

An investigation of some physical and mechanical properties of laminated veneer lumber manufactured from black alder (*Alnus glutinosa*) glued with polyvinyl acetate and polyurethane adhesives

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Abstract

This study was designed to determine some physical and mechanical properties of laminated veneer lumber (LVL) made of black alder (*Alnus glutinosa*). Veneers were prepared from 2-mm and 4-mm-thick black alder and glued using polyvinyl acetate (PVA) and polyurethane (PU) adhesives. Results showed that the specific gravity and mechanical properties of the LVL produced from 2-mm veneers were higher compared to those from 4-mm veneers. In other words, as the thickness increases, a decrease is observed in the specific gravity and mechanical property values. Except for nail- and screw-holding strength values perpendicular to the glue line, all the other values obtained with the PVA adhesive were higher compared to those obtained with the PU adhesives.

Wood has been preferred for residential construction since ancient times because of its natural beauty and excellent properties, such as, high specific strength, heat insulation, and ease of handling and processing. Recently, increased attention has been focused on the development of composite products because of diminishing global forest resources and for environmental and economic reasons (Su 1997). With the development of wood composite technology, it is possible to use small-diameter logs for modified, particle, or layered composites. Particleboard and fiberboard are the main types of composite materials and can be substituted for wood only for certain end uses and cannot be considered a total substitute for all purposes because of certain inherent limitations (Jagadish 1991). The layered composite materials that are vertically and horizontally glued, such as laminated wood and laminated veneer lumber, have been developed as an alternative to solid wood because these composite materials retain the structural properties of wood (Kamala et al. 1999, Aydin et al. 2004). Veneers obtained from medium- or small-diameter logs can be converted into glued parallel laminates or laminated veneer

lumber (LVL), which have all the properties of thick wood planks (Kamala et al. 1999). Wood loss in veneering is low and veneer production is easy because of the chipless cutting (peeling) of the logs by the automatic lathe. It is possible to produce straight or bended structural members by using glued-laminated veneer construction.

Panel products also have various advantages over other sheet materials as well as conventional solid wood, including increased dimensional stability, uniformity, and mechanical

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Forest Prod. J. 56(9):56-59.

properties, plus availability in larger sizes, reduced processing cost, improved stress distributing properties, appealing appearance, and easy molding ability etc. (Shukla et al. 1999, Hoyle and Woeste 1989).

The grain of each layer of veneer assembled into LVL runs parallel with each adjacent ply. Being a homogeneous and dimensionally stable building material, LVL can be used where strength and stability are required (Uysal 2005). Laminated veneer panels are manufactured using different adhesives such as phenol-formaldehyde, urea-formaldehyde, melamine-formaldehyde, and polyvinyl acetate etc. depending on where they are used.

Wood laminated members are called by different names according to the thicknesses of the laminations used. Solid wood with thicknesses between 25.4 mm and 50.8 mm is used in large dimension laminated members for buildings, such as beams, columns, arches, etc. and the element obtained is called glued laminated timber (glulam). Wood veneers with a maximum thickness of 3.2 mm are used in the manufacture of structural elements of wood products such as furniture and these types of laminated elements are called LVL or Micro-lam (Stevens and Turner 1970).

Black alder (*Alnus glutinosa*) is a type of wood that is found extensively in Turkey and that has commercial importance. Its air-dry density is 0.49 g/cm³. It is used in the production of veneers, plywood, wood furniture, doors, and windows, and has a suitable hardness for bonding processes (Gursu 1967). There is no study related to the lamination characteristics of this wood type; however, some of its physical and mechanical characteristics as a solid material have been determined (Gursu 1967).

This study aims to determine the effect of the lamination thickness and type of adhesive on some physical and mechanical characteristics in LVL produced from black alder.

Materials and methods

The black alder (*Alnus glutinosa*) used in the study was obtained from the Meryemana Research Forest in the Trabzon Province of Turkey. The general principles of the ISO 4471 (ISO 1982) standard were complied with in the felling of the trees.

