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SOME MECHANICAL PROPERTIES OF PLYWOOD PRODUCED FROM EUCALYPTUS, BEECH, AND POPLAR VENEER

Bekir Cihad Bal [1,♠], İbrahim Bektaş[1]

ABSTRACT

In this study, we determined the flexural properties and tensile shear strength of five-ply plywood panels produced with eucalyptus (*Eucalyptus grandis*), beech (*Fagus orientalis*), and hybrid poplar (*Populus* x *euramericana*) using urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF) and phenol-formaldehyde (PF) adhesives. Flexural properties were tested on both parallel and perpendicular to grain samples. Tensile shear-strength tests were conducted on four glue lines of the plywood panels, and the effects of species of trees, type of adhesives, and direction of load were determined. The results of variance analyses showed that the effects of species of trees, direction of load, and type of adhesive on flexural properties were significant, but it was determined by specific flexural properties that the effect of the type of adhesive was based on the density of the plywood. In addition, as a result of findings, it can be said that specific mechanical properties may be a good predictor for comparative studies.

Keywords: Plywood, modulus of elasticity, modulus of rupture, specific modulus of elasticity, specific modulus of rupture.

INTRODUCTION

Plywood is one of the important wood-based composites produced from different tree species, and it has some superior advantages compared to solid wood. There are two classes of plywood, i.e., 1) construction and industrial plywood and 2) hardwood and decorative plywood (Youngquist 1999). It is referred to as the original engineered wood product because it was one of the first to be made by bonding pieces of wood together (APA 2012).

Plywood is produced from softwood and hardwood species of trees, and the species used in its manufacture determine the physical and mechanical properties of the plywood. The important factors that affect the physical and mechanical properties of plywood are the density of the wood, species of trees, type of adhesives, thickness of the veneer, number of plies, and the temperature at which the veneer was dried. Among these factors, the density of the wood has the greatest effect of the properties of the plywood (Özen 1981, Örs *et al.* 2002, Aydın and Çolakoğlu 2008).

In some other studies, the fast-growing species of trees that are used extensively for the manufacture of veneer and veneer-based composite materials have been tested. For example, some other researchers have investigated the fast-growing species of hybrid poplar (*Populus* x *eureamericana*) (Baldassino *et al.* 1998) and *Eucalyptus grandis* (Dias and Lahr 2004, Iwakiri *et al.* 2006, Juniar *et al.* 2009), as well as the slow-growing beech species (*Fagus orientalis*) for use in manufacturing plywood (Örs *et al.* 2002, Demirkır *et al.* 2005, Özalp *et al.* 2009).

[1] Kahramanmaraş Sütçü İmam University, Faculty of Forestry, Department of Forest Industry Engineering, 46100, Kahramanmaraş, TURKEY
♠Corresponding author: bcbal@hotmail.com
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In Turkey, poplar species, oriental beech (as native species), and hybrid poplars, are used extensively for producing plywood. Eucalyptus trees were first introduced in 1885 by a French company that was working on the railroads (Adalı 1944). The first *E. camaldulensis* plantation was developed in Tarsus-Karabucak in 1939. The Turkish government established the Eastern Mediterranean Forestry Research Institute in 1967 for conducting research on eucalyptus trees. Since then, the Institute has conducted experiments on 191 eucalyptus species from 609 origins (Özkurt 2002). It has been determined that *E. camaldulensis* and *E. grandis* produce average annual increments of 35 m^3/ha and 50 m^3/ha, respectively (Gürses *et al.* 1995).

Modulus of rupture (MOR) and modulus of elasticity (MOE) are the most important mechanical properties of load-bearing plywood applications (i.e., construction and industrial applications). In some comparative studies, unexpected results were obtained due to veneer heterogeneity. Some researchers have used specific modulus of rupture (SMOR) and specific modulus of elasticity (SMOE) to evaluate the results (Lee *et al.* 1999, Bao *et al.* 2001, Bal and Bektaş 2012). That is the reason that SMOR and SMOE were calculated to reduce the effect of density on flexural properties. Also, tensile-shear strength (TSS) was tested to determine bonding performance. In this study, our aims were:

- to determine and to compare some mechanical properties of plywoods produced from eucalyptus, beech, and poplar,
- to determine how some formaldehyde-based adhesives affect the MOR and MOE of plywood,
- to determine and compare TSS of plywood bonded with UF, MUF, and PF adhesives.

