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The Effect of Press Temperature and Duration on the Bonding Strength of American Poplar Laminated Veneer Lumber

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Abstract

In this study, the effect of press temperature and duration on bonding strength of laminated veneer lumber (LVL) was investigated. For this purpose, LVLs were produced from I 77/51 American poplar clone (*Populus deltoides*) by using 2 different press temperatures (140 and 170ºC) and 3 press duration (10, 15 and 20 minutes). Phenol formaldehyde (PF) adhesive was used for bonding of poplar veneers. The bonding strength and wood failure rate of produced LVLs were determined according to TS EN 314-1 standard. According to experimental results, the LVLs pressed at 170ºC showed better bonding strength compared to LVLs pressed at 140ºC. On the other hand, a decrease was observed in the wood failure rate due to the increase in temperature. The highest bonding strength was obtained by press duration of 10 minutes at press temperature of 170ºC and a significant decrease in bonding strength was observed when press duration was extended.

Keywords: Press temperature, press duration, bonding strength, laminated veneer lumber, American poplar, phenol formaldehyde.

Pres Sıcaklık ve Süresinin Amerikan Kavağı Tabakalı Kaplama Kerestenin Yapışma Dayanımı Üzerine Etkisi

Öz

Bu çalışmada, tabakalı kaplama kereste (TKK) üretiminde pres sıcaklığı ve pres süresinin yapışma direnci üzerine etkisi incelenmiştir. Bu maksatla I-77/51 Amerikan Kavağı klonu (*Populus deltoides*) kaplamaların, fenol formaldehit (FF) yapıştırıcısı kullanılarak 140ºC'de 10 dakika, 170ºC'de 10, 15 ve 20 dakika süreyle preslenmesiyle TKK'ler üretilmiştir. Elde edilen TKK'lerin yapışma dirençleri ve odun kırılma oranları TS EN 314-1 standardına göre belirlenmiştir. Deney sonuçlarına göre 170ºC'de preslenen numunelerin yapışma direnci 140ºC'de preslenenlere göre daha yüksek bulunmuştur. Diğer yandan, pres sıcaklığındaki artış sonucunda odun kırılma oranında düşme gözlemlenmiştir. Pres süresi incelendiğinde en yüksek yapışma direnci 170ºC'de 10 dakika preslenerek üretilen TKK'lerden elde edilmiş ve pres süresi uzatıldığında yapışma direncinde düşüş gözlemlenmiştir.

Anahtar Kelimeler: Pres sıcaklığı, pres süresi, yapışma direnci, tabakalı kaplama kereste, Amerikan kavağı, fenol formaldehit

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1. Introduction

The use of wood-based composite materials increases day by day according to developing technology and changing needs. LVL is one of the important wood-based composite and is produced by laminating of veneers together as parallel fiber directions with synthetic adhesives. LVLs stand out with more homogeneous structure than wood, dimensional stability, high strength in fiber direction, able to be produced in desired dimensions and more efficient use of raw materials (İlçe et al. 2015; Luy et al. 1968; Mengeloğlu and Kurt 2004).

Phenol formaldehyde is one of the most common adhesive for structural wood composites used in exterior with its low formaldehyde emission, high impact strength and high resistance to water-moisture, creep and chemicals. But phenol formaldehyde cures slower and needs higher press temperature than amino plastic based adhesives (Dunky and Niemz 2002; Huang 2010). Because of their effects on the production costs, optimizing the press temperature and press duration is of great importance.

The applied press temperature and duration are also important in terms of the bonding strength (Dunky and Niemz 2002; Kurt et al. 2011; Luy et al. 1968; Pangh and Doosthoseini 2017; Sedliačik et al. 2010). In order to obtain sufficient hardening in PF adhesives, pressing process should be carried out at temperatures above 100ºC (Bliem et al. 2020; Dunky and Niemz 2002). The ideal press temperature is in the range of 130 to 140ºC (Dunky and Niemz 2002; Sedliačik et al. 2010). Increasing the press temperature accelerates the condensation reaction, hardening and increases the degree of curing of the PF adhesive (Bliem et al. 2020; Sernek and Kamke 2007). In addition, the amount of methylene bond in the adhesive layer increases due to the increase of temperature, so it is possible to obtain a higher bonding strength and thermal stability (Chow, 1972; Dunky and Niemz 2002; Lin and Lee 2018). However, the PF adhesive penetrates the wood faster due to the increase of press temperature which may cause to starved glue line (Dunky and Niemz 2002; Huang 2010; Kamke and Lee 2007).

On the other hand, because of the high temperature influence, the structure of the amorphous components (hemicellulose and lignin), which have a low degree of polymerization, can be disrupted. As a result of that, the mechanical properties of wood can decrease (Aydemir et al. 2010; Gunduz et al. 2009). Another problem in LVL production is the vapor pressure caused by the evaporation of the water in the veneers and adhesive as a result of the high temperature (>100ºC) applied. Before the press pressure is removed, the evaporated water must be discharged. Otherwise, LVL panel may explode and delamination between LVL layers may occur due to the steam pressure (Huang 2010; Kollmann et al. 1975).

