PROPERTIES OF PARALLEL STRAND LUMBER FROM TWO HYBRID POPLAR CLONES USING MELAMINE UREA FORMALDEHYDE ADHESIVE

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Experimental parallel strand lumbers (PSLs) were manufactured from fast growing rotary peeled I-214 (*Populus x euramericana)* and I-77/51 (*Populus deltoides*) hybrid poplar clones veneer strands with melamine urea formaldehyde (MUF) adhesive. The results showed that hybrid poplar clones can be used in PSLs manufacturing. Physical and mechanical properties of PSLs were affected by clone types. The I-77/51 clone had better properties and was found to be more suitable for PSLs manufacturing compared to the I-214 clone. PSLs properties were higher than those of solid woods (SWs) and laminated veneer lumbers (LVLs) of the same poplar clones. This increase may be due to materials, densification as a result of high pressure use, and the manufacturing techniques. The degree of contribution of SWs properties to the PSLs properties was lower than that of LVLs. This indicated that factors other than SWs properties played more important roles in the strength increase of PSLs.

Keywords: Hybrid poplar clones; Parallel strand lumber (PSL); Melamine urea formaldehyde (MUF); Populus x euramericana; Populus deltoides

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INTRODUCTION

Structural composite lumber (SCL) is a family of engineered wood composite products that are produced from veneer, strands, or other small wood elements glued with the exterior adhesives to form lumber-like structural products (Nelson 1997). Parallel strand lumber (PSL) is one of the important SCLs. Recently, demand for high quality structural lumber has increased (Wu *et al.* 1998), and the need to find alternatives for solid-sawn lumber by using plantation timber led to development of PSLs in the 1970s at MacMillan Bloedel Ltd. to convert low-grade wood such as small-diameter logs into high strength lumber (Liu and Lee 2003). PSLs can be a suitable alternative to lumber and other lumber-like products, manufactured from veneer strands, glued parallel to the longitudinal axis of the member. They can be used as girders, posts, beams, headers, joists, studs, lintels, and columns (Nelson 1997; Canadian Wood Council 1997).

Similar to all SCLs, PSL has advantages over solid wood (SW) in strength, predictability of performance, available sizes, dimensional stability, treatability, and higher wood utilization rate (24% more than that of SW) (Nelson 1997). It is possible to use veneers that are considered waste/residue by plywood and laminated veneer (LVL) industries. In addition, PSL is less prone to shrinking, warping, cupping, bowing, or splitting (Canadian Wood Council 1997).

Douglas-fir, southern pines, western hemlock, and yellow poplar are reported to be used for manufacturing PSL (Berglund and Rowell 2005), but other species can be used as long as their physical and mechanical properties are acceptable. The use of new manufacturing techniques, adhesives, and treatment processes have made fast growing hybrid poplar clones possible to use in SCLs manufacturing (Kurt 2010a), including PSLs. Alternative utilization of fast growing hybrid poplar clones will provide relatively inexpensive and sustainable material to the PSLs industry (Kurt and Cavus 2011). Hybrid I-77/51 (*Populus deltoides*) and I–214 (*Populus x euramericana*) clones that supply almost half of the poplar production in Turkey (Zoralioglu and Kocer 1996) were selected for the present study due to their commercial availability.

Waterproof structural adhesives (typically phenol resorcinol formaldehyde) are used in PSL manufacturing for structural applications in exterior conditions (Nelson 1997). The use of adhesives other than phenolic-based is important for semi-structural and non-structural applications of PSL. The MUF adhesive is the main candidate to meet water and moisture resistance requirements in interior conditions (Kurt 2010a) with low formaldehyde emissions (Kim *et al*. 2007). MUF resins are produced in greater amounts than melamine formaldehyde (MF) resins in the field of adhesives, due to the relatively high cost of melamine (Pizzi 2003).

The objective of this research was to determine the suitability of two hybrid clones, I-214 and I-77/51, for use in the manufacture of PSL with the MUF adhesive under laboratory conditions for semi- and non-structural applications. Also, the effect of clone type on selected physical and mechanical properties of PSL was determined. The I-77/51 clone was used for the first time for PSL manufacturing in Turkey. PSLs mechanical properties were compared with those of PSLs made from yellow poplar and southern pine (Yihai and Lee 2003), LVLs (Kurt 2010a) (manufactured using the same species, glue, glue spreading rate, and pressure duration, but different press pressure), and SWs (Kurt 2010b) of the same species, as well as commonly used species for LVLs and PSLs manufacturing, *i.e*. Douglas fir and spruce SWs (Bozkurt and Erdin 2000).