MATERIALS AND METHODS

Beech (*Fagus orientalis* L.) and poplar (*Populus* x *euramericana* I-214 clone) trees were cut down in the Yenice-Karabük region, and the eucalyptus (*Eucalyptus grandis* W. Hill ex Maiden) logs were cut down in the Karabucak-Tarsus region in Turkey. The beech logs and eucalyptus logs were steamed at 80 oC for 50 and 15 hours, respectively. The poplar logs were not steamed because poplar wood is soft and has low density, therefore, it can be peeled without steaming process. Then, 3-mm-thick, rotary-peeled veneers were obtained from the logs and dried until the moisture content was 7±1%. The veneers were used to manufacture plywood using UF, MUF, and PF adhesives. The percentages of solids in the UF, MUF, and PF adhesives were 52±1%, 55±1%, and 47±1%, respectively. The UF adhesive consisted of a mixture of 100 units of adhesive, 30 units of wheat flour, and 10 units of hardener (15% $(NH_4)_2SO_4$ concentration). The MUF adhesive consisted of a mixture of 100 units of adhesive, 15 units of wheat flour, and 10 units of the hardener. No additives or filler materials were used with the PF adhesive. The press temperatures of the UF, MUF, and PF adhesives were 110, 110, and 140 oC, respectively. The press pressures for poplar, beech, and eucalyptus plywood were 0,8; 1,2 and 1,2 MPa, respectively. The adhesives were spread manually on the loose side of the veneers with a gluing machine such that the adhesive coverage was approximately 200 g/m^2. After gluing, five veneer sheets with a nominal size of 600 x 600 x 3 mm (length x width x thickness) were positioned with the fiber directions perpendicular to each other. These stacks were pressed in a hot press in the laboratory. Five panels were produced per group, and the panels were stored for a week after pressing. After a week of storage, 30-mm edges of the panels were trimmed off. Thereafter, test samples were prepared from these boards.

The air-dried density (D) was determined according to TS EN 323. Test samples for D were cut from each of the test samples after the flexural tests. The MOR and MOE test samples were prepared for both the parallel and perpendicular directions to the grain of the surface layers. The tests were conducted according to TS EN 310. Fifteen test samples were prepared for each group. For the TSS test, 15 test samples to each glue line were prepared (a total 60 test samples to each groups for air-dried tests and a total 60 test samples to each groups for pre-treatment tests), and the tests were conducted according to

TS 3969 EN 314-1 and TS EN 314-2. The TSS tests were conducted on air-dried samples, and after pre-treatment with cold water (for UF and MUF samples) and boiling water (for PF samples). Pre-treatment with cold water was conducted for 24 hours, and pre-treatment with boiling water was conducted for 6 hours. The samples were tested immediately after the pre-treatments were completed. MOR, MOE, SMOR, SMOE were calculated following formulas 1, 2, 3 and 4, respectively.

$$MOR=\frac{3.Fmax.L}{2.b.h^2} \text{ (MPa)} \quad (1)$$

Where Fmax is the maximum force at the time of rupture (N), L is the span between supports (mm), b is the width of the samples (mm), h is the height of the samples (mm).

$$MOE=\frac{\Delta F.L^3}{\Delta a.4.b.h^3} \text{ (MPa)} \quad (2)$$

Where ΔF is the Load increment, L is the span between supports (mm), Δa is the deflection (mm), b is the width of the samples (mm), h is the height of the samples (mm).

$$SMOR=\frac{MOR}{D} \text{ (km)} \quad (3)$$

Where, SMOR and MOR are the specific modulus of rupture and the modulus of rupture, respectively. D is the air-dried density at 12% moisture content (kg/m^3).

$$SMOE=\frac{MOE}{D} \text{ (km)} \quad (4)$$

Where, SMOE and MOE are specific modulus of elasticity and modulus of elasticity respectively. D is the air-dried density at 12% moisture content (kg/m^3).

The results were analyzed using Two-way ANOVA for TSS and Three-way ANOVA ($p = 0,05$) for flexural properties from the SPSS statistical software program, and significant differences were determined by Tukey HSD (Honestly Significant Difference) Multiple Comparison Test ($\alpha = 0,05$).

RESULTS AND DISCUSSION

Table 1 provides the mean values, standard deviations, and coefficients of variation of D, MOR, MOE, SMOR, and SMOE for the parallel and perpendicular test samples of plywood produced from eucalyptus, beech, and poplar veneers using UF, MUF, and PF adhesives.

