Mechanical Properties of Laminated Veneer Lumber Made from Ash and Red Pine Woods

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The purpose of this study was to determine the best laminated veneer lumber (LVL) in terms of the density, modulus of rupture (MOR), and elasticity (MOE). This study was planned as a laboratory work for non-structural purpose. LVL were formed with five different layer arrangements (APPPPPA, APPAPPA, APAPAPA, AAPPPAA, and AAPAPAA) using 3-mm thick ash (A) (*Fraxinus angustifolia* Vahl) and Turkish red pine (P) (*Pinus burita* Ten.) veneers. Accordingly, the LVL materials (12% ± 0.5 moisture level) were made and polyvinyl acetate was preferred for bonding the veneers because it was very easy to apply in laboratory applications. The test specimens were conditioned at a relative humidity of 65% ± 2% and temperature of 20 °C ± 2 °C, until attaining a constant mass, at every stage of wood sheets production and before testing. The density, MOR, and MOE tests were conducted according to the conditions specified in different standards. The results confirmed that, as the amount of the solid ash material increased in the LVL, the material had values closer to those of solid ash sample. Additionally, as a result of the experimental measurement results, the best results in terms of the density, MOR, and MOE were achieved with the AAPAPAA-layered LVL.

Keywords: Ash; Red pine; LVL; Modulus of rupture; Elasticity; Density

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INTRODUCTION

Wooden materials have been widely used in many different types of products, and besides wood is still a preferred material today because of its intrinsic excellent natural properties. However, it is well known that the forest areas are declining all over the world as a result of an excess of external factors, such as wood not being as durable as other materials, overuse of wood products and structures requiring repeated maintenance (Keenan *et al*. 2015; Kim *et al*. 2015; Sloan and Sayer 2015). Scientists have endeavored to solve these problems by using solutions such as lamination techniques (Burdurlu *et al.* 2007; Ribeiro *et al.* 2009; Kılıç 2011), integration of wood materials with plastic (Ebe and Sekino 2015; Ilçe *et al*. 2015; Cavdar *et al*. 2018), thermal modification and dimensional stabilization of wooden materials (Korkut and Akgül 2008; Esteves and Pereira 2009; Bal 2018) for longer life and durability in product life time, so that wooden materials and products can be even more useful in technological and industrial applications. Laminated veneer lumber (LVL) was produced in this study by adhering wood sheets that had a maximum thickness of 3.2 mm in the vein direction parallel to each other (Burdurlu *et al.* 2007). LVL can be manufactured from large wood veneers that may have equal or different thicknesses and can be obtained from the same or different tree species. The obtained materials are then adhered using various adhesives (Burdurlu *et al.* 2007; de Souza *et al.* 2011; Bal and Bektaş 2012; Bal 2014a,b; Percin and Altınok 2017; Subhani *et al.* 2017). It should be mentioned that LVL is ideal for use in furniture manufacturing applications (Eckelman 1993).

Burdurlu *et al.* (2007) described the positive and negative aspects of the usage of LVL in terms of the modulus of rupture (MOR) and elasticity (MOE). The wood species used in the laminating sector can increase or decrease the MOR of LVL (Tichy and Bodig 1978). The beams produced from first-grade veneer exhibited higher MOR compared with those produced from second or third grade veneers (Burdurlu *et al.* 2007). In another study, it was shown that either an increase in the number and size of knots or a decrease in the distance between knots noticeably decreased the MOR of the laminate (de Souza *et al.* 2011). The width of the sheets used in lamination does not affect the MOR and MOE of LVL. This is because the MOR decreases with an increase in the thickness of the sheets and the MOE changes based on the wood genus (Baş 1995; Şenay 1996; Kılıc 1997). Additionally, it should be emphasized here that the adhesive type and wood genus affect the bending resistance of LVL (Aydın *et al.* 2004; Baş 1995).

The LVL technique is capable of producing higher quality, durability, stability, comfortability, and flexible designability in the furniture sector as compared to the virgin woods. The selected sheets can be suitably laid within LVL, and it is feasible to fabricate a new LVL with well-designed physical and mechanical properties (Wang *et al.* 2003; Rahayu *et al.* 2015). In the literature, it was found that wood and other materials can be combined to manufacture strength composites with different physical and mechanical properties (Celebi *et al.* 2006; Burdurlu *et al.* 2007; Bal 2014a; Yang *et al.* 2014; İlçe *et al.* 2015; Özkaya *et al.* 2015).

In light of these facts, the objectives of this work were to determine the density, MOR, and MOE of non-structural LVL samples (produced from ash, red pine, and PVA) fabricated with different layer organizations in the laboratory, and to choose the most appropriate layer organization for different uses.

