Turk J Agric For
28 (2004) 109-113
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Some Technological Properties of Laminated Veneer Lumber Manufactured from Pine (*Pinus sylvestris* L.) Veneers with Melamine Added - UF Resins

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Received: 06.05.2003

Abstract: The objectives of this study were to compare the modulus of elasticity, bending strength, shear strength and formaldehyde emissions of laminated veneer lumber (LVL) bonded with melamine added urea formaldehyde resin (UF+M) and produced with other resins such as urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF) and phenol formaldehyde (PF), and to determine the effects of 2 different climate conditions on the bending strength and modulus of elasticity of pine LVL panels. After the panel production, the test specimens were divided into 2 groups for all tests. The first group of test specimens were conditioned at 20 °C and 45% R.H., while the rest of the samples were conditioned at 20 °C and 65% R.H for about 2 weeks prior to testing. According to the test results, the bending strength and modulus of elasticity values of the specimens conditioned at 20 °C and 45% R.H. were higher than those of the specimens conditioned under the other climate condition. The increases in those strength values determined for the specimens bonded with PF adhesive were more obvious than those of the specimens bonded with other adhesives. Formaldehyde emission values decreased and shear strength values increased with the addition of melamine to the glue mixture.

Key Words: LVL, resin type, climate condition, technological properties, formaldehyde emission

Çam Kaplamalarından Melamin İlaveli Üre-Formaldehit Reçinesiyle Üretilen Lamine Edilmiş Tabakalı Malzemenin Bazı Teknolojik Özellikleri

Özet: Bu çalışmanın amaçları, melamin ilaveli üre formaldehit reçinesiyle üretilmiş olan lamine edilmiş tabakalı malzemeler (LVL) ile üre formaldehit, melamin-üre formaldehit ve fenol formaldehit reçineleri ile üretilmiş olan lamine edilmiş tabakalı malzemelerin elastikiyet modülü, eğilme direnci, makaslama direnci ve formaldehit emisyonu değerlerini karşılaştırmak ve iki ayrı iklimlendirme koşullarında kondisyonlama işleminin çam lamine edilmiş tabakalı malzemelerin eğilme direnci ve elastikiyet modülü üzerine olan etkilerini belirlemektir. Levhaların üretiminden sonra test örnekleri, tüm testler için iki gruba ayrılmıştır. Test edilmeden önce ilk gruptaki örnekler 20 °C sıcaklık ve % 45 bağıl nem, diğer gruptaki örnekler ise 20 °C sıcaklık ve % 65 bağıl nem koşullarında yaklaşık iki hafta süre ile bekletilmiştir. Deney sonuçlarına göre, 20 °C sıcaklık ve % 45 bağıl nem koşullarında bekletilen örneklerin eğilme direnci ve elastikiyet modülü değerleri, diğer iklim koşulunda bekletilen örneklerden daha yüksektir. Bu direnç değerlerindeki artışlar, fenol formaldehit tutkalı ile üretilen örnekler için, diğer tutkal türleri ile üretilenlerden daha belirgindir. Melamin ilavesi ile formaldehit emisyonu azalmış, çekme-makaslama direnci değerleri ise artmıştır.

Anahtar Sözcükler: LVL, tutkal türü, iklimlendirme koşulları, teknolojik özellikler, formaldehit emisyonu

Introduction

The demand for engineered wood products (such as oriented strand board, glulam and laminated veneer lumber - LVL) has increased due to a constant increase in the global population. The grain of each layer of veneer assembled into LVL runs parallel with each adjacent ply (Baldwin, 1995). Being a homogeneous and dimensionally stable building material, LVL can be used where strength and stability are required.

LVL panels, like plywood, are manufactured using different synthetic resins depending on where they are used. Phenol formaldehyde (PF) resins are generally used as a binder for exterior grade panel production. Melamine-urea formaldehyde (MUF) resins are also used

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for panels are evaluated in damp conditions. However, it was stated (Pizzi, 1993) that the panel bonded with MUF resin under exterior conditions was not as resistant as the panel bonded with PF resin. To increase water repellency, the addition of melamine to a urea formaldehyde (UF) glue mixture was found to be quite effective by Cremonini et al. (1997) and Cremonini and Pizzi (1999). In the same study, better shear strength results were obtained from the UF glue mixture that included 10-11% melamine compared with those of the MUF resin (melamine/urea mol ratio = 30/70). Although the water repellency in the glue lines of panels bonded with MUF and melamine added UF (UF+M) adhesive was investigated extensively in the studies mentioned above, the effects of adhesive types on the bending properties of the panels were not studied. Furthermore, the effects of changes in the moisture content of the panels bonded with aminoplast resins on the bending strength had not been investigated before. Therefore, the aim of this study was to compare the modulus of elasticity, bending strength, shear strength and formaldehyde emissions of LVL bonded with UF+M resins and produced with the other adhesives such as UF, MUF, PF and to determine the effects of the 2 different climate conditions on the bending strength and modulus of elasticity of pine LVL panels.

