thought to occur because the density of alder is higher than that of poplar. Burdurlu et al. (2007) produced LVLs in different combinations by using beech and poplar veneers in their study and found that the board density increased with the increase in the use of beech veneer.

Table 3. Physical Test Results of The Groups

	OD	EMC	TS					WA				
			2 h	24 h	168 h	336 h	504 h	2 h	24 h	168 h	336 h	504 h
	g/cm^3	%	%					%				
A	0,56 0,01*	9,16 0,12	4,43 0,34	6,12 0,52	6,75 0,54	6,92 0,55	7,04 0,61	30,70 2,51	58,99 2,17	77,61 2,01	93,98 2,60	102,04 2,96
1A	0,48 0,02	9,50 0,12	3,06 0,42	5,28 0,72	5,93 0,84	6,04 0,94	6,17 0,85	27,08 0,85	69,06 1,36	109,86 3,77	123,81 5,13	130,32 5,35
2A	0,51 0,01	8,89 0,06	4,13 0,29	6,68 0,52	7,49 0,63	7,77 0,72	7,85 0,73	29,42 2,02	67,42 2,47	103,26 3,80	119,55 5,09	127,16 4,64
3A	0,56 0,01	9,21 0,44	3,40 0,22	5,87 0,26	6,68 0,31	6,82 0,31	6,97 0,31	26,15 1,64	58,62 0,93	87,01 2,42	102,04 2,67	108,88 3,01
AB	0,53 0,02	9,23 0,17	3,24 0,35	5,23 0,53	5,79 0,65	5,90 0,76	5,99 0,78	29,52 3,26	64,54 3,50	95,23 3,46	110,82 5,56	117,36 5,65
BA	0,52 0,01	8,75 0,06	3,32 0,26	5,61 0,39	6,31 0,51	6,47 0,51	6,39 0,63	28,88 2,15	65,84 1,68	97,79 2,90	113,43 3,10	120,73 3,19
B	0,48 0,01	9,12 0,18	3,61 0,31	7,28 0,53	8,21 0,53	8,54 0,61	8,75 0,60	25,69 1,08	69,40 1,81	112,31 3,69	129,52 3,63	137,13 3,94
1B	0,56 0,01	9,14 0,12	3,24 0,56	5,31 0,52	5,96 0,62	6,07 0,61	6,12 0,68	29,68 3,61	60,95 2,66	83,64 2,96	98,37 2,79	106,48 3,64
2B	0,50 0,01	9,11 0,12	2,97 0,34	5,11 0,34	5,62 0,28	5,67 0,27	5,86 0,40	30,63 4,06	64,97 2,66	96,92 2,46	112,49 2,84	119,46 2,63
3B	0,48 0,02	9,26 0,13	3,50 0,31	5,76 0,38	6,52 0,41	6,70 0,46	6,83 0,51	31,37 2,12	65,48 2,33	101,89 5,01	118,71 5,34	125,80 5,47

*standard deviation

As et al. (2001) determined the oven-dry specific gravity value of alder as 0.49 g/cm^3 and the oven-dry specific gravity value of poplar as 0.41 g/cm^3 in their study. Oven-dry specific gravity values of LVLs produced in our study were higher than the oven-dry specific gravity values of alder and poplar solid woods. In LVL production, the oven-dry specific gravity value increases due to the use of glue and the compression during the pressing. Similar results were found in the literature (Bal, 2011; Bao et al., 2001; Wang and Dai, 2005; Çolak et al., 2007).