In some processes such as densification and bending, which may be integrate into the LVL production, high press temperatures and long press time may be required. As mentioned above, the application of different press temperatures and times in LVL production may affect the bonding strength. The objective of this study was to investigate the effect of high press temperature and long press duration on the bonding strength of LVL produced from American poplar (I-77/51) veneers by using phenol formaldehyde adhesive.

2. Material and Methods

In this study, the 1.8 mm thick veneers were used, which were peeled from I-77/51 clone American poplar (Populus deltoides) logs grown in Duzce. The poplar logs were peeled after 3 days from cutting (in green state). The rotary cut veneers were cut in dimension of 30x30 cm and conditioned at 20ºC and in 65% relative humidity until they reached the equilibrium moisture content. A commercial phenol formaldehyde (PF) resin (Polifen 47 from Polisan A.Ş./Turkey) was used to bond the veneers together. Bekhta et at. (2014) reported in their study that the wheat starch absorbed water very well and took the excessive water vapor from the glue line. After some preliminary experiments 2 wt% wheat starch was added to the PF resin to reduce the risk of delamination caused by steam pressure. So, the PF adhesive had been prepared and was applied on one side of the veneers in amount of 180 g/m2 with a glue application roller. Technical information about the PF resin is given in Table 1.

Table 1. Specification of the PF resin (Polifen 47).

Specifications	Value	Units
Density (at 20ºC)	1,207	g/cm^3
Viscosity (at 20ºC)	0,5	Pa.s
Solid content (2h, at 120ºC)	47,61	%
Gelling time (at105ºC)	13	min.

6-ply LVLs were produced in hydraulic press with capacity of 180 tones (Cemil Usta SSP-180) under 1 N/mm^2 pressure. Two different press temperature (140ºC and 170ºC) and three different pressing time (10, 15, 20 min.) were applied during pressing (Table 2). 6 samples were cut for each test groups from the 6-ply LVLs (Figure 1) and conditioned at 20ºC and in 65% relative humidity before testing.

Table 2. Press parameters of LVLs.

Samples	Press Temperature (ºC)	Press Duration (min.)
A	140	10
B	170	10
C	170	15
D	170	20

The density of LVLs was determined according to TS EN 323 standards. The bonding strength of the produced LVLs was determined according to the standard TS EN 314-1. The lap-shear test was applied to determine the bonding strength by using of universal test machine (UTEST 7012) with the capacity of 50kN. The loading rate was set to 5 mm/min. and the bonding strength was calculated by following equation:

$$BS = \frac{T}{l \times w} \ (N/mm^2) \quad (1)$$

where *BS* is bonding strength, *F* is the force at breaking point, *l* is the shear length (25 mm) and *w* is the bond surface width (25mm). The wood failure rate was estimated visually using a magnifying glass as specified in the TS EN 314-1standard.

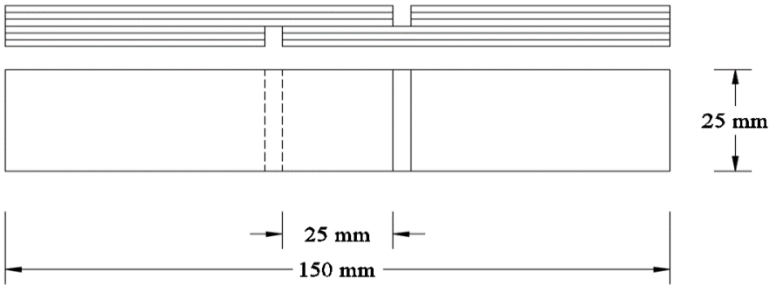

Figure 1. Lap shear test sample to determine bonding strength of LVLs according to TS EN 314-1.

One-way ANOVA (p≤0,05) was used to compare bonding strength of the LVLs according to press temperature. Mean differences between bonding strength of LVLs according to press duration were determined with Duncan's Multiple Range Test (p≤0.05). Before statistical analysis, it was determined that the data was normally distributed and the variances were equal.

3. Results and Discussion

In this study, the effects of different press temperatures and durations on the bonding strength of poplar LVLs produced using PF adhesive were investigated. The density, wood failure rate and bonding strength of the LVLs were produced at different press temperatures shown in Table 3.

Table 3. The density, wood failure rate and bonding strength of LVLs produced at different press temperature and the results of one-way ANOVA.

