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Full Length Research Paper

Laminated veneer lumber from Rowan (*Sorbus aucuparia* Lipsky)

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This study was designed to determine some physical and mechanical properties and surface roughness of laminated veneer lumber (LVL) made from *Sorbus aucuparia* Lipsky wood which has no detailed research in the literature. The sample trees were taken from the Küre district in Kastamonu, Turkey. The 12 ply LVLs manufactured from 1.6 mm thick rotary peeled veneers and bonded with urea formaldehyde adhesive. Conventional methods followed and the test procedures were performed on small clean specimens. Also, this study involves the comparison of the mechanical properties of LVL made from *S. aucuparia* Lipsky wood to those of conventional LVLs. It was found that air-dry density, thickness swelling, thermal conductivity, MOR and MOE, compression strength, surface hardness, shear strength and surface roughness (Ra) were 0.737 g/cm^3, 3.63%, 0.2259 W/m-K, 80.6 N/mm^2, 6985.6 N/mm^2, 58.36 N/mm^2, 29.15 N/mm^2, 5.28 N/mm^2 and 5.13 µm respectively. When *S. aucuparia* L. wood is used to produce LVL for use in the furniture industry, the resulting physical and mechanical property values are sufficient to produce an acceptable product. Also, it appears to be a suitable alternative to currently used alnus spp. and fagus spp. according to usage area.

Key words: *Sorbus aucuparia* lipsky, laminated veneer lumber, physical properties, mechanical properties.

INTRODUCTION

Wood is one of the most important renewable raw materials, which have been used by human beings since early years. Increased demand for wood has, however, caused a dramatic decrease in forest resources. Due to increasing consumption and costs of wood and wood-based materials, there is a need to utilize native forest resources more efficiently and develop substitutes for wood source in terms of using undervalued wood sources and fast-growing wood species in order to meet this ever increasing demand.

Researchers are showing increased interest in the benefits of composite technology for wood-based materials for structural and non-structural usage (Fridley, 2002). The layered composite materials that are vertically and horizontally glued, such as laminated wood and laminated lumber, have been developed as an alternative to solid wood. Laminated veneer lumber (LVL) has been manufactured by using appropriate adhesives, processing conditions, veneers from different wood species at different orientations (Shukla and Pascal Kandem, 2008). Laminated Veneer Lumber has typically been manufactured from softwood and hardwood species. Two major potential uses of hardwood LVL have been investigated in the studies: domestic and industrial structures and various furniture components. In summarizing the research studies on the use of hardwood LVL in furniture, it should be pointed out that selecting potential uses of LVL in furniture must be based on: the aesthetic requirements when used in exposed parts; bending strength, shear, stiffness, and joint requirements when used for structural parts; warping and dimensional stability requirements when used for at panel surfaces; and economics (Ozarska, 1999).

Sorbus aucuparia Lipsky wood is a fast-growing tree species naturally distributed throughout north and North-west Anatolia in Turkey and shows an expansive distribution from Avrupa, Sibirya, and Kafkasya. Most of the research work in Turkey has been done on hardwood LVL such as poplar, pine, beech and oak, but the need to

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use native forest resources more efficiently has stimulated research on hardwood reconstituted products. *S. aucuparia* Lipsky wood is less utilized specie of Turkey forest and has been used at turnery, carving and production of pole and walking staff due to hard and flexible structure. But, high value products may be developed using appropriate processing technology. The proposed research is therefore aimed to explore the possibility of developing 12 ply LVL high value wood engineered wood product using this specie. This study evaluated some technological properties of LVL from *S. aucuparia* Lipsky wood to obtain essential information for encouraging more effective use of its wood.

MATERIAL AND METHODS

Wood veneers

Five *S. aucuparia* Lipsky trees were taken from the Küre district in Kastamonu, Turkey. The diameter of the trees varied between 30 - 35 cm. Veneer logs were cut from the felled trees between the heights of 1.30 and 2.30 m. The rotary-peeled veneers (1.6 mm thick) were manufactured from the logs. Veneers 500 mm long by 500 mm wide by 1.6 mm thickness, were used for making 12 ply laminated veneer lumber. The average moisture content of the dried veneers varied between 6 - 8%. The veneers, nearly defect-free (to reduce variability in mechanical properties resulting from random placement of defects in interior veneers) were used in LVL production.

Adhesive

Urea-formaldehyde (POLISAN, Izmit, Turkey) was used for producing these 12 ply LVL boards in duplicate. The read-to-use adhesive has a viscosity of 250 - 400 cp at 20℃, pH 7.5 - 8, solid material 55 ± 1% and a density of 1.23 g/cm^3.The adhesive was spread at the rate of about 190 g/m^2 on single bonding surface of the veneers as recommended by the manufacture. Glue was spread uniformly on the veneers by manually hand brushing.

