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A review of the utilisation of hardwoods for LVL

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Abstract This review on the use of hardwoods for the production of LVL revealed that a large number of research studies have been carried out, particularly in North America and three Asian countries (Japan, Malaysia and China). However, the studies have been restricted to species of low to medium density, i.e. 290 to 693 kg/m^3. Two major potential uses of hardwood LVL have been investigated in these studies: domestic and industrial structures, and various furniture components. The production of structural LVL in North America and Asia was based predominantly on low density hardwoods. A study currently carried out in Europe aims at using medium density hardwoods for structural LVL. The LVL used for furniture components was produced from medium density hardwoods. No work has been undertaken outside Australia on the use of high density species for LVL. In Australia, studies undertaken on the production of LVL and hardwood plywood from eucalypts revealed that there were significant problems in gluing the dense raw material which often had a high level of extractives. Peeling low quality, small diameter eucalypt logs also created problems when the traditional plywood processing techniques were used.

Introduction

Laminated Veneer Lumber (LVL) has typically been manufactured from softwood species, but the need to use native forest resources more efficiently has stimulated research on hardwood reconstituted products. The development of eucalypt hardwood LVL would not only complement the existing range of softwood products but the superior strength properties of hardwood would allow for the reduction in dimension of engineered products and would be more acceptable in architectural applications.

This review covers the research on LVL used for structural timber products and furniture use. It was undertaken as background work for a forthcoming collaborative Australian project to investigate the potential use of low quality, small diameter eucalypt logs for the production of LVL.

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Hardwood LVL for structural use

North America

Most of the research work on hardwood LVL for structural use has been carried out in North America. At present there are only two major hardwood species considered: aspen and poplar. The density of these species ranges from 390 to 500 kg/m^3, which is very similar to that of North American softwoods. No trials have been undertaken on high density species similar to the Australian eucalyptus (O'Halloran, 1995).

Utilization of so called 'weed' hardwoods has received growing attention from North American wood processors over the last 20 years. In British Columbia, utilization of hardwoods, especially aspen (*Populus tremuloides*) and balsam poplar (*Populus balsmifera*), has become a crucial resource for the forest industries. This situation has arisen as a result of depletion of the more commonly utilized softwood species and the need to utilize the hardwood forests which can account for up to 30% of total inventory in some areas. Some trials have been done on other hardwood species such as red oak, red maple and birch.

According to Durand-Raute Industries Ltd there is presently only the Tempec Inc. plant in Ville Marie, Quebec, Canada producing aspen LVL which is known under the trade name SELECTEM®.

Annual production is about 19,000 m^3. LVL is manufactured from selected aspen veneers using the Durand-Raute manufacturing technology and has been tested in accordance with the latest ASTM recommendations for Structural Composite Lumber. SELECTEM® has been used for residential, commercial and industrial applications (e.g. header, girder and door heaer) as an alternate product to large sawn beams, steel beams and long-span trusses (Klemarewski, 1995).

The Trus Joist MacMillan Limited, one of the largest integrated timber companies in North America, has been producing structural engineered panels based on softwood for many years. The main products include Microllam™ Laminated Veneer Lumber (LVL), Parallam® Parallel Strand Lumber (PSL) and Timber-Strand® Laminated Strand Lumber (LSL). The company has been manufacturing Microllam™ LVL in limited quantities with yellow poplar for some time in two plants, and Parallam® PSL in one plant. In the past, the company manufactured limited quantities of Microllam™ LVL using other hardwoods, primarily oak.

The opening of two new Trus Joist plants in Buckhannon, West Virginia and in Hazard, Kentucky is imminent. The West Virginia plant will manufacture both Microllam™ LVL and Parallam® PSL using only yellow poplar which is a relatively low density hardwood. The Kentucky plant will be the second Timber Strand plant using aspen, another low density hardwood.