EXPERIMENTAL

In the preparation of the samples, it was carefully ensured with TS EN 14279 2010+A1 that there was no decay, knots, splitting, and color or density differences on the specimen surfaces. The woods red pine and ash were used as the main wooden materials in this study. It is well known that red pine wood is widely grown in Turkey; hence such wood is abundant and cheap enough to be used in many different applications. Moreover, ash wood material is often used in the furniture industry, especially for dining and living room furniture pieces, such as tables, chairs, coffee tables, and showcases. In the current work, the ash and red pine woods were obtained in the form of lumber from Akyazı Forest Operation Management in Sakarya and Dursunbey Forest Operation Management, Turkey and was cut roughly (5 mm × 58 mm × 454 mm (thick × width × length). The samples were then immediately exposed to the drying process so that the moisture content decreased towards 12% as evaluated by TS 2471 2005. The moisture measurement was verified with the MC-7806 (Mextech Instruments, Mumbai, India) device. Finally, the samples were shaped into the dimensions of 4 mm × 54 mm × 450 mm with circular saw machine (Version 1500 Törk Machine Company, Istanbul, Turkey). Both the surfaces of specimens were sanded with a wide belt sanding machine (Version 1100 Melkuç Machine Company, Ankara, Turkey) with a grit number of 60 to achieve thicknesses of 3 mm.

Before gluing, the samples were stored in a climatization box at a temperature of 20 °C ± 2 °C and relative humidity of 65% ± 2% until a stable mass was attained. Kleibert 303 (160 g/m^2), which is a vinyl-based (polyvinyl acetate; PVAc) adhesive with a D4 norm (Klebchemie, Weingarten, Germany), was applied according to the recommendation provided by the supplier to one surface of every sheet.

The adhered sheets were gathered in seven layers with the stacked surfaces on top of each other and were pressed using a pressing machine (Cemilusta Wood Working Machinery Ind. Inc., Ankara, Turkey) for 24 h under a static load of 0.7 N/mm² at 20 °C ± 2 °C. This process was done for five different LVL layer arrangements: APPPPPA, APPAPPA, AAPPPAA, APAPAPA, and AAPAPAA (each one includes 10 sample, and A represents ash and P represents red pine). The arrangements are displayed in Fig. 1.

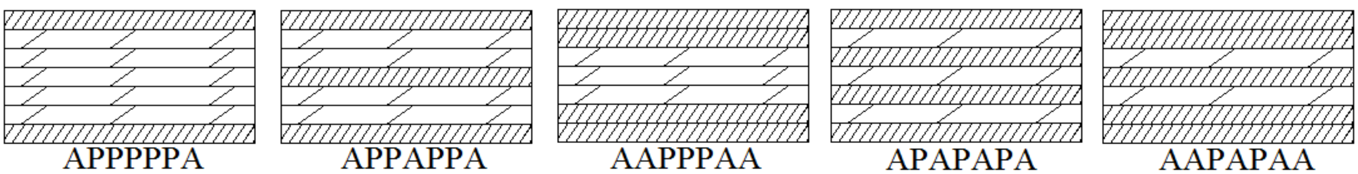

Fig. 1. Sheet arrangements of the LVL samples (each one includes 10 sample)

Then, some LVL samples were cut to the dimensions 20 mm × 50 mm × 50 mm (thick × width × length) for the density measurements, while other LVL samples were cut to the dimensions 20 mm × 20 mm × 430 mm for the experimental MOR and MOE measurements. Solid ash and red pine specimens were also manufactured with these measurements as a control set. The specimens were stored in a climate box at a temperature of 20 °C ± 2 °C and relative moisture of 65% ± 5% until the masses of the specimens remained stable with up to a 12% moisture content. The determination of the air-dried densities of the LVL samples was conducted in compliance with TS 2472 (2005). Similarly, Figure 2 indications that the determination of the MOR and MOE was performed in compliance with a universal testing machine (Version 7012-50kN, Utest, Ankara, Turkey) TS EN 310 (1999). All of the experimental data was statistically examined using SPSS software 21.0 (SPSS Inc., Chicago, IL, USA). The correlation between the solid wood and all of the LVL arrangement types was further analyzed with a one-way analysis of variance (ANOVA). Significance between groups was determined with Duncan's multiple range test at a 95% (α = 0.05) confidence level.

