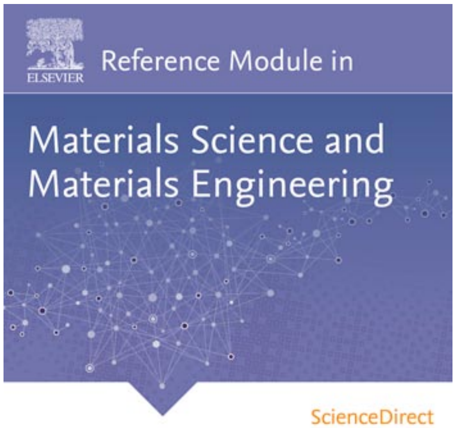

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Lumber: Laminated Veneer ☆

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1 Introduction

Laminated veneer lumber (LVL), also known as parallel-laminated veneer, is one of the most suitable products for the dispersion of natural defects of wood (knots, etc.) by glue lamination of veneer (Porteous and Kermani, 2007; Buchanan, 2007) LVL can be produced with higher yields, in a greater range of dimensions and shapes, and with less time and labor than glued laminated timber or plywood. LVL is composed of mostly parallel grain laminations of veneer bonded to obtain lumber-size thickness. LVL has been approved as an engineering material with reliable strength and stiffness (Zhong *et al.*, 2015).

Most LVL is produced in flat shapes. When thin veneers are used as laminas, the manufacture of molded LVL with a small radius of curvature is possible. Curved (molded) LVL is used for door or window fittings and for furniture frameworks. Even cylindrical LVL with hollow or reinforced cores has been produced (Sasaki *et al.*, 1996).

Development of LVL began with the production of high-strength wooden members in aircraft in the 1940s. In the following decades the machinability, natural appearance, and uniformity of mechanical properties of LVL were used to advantage in the production of curved furniture parts. Since the supply of high-quality saw logs has diminished, LVL has become more important because of its higher yield potential, adaptability to engineering end-use designs, and the introduction of automatic production methods. Since the beginning of the 1970s LVL has also been used for structural members (e.g., tension chords of trusses or I-beams and outer laminas of glued laminated beams) in place of lumber components because of its reliability in strength.

LVL is manufactured in a manner similar to plywood but contains mostly parallel laminas. Rotary-cut veneers are usually used. With the decrease in the diameter of available logs, more efficient lathes have been developed to get higher veneer yields. Rotary lathes with peripheral driving devices make it possible to peel logs down to very small (50 mm) core diameters.

Veneers are sometimes treated with preservatives, fire retardants, or other chemicals before drying. These chemicals can also be mixed with adhesive. Normally, veneers are dried to about 5% moisture content in conventional hot air circulating, jet, or press dryers. Thin veneers can be dried more economically than thick veneers; however, the production of LVL with thinner veneer requires more adhesive. The balance of these factors, as well as the improved properties of LVL achieved with thinner veneer, must be considered in the choice of veneer thickness.

Phenolic-type or other equivalent adhesives (e.g., melamine, isocyanates) are used in the production of structural LVL, while urea resin is generally used for furniture or nonstructural materials.

Butt joints of veneer ends are significant defects in LVL. The joints must be staggered and distributed as evenly as possible. When the number of laminations is high, butt joints are acceptable because the decrease in the mechanical properties becomes less. Scarf joints in veneer ends are also employed in some cases. Although LVL with scarf-jointed veneer has better strength and appearance, the process is more complex than for butt joints. To obtain high tensile strength in a simpler process, crushed lap joints have been used in commercial LVL (Micro-Lam), where high processing pressure is applied to crush overlapping veneer ends.

Since LVL production started as an extension or variation of plywood production, most LVL is hot pressed in multiopening presses, where LVL is limited in length. Modern plants for the production of structural LVL tend to employ a continuous veneer assembly and hot pressing, in which the joints are well distributed. This makes LVL production less labor intensive than the production of plywood or glued laminated timber. A tractor-tread press with electrical heating units is employed to produce high-tensile-strength LVL (Micro-Lam). Another type of tractor-tread press uses radio frequency heating in which electrodes are set at the surfaces of the treads. Steel belt type presses use residual heat from veneer drying or hot platens set behind the belts. With these continuous presses, high yield and highly efficient production of continuous LVL is feasible. In the case of molded LVL, layers of thin veneer are pressed between male and female molds with radio frequency heating devices.

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Cylindrical LVL is produced using a spiral winding method (**Figure 1**) (Yamauchi *et al.*, 1998). For instance, to manufacture an LVL cylinder with a 500 mm diameter, a continuous glued-veneer tape of 150 mm width (parallel to the fiber direction) and 2.5 mm thickness is wound spirally on a steel mandrel. A pressure of about 0.5 MPa is applied with an elastic belt. The steel mandrel, formed veneer cylinder, and pressure belt are then heated in an oven to cure the adhesive.

Figure 1 Cylindrical LVL manufacture using a prototype spiral winder.