Table 1. The test results of D, MOR, MOE, SMOR, and SMOE for parallel and perpendicular test samples bonded with UF, MUF, and PF (α = 0,05).

	D	MOR	MOE	SMOR	SMOE	D	MOR	MOE	SMOR	SMOE	D	MOR	MOE	SMOR	SMOE
	kg/m^3	MPa		km		kg/m^3	MPa		km		kg/m^3	MPa		km	
	UF					MUF					PF				
PARALLEL SAMPLES															
Eucalyptus grandis	**615**	**79,9**	**9346**	**13,0**	**1524**	**614**	**79,2**	**9740**	**13,0**	**1596**	**605**	**72,4**	**9173**	**12,0**	**1519**
	20,7	7,1	717	1,3	131	35,7	10,4	720	2,0	180	24,1	11,8	917	1,8	142
	(3,4)	(8,9)	(7,7)	(10,1)	(8,6)	(5,8)	(13,1)	(7,4)	(15,0)	(11,3)	(4,0)	(16,3)	(10,0	(14,7)	(9,3)
Fagus orientalis	**680**	**89,0**	**8636**	**13,1**	**1272**	**664**	**84,1**	**8231**	**12,7**	**1242**	**656**	**80,2**	**8258**	**12,3**	**1262**
	18,2	4,6	495	0,9	74	15,0	9,3	652	1,3	83	26,0	6,1	391	1,0	74
	(2,7)	(5,1)	(5,7)	(6,7)	(5,8)	(2,3)	(11,0)	(7,9)	(9,9)	(6,6)	(4,0)	(7,6)	(4,7)	(8,4	(5,9)
Populus x euramericana	**472**	**59,0**	**6875**	**12,5**	**1459**	**441**	**56,3**	**6634**	**12,8**	**1506**	**440**	**56,6**	**6774**	**12,9**	**1548**
	20,8	3,6	433	0,8	73	12,8	4,7	532	1,0	114	26,5	4,8	396	1,2	121
	(4,4)	(6,1)	(6,3)	(6,0)	(5,0)	(2,9)	(8,3)	(8,0)	(7,9)	(7,5)	(6,0)	(8,6)	(5,9)	(9,6)	(7,8)
PERPENDICULAR SAMPLES															
Eucalyptus grandis	**618**	**41,1**	**2939**	**6,7**	**477**	**608**	**39,8**	**3129**	**6,5**	**515**	**600**	**37,2**	**2903**	**6,2**	**484**
	26,6	5,5	420	0,8	68	47,5	6,9	434	0,9	45	46,9	5,5	363	0,7	36
	(4,3)	(13,4)	(14,)	(12,2)	(14,3)	(7,8)	(17,3)	(14)	(13,1)	(8,8)	(7,8)	(14,7)	(12)	(12,0)	(7,4)
Fagus orientalis	**677**	**38,0**	**2661**	**5,6**	**394**	**664**	**36,1**	**2671**	**5,4**	**403**	**656**	**39,4**	**2640**	**6,0**	**403**
	17,5	2,7	191	0,4	32	15,0	3,1	217	0,4	34	26,0	5,3	263	0,8	40
	(2,6)	(7,1)	(7,2)	(6,9)	(8,1)	(2,3)	(8,5)	(8,1)	(7,8)	(8,3)	(4,0)	(13,5)	(10,0)	(13,9)	(9,9)
Populus x euramericana	**460**	**27,2**	**2191**	**5,9**	**478**	**455**	**27,3**	**2104**	**6,0**	**464**	**441**	**27,0**	**2011**	**6,2**	**458**
	26,6	3,0	126	0,5	22	14,9	3,2	172	0,9	48	13,6	2,2	115	0,6	33
	(5,8)	(11,0)	(5,8)	(8,3)	(4,6)	(3,3)	(11,7)	(8,2)	(14,2)	(10,4)	(3,1)	(8,2)	(5,7)	(9,3)	(7,3)

The mean values are in bold font, the standard deviations are in normal font, and coefficients of variation (COV) are in parentheses.

The D values of parallel and perpendicular samples produced from the same tree species and using the same adhesive were similar. But the parallel samples had values of MOR, MOE, SMOR, and SMOE that were clearly greater than those of the perpendicular samples. This result occurred because the load direction of the load apparatus was perpendicular to the grain direction in the surface layers of the parallel samples, whereas it was parallel to the grain direction of the surface layers of the perpendicular samples. As a result, the flexural properties of the parallel samples were better than those of the perpendicular samples.

