EFFECT OF PRESSURE DURATION ON PHYSICAL, MECHANICAL, AND COMBUSTIBILITY CHARACTERISTICS OF LAMINATED VENEER LUMBER (LVL) MADE WITH HYBRID POPLAR CLONES

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Experimental eight-ply laminated veneer lumbers (LVLs) from rotary peeled I-214 (*Populus x Euramericana)* and I-77/51 (*Populus deltoides*) fast growing hybrid poplar clones were successfully manufactured using three different press durations (18, 24, and 30 min) with a melamine urea formaldehyde (MUF) adhesive. The effect of press durations on LVLs' selected physical, mechanical, and combustibility characteristics were determined. The results showed that press duration affected dimensional stability (thickness swelling and water absorption), modulus of rupture, and/or compression strength parallel to grain, depending on the clone types. Improvement in dimensional stability and some mechanical properties of LVLs can be achieved by proper curing of the MUF adhesive. On the other hand, the press durations did not affect oven-dry densities, modulus of elasticity, and the combustibility (weight loss after completion of the test). For improved physical and mechanical properties, up to a 30 min press duration can be recommended. This is necessary for LVLs when they are to be used under conditions where water and/or high humidity is present.

Keywords: Hybrid poplar clones; Laminated veneer lumber (LVL); Press durations; Melamine urea formaldehyde (MUF); Populus x Euramericana; Populus deltoides

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INTRODUCTION

Hybrid poplar I-214 (*Populus x Euramericana Canadensis*) and recently I-77/51 (*Populus deltoides*) are two of the well known fast growing poplar clones in Turkey. According to Zoralioglu (2003), approximately 130,000 ha of poplar plantation are standing in Turkey, of which 61,000 ha are from *Populus nigra* clones and the rest are from of *Populus x Euramericana* and *Populus deltoides*. Altogether 3.87 million m³ of poplar wood is harvested annually, of which 55% comes from hybrid poplar clones (Zoralioglu 2003).

Hybrid poplar provides raw material for variety of uses in the forest products industry, including pulp, paper, wood composites, packaging, pallets, and moldings. Hybrid poplar use for the pulp and paper industry has decreased, prompting interest in finding alternative value-added markets (Stanton et al. 2002), including laminated veneer lumber (LVL). Utilization of *Populus x Euramericana* (Wu et al. 1998; Kurt and

Mengeloglu 2008), and *Populus deltoides* (Shukla et al. 1996; Zhu and Zhang 2003; Nimkar and Mohapatra 2002; Kurt 2010a) have been reported in LVL manufacturing.

Laminated veneer lumber (LVL) may be defined as a lumber-like product, manufactured from layered composite of wood veneers with fibers principally in the same direction (BS EN14279 2004). Commercial production and use of LVLs began in the 1980's in many areas, including in North America, Europe (especially Finland), and the Far East for structural and non-structural uses such as girders, beams, joists (including I-joists), headers, lintels, and columns, as well as scaffold planks (Nelson 1997) and panels.

The general sequence of manufacturing processes of LVLs consists of eleven steps. These are selection of logs, debarking, heating/conditioning, peeling, veneer clipping, drying, gluing and assembling, applying pressure and curing, finishing (edge trimming and end cutting), grading and quality control, wrapping, and transport. It is necessary to control manufacturing processes that affect strength and durability of LVLs, such as gluing and assembling as well as applying pressure and curing steps.

The main objective of gluing and assembling is to convert veneers into a lumber-like form. Glue bond quality is one of the most critical factors in the performance of LVLs. Thus, information regarding methods and rate of spread of adhesive, open and closed assembly time, glueline pressure, and curing temperature, pressure, and conditioning duration should be specified in advance to the any wood based composites manufacturers (BS 4169 1988).

Use of structural wood adhesives (synthetic resin based) for bonding LVLs can provide adequate strength, stiffness, and durability for exterior applications. The traditional adhesives show very good strength and durability when proper bonding is present (Serrano and Källander 2005). Usually phenolic adhesives (including phenol formaldehyde (PF) and phenol resorcinol formaldehyde (PRF)) are used in exterior LVL manufacturing, and urea formaldehyde (UF) adhesives are recommended for interior LVL manufacturing. The use of adhesives other than phenolic-based is important for semi-structural and non-structural applications of LVL. The MUF adhesive is the main candidate to meet water and moisture resistance requirements in interior conditions. MUF resins are among the most used adhesives for semi-exterior wood panels (Pizzi 2003). According to Pizzi (2003), despite their widespread use and economical importance, the research on melamine based resins is only a small fraction of that dedicated to UF resins.