MATERIALS AND METHODS

Veneer Strands

Twelve-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 the Adapazari region. They were not steamed due to their high moisture content and low density. Logs were rotary-peeled into 3.0±0.1 mm thick veneers and dried to a moisture content of 6 to 8% at a plywood mill in Sakarya, Turkey. They were transferred to Kahramanmaras Sutcu Imam University, Turkey and clipped to approximately 600 mm x 19 mm x 3 mm strands for manufacturing PSLs.

Adhesive

A commercial 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 density of 1.24 g cm^{-3} at 20^{o}C (Polisan 2012). The adhesive spreading rate was 200 g m^{-2}.

PSL Manufacturing

There were six PSLs, three of which were made from I-214 and three made from I-77/51. The adhesive was spread to strands using a double roller glue spreading machine on both sides. The weights of strands before and after glue spreading were used for the gram weight pick up calculation according to procedures described in ASTM D899 (2000). After spreading adhesives to strands surfaces, they were immediately assembled with their grain directions parallel to each other. Typically, eight layers of strands were used to achieve a target thickness of approximately 20 mm. The press temperature, pressure, and time were 110 °C, 1.7 MPa, and 30 min, respectively. After the pressing period, each PSL measured 20 mm in thickness by 600 mm in width by 600 mm in length. 50 mm edges were trimmed off every PSL to prevent influence of density variations and effect of edges on the properties. They were conditioned in an environmentally controlled room in a relative humidity of 60±5% and a temperature of 23±2°C until they reached an equilibrium moisture content of 12%. PSLs were further cut in accordance with specific test dimensions according to Turkish standards.

Testing

Oven-dry specific gravity (SG), moisture content (MC), modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength (CS) (parallel to grain) properties of PSLs were determined. Specimens' dimensions and test procedures are given in Table 1 according to Turkish standards.

Table 1. Dimensions of Specimens and Test Procedures According to Turkish Standards

Properties	Dimensions (mm)	Procedure
Oven-dry specific gravity Moisture content	Thickness of PSL x 30(w) x 30(l)	TS 2472 (1976a) TS 2471 (1976b)
Modulus of rupture Modulus of elasticity	Thickness of PSL x 20(w) x 360(l)	TS 2474 (1976c) TS 2478 (1976d)
Compression strength parallel to grain	Thickness of PSL x 20(w) x 30(l)	TS 2595 (1977)

PSLs were tested flat-wise to failure in bending under center point loading to determine MOR and MOE. The span to depth ratio was 15 in the bending tests. A cross head speed was adjusted to achieve maximum load in about 1.5±0.5 min for MOR and CS specimens according to the standards. MOR, MOE, and CS specimens were tested using a Zwick Roell (Z010) testing machine (Zwick, Germany). Ten replicates were used to test each property.

To explain the strength increases (MOR and MOE) of PSLs compared to SWs properties, an improvement rate (*IR*) and a compaction factor (*CF*) were calculated.

MOR and MOE values were used for the analysis, since the bending strength can be considered to be the most important to PSLs structural performance similar to LVLs performance (Bao *et al*. 2001). To determine the effect of SWs properties on PSLs strength, a contribution factor (C_f) was calculated.

High *IR* values indicate high increase in strength properties of PSLs compared to SWs. *IR* can be expressed as,

$$IR\,(\%) = \left(\frac{P_L - P_S}{P_S}\right)*100 \quad (1)$$

where, P_L is PSL strength and P_S is SW strength.

CF was calculated according to Bao *et al*. (2001). High *CF* ratios indicate higher densification. *CF* was calculated in accordance with Bao *et al*. (2001). *CF* can be expressed as,

$$CF = D_L / D_S \quad (2)$$

where D_L is PSLs SG and D_S is SWs SG.

High C_f values indicate a large effect of SW properties on PSL, and low C_f values indicate a low effect of SW properties. C_f can be expressed as,

$$C_f\,(\%) = (P_S / P_L)*100 \quad (3)$$

where P_S is SWs strength and P_L is PSLs strength.

Statistical Analysis

Analysis of variance (ANOVA) was used to determine the effect of clone types on selected physical and mechanical properties of PSLs, 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. Statistical comparisons were made only between PSL specimens.