Process

The boards were pressed at a pressure 0.7 N/mm^2, at 120℃ for 30 min in a hot-press. The resulting LVL panels were allowed to cool for 72 h before cutting into specimens.

Testing methods

Tests for physical and mechanical properties were conducted on specimens cut from the experimental LVL panels. Prior to the testing, the specimens were conditioned for at least 4 weeks at 20 ± 2℃ and 65 ± 2% relative humidity (RH). The following properties were tested: air-dry and oven-dry densities, thickness swelling, thermal conductivity, modulus of rupture (MOR) and modulus of elasticity (MOE), compression strength (CS), surface hardness, shear strength and surface roughness. Twenty samples were used for each test methods.

Density and moisture content

For density and moisture content tests, average sample size used was 30 mm long by 20 mm wide by thickness of LVL. The moisture content was determined by weighing the samples and then placing them in an oven set at 103 ± 2℃ for 48 h (TS 2471 same ISO 3130). The air-dry and oven-dry densities were computed based on the air- or oven-dry weights divided by the volume of the samples in air- or oven-dry condition (TS 2472 same ISO 3131). These properties were also computed for the specimens used for static bending, surface hardness and impact bending tests.

Thickness swelling

For thickness swelling test, average sample size used was 30 mm long by 20 mm wide by thickness of LVL. For thickness swelling, the specimens were submerged such that the top face of each specimen was about 2.5 - 3.0 cm from the surface of water. After 48 h, the specimens were removed; extra water at the surface was wiped off with tissue paper and measurements were taken of weight and dimensions and then samples were in the air for 15 h before oven drying. After oven drying, thickness and weight measurements were once again repeated quickly. According to TS 4084 (same ISO 4859), thickness swelling was computed using the formula TS (%) = $((T_w - T_{o)}$ / $T_o)$, where T_w is wet thickness of specimen after water saturation for 48 h, and T_o is the oven-dry thickness of specimens.

Thermal conductivity

For thermal conductivity measurement, a quick thermal conductivity meter based on ASTM C 1113 – 99hot-wire method was used. The QTM 500 meter was made by Kyoto Electronics Manufacturing, Japan. Variac (power supply) was used to supply constant electrical current to the resistance. The measurement range is 0.0116 - 6 W/mK. Measuring time is standard 100 - 120 s. Sample size used for thermal conductivity measurement was 100 mm long by 50 mm wide by thickness of LVL according to the procedure of ASTM C 177/C 518.

Surface roughness

The points of roughness measurements were randomly marked on the surface of the samples. Surface roughness of LVL samples was measured by a profilometer (Mitutoyo Surftest SJ-301) with the profile method using a stylus device standard. Tracing speed, stylus tip diameter, and tip angle were 10 mm/min, 4 µm and 90° respectively. Fifteen mm tracing length (L_t) with 2.5 mm cut-off was used for the measurements. The measuring force of the scanning arm on the surfaces was 4 mN (0.4 g) which did not put any significant damage on the surface. Roughness values were measured with a sensitivity of 0.5 µm. Measurements were done at room temperature and stylus pin was calibrated before the tests. Two roughness parameters, mean arithmetic deviation of profile (R_a) and maximum roughness (R_{max}) which are by far commonly used parameter in surface finish measurement were measured to evaluate surface roughness of LVL surfaces. R_a is the average distance from the profile to the mean line over the length of assessment. R_{max} is the distance between peak and valley points of the profile which can be used as an indicator of the maximum defect height within the assessed profile (ISO 4287). Specification of this parameter is described by Hiziroglu (1996) and Hiziroglu and Graham (1998).

Measurement of strength properties

The mechanical tests were carried out in a ZWICK Z/50 universal

Table 1. Physical and mechanical tests results of LVL made from *Sorbus aucuparia* Lipsky.