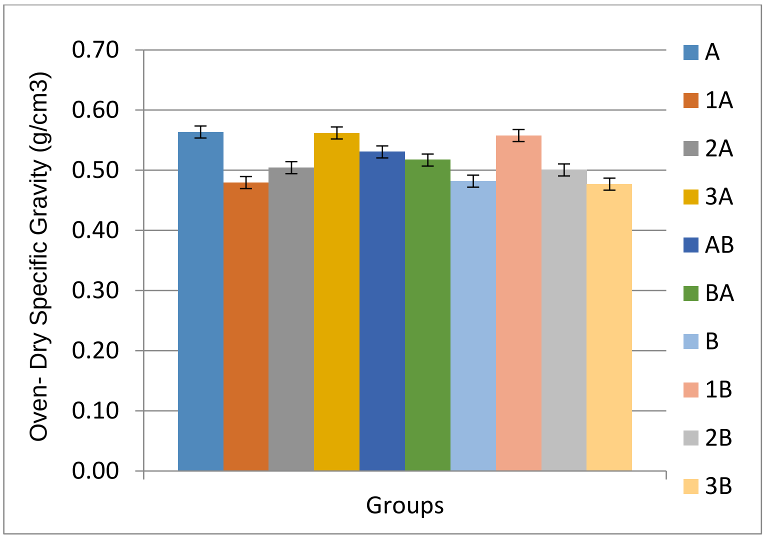

Figure 2. The Graph of the Oven-Dry Specific Gravity Value of LVLs

The ply combination had a significant effect on equilibrium moisture content value ($P<0.0001$). The graph of equilibrium moisture content value of LVLs is shown in Figure 3. According to the test results, the equilibrium moisture content values were found in the range of 9.498% - 8.754%. None of the groups reached 12% equilibrium humidity. Similar results were found in the literature. Bal and Bektaş (2013) kept LVLs produced with three different glues using eucalyptus, beech and poplar veneers for 936 hours at 20ºC and 65% relative humidity, and none of the samples could reach 12% equilibrium moisture in their study.

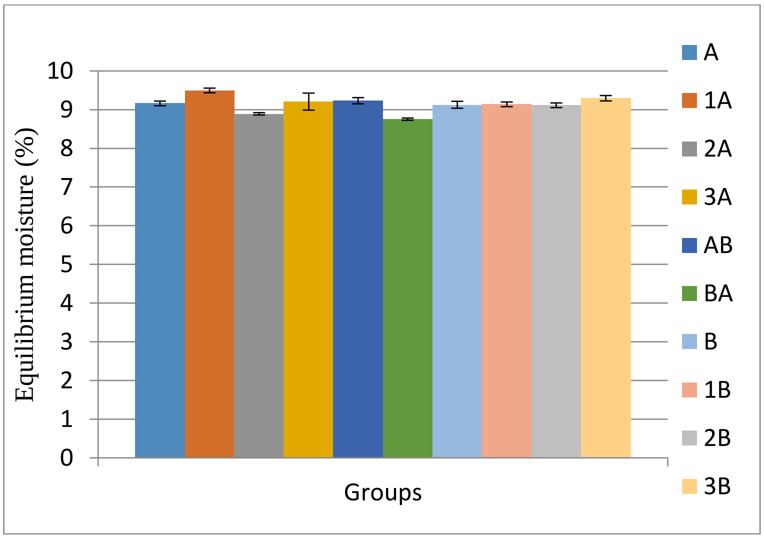

Figure 3. The graph of the Equilibrium Moisture Value of LVLs

Table 4. Duncan Test Results for Oven-Dry Specific Gravity

Board Groups	α=0,05 a	b	c	d	e
A	0,564				
3A	0,562				
1B	0,558				
AB		0,530			
BA		0,517	0,517		
2A			0,505	0,505	
2B				0,499	
1A					0,480
B					0,480
3B					0,477

Table 5. Duncan Test Results for Equilibrium Moisture Content

Board Groups	α=0,05 a	b	c
1A	9,498		
3B		9,259	
AB		9,231	
3A		9,206	
A		9,161	
1B		9,138	
B		9,124	
2B		9,113	
2A			8,893
BA			8,754

Statistical analysis showed that the ply combination had a significant effect on thickness swelling value (P<0,0001). According to the test results, the highest increase in thickness swelling was observed in the B group, while the lowest value was found in the 2B group. The interaction graph showing the effect of ply combination and soaking time on the thickness swelling of the LVL is given in Figure 4. The amount of thickness swelling of the samples increased significantly until the 336th hour. However, the amount of thickness swelling between 336th and 504th hours were determined similar results.