In general, the MOR and MOE values of plywood made from poplar were lower than those for plywood made from beech and eucalyptus woods. However, the SMOR and SMOE values of the plywood made from poplar wood were greater than those for plywood made from beech wood. In general, the SMOR and SMOE values of the plywood made from eucalyptus wood were found to be the highest (except for several groups).

Table 2 shows the significance levels (p) of the three-way ANOVA test results for D, MOR, MOE, SMOR, and SMOE. Clearly, the effects of load direction on D were insignificant ($p > 0,05$) because the perpendicular and parallel samples were prepared from the same boards for all groups, but the effects of load direction on MOR, MOE, SMOR, and SMOE were significant ($p < 0,001$). The effects of tree species (TRS) on all properties were significant ($p < 0,001$). The effect of interaction of tree species and adhesive type on density was insignificant although the effect of tree species, and adhesive type was significant ($p < 0,001$). It is thought that the reason of this is that mean densities of MUF and PF groups were similar, and mean density of UF was not more different than others (Table 3).

Table 2. Significance levels (P) of three-way ANOVA test results (α = 0,05).

Sources of variance	D	MOR	MOE	SMOR	SMOE
LD	0,753	0,000	0,000	0,000	0,000
TRS	0,000	0,000	0,000	0,000	0,000
AT	0,000	0,001	0,080	0,376	0,283
LD * TRS	0,900	0,000	0,000	0,033	0,000
LD * AT	0,713	0,013	0,567	0,125	0,585
TRS * AT	0,678	0,129	0,020	0,045	0,094
LD * TRS * AT	0,458	0,282	0,274	0,408	0,154

LD: load direction, TRS: tree species, AT: adhesives type, D: density, MOR: modulus of rapture, MOE: modulus of elasticity, SMOR: specific modulus of rapture, SMOE: specific modulus of elasticity.

Table 3. Tukey test results of the mean values of Tree species, Adhesive type, and Load direction factors for D, MOR, MOE, SMOR, and SMOE (α = 0,05).

	Tree species			Adhesive type			Load direction		
	Trees	N	Groups	Adhesives	N	Groups	Directions	N	Groups
D (kg/m^3)	*Populus* x *euramericana*	90	451A	PF	90	566A	Parallel	135	576,4A
	Eucalyptus grandis	90	610B	MUF	90	574A	Perpendicular	135	575,4A
	Fagus orientalis	90	666C	UF	90	587B			
MOR (MPa)	*Populus* x *euramericana*	90	42,2A	PF	90	52,1A	Parallel	135	72,9A
	Eucalyptus grandis	90	58,2B	MUF	90	53,7AB	Perpendicular	135	34,7B
	Fagus orientalis	90	61,1C	UF	90	55,6B			
MOE (MPa)	*Populus* x *euramericana*	90	4431A	PF	90	5293A	Parallel	135	8185A
	Eucalyptus grandis	90	5516B	MUF	90	5418A	Perpendicular	135	2583B
	Fagus orientalis	90	6205C	UF	90	5441A			
SMOR (km)	*Fagus orientalis*	90	9,2A	PF	90	9,3A	Parallel	135	12,7A
	Populus x *euramericana*	90	9,4AB	MUF	90	9,4A	Perpendicular	135	6,06B
	Eucalyptus grandis	90	9,6B	UF	90	9,5A			
SMOE (km)	*Fagus orientalis*	90	829A	UF	90	934A	Parallel	135	1436A
	Populus x *euramericana*	90	985B	PF	90	946A	Perpendicular	135	452B
	Eucalyptus grandis	90	1019C	MUF	90	954A			