MUF adhesives are classified as thermosetting polymers and are produced by a condensation reaction between melamine, urea, and formaldehyde. MUF polymers can be formulated to provide various degrees of water and weather resistance for use in exterior (service class 3), humid (service class 2) and interior (service class 1) conditions (Funch 2002). The MUF adhesives can replace other adhesives that are used for some exterior applications (Frihart 2005). The use of MUF resins has allowed the development of moisture-resistant panels with low formaldehyde emissions and excellent strength properties (Kim et al. 2007).

One of the main advantages of melamine urea formaldehyde (MUF) resins is an increased resistance against humidity, water, and weather compared to that of urea formaldehyde resins. Also, the buffering capacity of melamine results in a slower decrease of the pH in the bond line (Dunky 2002, 2003), which can lead to a decrease of the hardening rate of the resin, requiring an increase of the hot press duration (Dunky 2003). The pressure duration depends on the adhesive type, heat, pressure, and factory technical conditions. Short press time is one of the important factors that causes common failures or delaminations in glued members; such problems may be related to the production process (Serrano and Källander 2005; Huang 2011).

The objective of this research was to determine the effect of pressure durations (18, 24, and 30 min) on selected physical, mechanical, and combustion-related properties of LVLs manufactured from two hybrid clones, I-214 and I-77/51, with the MUF adhesive under laboratory conditions.

MATERIALS AND METHODS

Wood Veneers

12 year-old I-214 (*Populus x Euramericana*) logs with 35 cm diameter and 240 cm length and I-77/51 (*Populus deltoides*) logs with 36 cm diameter and 240 cm length were harvested from İzmit, Turkey. The logs were rotary peeled in a private plywood mill to approximately 600 mm x 600 mm x 3 mm. The final moisture content of dried veneers was 6 to 8%. The veneers were pre-selected for strength and appearance. They were without any stain, decay, and fungi, and also free of splits, knots, and knot holes.

Adhesive

A commercial MUF adhesive was used. The MUF adhesive has a pH of 9.50 with a viscosity of 130 cP, a solid content of 54±2%, and density of 1.24 g cm^{-3} at $20^{o}C$ (Polisan 2011). The adhesive spreading rate was 200 g m^{-2}. The gram weight pick up was calculated according to ASTM D899 (1994).

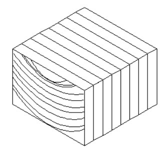
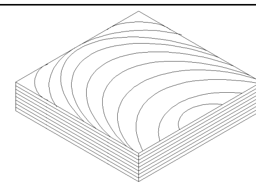
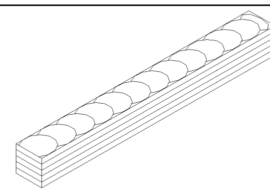
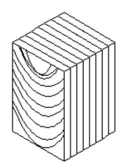
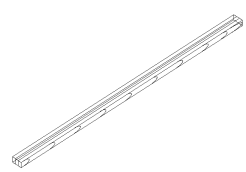
LVL Manufacturing

Experimental eight-ply LVLs were manufactured from two rotary peeled hybrid poplar clone veneers; I-214 and I-77/51. They were pressed at a pressure of 1.2 MPa using three different press durations of 18, 24, and 30 min with their grain directions parallel to each other with the MUF adhesive. The pressing temperature was 110 °C. Three sets of LVLs were manufactured for all pressing durations. They were further cut in accordance with specific test dimensions. 50 mm edges of every LVL were trimmed off to prevent any effects related to use of edges on the properties. Thus, LVLs final dimensions were reduced to approximately 500 mm x 500 mm x 20 mm.