Handling and gluing yellow poplar is very similar to that for softwoods commonly used. The oak LVL made on a trial basis was not used in a normal structural role but mainly for furniture components. For this reason, the design properties for general structural use of the material have not been established. Small test runs of a few other (mostly low-density) hardwoods were conducted. No research has been undertaken on LVL made from high density hardwoods (Sharp, 1995).

As early as 1973, the Western Forest Products Laboratory (WFPL) in Canada carried out preliminary research work on hardwood LVL which indicated that an acceptable quality of veneer could be obtained from aspen and that such veneer could be utilized in the production of LVL.

In late 1978 a comprehensive cooperative program involving major timber companies in Canada was undertaken to evaluate a possible utilization of aspen and balsam poplar in LVL. The results were encouraging and generated keen interest among truss manufacturers and furniture manufacturers (Caroll, 1980; Wellwood et al., 1980).

Durand-Raute Industries Ltd (1988) carried out a study on aspen LVL. This indicated that LVL made from aspen tends to have higher bending strength but lower stiffness than LVL made from southern yellow pine. For this reason, further research was undertaken to investigate whether the stiffness of aspen LVL can be improved by densification and whether aspen LVL can be easily made from short aspen veneer with proper veneer end-joints. The main conclusion of this study was that the MOE of aspen LVL can be increased if proper densification is achieved and that semi-scarf joints are adequate for producing aspen LVL with improved MOE.

Forintek Canada Corporation in Vancouver, British Columbia, conducted laboratory studies and plant trials on the production of LVL from aspen to determine the feasibility of producing LVL from short aspen veneers with lap joints instead of scarf joints and to demonstrate the potential of using a combination of aspen and birch in LVL production.

Full-scale testing was undertaken on the LVL according to ASTM D 143-83. The results of tests demonstrated that aspen LVL had bending properties comparable to softwood LVL. Even LVL made from a very low quality aspen veneer had respectable strength properies. The study demonstrated that, if required, the mechanical properties of aspen LVL can be improved by incorporating yellow birch veneer (Hsu, 1988).

Steiner et al. (1982), also at Forintek, examined the concept of using preheated veneers and phenol-formaldehyde (PF) adhesives for bonding LVL panels made from commercially peeled trembling aspen. The effects of veneer preheating temperature and press and assembly time was evaluated. The project demonstrated that the preheating of veneers was a promising method for substantially reducing the press time for thick LVL laminates made with a standard PF adhesive.

A number of studies have been undertaken to improve the properties of LVL made from poplar and make it more competitive for structural uses. Mechanical properties can be improved by increasing density, either by compression during processing or by impregnating some or all of the veneers with subsequently polymerized material. It has been proved that the densification by compression results in undesirable effects, such as swelling in thickness when the material is moistened. Adding a polymer has several advantages: reduction in moisture-induced thickness swelling, better weathering properties, and the possibility of localizing the denser material in regions of high stress.

The effects of resin impregnation and process parameters on some properties of poplar LVL were researched at the University of New Brunswick, Canada (Zhang et al., 1994). Two types of LVL boards were made: one type had all veneers impregnated with a water soluble, phenol-formaldehyde resin, and the other one had only the outer veneers impregnated. Improved mechanical properties (MOE, MOR and horizontal shear) and dimensional stability were obtained when all veneers or only surface veneers were impregnated with a PF resin.

The School of Forest Resources, Pennsylvania State University, and Trus Joist Corporation, Valdosta, Georgia, assessed LVL from mixed northeastern hardwoods in the US (Janowiak et al., 1993). Strength and stiffness were evaluated along with nail performance for varying LVL construction patterns. Construction patterns included homogeneous red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*) and Northern red oak (*Quercus rubra*) LVL as well as three different species combinations. The species combinations consisted of core to face layup patterns using yellow poplar core with both red maple and red oak face plies, and red maple core with red oak outer plies. An additional construction parameter selected was veneer thickness for the fabrication of ten different hardwood LVL group combinations. Mechanical property evaluation included bending strength, stiffness, compression strength, shear strength, and nail fastener performance. Test results were compared with a commercial SP LVL. On average, no hardwood LVL combination was observed with equivalent stiffness to that of the commercial southern yellow pine LVL product. Other mechanical properties were superior to SP LVL.