Materials and Methods

In order to manufacture laminated veneer panels, industrially produced 1.2 mm thick and 50 ¥ 50 cm sized rotary cut pine (*Pinus sylvestris*) veneers were used. Before the panel production, the veneers were conditioned until they reached 6.5-7% moisture content in an acclimation chamber. UF, MUF and PF resins were used as adhesives. In addition, 15% melamine (M) was added into the UF glue for preparation of UF+M adhesive. The formulations of the adhesive mixtures are given in Table 1.

The adhesive mixtures were applied to single bonding surfaces of each veneer at approximately 180 g m^{-2} using a roller gluing machine. A single daylight press was used for hot pressing. Press pressure and duration were 1.2 N mm^{-2} and 7 min, respectively. Press temperatures were applied as 110 °C for UF, MUF and UF+M adhesives and 140 °C for PF adhesive by considering the general curing temperatures recommended by their manufacturers. Six-ply, 7.5 mm thick, 55 x 55 cm sized LVL panels were produced. Four replicate panels were manufactured for each test group. Bending strength and modulus of elasticity samples (200 mm in length and 50 mm in width) and shear strength samples (110 by 25 mm) were prepared from these panels. After the sample preparation, each group of test samples was divided into 2 parts. To determine climate conditions' effects, half of them were conditioned at 20 °C and 45% R.H., while the other parts were conditioned at 20 °C and 65% R.H. The bending strength, modulus of elasticity, shear strength and formaldehyde emission values were determined according to EN 310, EN 314-2 and EN 717-3, respectively.

Results

The average moisture content values of the panels conditioned at different climate conditions are given in Table 2.

The maximum decrease in moisture content was determined for the panels bonded with PH adhesive. It was stated (Jellinek and Müller, 1976) that the hygroscopicity of the particleboard increased clearly with

Table 1. The formulation of adhesive mixtures (all units are parts by weight).

Adhesive Ingredient	UF[1] (55%)*	M +UF[2] (55%)*	MUF[3] (55%)*	PF[4] (47%)*
Resin	100	100	100	100
Wheat flour	30	15	10	-
NH_4Cl	10	10	10	-
Melamine	-	15	-	-
Polifen 10**	-	-	-	30

* resin solid content, ** commercial name of the hardener for PF
[1] Urea Formaldehyde, [2] Melamine + Urea Formaldehyde, [3] Melamine-Urea Formaldehyde, [4] Phenol Formaldehyde

Table 2. Moisture content mean values of laminated veneer lumber panels.

Adhesive Type	Moisture content (%)							
	65% RH / 20 °C (n = 20)				45% RH / 20 °C (n = 20)			
	Min.	Max.	Mean	S.D.*	Min.	Max.	Mean	S.D.
UF + M[1]	9.5	11.0	10.4	0.4	8.0	8.7	8.5	0.2
UF[2]	9.4	10.1	9.8	0.2	7.8	8.5	8.2	0.3
MUF[3]	9.1	10.3	9.9	0.3	8.6	9.2	8.8	0.2
PF[4]	9.4	10.0	9.8	0.1	7.0	8.1	7.7	0.4

* S.D. is standard deviation [1] Melamine + Urea Formaldehyde, [2] Urea Formaldehyde, [3] Melamine-Urea Formaldehyde, [4] Phenol Formaldehyde

increases in the alkali amount of the resin used as binder. Therefore, the moisture content of the panel bonded with PF adhesive being lower than those of the panels bonded with other adhesives was quite expected.

The formaldehyde emission values of the LVL panels bonded with different adhesives are shown in Figure 1.