Polyvinyl acetate (PVA) and polyurethane (PU) adhesives were used to bond the laminations on top of each other. Since PVA adhesive is used in the assembly of wood products used in interiors and PU adhesive is used in the assembly of wood products mostly in exteriors and humid environments, these types of adhesive were preferred in the study. The basic material of the PVA adhesive used in the study is a polyvinyl acetate dispersion. It contains a solid substance in the amount of 55 percent. Its density is 1.08 g/cm³. Its viscosity value is 12 to 18 Pa·s at a temperature of 20°C. The assembly time is 8 ± 1 minutes. It is used as purchased in accordance with the recommendations of the manufacturer. The PU adhesive has a solid substance amount of 100 percent. Its density is 1.2 g/cm³. It has a viscosity value of 4 to 5 Pa·s at a temperature of 20°C. It is a single component adhesive. Its assembly time is 15 to 40 minutes. It was used as purchased in accordance with the recommendations of the manufacturer.

Black alder veneers with thicknesses of 2 mm and 4 mm were obtained by rotary cutting in a plywood mill at industrial conditions. Before the bonding process, the veneers were stored in a climatization chamber until they reached a mois-

Table 1. — Pressing conditions of LVL made from black alder.

Adhesive type	Pressing pressure (kg/cm ²)	Pressing temperature (°C)	Pressing duration (min)
PVA	6	50	120
PU	6	50	90

ture content of about 12 percent. The PVA and PU adhesives were applied on a single bonding surface of veneers at approximately 180 g/m² and 250 g/m², respectively. Adhesives were applied by using a roller coater. After the gluing process, veneers with the dimensions of 35 by 70 cm were pressed with the grains of all veneers in the same direction. The pressing conditions of the LVL are given in Table 1. The physical and mechanical properties of the LVL are summarized in Table 2. Thirty replicate specimens were used for each test method.

Results and discussion

Some physical and mechanical characteristics connected to the type of adhesive and lamination thickness of the LVL are given in Table 3. The results emerging with the analysis of the table and the factors thought to be influential on these results, are given below:

1. As expected, the density of the LVL manufactured with laminations having a thickness of 2 mm is greater compared to the density of the laminations having a thickness of 4 mm. The density of both types of adhesives is greater than the density of the black alder. The density increases because more adhesive is used in the LVL produced from the laminations with a thickness of 2 mm.
2. All the values for the mechanical characteristics of the LVL produced from the 2-mm laminations tested were higher compared to those manufactured from the 4-mm laminations. In other words, as the thickness increases, a decrease is observed in the mechanical values. This result is also in agreement with the existing literature (Youngquist et al. 1984, Bas 1995, Senay, 1996). A larger glueline emerges in the LVLs produced from thinner veneers and more adhesive is used. The fact that the cohesion strength of the adhesive is greater than the cohesion strength of the wood when any force is applied explains why the breakage is from the wood rather than at the glueline. The following could be influential on this result: 1) the increase in cohesion strength stemming from the larger glueline; and 2) the improvement in splitting strength because of the small differences in grain direction of the plies that produce an interlocked grain effect.
3. Other than the nail- and screw-holding strength values perpendicular to the glueline, all the other values obtained with the PVA adhesives were higher compared to those obtained with the PU adhesives. The PVA is a vinyl-based adhesive and produces a flexible layer; whereas the PU adhesive produces a crystallized and hard layer. When any force is applied to a crystallized glue layer, which has completed bond formation, the layer easily disintegrates. The flexible layer structure of the PVA adhesive could have been influential in obtaining higher mechanical values.
4. The screw-holding strength perpendicular to the glueline is higher for the LVL with 2-mm laminations with PU adhesive compared to the specimens with PVA adhesive; whereas the screw-holding strength of the LVL with 4-mm laminations is lower. However, the screw-holding strength for LVL with

Table 2 — The physical and mechanical properties of the LVL made from black alder.