Pennsylvania State University investigated the performance enhancement of experimental hardwood LVL materials through the application of ultrasonic sorting of veneer quality (Kimmel et al., 1995). LVL was manufactured from red maple and yellow-poplar. Ply quality was subsequently evaluated using an automated veneer testing machine to measure ultrasonic propagation time (UPT), which served as a basis for veneer segregation into plies of high and low quality for layup fabrication of two different LVL materials. The study indicated that some improvements are possible for either red maple or yellow-poplar LVL by using UPT grading technology.

Japan, Malaysia and China

Several fast-growing tropical species continue to be planted in Asian countries. The mechanical properties of this young timber are generally relatively poor and variable when it is used as solid wood lumber. The Wood Research Institute, Kyoto University, Japan in collaboration with the University Pertanian, Serdang, Malaysia sought to improve the properties of tropical hardwood thinnings by processing the logs into LVL (Sasaki et al., 1993). An application of LVL material as flanges of a composite 'I' beam with a particleboard web was evaluated for nine-year old thinnings taken from a plantation in Sabah, Malaysia. The species used were *Acacia mangium*, *Gmelina arborea*, *Albizia falcata* and *Eucalyptus deglupta.* The densities of these species are presented in Table 1.

The average diameter of the peeler logs varied between 185 mm and 228 mm. Nine-ply LVL was constructed using staggered scarf joints and urea-melamine-formaldehyde adhesive. Mechanical properties of LVL and composite beams were evaluated. The test results showed that the mechanical properties of LVL were more consistent than the solid wood boards made from the same species. The application of LVL to the flanges of a composite beam provided consistently high stiffness. However, the overall strength level was not high enough and further technological development was considered necessary.

The utilization of Sabah plantation thinnings of kamerere (*Eucalyptus deglupta*) as LVL beam flanges was further investigated by the above research team (Qian et al., 1992). The adhesion conditions between webs and flanges of composite beams bonded with isocyanate resin (IC) and phenol resorcinol resin (PRF) were investigated. The IC adhesive produced a better bond, and a lower amount of glue spread was required to provide adequate bonding.

The use of forest plantation thinnings and agricultural residues in LVL was evaluated by the University Pertanian, Malaysia (Razali et al., 1994). Ten-year old *Acacia mangium* thinnings and old-growth *Hevea brasiliensis* (rubberwood) were

Table 1. Hardwood species used for experimental production of LVL

Species botanical name	Species common name	Country carrying out research	Air-dry density (kg/m³)	Age of timber	Potential market for LVL
Albizzia falcataria	Batai	Malaysia & Japan	290	9 yo plantation	Structural
Populus spp.	Poplar	Europe	420	not specified	Structural
Populus balsmifera	Balsam poplar	Canada & US	430	oldgrowth	Structural
Populus deltoides	Eastern cottonwood	China	430	plantation	Not specified
Populus tremuloides∗	Quaking aspen	Canada & US	450	oldgrowth	Structural
Liriodendron tulipifera∗	Yellow poplar, tulipwood	US	405–450	oldgrowth	Structural, Furniture
Gmelina arborea	White beach	Malaysia & Japan	490	9 years, plantation	Structural
Eucalyptus deglupta	Kamarere	Malaysia & Japan	490	9 yo plantation	Structural
Acer rubrum	Red maple	US	520	oldgrowth	Structural
Liquidambar styraciflua	Sweetgum	US	530	oldgrowth	Furniture
Acacia mangium	Mangium	Malaysia & Japan	540	9 & 10 yo logs from plantation	Structural
Alnus incana	Alder	Europe	576	not specified	Structural
Betula spp.	Common birch	Japan	575–640	not specified	Furniture
Quercus rubra	Red oak	US	643	oldgrowth	Structural, Furniture
Betula verrucosa	Birch	Europe	649	not specified	Structural
Hevea brasiliensis	Rubberwood	Malaysia	693	25–30 yo	Structural
Quercus cerris	Turkey oak	Europe	720	not specified	Structural
Fagus silvatica	Beech	Europe	727	not specified	Structural
Eucalyptus obliqua and *Eucalyptus delegatensis*	"Ash" eucalypts	Tasmania	820	regrowth	Structural