Testing

Manufactured LVLs were tested in terms of physical, mechanical, and combustibility characteristics. Physical properties; oven-dry density (*OD*), moisture content (*MC*), dimensional stability (thickness swelling (*TS*), and water absorption (*WA*) (24 hours)) were determined according to TS 2472 (1976a), TS 2471 (1976b), and TS 3639 (1988), respectively. Mechanical properties; modulus of rupture (*MOR*), modulus of elasticity (*MOE*), and compression strength (*CS*) (parallel to grain) were determined according to TS 2474 (1976c), TS 2478 (1976d), and TS 2595 (1977), respectively. LVLs were tested flatwise to failure in bending under center point loading to determine modulus of rupture (*MOR*) and modulus of elasticity (*MOE*). The span-to-depth ratio was 15 in the bending tests. Mechanical properties specimens' were tested using a Zwick Roell (Z010) testing machine (Zwick, Germany). 10 replicates were used to test each mechanical property. Combustibility characteristics of LVLs were determined according to ASTM E69 (2002) procedure B. Five replicates were tested for each group, as required by the standard. At the end of the testing, weight loss (*WL*) percentage of specimens exposed to the flame is reported. Dimensions and shapes of specimens for specified tests are given in Table 1.

Table 1. Dimensions and Shapes of Specimens for Specified Tests

Test	Dimensions (mm)	
Oven-dry density (*OD*) Moisture content (*MC*)	30(w) x 30(l) x 20 (t)	
Thickness Swelling (*TS*) and Water Absorption (*WA*)	100(w) x 100(l) x 20 (t)	
Modulus of rupture (*MOR*) Modulus of elasticity (*MOE*)	20(w) x 360(l) x 20 (t)	
Compression strength parallel to grain (*CS*)	20(w) x 30(l) x 20 (t)	
Combustion	9.5(w) x 1016(l) x 19.5(t)	

To explain variations in selected physical and mechanical properties of LVLs compared to solid wood (SWs') properties, 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 OD and D_S is SW's OD. High *CF* ratios indicate higher densification.

Statistical Analysis

Analysis of variance (ANOVA) was used to determine the effect of pressure durations on selected physical, mechanical, and combustion 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 (Bon.) t-test. ANOVA and Bonferroni t-test results of properties were conducted for each clone type separately.

RESULTS AND DISCUSSION

Results of the average physical, mechanical, and combustion characteristics of LVLs, including their standard deviations, are given in Table 2.

The mean *OD* values of I-214 and I-77/51 LVLs fell within a narrow range, between 0.420-0.455 g cm^{-3} and 0.443-0.463 g cm^{-3} (Table 2), respectively. The *OD*s of I-214 and I-77/51 SWs were 0.32 and 0.37 g cm^{-3} respectively (Kurt 2010a). *CF*s were calculated using SWs and LVLs *OD*s. *CF*s of I-214 and I-77/51 were found to be up to 1.42 and 1.25, respectively. Although the ANOVA (α=0.05) results indicated that significant differences in mean *OD*s were observed, the increase in *CF* values were not continuous for all press durations. Thus, the significant differences in *OD*s of LVLs were due to anatomical and manufacturing variables rather than the pressure duration effect. I-77/51 had higher *OD* compared to I-214. *MC* values were found to be 10 ± 2%.

The mean *TS* values of I-214 and I-77/51 LVLs were between 2.18-3.59 % and 2.28-3.08% (Table 2), respectively. The mean *WA* values of I-214 and I-77/51 LVLs were between 39.07-45.88% and 37.72-45.97% (Table 2), respectively. There was a correlation between the pressure duration and the curing of MUF resins. The press duration affected the curing time of MUF resins. As the pressure duration increased, the *TS* and *WA* rates decreased. It is assumed that probably prolonged pressing time improved the level of crosslinking developed in LVLs. This cross-linked polymerization is the main cause for reduced *TS* and *WA* ratios. Similar findings were reported by Ohlmeyer and Kruse (1999) and Gündüz et al. (2011) for boards. High TS and WA rates were found especially for the press durations of 18 min. High TS rates have been explained as being a result of insufficient pressure duration for the hardening of the adhesive in OSB production (Gündüz et al. 2011). The ANOVA results showed that the *TS* and *WA* ratios for the 30 min pressure duration were lower than those of the pressure durations of 18 and 24 min in most cases. According to the Bon. t-test results, there was a significant difference between *TS* values for the press durations of 30 and 18-24 min of I-214 and I-77/51 LVLs. Significant differences were found between *WA* values of the press durations 30 and 18-24 min of I-214 LVLs. On the other hand, Bon. t-test results showed that there was no significant difference between the press durations of 24 and 30 min with respect to *WA* values.