The effect of adhesive type (AT) on D was significant, which was thought to have resulted from the heterogeneity of veneer density among the groups, and the amount of extender (30 units of wheat flour). Especially, the D values of the plywood that was bonded with UF were higher than those for plywood that was bonded with MUF or PF. As a result of these differences, the effect of adhesives type on the MOR values was determined to be significant. This was an unexpected result, since all adhesives used in the study were formaldehyde-based adhesives. It seemed more likely that such differences would have been observed if different types of adhesives had been used. On this topic, Shukla and Kamdem (2009) studied laminated veneer lumber (LVL) produced from Liriodendiron tulipifera using MUF, MF, UF, and PVAc, and the results showed no differences, whereas the MOR and MOE values of LVL bonded with PVAc were slightly lower than LVL bonded with thermosetting adhesives. In addition, Shukla and Kamdem (2009) stated that *"based on the nature of the adhesive, it is evident that LVL made with thermoplastic resin is less rigid and more plastic than the LVL made with thermosetting adhesives"*. To reduce this difference that is based on density, the SMOR and SMOE values were calculated and evaluated statistically. The results showed that the effects of adhesives type on SMOR and SMOE were insignificant ($p < 0.001$) (Table 2). Thus, it can be said that the effects of adhesives type on MOR and MOE were based on D. Özalp *et al.* (2009) studied the effects of several adhesives on MOR and MOE, including polyvinyl acetate, polyurethane, and epoxy, and found no statistical differences.

The mean values of load direction, tree species, and adhesives type factors for D, MOR, MOE, SMOR, and SMOE are given in table 3. The mean D values of the tree species groups were found to be the lowest for poplar plywood and the highest for beech plywood. The mean D values of adhesives type groups were found to be higher for plywood bonded with UF than with either MUF or PF. No differences were determined between the load direction groups.

The mean MOR and MOE values of the tree species groups were found to be the lowest for poplar plywood and the highest for beech plywood. The mean MOR and MOE values of the adhesives type groups were found to be the lowest for plywood bonded with PF and highest for plywood bonded with UF. But the differences between the MOE values for the different adhesive type groups were insignificant.

The mean values of SMOR and SMOE of the tree species groups were found to be the lowest for plywood produced from beech and the highest for plywood produced from eucalyptus. No differences were found among the mean values of SMOR and SMOE for the different adhesive type groups. The differences in the mean values of MOR, MOE, SMOR, and SMOE were significant between the parallel and perpendicular samples in the load direction groups. On this topic, Özen (1981) expressed that the MOR and MOE values of the parallel samples were found to be greater than those of the perpendicular samples because the direction of the fibers of the surface layers of the parallel samples was perpendicular to the load direction. In our study, three layers of the parallel samples were perpendicular to the direction of the load, and two layers were parallel to the direction of the load. According to Özen (1981), inner layers of the samples that are parallel to the direction of the load generated neutral layers to the loads.

In a similar study, Dias and Lahr (2004) conducted experiments with plywood that was produced from *E.grandis* veneers bonded with castor oil-based polyurethane adhesive, and the MOR and MOE values of the five-ply plywood samples were found to be greater in the parallel samples than in the perpendicular samples.

The results of TSS tests are presented in table 4. All of the TSS findings were greater than the 1 MPa limit value expressed in the related standard (TS EN 314-2). Similar results for the TSS of plywood produced from beech veneer bonded with UF were obtained by Örs *et al.* (2002); they reported values of 3.08 MPa for air-dried samples and 2.62 MPa for wet samples. Iwakiri *et al.* (2006) and Junior *et al.* (2009) also determined the TSS values for plywood produced from *E.grandis* bonded with PF after pre-treatments with cold water and with boiling water, but their values were less than those obtained in the present study. It is thought that the differences resulted from the different thickness of the veneers that were used and the amounts of adhesives that were used.

Table 4. TSS results of air-dried and pre-treated samples (α = 0,05).

	TSS of Air-dried samples (MPa)			TSS of Pretreated samples (MPa)		
n:60	UF	MUF	PF	UF	MUF	PF
				Cold water		Boiling water
Eucalyptus grandis	**2,54**	**2,59**	**2,42**	**2,13**	**2,27**	**2,04**
	0,41	0,35	0,40	0,44	0,39	0,32
Fagus orientalis	**3,57**	**3,45**	**3,65**	**2,57**	**2,76**	**2,44**
	0,40	0,39	0,33	0,39	0,41	0,35
Populus x *euramericana*	**1,82**	**1,56**	**1,85**	**1,15**	**1,21**	**1,37**
	0,33	0,26	0,4	0,21	0,28	0,28

The mean values are in bold font and the standard deviations are in normal font

According to two-way ANOVA (Table 5), the effects of tree species and adhesive type on TSS of air-dried samples and samples pre-treated with cold water were significant, and the significance levels were $p < 0,001$ and $p < 0,05$ respectively. In general, it was noted that the phenolic adhesives had superior exposure performance than UF, MUF, MF, and acid-catalyzed PF adhesives (Gillespie and River 1976). The reason for this was considered to be the hydrolytically-stable, C-C bonding in the PF resins (Dunky 2004).