Tests	Standards	Dimensions
		(mm)
Air-dry density	TS 2472 (TSI 1976a)	20 by 30 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Ovendry density	TS 2472 (TSI 1976a)	20 by 30 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Shear strength parallel to glueline	ASTM D 905-98 (ASTM 1998)	50.8 by 44.5 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Compression strength parallel to glueline	TS 2595 (TSI 1977)	20 by 30 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Bending strength perpendicular to glueline	TS 2474 (TSI 1976b)	20 by 360 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Modulus of elasticity ^a in static bending	TS 2474 (TSI 1976b)	20 by 360 by thickness of LVL (2 mm for 10 layers and 4 mm for 5 layers)
Screw holding strength perpendicular to glueline	ASTM D 1761-88 (ASTM 2000)	50 by 50 by thickness of LVL (2 mm for 25 layers and 4 mm for 13 layers)
Nail holding strength perpendicular to glueline	TS 6094 (TSI 1988)	50 by 50 by thickness of LVL (2 mm for 25 layers and 4 mm for 13 layers)

^aPerpendicular to glueline

Table 3. — Some physical and mechanical properties of LVL made from black alder.

Properties	Adhesive types/veneer thickness			
	PVA		PU	
	2 mm	4 mm	2 mm	4 mm
Air dry density (g/cm ³)	0.590 (0.051) ^a	0.475 (0.047)	0.587 (0.038)	0.476 (0.044)
Oven dry density (g/cm ³)	0.594 (0.064)	0.437 (0.042)	0.546 (0.058)	0.447 (0.039)
Shear strength PVA parallel to glueline (kp/cm ²)	136.95 (8.54)	77.29 (5.60)	119.02 (9.70)	48.75 (6.13)
Compression strength parallel to glueline (kp/cm ²)	541.25 (23.74)	423.23 (16.82)	536.25 (28.90)	484.11 (16.18)
Bending strength perpendicular to glueline (kp/cm ²)	905.26 (67.82)	582.88 (16.82)	883.59 (55.64)	549.35 (20.50)
Modulus of elasticity ^b in static bending (kp/cm ²)	106082 (5783)	47805 (3437)	86471 (4845)	46846 (3953)
Screw holding strength perpendicular to glueline (kp/cm ²)	67.31 (9.50)	58.64 (7.65)	74.39 (8.75)	50.27 (6.58)
Nail holding strength perpendicular to glueline (kp/cm ²)	42.30 (5.50)	38.68 (4.64)	49.85 (6.72)	43.10 (5.80)

^aValues in parentheses are standard deviations.

^bPerpendicular to glueline.

both lamination thicknesses with PU adhesive is higher compared to the LVL with PVA adhesive. It could be that the hard and strong structure of the PU adhesive could have created a higher force during the pulling of the screws and nails. It is thought that the filling of a harder material among the grooves of the screws and nails and the growing difficulty in displacement of the small adhesive particles emerging at the end of structural breaking at the moment of pulling could be influential in an increase in this force.

5. The PVA used in this study is a water-based adhesive. It should be preferred in structural elements for interiors due to this structural characteristic. In the production of structural elements for exteriors, the PU adhesive should be preferred. Furthermore, there are also types of the PVA adhesive that are water-resistant and that have developed strength characteristics.

Conclusion

This study was designed to investigate some physical and mechanical properties of LVL manufactured from 2-mm and 4-mm veneer thicknesses and glued with PVA and PU adhesives.

The results showed that except for screw- and nail-holding strength, higher veneer thickness values result in lower wood density and strength values. The adhesive types used in LVL production also affect density and strength values. In general, the PVA adhesive provided higher mechanical properties than the PU adhesive. However, it may not be always suitable to choose adhesives with higher strength in practice, because it is

also necessary to take into account adhesive properties such as resistance to water, heat, and fire in service conditions.

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