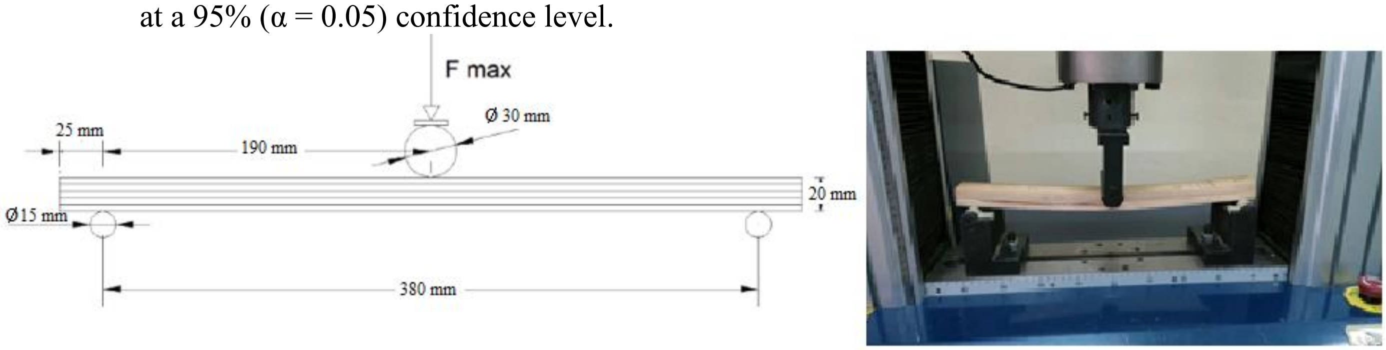

Fig. 2. The test setup of MOR and MOE

RESULTS AND DISCUSSION

Figure 3 shows that the density decreased systematically as the proportion of red pine in the LVL increased. This was because of the low density of red pine used in the LVL production. This conclusion was supported by the results of previous studies in the literature (Celebi *et al.* 2006; Burdurlu *et al.* 2007; Bal 2014a; İlçe *et al.* 2015).

For beech and cardboard lamination, the density decreased gradually with an increase in the amount of paperboard as a result of usage of a filler with far lower density than that of wood materials (Celebi *et al.* 2006). Similarly, Burdurlu *et al.* (2007) confirmed that the density was enhanced with the decrement in the number of red pine in the LVL in the case of lamination of beech and poplar materials.

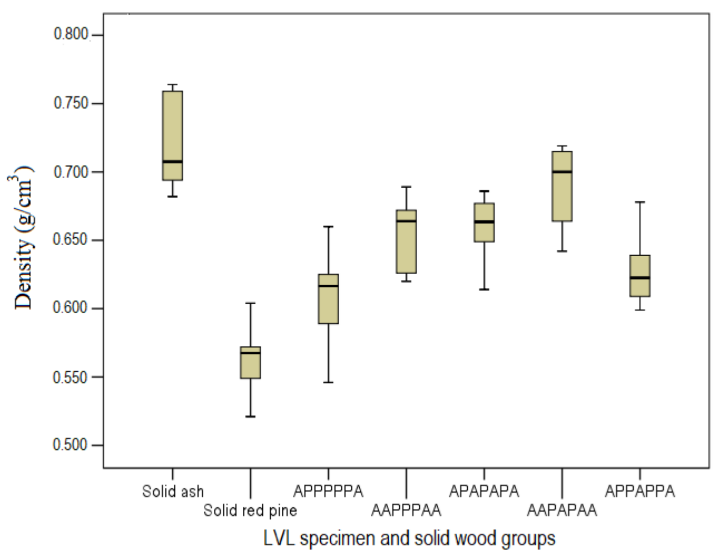

Fig. 3. Air-dry density of the LVL samples

For the statistical modeling studies, a statistically significant difference was defined in the ANOVA test between the LVL production combinations and their MOR (Table 1). This is because an F-obtained greater than F-critical value is equivalent to a P-value less than alpha and both mean that you reject the null hypothesis.

Table 1. ANOVA Test Results for the LVL Samples – MOR

LVL specimen and solid wood groups (each one includes 10 sample)	MOR values (N/mm2)				F-value*	P-value
	Mean	Standard Deviation	Minimum	Maximum		
Solid ash	129. 70	4. 54	119. 75	137,10	65.17	0.000
Solid red pine	90. 33	4. 64	81. 98	96. 81		
APPPPPA	100. 82	5. 58	92. 12	110. 35		
AAPPPAA	108. 47	5. 50	100. 23	119. 08		
APAPAPA	110. 78	4. 42	101. 60	115. 36		
AAPAPAA	119. 60	5. 29	111. 02	127. 19		
APPAPPA	99. 79	5. 97	92. 04	109. 71		

*$df1$:6, $df2$:63, α=0.05, F-obtained:65.17, F-critical:2.25

According to the Duncan's test results given in Table 2, the LVL arrangement was determined to cause a significant difference. Accordingly, the inter-group differences between the APPPPPA-APPAPPA and APAPAPA-AAPPPAA production types were insignificant. Namely, the material of APPPPPA (APAPAPA) can be used in the furniture production instead of APPAPPA (AAPPPAA), or vice versa. The scenario based on the modeling results suggested that all of the materials are useful for application.