RESULTS AND DISCUSSION

Results of the average SG, MOR, MOE, and CS tests, including the standard deviations of PSLs made from two hybrid poplar clones, are given in Table 2, along with the values of PSLs made from southern pine and yellow poplar (Yihai and Lee 2003), LVLs, and SWs of the same poplar clones. The ANOVA (α=0.05) results indicated that the difference in mean SG and mechanical properties values were observed when different clone types were used. Moisture content values were found to be 10 ± 2%.

The mean SG values of PSLs fell within a narrow range, between 0.56 and 0.57 g cm^{-3} (Table 2). The ANOVA results showed that there was a significant difference ($p<.0314$) between SGs of I-214 and I-77/51. I77/51 had significantly higher SG compared to I-214 clone. The SG of PSLs was higher than those of LVLs and SWs by up to 33.33% and 75%, respectively. This may be largely as a result of using a higher pressure (1.7 MPa) during pressing of PSLs than that of LVLs (1.2 MPa). Applied pressure determines the formation of the density (Pichelin and Dunky 2002). It is necessary to use higher pressure for PSLs to generate good bonding through greater interfacial contact between veneer strands similarly for particles and fibers, as noted by Chapman (2006). PSLs are heavier than equivalent size lumber, LVLs, and glued-laminated lumber (Canadian Wood Council 1997) due to their high SG values. On the other hand, The SG of PSLs was higher than that of spruce (*Picea orientalis*) (0.41), Douglas fir (*Pseudotsuga menziesii*) (0.47), and willow (*Salix alba*) (0.52) SWs (Bozkurt and Erdin 2000).

Table 2. SG and Some Mechanical Properties of PSLs, LVLs, and SWs

	PSL		PSL[1]		LVL[2]		SW[3]	
	I-214	I-77/51	S. Pine	Y. Poplar	I-214	I-77/51	I-214	I-77/51
SG	0.56 (0.01)	0.57 (0.01)	0.68 (0.04)	0.62 (0.04)	0.42 (0.02)	0.44 (0.01)	0.32 (0.04)	0.37 (0.01)
MOR (MPa)	76.25 (8.91)	84.17 (7.40)	80.2 (15.1)	87.5 (7.40)	75.08 (11.3)	80.2 (4.7)	48.54 (9.79)	59.77 (9.03)
MOE (MPa)	6578.33 (353.55)	7070.94 (362.83)	11790 (2827)	10963 (1172)	6305.01 (526.7)	6504,57 (612)	4777.8 (1174.9)	5442.6 (729.85)
CS (MPa)	56.56 (2.80)	63.20 (1.22)	54.2 (6.0)	48.6 (6.0)	46.34 (1.4)	49.41 (1.5)	35.11 (5.40)	31.07 (2.06)

S.; Southern, Y.; Yellow, [1]; PSLs values are adopted from Yihai and Lee (2003), [2]; LVLs values are adopted from Kurt (2010a), and [3]; SWs values are adopted from Kurt (2010b). Standard deviations are given in parenthesis.

PSLs made of I-214 had lower MOR, MOE, and CS values compared to that of I-77/51 clones. Higher mechanical properties of I-77/51 clone may be explained by its greater fiber length values (0.87 mm) compared to that of I-214 clones (0.82 mm) (Kurt 2010a), since fiber lengths affect the maximum load capacity (*i.e.* MOR) (De Boever *et al.*2007), in addition to SG. Thus, I-77/51 clone may be more suitable for PSL manufacturing than I-77/51 since it performed better. ANOVA results of MOR ($p<.0445$), MOE ($p<.0065$), and CS ($p<.0014$) showed that mean mechanical strength values of PSLs were affected by the clone types. The MOR and CS of PSLs were higher than that of spruce (*Picea orientalis*) (76 and 49 MPa), Douglas fir (*Pseudotsuga menziesii*) (77 and 46 MPa), and willow (*Salix alba*) (37 and 34 MPa) (Bozkurt and Erdin 2000). Strength property values of PSLs were comparable to that of commonly used wood species.

As to the I-214 poplar clone, the *IR*s of MOR and MOE were up to 57.09% and 37.68%, respectively, compared to SWs (Table 4). The increase in SG of PSLs made from I-214 veneers was higher than that of I-77/51 clones. The *CF* value is a good indicator to determine the degree of compaction or densification. The *CF*s of I-214, and I-77/51 clones were 1.75 and 1.54, respectively (Table 4). A higher *CF* of I-214 corresponded to a higher *IR* of MOR and MOE (Table 4). *CF* results and their relationships to MOR and MOE were similar to the study of Bao *et al.* (2001), Kurt

(2010a), and Kurt *et al.* (2012). *IR*s and *CF*s values of SWs *vs.* PSLs were higher than those of SWs *vs*. LVLs as a result of using higher pressure for PSLs manufacturing.