∗ Also produced commercially

peeled to 3.6 mm thick veneers and processed into 15-ply LVL in a conventional plywood mill. The average log diameters were 240 and 290 mm for mangium and rubberwood respectively. Three types of resin adhesives, viz. melamine urea formaldehyde (MUF), phenol formaldehyde (PF) and urea formaldehyde (UF), were used.

The effects of two different veneer configurations (loose to loose side and loose to tight side) on the physical and mechanical properties of the LVL were also investigated. Using a 4-foot Meinan lathe, green veneer recoveries of 55 and 64% were recorded for mangium and rubberwood, respectively. Rubberwood but not *Acacia mangium*, demonstrated excellent compatibility with UF resin, less compatibility with MUF and least with PF. Neither configuration had significant effects on the dimensional and mechanical properties of the LVL.

Evaluation of LVL based on the Japanese Agricultural Standard for Structural LVL (1993) showed that, besides having negligible delamination and fulfilling the shear requirements for various LVL grades, all the LVL fabricated met the minimum MOE requirements for the Special Grade Structural LVL with exceedingly high MOR. The laminating process resulted in some 30% reduction in MOR, but a pronounced improvement in MOE by up to 86%, compared to clear solid wood, was achieved. Satisfactory veneer recoveries were obtained using peeling equipment designed for small-diameter logs.

Research on the technology of LVL of fast-growing poplar was carried out at Nanjing Forestry University, China by Hua Yukun et al., 1994. The LVL was made from 3.5 mm thick, fast-growing Italian poplar (*Populus deltoides*), also known as Eastern cottonwood. The purpose of the project was to study the drying process of veneers, the pressing techniques for the production of LVL and the effect of veneer joints on the bending strength and stiffness of LVL. The results indicated that the hot plate drying could be used for thick veneer of Italian poplar. There was no significant effect of the pressing technology (step by step or high-frequency) on the properties of LVL. Bending and stiffness of LVL were higher for scarf than butt joints.

Europe

A collaborative research project called ELVE (European Laminated Veneer Engineering) is currently being carried out in Europe to assess the viability of utilising eastern and central European hardwoods for the manufacture of LVL. The study covers medium to low quality hardwoods of relatively small dimensions such as poplar (*Populus* spp.) (density 420 kg/m^3), Turkey oak (*Quercus cerris*) (720 kg/m^3), alder (*Alnus incana*) (576 kg/m^3), birch (*Betula verrucosa*) (649 kg/m^3) and beech (*Fagus silvatica*) (727 kg/m^3). There is no detailed information available on the project, due to confidentiality agreements between collaborative partners. Britain's Building Research Establishment (BRE), in association with TRADA Technology and their partners in Denmark and France, investigates the use of poplar for LVL. So far, French poplar has been used successfully for commercial scale manufacture using facilities at a French plywood mill and a Finnish LVL factory (Spillard, 1996).

Australia

Various studies undertaken on the production of hardwood plywood from Australian eucalypts revealed that there are significant problems in gluing dense species (above 700 kg/m^3 air dry density) (Yazaki et al., 1993). There are a number of high density eucalypts which, when glued with phenol-formaldehyde (PF) or resorcinol-formaldehyde (RF) adhesives, give poor bond results, particularly after 72 hours immersion in boiling water. The bonding difficulties are caused by extractives present at the gluing surface of wood. A few adhesive formulations have been developed and patented which have enabled successful bonding of structural veneers made from dense eucalypts (Collins, 1985; Collins and Yazaki, 1994, 1996).