Table 5. The test results of Two-way ANOVA for TSS (α = 0,05).

The TSS of air-dried samples (for UF, MUF, and PF)					
	Sum of Squares	df	Mean Square	F	Sig.
Tree Species	74,5	2	37,2	690,7	0,000
Adhesives Type	0,5	2	0,3	4,8	0,010
TRS*AT	1,2	4	0,3	5,7	0,000
The TSS of samples pre-treated with cold water (for UF and MUF)					
	Sum of Squares	df	Mean Square	F	Sig.
Tree Species	34,4	2	17,2	300,0	0,000
Adhesives Type	0,3	1	0,3	5,1	0,026
TRS*AT	0,1	2	0,0	0,5	0,609

The effect of tree species on the TSS is well known, and some other studies have noted that high-density tree species has higher TSS values. The TSS values of plywoods that have greater veneer densities are greater than those for plywoods that have lower veneer densities (Özen 1981, Örs *et al.* 2002). So, the poplar plywood had the lowest TSS values and beech plywood had the highest TSS values in both air-dried samples and pre-treated samples (Table 6). In addition, it is thought that surface roughness of eucalyptus veneers had an adverse effect on TSS of plywoods produced with eucalyptus veneer. It is well-known that surface roughness affects the bonding quality of laminated materials. The layer of adhesive must be uniform thickness for high bonding quality. Aydın (2004) showed that the increase of surface roughness induces the increase of bonding quality. In another study, it was determined that the surface roughness of eucalyptus (*Eucalyptus camaldulensis*) was greater than that of beech (*Fagus orientalis*) (Aydın *et al.* 2004).

As can be seen in table 6, the highest TSS values of air-dried samples were determined in plywood bonded with UF (2,65 MPa), and it is thought that the reason was veneer density and heterogeneity. In addition, the TSS values of pre-treated samples from plywood bonded with MUF (2,10 MPa) were higher than those of plywood bonded with UF. Many other researchers have concluded that MUF adhesive is more stable than UF adhesive after cold-water pre-treatment (Shukla and Kamdem 2009) and that PF adhesive is more resistant to boiling water than UF and MUF (Çolak *et al.* 2004).

Table 6. Tukey test results of mean values of tree species and adhesives type factors for TSS results of air-dried and pre-treated samples (α = 0,05).

Air-dried samples						Pretreated with water samples (24 h)					
Tree Species			Adhesives type			Tree Species			Adhesives type		
Trees	n	TSS (MPa)	Adhesives	n	TSS (MPa)	Trees	n	TSS (MPa)	Adhesives	n	TSS (MPa)
Populus x *euramericana*	45	1,73 a	MUF	45	2,51 a	*Populus* x *euramericana*	30	1,17 a	UF	30	1.91a
Eucalyptus grandis	45	2,51 b	FF	45	2,63 b	*Eucalyptus grandis*	30	2,21 b	MUF	30	2.10b
Fagus orientalis	45	3,55 c	UF	45	2,65 b	*Fagus orientalis*	30	2,64 c			

CONCLUSIONS

In this study, we determined some mechanical properties of plywood produced from *Fagus orientalis, Populus x euramericana, Eucalyptus grandis* veneers using UF, MUF, and PF adhesives. The results showed that:

- The effect of adhesive type on MOR was significant, but it had an insignificant effect on SMOR. Clearly, it can be inferred that the effect of adhesive type on MOR is due to the difference of the densities of the veneers. Thus, specific mechanical properties may be a good predictor for comparative studies.
- *E.grandis* plywood had better mechanical properties than poplar plywood, and its properties were comparable to those of beech plywood; however, *E.grandis* is very fast-growing tree species, whereas beech is a slow-growing species.
- As a low-cost raw material, *E.grandis* wood can be used to manufacture plywood for construction and industrial applications.
- The effect of adhesive type on density was significant, which was thought to have resulted from the heterogeneity of veneer density among the groups, and the amount of extender.
- The highest TSS values of air-dried samples were determined in plywood bonded with UF. It is thought that the reason was veneer density and heterogeneity. In addition, tensile-shear strength values of pre-treated samples bonded with MUF were higher than UF.

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