

## EFFECTS OF PRESS PRESSURE ON GLUE LINE THICKNESS AND PROPERTIES OF LAMINATED VENEER LUMBER GLUED WITH MELAMINE UREA FORMALDEHYDE ADHESIVE

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Laminated veneer lumbers (LVLs) were manufactured from half-round sliced I-214 hybrid poplar clone veneers with MUF adhesives using press pressures ranging from 2.5 to 15 kg cm<sup>-2</sup>. The results showed that the press pressures affected the glue line thickness (GLT) and the physical and mechanical properties of the LVLs. Higher specific gravity (SG) and mechanical properties, but lower GLT were developed as a result of using higher press pressures. The optimum press pressure was found to be 10 kg cm<sup>-2</sup> in relation to GLT, SG, and mechanical properties. Significant linear correlations were found between GLT and mechanical properties. GLT can be used to determine the quality of wood bonding and may become a valuable tool for this purpose. Reliable data on the optimum GLT and press pressures can be used to design safe wood bonding applications in all aspects of wood based composites, as well as wood constructions when appropriate techniques are adopted to measure the GLT.

*Keywords:* Laminated veneer lumber (LVL); Melamine urea formaldehyde (MUF); *Populus x euroamericana*; Press pressure; Glue line thickness

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### INTRODUCTION

Engineered wood products (EWPs) are generally defined by the American Plywood Association (1999) as products manufactured by bonding wood strands, veneers, lumber, or other forms of wood fiber to produce a larger and integral composite unit. Laminated veneer lumber (LVL) is one of the most known and commercially produced EWPs that consists of defect-free veneers glued together to achieve beams with longer and thicker dimensions and high strength (Porteous and Kermani 2007). LVL is manufactured by laminating veneers with all of the plies parallel to the length (Cai and Ross 2010).

Gluing, pressing, and curing are key steps in LVLs manufacturing that determine strength and durability (Kurt *et al.* 2011). The quality and success of the pressing operation depends on suitable heat, press duration, and press pressure. Press pressures depend on the type of glue used, viscosity, pressing temperature, type and surface of wood (Baumann and Marian 1961), and physical properties of wood (Rabiej and Behm 1992). It is important to understand the role of pressure when assembling an adhesively bonded joint, *i.e.*, how much pressure to apply to a joint during the adhesive curing

process (Kellar 2005). The application of pressure is often required for the joint to achieve the required strength (Davis 1997). Pressure is used to produce a thin glue line, squeeze out excess glue, increase the penetration of the glue into wood, transfer the glue to the opposite un-spread surface of an adherent, and to position members (Marian 1967) and/or give their final forms. The press pressure is one of the main factors that control the glue line thickness (GLT) other than the adherent, adhesive, machining, and adhesive spreading. GLT introduces one of the fractious factors in a bond formation because it directly affects how the glue line functions (Marra 1992).

The GLTs for wood joints are generally 0.127 to 0.178 mm thick (Kurt 2003). When the GLT is within the optimum range, the adhesive will not fail prematurely as the load transfer is maximized and the creep is minimized (Kellar 2005). Thicknesses below this range may occur during the manufacturing process of products where high pressure and heat are used, *i.e.* EWPs.

There is a strong relationship between GLT and loss of joint strength (Kurt 2003). Usually, mechanical properties decrease as GLT increases due to an increased eccentricity in test specimens, a decrease in the physical strength of glue with increasing thickness (Cockrell and Bruce 1946), and a slight shrinkage of the adhesive from the interfaces during curing (Hylands and Sidwell 1980). In glued wood structures designed to close tolerances, thick glue lines are usually considered a basis for rejection (Cockrell and Bruce 1946). This is also important for structural composite lumbers *i.e.* LVLs that are designed to carry loads.

Research dealing directly with press pressures in relation to GLT has been limited. The objective of this research was to determine the effect of eight different press pressures (2.5, 5, 7.5, 10, 12.5, 15, 17.5, and 20 kg cm<sup>-2</sup>) on GLT, and selected physical and mechanical properties of LVLs manufactured from half-round sliced, I-214 veneers, glued with the MUF adhesive under laboratory conditions. A press pressure below 2.5 kg cm<sup>-2</sup> was found to be inadequate due to its ineffectiveness relative to the specific gravity of LVLs and taken as a control press pressure. This can also cause low penetration into the wood surface because that allows only a small amount of internal surface contact for chemical bonding or mechanical interlocking (Scheikl 2002). LVLs could not be manufactured for the press pressures of 17.5 and 20 kg cm<sup>-2</sup> due to joint starvation problems. As a result, only six different press pressures (2.5, 5, 7.5, 10, 12.5, and 15 kg cm<sup>-2</sup>) were used to manufacture LVLs. The relationships between GLT and physical and mechanical properties of LVLs were studied. The optimum press pressure was determined in relation to GLT, specific gravity (SG), and mechanical properties.