Peeling low quality, small diameter eucalypt logs presents special problems when traditional peeling equipment and techniques are used (McCombe and Ozarska, 1996a). In recent years, significant development in hardwood veneer manufacturing technology appears to have been made by the Meinan Machinery Works in Obu, Japan (Meinan Catalogue). The company developed the 'Arist-lathe' which can peel logs to the minimum core diameter of 60 mm. The lathe uses a fixed nosebar rather than a powered roller nosebar as on modern American lathes. The quality of veneer peeled on the Meinan lathe with regard to surface smoothness was assessed by McCombe and Ozarska (1996b) and found to be better than achievable with conventional lathes. The key to success in maintaining smooth surfaces and tight veneer when peeling difficult species is believed to lie in applying relatively high nosebar pressure. The Meinan lathe succeeds with eucalypts in this regard, whereas with other lathes only a few percent nosebar compression can be applied.

A research study on the production of LVL from Tasmanian regrowth eucalypts of an average diameter of 45 cm was carried out by McCombe (1992), and McCombe and Collins (1993). Commercially-produced boards of 820 kg/m^3 density were made from mixed veneers of *Eucalyptus obliqua* and *E. delegatensis* from Tasmania.

The recovery of 44% obtained for the LVL production was less than the 50% obtainable for radiata pine LVL. End-splits in veneer, as well as high volumetric shrinkage in drying were significant loss factors. Output of spliced sheets was also notably high, but an improvement in this regard, as well as in recovery, would be achieved through the use of the traditional practice for growth stress relief in veneer logs.

Permissible working stresses in bending, tension and compression parallel to the grain were determined for the LVL product and found to be more than twice that for the dry sawn product of the same species. Significantly, shear strength was not outstanding, presumably because of deep peeler checks present in the veneer. The coefficient of variation for the test result populations was 6.5% or less, compared with 20% or higher for the sawn product. The strength, stiffness and permissible working stresses of LVL were evaluated according to Australian standard (AS/NZS 4063). Modulus of elasticity for design purposes was 21,850 MPa compared with 14,000 MPa for the dry sawn product. The corresponding values for permissible tension parallel to the grain were 34.4 MPa and 14.0 MPa respectively.

Hardwood LVL for furniture applications

North America

A significant number of research studies have emphasised the practicality of substitution of solid wood with hardwood LVL for furniture manufacture. LVL has potential value to the furniture industry for both aesthetic and economic reasons and can be produced to meet specified technical and strength requirements. The use of LVL in furniture is not new as it has been used for curved laminated components for years. More recently, it has also been used for curved, unexposed structural features such as side rails, and also as flat areas for furniture frames.

A cooperative research project has been continuing for many years between Purdue University, Indiana, and the U.S. Forest Products Laboratory, Madison, Wisconsin, to develop a systematic procedure for designing and specifying LVL to be used in the production of dimension parts for furniture. A series of studies have been conducted on red oak (*Quercus rubra*), sweetgum (*Liquidambar styraciflua*) and yellow-poplar (*Liriodendron tulipifera*). The average densities of these species were 643 kg/m^3, 530 kg/m^3 and 405 kg/m^3, respectively. The first study, led by Prof. C.A. Eckelman, considered the feasibility of producing and utilising red oak LVL (known as Press-Lam) as framing material for upholstered furniture. Feasibility was assessed from the standpoints of engineering performance, marketability and the rate of return to the LVL manufacturer (Hoover et al., 1978, 1979, 1981).

Upholstered furniture frames are generally produced from mixed hardwood lumber. Although oak is preferred by many manufacturers because of its greater strength, lower strength species such as yellow poplar are also commonly used. There is a growing problem obtaining adequate quantities of long and /or wide parts as furniture rails from the lower grades of timber. If timber is used for the upholstered furniture frame, the appearance is not a factor since the frame is covered by upholstery.