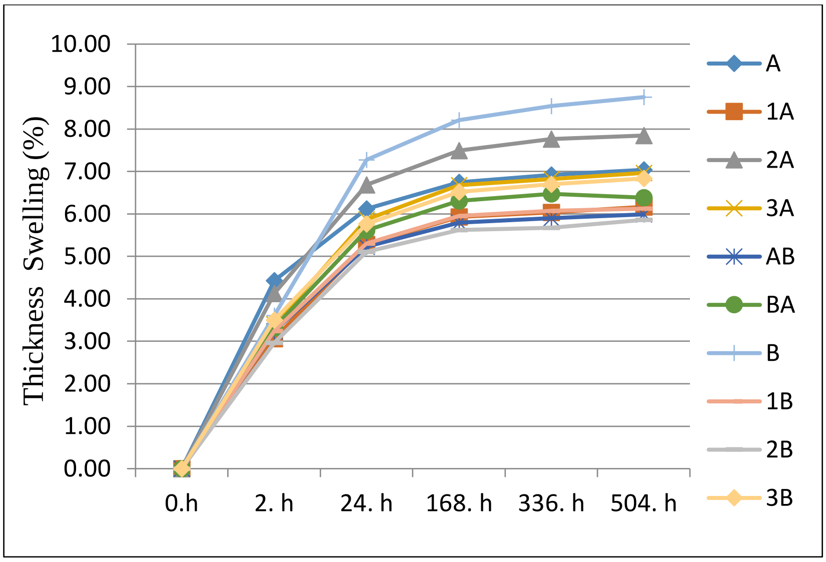

Figure 4. Thickness Swelling Interaction Graph

Table 6. Duncan Test Results for Thickness Swelling

Board Groups	α=0,05 a	b	c	d	e	f	g
B	7,28						
2A		6,78					
A			6,25				
3A				5,95			
3B				5,86			
BA					5,62		
1B						5,34	
1A						5,30	
AB						5,23	5,23
2B							5,05

The ply combination had a significant effect on water absorption value (P<0,0001). According to the test results, the highest increase in water absorption was observed in the B group, while the lowest value was found in the A group. The interaction graph showing the effect of ply combination and soaking time on the water absorption of the LVL is given in Figure 5. The water absorption value of the samples increased with the increase in the soaking time. In addition, an increase in the amount of water absorption was observed with the increase in the use of poplar veneer in the ply combination. Similar results were found in the literature (Bal and Bektaş, 2013).

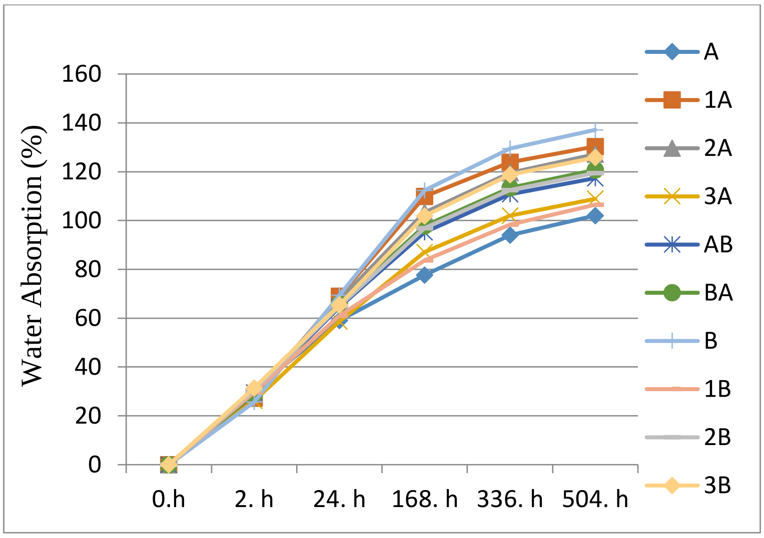

Figure 5. Water Absorption Interaction Graph

Table 7. Duncan test results for water absorption

Board Groups	α=0,05 a	b	c	d	e	f	g
B	94,81						
1A		92,06					
2A			89,36				
3B			88,65				
BA				85,3			
2B				84,89			
AB					83,50		
3A						76,54	
1B							75,83
A							72,66

Mechanical Properties

The data that were obtained for modulus of rupture (MOR), modulus of elasticity (MOE), compression strength parallel to grain (CS) and tensile-shear strength (TSS) are given in Table 8. Duncan's multiple range test was used to find out between which groups there are differences. The homogeneity groups found as the result of the test for modulus of rupture, modulus of elasticity, compression strength parallel to grain and tensile-shear strength was shown in Table 9, Table 10, Table 11 and Table 12, respectively.