Property		Arithmetic mean (x)	Standard deviation (SD)	Variance (V)	Minimum value (Min.)	Maximum value (Max.)
Oven-dry density (g/cm^3)		0.712	0.0135	0.000183	0.688	0.731
Air-dry density (g/cm^3)		0.737	0.0133	0.000178	0.709	0.757
Thermal conductivity (W/mK)		0.2259	0.0059	3.48E-05	0.2158	0.2399
Swelling (%)		3.63	0.3538	0.125183	3.048	4.386
MOR (N/mm^2)		80.61	7.4801	55.95333	69.15	95.92
MOE (N/mm^2)		6985.6	355.9914	126729.8	6391.2	7827.3
CS (N/mm^2)		58.36	1.1434	1.307484	55.97	59.68
Hardness (N/mm^2)		29.15	4.839	23.4234	22.3	39.4
Bonding quality (N/mm^2)		5.28	0.5367	0.288049	4.35	6.07
Surface roughness	R_a	5.13	0.7238	0.524027	4.01	6.43
(µm)	R_{max}	31.82	4.2144	17.76179	24.9	39.45

testing machine. Perpendicular to the fiber and glue line modulus of rupture (MOR) and modulus of elasticity (MOE) tests were carried out TS 2474 (same ISO 3133) and TS 2478 (same ISO 3349), respectively. Specimen size for the tests was 300 mm long by 20 mm wide by thickness of LVL.

Compression strength parallel to face tests (CS) was carried out according to TS 2595 (same ISO 3787). The dimension of test samples was 30 mm long by 20 mm wide by thickness of LVL.

Surface hardness tests were carried out according to TS 2479 (same ISO 3350). The specimen size for surface hardness was 50 mm long by 50 mm wide by thickness of LVL.

The test of shear strength was carried out according to the principles of TS EN 205 (same BS EN 205) standard. Specimen size for the shear test was 150 mm long by 20 mm wide by 10 mm thick and the glue shearing area was kept 10 mm long by 20 mm wide. The shear tests were carried out in a ZWICK Z/50 universal testing machine. A loading rate of 12 mm/min was used in all tests according to TS EN 205. Loading was continued until separation between the surfaces of the specimens occurred.

RESULTS AND DISCUSSION

In Table 1, the resulting physical and mechanical properties of the LVL specimens are summarized. Comparative results from LVL specimens made from *Sorbus aucuparia Lipsky* wood and LVLs from different species are given in Table 2 and 3.

Air-dry SG values of LVLs from *Pterocarya fraxinifolia, Fagus orientalis, Pinus sylvestris*, *Cedrus libani* and *Quercus petraea* are lower than those of *Sorbus aucuparia.* Swelling values of *Sorbus aucuparia* LVLs are similar to *Cedrus libani* and smaller than *Fagus orientalis, Pinus sylvestris* and *Quercus petraea*. Swelling value of *Sorbus aucuparia LVLs* is relatively lower than those of other wood species LVLs compared in Table 1. This can be caused by the fact that the adhesives used in lamination production hinder swelling of LVLs by filling up the surface cell cavities.

The thermal conductivity of *Sorbus aucuparia* LVLs are higher than *Pterocarya fraxinifolia, Fagus orientalis, Pinus sylvestris*, *Cedrus libani* and *Quercus petraea.* Kamke and Zylkowski (1989) were reported that the thermal conductivity of wood based composites, as for wood, are strongly depended on density. The densities of *Sorbus aucuparia* LVLs were higher than that of other LVLs from different wood species (Table 2). The general trends of SGs of the LVLs from different wood species are identical to those of the thermal conductivity values of LVLs. Thermal conductivity is a very important parameter in determining heat transfer rate and is required for development of drying models and in industrial operations such as adhesive cure rate (Gu and Zink-Sharp, 2005). According to the results of this study, *Sorbus aucuparia* LVLs can be used as a material in construction where the thermal conductivity is required.

Gungor et al. (2006) found that surface roughness values R_a and R_{max} were 6.83 µm and 27.66 µm, respectively for *Pterocarya fraxinifolia* LVL. Goker et al. (1997)

Table 2. Physical properties of *Sorbus aucuparia* Lipsky LVL in comparison with LVL made of different wood species.

Species	Air-dry SG	Thermal Conductivity	Swelling	Surface roughness		Reference
				Ra	Rmax	
	(g/cm³)	(W/m-K)	%	………(µm)….		
Sorbus aucuparia L. LVL	0.737	0.2259	3.63	5.13	31.82	
Pterocarya fraxinifolia LVL	0.610	-	-	6.83	27.66	Gungor et al. (2006)
Fagus orientalis Lipsky LVL	0.680	0.1890	5.18	-	-	Keskin (2001)
Pinus sylvestris L. LVL	0.519	0.1616	5.04	-	-	Keskin (2001)
Cedrus libani A. Rich LVL	0.509	0.1454	4.98	-	-	Keskin (2001)
Quercus petraea Liebl. LVL	0.627	0.1821	5.12	-	-	Keskin (2001)

Table 3. Mechanical properties of *Sorbus aucuparia* Lipsky LVL in comparison with LVL made of different wood species.