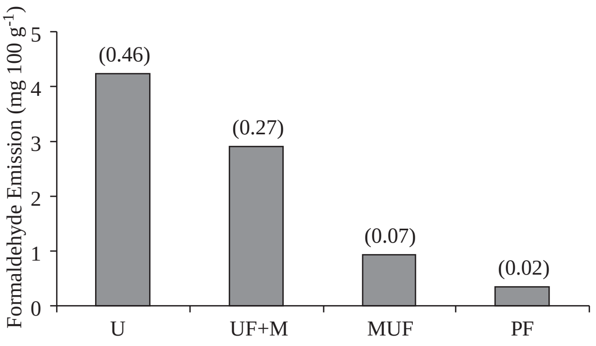

Figure 1. Formaldehyde emissions of the laminated veneer lumber panels (values in parentheses are standard deviations).

The effect of moisture content on the formaldehyde emission of particleboard and MDF bonded with UF+M adhesive was investigated by Roffael et al. (2001). They stated that the content of extractable formaldehyde (according to the perforator method) and formaldehyde emissions of UF- and MUF-bonded particle- and medium density fibreboard increased by increasing the moisture content of boards. Therefore, the formaldehyde emissions of the panels conditioned at 20 °C and 65% R.H. were determined, but the effects of moisture content on the formaldehyde emissions of the panels were not. The lowest formaldehyde emission values were found for PF-bonded panels, while the highest values were obtained from UF-bonded panels. The formaldehyde emissions of the panels bonded with MUF adhesive were higher than those of the panels bonded with PF adhesive, but clearly lower than those of the panels bonded with the other adhesives (UF, M+UF). The addition of melamine to the E2 emission class of UF adhesive mixture decreased formaldehyde emissions by 31%.

The bending strength, modulus of elasticity and shear strength values of the panels are given in Table 3.

According to the variance analysis, the effects of adhesive type and moisture content on the bending strength values of LVL panels were statistically significant. The interaction between adhesive type and moisture content of the panels was statistically identical ($P \leq 0.05$). The effects of variation sources on the modulus of elasticity values of the LVL panels were also the same as those of the bending strength properties.

The effect of adhesive type on the shear strength values for the samples kept in 20 °C water and those determined after the boiling process was significant ($P < 0.001$) according to the results of the t-test conducted for shear strength.

The mean values of the variation sources that were found to be significant were compared using Duncan's test and the results are summarized in Table 4.

Discussion

According to the Duncan's test results, the bending strength and modulus of elasticity values of the LVL panels conditioned at 20 °C and 45% R.H. were different from those of the panels conditioned at 20 °C and 65% R.H. There was no significant difference between the shear strength values of the samples bonded with UF and

Table 3. The effects of moisture content and adhesive type on some mechanical properties of pine laminated pine veneer lumber panels.

Adhesive	Bending Strength (N mm^{-2}) (n = 20)				Modulus of Elasticity (N mm^{-2}) (n = 20)				Shear Strength (N mm^{-2}) (n = 30)			
	20 °C / 65% RH		20 °C / 45% RH		20 °C / 65% RH		20 °C / 45% RH		left for 24 h in water		Boiled for 6 h	
Type	Mean / S.D.*	Min/Max Values	Mean / S.D.	Min/Max Values	Mean / S.D.	Min/Max Values	Mean / S.D.	Min/Max Values	Mean / S.D.	Min/Max Values	Mean / S.D.	Min/Max Values
UF+M[1]	91.1 9.3	50.1 111.3	99.1 8.7	82.3 112.2	5766 646	4701 7228	5875 462	5379 6820	2.96 0.38	2.15 3.40	1.84 0.37	1.19 2.48
UF[2]	102.3 13.2	73.9 110.5	105.8 11.1	80.9 127.5	6018 685	4738 7202	6332 656	5129 7244	2.52 0.46	1.33 3.35	Failed	
MUF[3]	90.7 6.0	79.6 103.0	92.2 8.4	81.6 108.3	6002 351	5189 6627	5888 338	5208 6362	2.53 0.31	2.08 3.28	Failed	
PF[4]	97.7 10.6	78.2 112.4	105.2 11.3	85.0 122.0	6070 495	5267 6724	6457 517	5236 7311	2.82 0.45	2.00 3.81	2.57 0.47	1.96 3.62

* S.D. is standard deviation, [1] Melamine + Urea Formaldehyde, [2] Urea Formaldehyde, [3] Melamine-Urea Formaldehyde, [4] Phenol Formaldehyde

Table 4. Duncan's test results of laminated veneer lumber panels (P < 0.05)*.