Table 8. Mechanical Test Results of The Groups

	MOR	**MOE**	**CS**	**TSS**
	MPa	**MPa**	**MPa**	**MPa**
A	109,01 3,46*	9030,95 239,00	60,04 2,17	3,21 0,26
1A	88,47 4,52	8990,80 245,64	52,31 1,16	3,80 0,45
2A	91,67 4,56	8934,30 222,77	56,77 1,98	3,79 0,52
3A	93,94 2,79	8616,77 154,45	56,30 1,14	3,69 0,57
AB	93,97 4,26	8712,33 346,03	55,76 3,71	3,49 0,26
BA	88,07 7,27	7768,17 456,48	55,46 1,79	3,25 0,54
B	84,95 3,52	8157,34 267,41	50,93 1,03	4,01 0,38
1B	82,44 4,86	7852,59 469,39	58,30 1,08	3,46 0,46
2B	82,779 3,04	7758,66 278,97	54,32 1,48	3,88 0,50
3B	74,36 4,87	7521,05 191,17	51,73 2,06	3,61 0,61

*standard deviation

Statistical analysis showed that the ply combination had a significant effect on modulus of rupture value ($P<0,0001$). The graph of the modulus of rupture value of LVLs is shown in Figure 6. The highest modulus of rupture value was found in group A (109,01 MPa) and the lowest modulus of rupture value was found in group 3B (74,36 MPa). Tensile stress occurs on the bottom surface of the specimen subjected to bending and fracture starts from the surface. Therefore, the modulus rupture values of samples were increased with the rising in the use of alder veneers on the outer ply in production while decreased with the rising in the use of poplar veneers. This is because the modulus of rupture value of alder wood is higher than that of poplar wood. In previous studies, many researchers determined that the use of high-strength tree species in the outer ply increases the modulus of rupture values of the board (Burdurlu et al., 2007).

As et al. (2001) determined that the modulus of rupture value of alder is 85 MPa and modulus of rupture value of poplar is 65 MPa in their study. The modulus of rupture values of the boards produced in our study was found to be higher than the modulus of rupture values of solid wood. The reason for the increase in modulus of rupture with LVL production compared to solid wood is due to the use of glue and the compression of the board during pressing. Many researchers obtained the same results in the literature (Bao et al., 2001; Budurlu et al., 2007; Kurt, 2010).

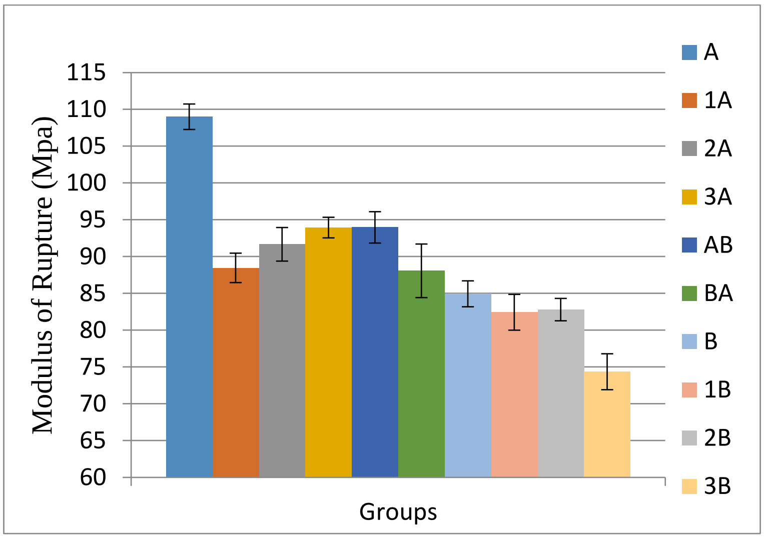

Figure 6. Modulus of Rupture Interaction Graph

Table 9. Duncan Test Results for Modulus of Rupture

Board Groups	α=0,05					
	a	b	c	d	e	f
A	109,01					
AB		93,97				
3A		93,94				
2A		91,67	91,67			
1A			88,47	88,47		
BA			88,07	88,07		
B				84,95	84,95	
2B					82,80	
1B					82,44	
3B						74,36

The ply combination had a significant effect on modulus of elasticity value (P<0,0001). The graph of the modulus of elasticity value of LVLs is shown in Figure 7. The highest modulus of elasticity value was found in group A (9030,95 MPa) and the lowest modulus of elasticity value was found in group 3B (7521,05 MPa). The modulus elasticity values of samples were increased with the rising in the use of alder veneers on the outer ply in production while decreased with the rising in the use of poplar veneers. This is because the modulus of elasticity value of alder wood is higher than that of poplar wood. Similar results were also found in the literature (Burdurlu et al., 2007).