## MATERIALS AND METHODS

### Wood Veneers

The LVLs were manufactured from half-round sliced veneers of *Populus x euramericana* (I-214) with dimensions of approximately 600 mm x 150 mm x 3 mm and a moisture content of 6 to 8%. They were purchased from a veneer manufacturer in Düzce, Turkey.

## Adhesive

Commercial melamine urea formaldehyde (MUF) adhesive was used. MUF adhesive has a pH of 9.50 with a viscosity of 130 cPs, a solid content of 54±2%, and a specific gravity of 1.24 g cm<sup>-3</sup> at 20°C (Polisan 2012). The adhesive spreading rate was 200 g m<sup>-2</sup>, and it was held constant for all of the press pressures. The gram weight pick up was calculated according to the procedures described in ASTM D899 (1994).

## LVL Manufacturing

Experimental eight-ply LVLs were manufactured from half-round sliced I-214 hybrid poplar clone veneers using MUF adhesive. After spreading the adhesives onto the veneer's surfaces, they were immediately assembled with their tight sides facing out on each veneer. Billets were pressed at 110 °C for 30 min with their grain directions parallel to each other. Six different pressures were used; 2.5, 5, 7.5, 10, 12.5, and 15 kg cm<sup>-2</sup> for the manufacturing of LVLs. For each pressure, 12 LVLs (150 (w) by 600 (l) mm) were manufactured. They were further cut in accordance to specific test dimensions and conditioned at a relative humidity of 65±1% and a temperature of 20±3 °C until they reached the equilibrium moisture content of 10±2%.

## Testing

Moisture content (MC) and oven dry SG values of LVLs were determined in accordance with TS 2471 (1976a) and TS 2472 (1976b), respectively. Dimensions of the SG and MC specimens are given in Table 1. The modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength (CS) (parallel to grain) were determined according to procedures described in TS 2474 (Anonymous 1976c), TS2478 (Anonymous 1976d), and TS 2595 (Anonymous 1977), respectively. The specimens were tested using a Zwick Roell (Z010) testing machine (Zwick, Germany). A total of 30 replicates were used to test each property. Dimensions of MOR, MOE, and CS specimens are given in Table 1. LVLs were tested flatwise to failure in bending under the center point loading to determine MOR and MOE. The span-to-depth ratio was fixed to 15 and adjusted for each specimen due their thickness differences as a result of using different pressures.

**Table 1.** Dimensions of Specimens for Specified Tests

Test	Dimensions (mm)
Oven-dry specific gravity (SG)	Thickness x 30(w) x 30(l)
Moisture content (MC)	
Modulus of rupture (MOR)	Thickness x 20(w) x 360(l)
Modulus of elasticity (MOE)	
Compression strength parallel to grain	Thickness x 20(w) x 30(l)

GLTs of each specimen were examined through a light microscope (Soif SZM45-B2), measured using an image analysis technique by operating a package program and recorded to the nearest 0.001 mm. A total of 12 measurements were made (six of each side) in the middle glue line (between the 4<sup>th</sup> and 5<sup>th</sup> plies) and were averaged for each specimen. For each group, the average GLT was calculated using a total of 1080

measurements (three different properties testing (SG, MOE/MOR, and CS) x 30 specimens x 12 measurements).

To explain the improvement in strength properties of LVLs compared to corresponding solid wood (SW), a compaction factor (*CF*) was calculated according to Bao *et al.* (2001). *CF* can be expressed as,

$$CF = D_L / D_S \quad (1)$$

where  $D_L$  is LVL's SG and  $D_S$  is SW's SG. The SG of SW's was found to be 0.34. High *CF* ratios indicate higher densification.

### Statistical Analysis

Analysis of variance (ANOVA) was used to determine the effect of pressure on GLT, SG, and mechanical properties of LVLs using the SAS statistical package program (SAS Institute 2001). The resulting F value was compared to the tabular F value at the 95% probability level. When there was a significant difference as a result of F tests, comparisons between means were made by the Bonferroni t-test. Relationships between GLT/SG and mechanical properties were analyzed.

## RESULTS AND DISCUSSION

Results of the average GLT, SG, MOR, MOE, and CS tests, including their standard deviations of LVLs, are given in Table 2 along with the values of the respective press pressure values. The ANOVA ( $\alpha=0.05$ ) results indicated that the difference in the mean GLT, SG, MOR, MOE, and CS values were observed when different press pressures were used. A Bonferroni t-test result is given for each property separately. MC values were found to be  $10 \pm 2\%$ .