Sources of Variance	Shear Strength (N mm^{-2})		Bending Strength (N mm^{-2})		Modulus of Elasticity (N mm^{-2})	
	n	x	n	x	n	x
Adhesive Type						
MUF[1]	30	2.53 a	40	91.6 a	40	5951 ab
UF + M[2]	30	2.96 b	40	98.1 b	40	5821 a
PF[3]	30	2.82 b	40	101.5 bc	40	6264 c
UF[4]	30	2.52 a	40	104.2 c	40	6175 bc
Climate Condition						
45% R.H.	---		80	100.7 a	80	6142 a
65% R.H.	---		80	97.0 b	80	5964 b

* The mean values marked with the same symbol are statistically identical.
[1] Melamine-Urea Formaldehyde, [2] Melamine + Urea Formaldehyde, [3] Phenol Formaldehyde, [4] Urea Formaldehyde

MUF adhesives and kept in 20 °C water. In addition, no difference was found between the shear strength values of the panels bonded with PF and UF+M adhesives, while the difference between the strength values of the panels bonded with UF and MUF adhesive was significant at the 5% significance level.

The highest mean values of shear strength were obtained from the samples bonded with PF and UF+M adhesives and left for 24 h in water. In addition, no difference was found between the shear strength values of the panels bonded with MUF adhesive, which is useful for damp indoor conditions, and UF adhesive, which is useful for dry ambient conditions. When compared with the other groups, the highest shear strength value was obtained from the samples bonded with PF adhesive and tested after boiling for 6 h according to the TS EN 314-2 standard test method. The samples produced with UF adhesive failed this test, as expected. After boiling for 6 h, the samples bonded with UF+M adhesive had a mean shear strength of 1.84 N mm^{-2}. This result is consistent with the literature (Cremonini and Pizzi, 1999).

Among the LVL panels conditioned at 20 °C and 65% R.H., the highest bending strength value was found for the panels bonded with UF adhesive, whereas the lowest value was found for the panels bonded with MUF adhesive (Table 3). No significant difference was found between the bending strength values of the panels bonded with PF and UF+M adhesive. The effect of the adhesive type on the bending strength values of the panels conditioned at 20 °C and 45% R.H. was similar to that of the panels conditioned at the other climate condition. However, the bending strength values of the panels conditioned at the 20 °C and 45% R.H. were higher than those of the panels conditioned at 20°C and 65% RH. In addition, the maximum difference among the bending strength values of the LVL panels was found for the panels bonded with PF adhesive. This may be due to the maximum decrease in the moisture content of the panels after conditioning under different climate conditions being found for the panels bonded with PF adhesive.

Climate conditions did not affect the modulus of elasticity values of UF- or MUF-bonded LVL panels. The modulus of elasticity values of the panels bonded with UF and PF adhesive increased significantly with decreasing moisture content in the panels. The effect of adhesive type on the modulus of elasticity values of the panels conditioned at 20 °C and 65% R.H. was not statistically significant while the effect on the values panels conditioned at 20 °C and 45% R.H. was significant. The highest modulus of elasticity values were determined for the panels bonded with UF (6332 N mm^{-2}) and PF (6457 N mm^{-2}) adhesives. After conditioning under different climate conditions, the maximum difference among the modulus of elasticity mean values of the LVL panels was found for those bonded with PF adhesive (Table 3). This situation, similar to that of bending strength, can be explained by the difference between the moisture contents of the 2 sample groups of the PF-bonded panels conditioned under different climate conditions being higher than those of the panels bonded with the other adhesives. In general, changes in moisture content affect the bending strength and modulus of elasticity values of LVL panels like in solid wood and these strength values of the panels increase with decreases in moisture content.

In conclusion, the bending strength and modulus of elasticity values of the panels conditioned at lower relative humidity (45% R.H.) were higher than those of the panels conditioned at 65% R.H. For example, the mean bending strength of the panels conditioned at 20 °C and 65% R.H. and bonded with UF was 102.3 N mm^{-2} while that of the panels conditioned at 20 °C and 45% R.H. was 105.8 N mm^{-2}. Similar results were also found for other adhesives, as shown in Table 3. The differences in these strength values for the PF- bonded panels were clearer. The bending strength and modulus of elasticity mean values of the panels bonded with PF adhesive and conditioned at 20 °C and 65% R.H. were 97.7 N mm^{-2} and 6070 N mm^{-2}, while those of the panels conditioned at 20 °C and 45% R.H. were 105.2 N mm^{-2} and 6457 N mm^{-2}, respectively. The addition of melamine to the UF glue mixture caused a decrease in formaldehyde emissions and an increase in shear strength values.

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