Table 2. Oven-dry Density (*OD)*, Moisture Content (*MC*), Thickness Swelling (*TS*), Water Absorption (*WA*), Modulus of Rupture (*MOR*), Modulus of Elasticity (*MOE*), Compression Strength (*CS*) (parallel to grain), Weight Loss (*WL*) of LVLs

Properties	I-214			I-77/51		
	18 min	24 min	30 min*	18 min	24 min	30 min*
OD ($g\ cm^{-3}$)	0.445 **A** (0.02)	0.455 **AB** (0.03)	0.420 **B** (0.02)	0.450 **AB** (0.01)	0.463 **A** (0.02)	0.443 **B** (0.01)
TS (%)	3.34 **A** (0.55)	3.59 **A** (0.65)	2.18 **B** (0.32)	3.08 **A** (0.52)	2.95 **A** (0.44)	2.28 **B** (0.43)
WA (%)	45.78 **A** (1.51)	45.88 **A** (2.39)	39.07 **B** (1.55)	45.97 **A** (4.66)	34.72 **B** (4.39)	36.66 **B** (1,48)
MOR (MPa)	66.89 **A** (3,68)	73,85 **A** (11,60)	75,08 **A** (11,30)	67,65 **B** (2,81)	76,19 **A** (3,94)	80,23 **A** (4,66)
MOE (MPa)	6577 **A** (170)	6311 **A** (612)	6305 **A** (527)	6385 **A** (140)	6750 **A** (716)	6505 **A** (612)
CS (MPa)	42.77 **B** (1.16)	46.47 **A** (4.72)	46.34 **A** (1.39)	42.81 **C** (1.57)	45.37 **B** (1.59)	49.41 **A** (1.45)
WL (%)	81.45 **A** (0.83)	81.47 **A** (0.68)	80.47 **A** (1.20)	82.78 **A** (0.90)	82.57 **A** (1.58)	82.34 **A** (0.45)

*: Values were adopted from Kurt (2010b). Bonferroni t-test (Bon) groupings are given in capital letters; means with the same letter are not significantly different. Standard deviations are given in parenthesis.

MOR, *MOE*, *CS*, and *WL* values of LVLs ranged from 66.89-80.23 MPa, 6305-6750 MPa, 42.77-49.41 MPa, and 80.47-82.78%, respectively (Table 2). According to ANOVA results, mean *MOR*, *MOE*, and *WL* values of I-214 LVLs were not affected significantly by the press durations. Although the *MOR* values were increased when the pressure duration increased, this increase was not sufficient for significant difference (α=0.05) in *MOR* values of I-214 LVLs. This can be due to a high compaction rate (1.39) at even the pressure duration of 18 min. Shukla and Kamdem (2008) also found that these values were not affected by the press durations. *CS* values of I-214 LVLs were changed due to pressure durations, and thus their Bon. groupings were different. Bon. t-test results showed that there was a significant difference between 18 and 24-30 min pressure durations in I-214 LVLs' *CS* values. On the other hand, *MOE* and *WL* values of I-77/51 LVLs were not affected significantly by the press durations. *MOR* and *CS* values of I-77/51 LVLs were changed due to pressure durations, and thus their Bon. groupings were different. Bon. t-test results showed that there was a significant difference between 18 and 24-30 min pressure durations in I-77/51 LVLs' *MOR* values and between 18, 24, and 30 min pressure durations in I-77/51 LVLs' *CS* values. Similar findings have been reported for OSBs' *MOR* values by Gündüz et al. (2011).

CONCLUSIONS

1. LVLs were successfully manufactured from two different, rotary-peeled hybrid poplar clones (I-214 and I-77/51). The veneers were bonded with the MUF adhesive using three different press durations (18, 24, and 30 min). For improved physical and mechanical properties, longer press duration (30 min) can be recommended. This is

especially important for use under conditions where water and/or high humidity is present.
2. The results indicated that the difference in mean *TS*, *WA*, *MOR*, and/or *CS* values were observed when different pressure durations were used, depending on the clone type. *CF* values were used to explain variations in *OD*s and *MOR* due to press durations.
3. *OD*, *MOE*, and *WL* were not affected from the pressure durations.
4. Complete curing of the MUF adhesive provided better physical and mechanical properties. Improvement of dimensional stability properties including *TS* and *WA* rates as well as some mechanical properties can be gained as results of successful bonding process. Lower *TS* and *WA* should be requested for a better appearance as well as lower decrease in mechanical properties of LVLs (Ohlmeyer 2010).

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