The modulus of elasticity values of the boards produced in our study was found to be higher than the modulus of elasticity values of solid wood. The reason for the increase in modulus of rupture with LVL production compared to solid wood is due to the use of glue and the compression of the board during pressing (Bao et al., 2001; Budurlu et al., 2007; Kurt, 2010).

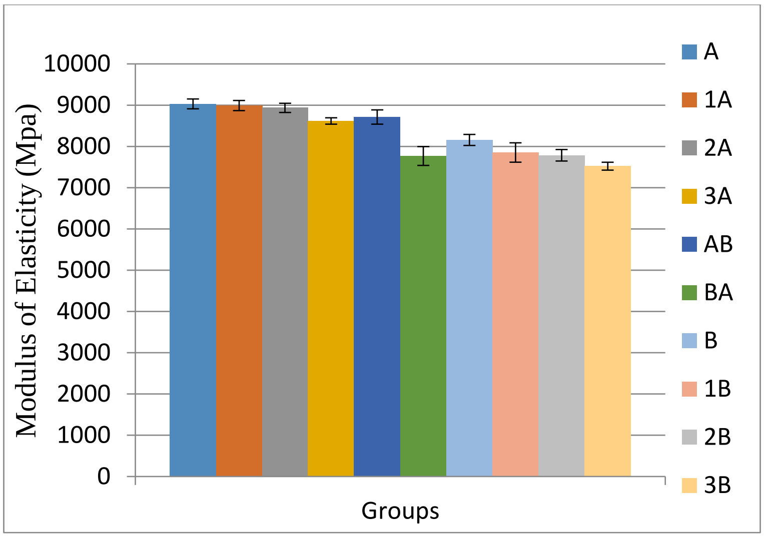

Figure 7. Modulus of Elasticity Interaction Graph

Table 10. Duncan test results for modulus of elasticity

Board Groups	α=0,05 a	b	c	d	e	f
A	9030,95					
1A	8990,80	8990,80				
2A	8934,30	8934,30				
AB		8712,33	8712,33			
3A			8616,77			
B				8157,34		
1B					7852,59	
2B					7785,66	7785,66
BA					7768,17	7768,17
3B						7521,05

Statistical analysis showed that the ply combination had a significant effect on compression strength parallel to grain. The graph of the compression strength parallel to grain of LVLs is shown in Figure 8. The highest compression strength parallel to grain was found in group A (60,04 MPa) and the lowest compression strength parallel to grain was found in group B (50,93 MPa). The compression strength parallel to grain of samples were increased with the rising in the use of alder veneers in production while decreased with the rising in the use of poplar veneers. This is because the compression strength parallel to grain of alder wood is higher than that of poplar wood. In addition, the compression strength parallel to grain of the produced LVLs were found to be higher than the compression strength parallel to grain of the solid alder and poplar. In the study conducted with alder and poplar in the literature, the compression strength parallel to grain of the alder was 47 MPa, and the compression strength parallel to grain of the poplar was 35 MPa.