Species	Air-dry SG	MOR	MOE	CS	Hardness	Bonding	Reference
	(g/cm³)	……………………(N/mm²)……………………					
Sorbus aucuparia L. LVL	0.737	80.61	6985.6	58.36	29.15	5.28	
Fagus orientalis Lipsky LVL	-	111.5	17230.0	50.7	21.4	-	Çolakoğlu et al. (2003)
Fagus orientalis Lipsky LVL	0.721	93.4	12067.9	52.38	-	-	Senay (1996)
Pinus sylvestris L. LVL	0.519	105.04	10223.4	57.29	-	8.42	Keskin (2001)
Pinus sylvestris LVL	-	102.3	6018.0	-	-	-	Çolak et al. (2004)
Pterocarya fraxinifolia LVL	0.610	87.81	9541.02	-	-	2.86	Gungor et al. (2006)
Quercus petraea Liebl. LVL	0.639	109.03	10985	70.027	-	-	Keskin (2004)
Alnus glutinosa LVL	-	90.50	10608.2	-	-	-	Kilic and Guray (1997)
Cedrus libani A. Rich LVL	0.509	92.81	8303.01	55.36		7.70	Keskin (2001)
Populus nigra LVL	0.412	76.14	6749.2	40.68	-	-	Keskin and Togay (2003)
Populus tremula LVL	0.550	81.13	-	-	-		Altinok (2002)

(1997) determined that for 12-mm-thick plywood made from Okoume manufactured in Turkey, surface roughness values R_a and R_{max} were 11.54 µm and 102. 80 µm, respectively. Kantay et al. (2001) obtained surface roughness values R_a of sliced veneer of *Juglans regia* L. ranging from 8.95-10.66 µm. When these values are compared to the surface roughness values shown in Table 1, it is evident that the surface quality of the LVLs would be appropriate for various surface treatments.

MOR values of *Sorbus aucuparia* LVLs are similar to those of Alnus *glutinosa,* Pterocarya *fraxinifolia* and *Populus tremula* LVLs and lower than *Fagus orientalis, Pinus sylvestris, and Quercus petraea* LVLs. MOE of Sorbus *aucuparia* LVLs are lower than those of Fagus *orientalis, Pterocarya fraxinifolia, Alnus glutinosa* and *Cedrus libani and similar to Pinus sylvestris and Populus nigra.* The differences in the mechanical properties among compared wood species LVLs are related to one or more their specific characteristics for example; anatomical structure, chemical content of wood species, adhesives and LVL production conditions e.g. pressure. Among these, anatomical structure, chemical content of wood species and adhesives may be decisive. Fibres of *Sorbus aucuparia* Lipsky wood are very thin-walled and have medium wall thickness (Richter and Dallwitz, 2000). This may cause decrease of MOR and MOE.

CS value of *Sorbus aucuparia* LVLs is similar to wood species LVLs compared in Table 3. This indicates that *Sorbus aucuparia* LVLs can be used instead of the compared wood species LVLs in the usage areas which are exposed to compression.

Hardness value of *Sorbus aucuparia* LVLs is similar to

Fagus orientalis LVLs. Thus, *Sorbus aucuparia* LVLs may be used instead of *Fagus orientalis* LVLs for flooring, stairs and ceiling wall.

When the shear strength value of *Sorbus aucuparia has* been compared with the other wood species LVLs, it is clear that bonding quality of *Sorbus aucuparia would* be appropriate for producing an acceptable product (Table 3). Gluing of the veneers is closely related to vessel diameter. Average tangential vessel diameter of *Sorbus aucuparia Lipsky* is 50 - 60 µm and average tangential diameter of vessel lumina is medium (Richter and Dallwitz, 2000). For this reason, in the LVLs made from *Sorbus aucuparia,* sufficient glue penetration is achieved, which increases bonding strength.

Conclusions

Sorbus aucuparia L. has been considered as an under utilized wood species in Turkey. Taking into account the results of this study, it can be said that *Sorbus aucuparia* L. wood may serve as a valuable wood source for the forest products industry. When *Sorbus aucuparia* L. wood is used to produce LVL for use in the furniture industry, the resulting physical and mechanical property values are sufficient to produce an acceptable product. Also, this wood species LVLs can be used in structural and non-structural applications, stairs, ceiling, wall and flooring, door, window, border production based on the obtained physical and mechanical properties. We suggest that this wood species can provide a suitable alternative for *Fagus orientalis*, *Pterocarya fraxinifolia and Alnus glutinosa* LVLs according to desired properties.

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