LVL groups	Press temperature (ºC)	Density (g/cm3)	Wood failure rate (%)	Bonding strength (N/mm^2)	F	p≤0,05
A	140	0,52	88	5,28 (0,18)	35,686	0,000
B	170	0,51	40	7,21 (0,70)		

Standard deviation range shown in parentheses

To determine the effect of press temperatures on the bonding strength, the LVL groups A and B (pressed at 140ºC and 170ºC) were compared. As a result, a statistically significant increase ($p \leq 0.05$) in bonding strength from 5.28 N/mm2 to 7.21 N/mm2 was observed when the press temperature increased from 140ºC to 170ºC. PF adhesives cure rein with temperature and the curing rate increase while press temperature increase (Chow, 1972; Dunky & Niemz, 2002) which may be the reason for this increase on bonding strength. Lin and Lee (2018) also found that the bonding strength of plywood's pressed with PF at different temperatures between 135ºC and 165ºC for 5 minutes increased as the press temperature increased.

Table 4. The density, wood failure rate and bonding strength of LVLs pressed at different press duration and the results of Duncan's multiple range tests.

LVL groups	Press duration (min.)	Density (g/cm^3)	Wood failure rate (%)	Bonding strength (N/mm^2)	
				HG 1	HG 2
B	10	0,51	40	7,21 (0,70)	
C	15	0,52	45		5,75 (1,18)
D	20	0,52	45		5,39 (0,42)
Sig				1,000	0,464

HG: Homogeneity groups, Standard deviation range shown in parentheses.

To determine the effect of the press duration at high press temperature (170ºC) the specimens groups B (10 min.), C (15 min.) and D (20 min.) are compared. The density, wood failure rate and bonding strength results of these groups are shown in Table 4. As a result, the highest bonding strength (7.21 N/mm2) was determined in LVL, which was pressed for 10 minutes at 170ºC. Prolonging the pressing time causes a statistically significant ($p \leq 0.05$) decrease in bonding strength. However a decrease in bonding strength observed by extending the pressing time from 15 to 20 minutes is not statistically significant. The press temperature should be kept as high as possible to complete the curing of PF adhesives. However, wood material can be damaged due to the effect of longer press duration at high press temperature (Aydemir et al. 2010; Bliem et al. 2020; Dunky and Niemz 2002; Gerhards 1982; Gunduz et al. 2009; Sinha et al. 2011; Zhou et.al. 2012) which may be responsible for the decrease of bonding strength due to the extending of press time.

In the literature, there are some studies about bonding strength of LVL produced from poplar veneers with PF adhesives. Bao et al. (2001) pressed LVLs 20 minutes at 160ºC and found their bonding strength between 8.82 N/mm^2 and 10.32 N/mm^2. Kurt et al. (2012) obtained 7.03 N/mm^2 bonding strength in LVL pressed 24 minutes at 140ºC press temperature. It is observed that LVL produced by pressing for 10 minutes at 170ºC has similar bonding strength (7.21 N/mm^2) compared to the studies in the literature.

When fracture surfaces were examined, a high rate of wood failure was observed for the LVLs pressed at 140ºC for 10 minutes, as expected (Figure 3a). On the other hand, a lower rate of wood failure was observed in LVLs pressed at 170ºC, although they showed higher bonding strength (Figure 3b, c, d). The adhesive viscosity decreases due to the increase of temperature, so the adhesive penetrates more into the veneer (Dunky and Niemz 2002; Kamke and Lee 2007). As a result of the deeper penetration, the rate of pure wood failure may have reduced. It is also thought that the PF adhesive improves the mechanical properties by filling the micro cracks in veneer. Furuno et al. (1983) reported that the lap shear specimens with greatest penetration showed better shear strength and lower wood failure rate, similar to our results.

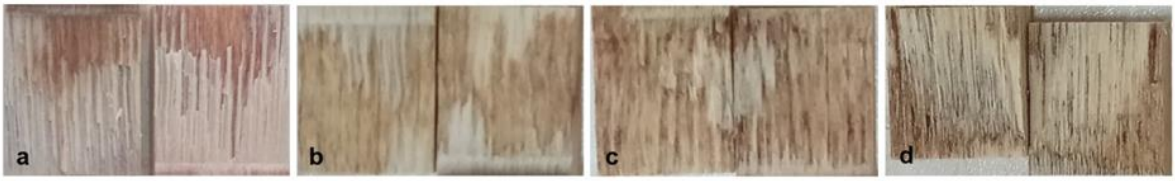

Figure 2. Fracture surfaces of produced LVLs pressed a) at 140ºC for 10 minutes, b) at 170ºC for 10 minutes, c) at 170ºC for 15 minutes, d) at 170ºC for 20 minute.

4. Conclusion

In this study, the effect of press temperature and duration on the bonding strength of poplar LVL produced by using PF adhesive is examined and the results are listed below.

- An increase in bonding strength was observed by increasing the press temperature from 140°C to 170°C.
- Although the bonding strength of the LVLs pressed at 170 is higher than those pressed at 140, they showed lower wood failure rate.
- The lowest bonding strength was observed in LVLs pressed at 140ºC for 10 minutes.
- The highest bonding strength was obtained with LVLs pressed at 170ºC for 10 minutes. A decrease in bonding strength was observed when the press time is extended.

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