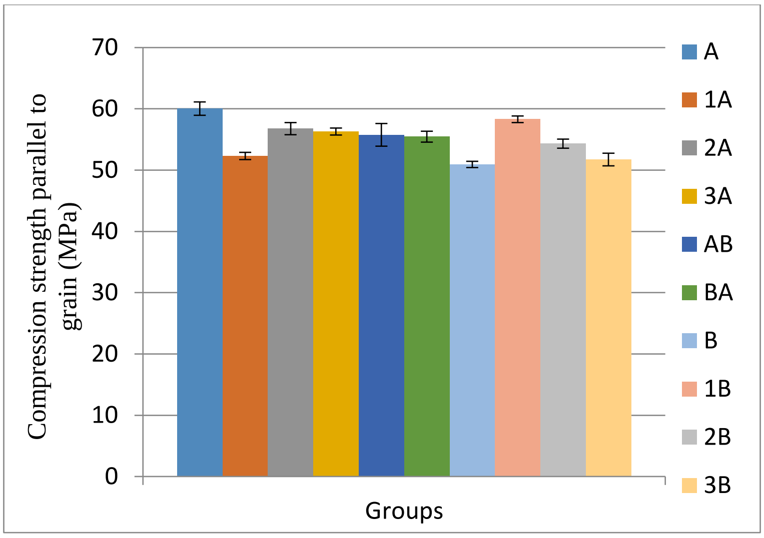

Figure 8. Compression Strength Parallel to Grain Interaction Graph

Table 11. Duncan Test Results for Modulus of Compression Strength Parallel to Grain

Board Groups	α=0,05 a	b	c	d	e
A	60,04				
1B		58,30			
2A		56,77	56,77		
3A			56,30		
AB			55,76	55,76	
BA			55,46	55,46	
2B				54,32	
1A					52,31
3B					51,73
B					50,93

5/4 glue line in groups (A, 1B, 2B, 3B),(B, 1A, 2A, 3A), (AB, BA) consists of adhesion of alder-alder, poplar-poplar and alder-poplar veneers, respectively. Statistical analysis showed that the ply combination had a significant effect on tensile-shear strength. The highest tensile-shear strength value was found in group B (4,01 MPa) and the lowest tensile-shear strength value was found in group A (3,21 MPa).

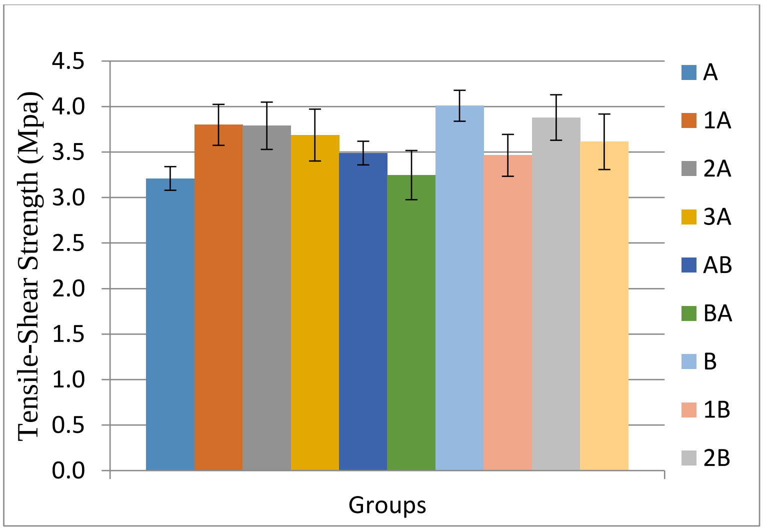

Figure 9. Tensile-Shear Strength Interaction Graph

Table 12. Duncan test results for modulus of tensile-shear strength

Board Groups	α=0,05 a	b	c	d
B	4,01			
2B	3,88	3,88		
1A	3,80	3,80		
2A	3,79	379		
3A	3,67	3,67	3,67	
3B	3,61	3,61	3,61	3,61
AB		3,49	3,49	3,49
1B		3,46	3,46	3,46
BA			3,25	3,25
A				3,21

CONCLUSION

As a result of this study;

- With the rising in the use of alder veneer in LVL production, the oven-dry specific gravity and compression strength parallel to grain increased.
- The mechanical strength values of the boards produced in our study was found to be higher than the mechanical strength values of solid wood.
- With the rising in the use of poplar veneer in LVL production, an increase in the amount of thickness swelling and water absorption was observed. The amount of the thickness swelling of the samples increased significantly until the 168th hour. The amount of water absorption increased significantly until the end of the test period (504 hours).
- An increase in the modulus of rupture and modulus of elasticity of LVL was determined with the use of alder veneers in the outer layer.

AUTHOR CONTRIBUTIONS

İlkay Atar: Designing the study, collecting data, analyzing data, analysis interpretation of the results, writing the article, **Fatih Mengeloğlu:** Analyzing data, analysis interpretation of the results, writing the article.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

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