**Table 2.** GLT, SG, CF, MOR, MOE, and CS of LVLs

Properties	Press Pressure (kg cm <sup>-2</sup> )					
	2.5	5	7.5	10	12.5	15
GLT (mm)	0.123 <b>A</b> (0.008)	0.101 <b>B</b> (0.004)	0.092 <b>C</b> (0.005)	0.084 <b>D</b> (0.005)	0.059 <b>E</b> (0.006)	0.044 <b>F</b> (0.004)
SG	0.35 <b>D</b> (0.02)	0.36 <b>D</b> (0.01)	0.37 <b>CD</b> (0.04)	0.38 <b>C</b> (0.02)	0.42 <b>B</b> (0.03)	0.48 <b>A</b> (0.05)
CF	1.09	1.13	1.16	1.19	1.31	1.50
MOR (MPa)	55.91 <b>A</b> (8.13)	59.91 <b>AB</b> (6.26)	63.41 <b>BC</b> (9.00)	66.30 <b>BC</b> (8.38)	68.37 <b>CD</b> (10.36)	74.69 <b>D</b> (7.52)
MOE (MPa)	5588.78 <b>A</b> (443.28)	5629.32 <b>A</b> (494.70)	5853.88 <b>AB</b> (539.07)	5946.54 <b>AB</b> (407.69)	6031.71 <b>B</b> (550.04)	6461.82 <b>C</b> (510.55)
CS (MPa)	55.43 <b>A</b> (4.71)	65.16 <b>A</b> (7.73)	69.67 <b>B</b> (7.54)	75.27 <b>BC</b> (8.65)	84.52 <b>C</b> (9.13)	87.93 <b>D</b> (10.08)

Bonferroni t-test groupings are given in bold capital letters; means with the same letter are not significantly different. Standard deviations are given in parenthesis.

Higher SG and mechanical properties, but lower GLT were developed as a result of using higher press pressures. Press pressure in excess of  $10 \text{ kg cm}^{-2}$  resulted in a very sharp increase in SG, MOE, and MOR, and a decrease in GLT. The optimum press pressure would appear to be  $10 \text{ kg cm}^{-2}$ . ANOVA results significantly separated the press pressure of  $15 \text{ kg cm}^{-2}$  from the others. Beyond a press pressure of  $15 \text{ kg cm}^{-2}$ , LVLs' productions were not possible due to joint starvation. A joint starved of adhesive will be very weak and highly susceptible to defects such as voids and dry/poorly wetted areas (Scheikl 2002). The spreading rate of adhesive  $200 \text{ g m}^{-2}$  was found to be satisfactory for press pressures of up to  $15 \text{ kg cm}^{-2}$ .

The mean GLT values of LVLs fell within a wide range, between 0.044 and 0.123 mm (Table 2). The results proved that GLT is a function of press pressure as well as gluing factors. Increased press pressures showed a significant reduction in GLT. The percentage of GLT reduction ranged from a low of 17.88 to a high of 64.22 percent compared to that of the press pressure of  $2.5 \text{ kg cm}^{-2}$ . The largest reduction in GLT was found in LVLs pressed with  $15 \text{ kg cm}^{-2}$  of press pressure. A trend of increased mechanical properties accompanies the decrease in GLT. The highest mechanical properties were obtained when thinnest GLT was present. No significant differences were found for thicker glue lines in the range of 2.5 to  $5 \text{ kg cm}^{-2}$ . When a press pressure of more than  $10 \text{ kg cm}^{-2}$  was used, GLT decreased at a greater rate than normal (12 to 13 percent per interval).

A relationship exists between GLT and SG, MOR, MOE, and CS. A very strong linear correlation was found between GLT and MOR, MOE, and CS, with the coefficient of determinations ( $R^2$ ) of 0.96, 0.89, and 0.98, respectively.  $R^2$  values of GLT were higher than that of SGs'. GLT can be a function of strength properties since it is an important indicator of the degree of penetration into wood, in addition to the resin system and the manufacturing processes, as they are of the wood being incorporated into the wood-based products (Chapman 2006). In light of these relationships, GLT may be used to control the quality of LVLs when appropriate techniques are adopted to measure GLT during manufacturing.