Table 3. Compaction Ratio (*CF*), Contribution Factor (C_f), and Improvement Rate (*IR*) of SWs *vs*. PSLs and SWs *vs.* LVLs

LVL/SW *vs.* PSL	*CF*	MOR		MOE	
		C_f (%)	*IR* (%)	C_f (%)	*IR* (%)
SW I-214 *vs.* PSL I-214	1.75	63,66	57,09	72,63	37,68
SW I-77/51 *vs.* PSL I-77/51	1.54	71,01	40,82	76,97	29,92
SW I-214 *vs.* LVL I-214[1]	1.31	64.65	54.68	75.78	31.96
SW I-77/51 *vs.* LVL I-77/51[1]	1.19	74.50	34.23	83.67	19.51

[1]; LVLs values are adopted from Kurt (2010a)

In MOR and MOE, the C_f was the highest in I-77/51 clone and the lowest in I-214 clone (Table 3). A comparison of the MOR and MOE among the two poplar clones showed two types of relationships; higher MOR/MOE values of SWs, as in I-77/51 (*Populus deltoides*) clone, corresponded to higher C_f and was associated with higher PSLs MOR and MOE values and lower MOR/MOE values of SWs; the I-214 clone corresponded to lower C_f and was associated with lower PSLs MOR and MOE values (Table 3). A similar trend was observed for LVLs (Kurt 2010a). C_f values of PSLs were lower than that of LVLs. This indicates that the manufacturing technique (such as reducing variations, gluing, and pressing) played a more important role in the strength increase (Bao *et al.* 2001; Liu and Lee 2003) of PSLs than LVLs.

The results showed that the mechanical properties of PSLs were higher than those of the LVLs and SWs of the same poplar clones and compared well with PSLs made from southern pine and yellow poplar, but their MOEs are lower (Yihai and Lee 2003). Similar to bamboo PSLs, poplar PSLs may be used as compression and bending members because of their comparable MOR and CS values, but due to their low MOE, they could have difficulty meeting deflection requirements (Ahmad and Kamke 2011). According to Huang (2011), pressure is an important factor that influences the complicated adhesive-wood interaction in the bonding process of strand products like PSLs.

In PSLs manufacturing, strength is improved by increasing the amount of densification instead of layering veneer strands by grade, as in LVLs manufacturing (Nelson 1997), by using higher press pressure. Also, it is possible to eliminate voids and then overcome surface irregularities. It is well known that most mechanical properties of wood are correlated with density (Kamke 2006). On the other hand, an increase in bond pressure promotes adhesive penetration (Frihart 2005) that ensures veneer strands are evenly distributed and that the resin has thoroughly interlocked with the strands, and thus strong bonds between the veneer strands are achieved (Huang 2011). The results proved that strength properties are as much a function of the resin system and the manufacturing processes including press pressure as they are of the wood being incorporated into the wood-based products (Chapman 2006). Also, in contrast with SWs, the strength-reducing characteristics that have a considerable effect on strength properties are dispersed (Cai and Ross 2010) or removed from strands in advance.

CONCLUSIONS

1. The results indicated that hybrid I-214 (*Populus x euramericana*) and I-77/51 (*Populus deltoides*) poplar clones with the MUF adhesive can be successfully used in PSLs manufacturing. Clone types affected physical and mechanical properties of PSLs. PSLs made of I-77/51 had favorable SG and some mechanical properties. This can be explained by its higher density and fiber length values compared to that of I-214. Thus, the *Populus deltoides* clone has good potential for the manufacture of PSLs. Strength properties of PSLs are comparable to commonly used wood species for PSLs.
2. PSLs showed improved physical and mechanical properties as compared with their respective SWs and LVLs. Strength increases were explained by *CF* and *IR*. PSLs *IR* and *CF* values were higher than that of LVLs. The effect of SWs properties on PSLs properties was explained by C_f. Low C_f values indicated that contributions of the material and manufacturing technique to the strength increase of PSLs are more important than that of LVLs.
3. The utilization of hybrid poplar clones could be expanded by using them for value-added applications including PSLs.

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