Table 2. Duncan's Test Result of the LVL Samples – MOR

LVL Specimen and solid wood groups(each one includes 10 sample)	Homogeneous Subsets Subset for α = 0.05			
	1	2	3	4
Red pine	90.33			
APPPPPA		99.79		
APPAPPA		100.82		
APAPAPA			108.47	
AAPPPAA			110.78	
AAPAPAA				119.60
Ash				129.70

At the same time, the variation in the flexural resistance with the ash and red pine ratios in the LVL was also investigated. The flexural resistance constantly shifted to higher values as the number of low-density layers in the LVL arrangements was reduced. Previous studies also favored these findings (Celebi *et al.* 2006; Burdurlu *et al.* 2007; Gaff and Gašparík 2015). In addition, it is to be mentioned that the contribution of layer numbers to the flexural resistance constitutes the significant difference (Gaff and Gašparík 2015).

As for the mechanical performances, the MOE of the LVL specimens exhibited a similar behavior to that of the flexural resistance (Table 3).

Table 3. ANOVA Test Results for the LVL Samples – MOE

LVL specimen and solid wood groups (each one includes 10 sample)	MOE values (N/mm2)				F-value*	P-value
	Mean	Standard Deviation	Minimum	Maximum		
Solid ash	132,12	145,86	159,60	173,34	107.48	0.000
Solid red pine	92,63	102,31	111,99	121,67		
APPPPPA	106,00	117,51	129,02	140,54		
AAPPPAA	114,96	127,61	140,27	152,92		
APAPAPA	110,77	121,86	132,95	144,04		
AAPAPAA	122,90	135,75	148,60	161,45		
APPAPPA	105,84	117,42	129,00	140,59		

**df1*:6, *df2*:63, α=0.05, F-obtained: 107.48, F-critical: 2.25

According to the measurement results, the modulus of elasticity tended to decrease continuously with an increase in the number of red pine layers in the LVL materials. Likewise, the combination of a P value less than 0.05 and F-value of 107.48 verified the statistical significance. In other words, the statistical findings verified that the terms chosen for the present work, which are provided in Table 4, were significant. Another vital conclusion of this work was that the statistical tests were sufficient to predict the response values of other probable characteristics due to their intrinsic high accuracy

Table 4. Duncan's Test Results for the of the LVL Samples – MOE

Composite Wood N = 10	Homogeneous Subsets Subset for α = 0.05			
	1	2	3	4
Red pine	8589.91			
APPPPPA		10993.56		
APPAPPA		11296.28		
APAPAPA			11931.60	
AAPPPAA			12029.19	
AAPAPAA				12774.39
Ash				13252.74

Similar to the experimental results for the flexural resistance, the inter-group differences between the APPPPPA-APPAPPA and APAPAPA-AAPPPAA production types were insignificant and useful for various applications. According to the experimental results and text approaches that were performed, two important findings were made:

- The AAPAPAA LVL arrangement can be used for table and chair feet because of its lower density, MOR, and MOE compared with those of solid ash.
- The APPPPPA LVL arrangement can be used in furniture sector applications in place of solid red pine because of its higher density, MOR and MOE.

CONCLUSIONS

In this study, LVL that contained ash and red pine with seven layers and five different layer arrangements were produced. It was found that the density, MOR, and MOE improved depending on the amount of ash wood in the composite wood material.

1. The density, MOR, and MOE values that were closest to those of the solid ash were observed for the AAPAPAA arrangement. Alternatively, the APPPPPA arrangement presented density, MOR and MOE values closest to those of the solid red pine.
2. The AAPAPAA arrangement demonstrated a 4% lower density, 8% lower MOR, and 4% lower MOE compared with those of the solid ash. In contrast, the APPPPPPA arrangement had an 8% higher density, 10% higher MOR, and 27% higher modulus of elasticity compared with those of the solid red pine. In this respect, it was recommended to use the AAPAPAA arrangement to produce table and chair feet, instead of solid ash. Another crucial conclusion deduced from this work was that the APPPPPPA arrangement (instead of solid red pine) is ideal for fabricating furniture pieces with somewhat lighter feet, such as coffee tables.
3. The AAPAPAA arrangement, which had superior density, MOR values, and MOE values, is a pioneering material that can provide novel and feasible applications within the furniture sector.

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