2 Mechanical Properties

Figure 2 shows how the variations of strength are reduced in LVL compared to solid lumber from the same logs. The reliability in strength increases with increasing number of laminas. The relative improvement in strength is higher when the quality of the logs is lower. Similar relationships exist between the stiffness of LVL and solid lumber. The allowable design stress f_a can be estimated by the approximate form:

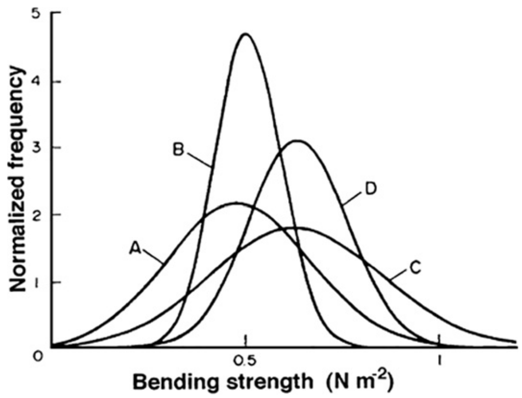

Figure 2 Comparison of bending strength between solid lumber and LVL processed from the same logs. A: solid sawn, 2″ × 4″, Siberian larch; B: 8-ply LVL, same log as A; C: solid sawn, 2″ × 4″, southern pine; D: 6-ply LVL, same log as C.

where f_m is the average strength, σ is the standard deviation, η is a coefficient depending on the shape of the strength distribution, and the factor 2.1 includes the effects of long-term loading, a safety factor, etc. In general, the 5% exclusion limit f_5 (the stress value below which the probability of failure occurring is 5%) is taken to be ($f_m - \eta\sigma$). If the distribution is Gaussian, η is 1.645. A number of experiments with LVL have shown that η should be taken as 2.0, considering safety factors in use (Koch, 1973; Bodig and Jayne, 1982).

As can be seen in **Figure 2**, the estimated allowable stress of LVL will be far greater than that of solid lumber. LVL manufactured commercially from 2.5–3.0 mm thick Douglas fir veneer (Micro-Lam) with 13 or more plies and crushed lap joints has been approved officially as a material having an allowable stress of 15.09 MNm^{-2} in tension and 19.21 MNm^{-2} in bending. The strength reduction due to butt joints in LVL decreases with increasing number of plies. The reduction is very small in 9-ply products and negligible for 12 or more plies. As derived from fracture mechanics theory, the tensile strength of LVL is inversely proportional to the square root of the thickness of the laminas. In addition, fracture mechanic gives the possibility to characterize situations with stress singularities which can lead to a failure including crack initiations and crack propagations (Franke and Quenneville, 2014). The distance between the butt joints in adjacent layers should be more than 16 times the lamina thickness to prevent strength reduction due to stress interaction (Laufenberg, 1983).

The tensile strength of products produced by end-jointing short LVL, in general, is more than 90% of the strength of unjointed LVL for scarf joints with a 1:9 slope, more than 70% for finger joints of 27.5 mm in length, and more than 60% for minifinger joints of 10 mm in length.

Low strength perpendicular to the long axis (i.e., cleavage and shear in the plane parallel to the fibers) is a drawback of LVL. This arises from lathe checks in veneers created during peeling. However, the average strength increases and the variation decreases with increasing number of plies, and thus the allowable stress perpendicular to the grain can be estimated to be the same value as for solid lumber.

Recently, Bal (2014) investigates into some physical and mechanical properties of LVL. The investigation test results indicated that density, impact bending, and shear strength increased. Conversely, tangential swelling, volumetric swelling, moisture content, and specific impact bending decreased. Increased dimensional stability of wood-based materials is a preferred property for many applications due to the increased service life. In addition, the increases in impact bending and shear strength, especially in the connection points and load-bearing points in structural applications.

3 Grading and Quality Control

One of the most promising characteristics of LVL is the capability of ensuring its structural performance by grading veneer according to quality and selecting the optimum combination or placement of the veneer. Visual grading of veneer which has been widely used in the plywood industry is not totally satisfactory for screening veneer used in stress-rated LVL. Mechanical methods of testing modulus of elasticity of veneer in tension are used in research, but the commercial application of this is not feasible. The stress-wave timing technique is one of the most promising nondestructive methods of estimating properties of each veneer piece before it is laminated into LVL in the industrial process (Jung, 1982).

4 Applications

The furniture and fittings industries prefer LVL because of its ease of processing, uniform properties, good adaptability to curved parts with small radius, stability, and better edge appearance. Arched door frames, staircases, chairs, beds, cabinets, counter tables, wardrobes, etc., are popular uses of this material.

The uniform mechanical properties of LVL, and especially its high allowable stress in tension compared to its weight, make this material useful for flanges of I-beams combined with plywood webs or steel pipe lattice webs. Such I-beams are widely used as joists in house construction. Open-web trusses combining LVL and steel pipe are used as roof trusses and second floor joists in large buildings such as factories and warehouses. These open-web trusses are also used for arched roofs of very large structures such as a 120 m span football stadium and exhibition halls. The uses are extending to stringers and decks of highway bridges, stringers of trailer cars, cross-ties, scaffold planks, and to other engineered members in wood construction (Kunesh, 1978). Cylindrical LVL can be used for columns in heavy wooden constructions and as arched frames with special functions such as ducting for ventilation, electrical wires, water pipes, etc. (Sasaki and Kawai, 1998).

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