The mean SG values of LVLs fell within a wide range, between 0.35 and 0.48 (Table 2). LVLs that were manufactured by applying the highest press pressure of  $15 \text{ kg cm}^{-2}$  showed the highest SG and mechanical properties followed by the press pressures of 12.5, 10, 7.5, and  $5 \text{ kg cm}^{-2}$  compared to that of  $2.5 \text{ kg cm}^{-2}$ . Similar findings have been reported for plywood on some mechanical properties of plywood (Örs *et al.* 2001). The SG of LVLs that were manufactured using the press pressure of  $15 \text{ kg cm}^{-2}$ , was higher than that of spruce (*Picea abies*), Douglas fir (*Pseudotsuga menziesii*), and willow (*Salix alba*) woods (Bozkurt and Erdin 1997).

Densification through pressing is one of the important approaches in LVLs manufacturing to improve their mechanical properties and increase the use of fast growing species such as poplar. It is well known that most mechanical properties of wood are correlated with specific gravity (Kamke 2006). A strong linear correlation was found between SG and MOR, MOE, and CS with an  $R^2$  value of 0.88, 0.91, and 0.81, respectively. The pressing process weakened the cell walls, where parenchyma cells were compressed (Sulaiman *et al.* 2009). Applied press pressure is one of the major factors responsible for enhancing the SG of wood based composites. An increase in press

pressure promotes adhesive penetration (Frihart 2005) and densification that may provide interlocking of the resin thoroughly, thus strong bonds between the veneers can be achieved (Huang 2011).

The *CF* value is a good indicator to determine the degree of compaction or densification. The *CF* values of LVLs fell within a wide range, between 1.09 and 1.50. An increasing trend was found for *CF* values as the press pressure increased. *CF* values increased since compressibility of wood is affected by the amount of press pressure. A press pressure above 10 kg cm<sup>-2</sup> caused a larger degree of compaction (up to 50%). Similar findings were found by Currier (1962) related to high press pressure. Marra (1980) reported that one of the penalties of excessively high pressure is compression of the wood beyond its proportional limit. According to Palka (1964), larger pressure causes a higher degree of densification and forces more liquids into the veneers which facilitate plastic deformation farther.

MOR, MOE, and CS values of LVLs ranged from 55.91 to 74.69, 5588.78 to 6461.82, and 55.43 to 87.93 MPa, respectively (Table 2). The test results showed that MOR, MOE, and CS increases by up to 33.59%, 15.62%, and 58.63%, respectively, at a press pressure of 15 kg cm<sup>-2</sup>. According to the Bonferroni t-test results, there was a significant difference between MOR values with a press pressure of 15 and 2.5 to 5 to 7.5 to 10 kg cm<sup>-2</sup> and also, there was a significant difference between MOE as well as CS values with a press pressure of 15 and 2.5 to 5 to 7.5 to 10 to 12.5 kg cm<sup>-2</sup>.

Press pressures in excess of 7.5 kg cm<sup>-2</sup> resulted in a very gradual increase of mechanical properties up to 12.5 kg cm<sup>-2</sup>. The highest mechanical properties were attained at the press pressure of 15 kg cm<sup>-2</sup>. The amount of adhesive penetrating into the wood substrate during the manufacture of plywood or other wood composite materials is known to affect bond quality (Scheikl 2002). The results showed that adhesive makes an important contribution to the strength of wood or wood based composites dependent upon the extent of glue penetration (Preston 1950). Adhesive impregnation into the cell cavities or as a result of combination with the cell wall to form an amalgam contributes to the improvement of MOE (Preston 1950) as well as MOR and CS.

## CONCLUSIONS

1. LVLs were successfully manufactured from half-round sliced veneers of *Populus x euramericana* (I-214). The veneers were bonded with the MUF adhesive using press pressures ranging from 2.5 to 15 kg cm<sup>-2</sup> in increments of 2.5 kg cm<sup>-2</sup>. GLT, SG, and mechanical properties of LVLs were affected by the press pressure. Applying high pressure increases SG and mechanical properties, but decreases GLT.
2. The results indicated that the difference in the mean GLT, SG, and mechanical property values were observed when different press pressures were used. *CF* values were used to explain variations between SGs and mechanical properties increase in relation to the SG due to press pressures.
3. Press pressures of 12.5 and 15 kg cm<sup>-2</sup> had a drastic effect on all properties. The critical press pressure was found to be 10 kg cm<sup>-2</sup>. Pressures higher than 15 kg cm<sup>-2</sup>

may be risky at this level of spreading rate and heat using the MUF adhesive because of possible over penetration.

4. Stronger relationships were found between GLT and mechanical properties than that of SG and mechanical properties. GLT may be used to control the quality of LVLs when appropriate techniques are adopted to measure GLT. Reliable data on optimum GLT and press pressures can be used for safer wood bonding applications. Advances are needed to measure GLT online during manufacturing that may provide more information to predict the mechanical properties of LVLs and other wood-based composites.

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