LVL was manufactured by the U.S. Forest Products Laboratory from Grade 3 tie and timber quality logs. The boards were made from four plies of peeled veneer (6.25 mm thick) glued with a phenol-resorcinal adhesive. A series of tests were made to determine machining characteristics, mechanical properties and fastener holding strength, as well as joint strength and the performance of full-size frames made from the LVL material. Red oak LVL appeared to have adequate bending strength, stiffness and fastener holding strength to substitute on a one-to-one basis for solid lumber in upholstered furniture frames. Lathe checks in red oak veneer, however, reduced the naturally superior properties of oak to those of some of the weaker species such as yellow poplar. In particular, the shear strength of oak LVL was reduced and consequently caused splitting in some parts, in particular the ends of dowelled stretchers.

Potential uses of LVL lumber in furniture, from both a structural and an economical point of view, were investigated by Eckelman (1993) and Hoover et al. (1987). A survey of the potential of LVL in furniture indicated that it could be used in place of, or as well as, solid wood in most furniture constructions. LVL can compete on a one-on-one basis with some of the materials currently used in furniture construction, such as upholstered furniture stock. Furthermore, in many applications it could be also used instead of panel-type materials (Eckelman, 1993).

Hoover et al. (1987) related to the design and specification of hardwood LVL for various furniture applications and determined material design factors for LVL. The species evaluated were red oak, sweetgum and yellow-poplar. The following design factors were investigated: the effect of species, the number of plies per unit thickness, the size and location of holes and the degree of location of cross grain in comparison with controls containing no defects. Bending and shear properties of all specimens were determined. A regression model was developed that predicted the effect of size, number, and location of holes on the maximum load. The material design factor could be reduced to determining the extent to which defects could be incorporated in panels to be cut into dimension parts of a specified width.

Japan

A research study on the utilisation of hardwood LVL as furniture-frame stock was carried out by the Hokkaido Industrial Research Institute, Japan (Watanuki et al., 1983). LVL was made of oak (*Quercus* spp.) and birch (*Betula* spp.). Mechanical properties (bending, shear, and cleavage) and performance characteristics (the dowel withdrawal, the dowel bending strength) were evaluated. It was concluded that the mechanical properties of LVL, particularly shear and cleavage strengths, were lower than those of solid wood because of peeler checks.

Summary and conclusions

1. This review indicates that a large number of research studies on hardwood LVL have been carried out overseas, particularly in North America and Japan, Malaysia and China. However, the studies have involved low and medium density species, i.e. from 290 to 693 kg/m^3.

2. Two major potential uses of hardwood LVL have been investigated in the overseas studies: domestic and industrial structures and various furniture components. Experimental hardwood LVL in the American studies was produced either using laboratory equipment or full scale manufacturing facilities (hardwood plywood or softwood LVL plants). No problems with peeling, drying or gluing have been noted.

3. Most research in Asian countries dealt with utilising young plantation timber of small diameter (180–290 mm). LVL was produced using either hardwood plywood processing plants or the Japanese Meinan 'Aristlathe' designed especially for processing small diameter, poor quality logs. The latter studies demonstrated that small diameter logs could be converted into veneers with satisfactory recovery using the Meinan lathe. Also, in the Australian studies, much better 'peel' quality was achieved for eucalypts using the Meinan lathe.

4. Various studies undertaken on the production of hardwood plywood from Australian eucalypts revealed that there were significant problems in gluing the dense eucalypts. Peeling low quality, small diameter eucalypt logs also created problems when traditional peeling technology was used.

5. As an engineering material the Australian eucalypt LVL made from better quality Australian eucalypt sawlogs would provide about twice the permissible working stresses in bending, and in tension and compression parallel to the grain, as that for graded kiln-dried solid wood products from the same resource. The permissible working stresses in shear for these studies were similar.

6. In summarising 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 flat panel surfaces; and economics.

7. The Australian eucalypt resource to be assessed under this project is much denser (680–900 kg/m^3) and generally of lower grade than that examined in overseas work; therefore, specialised technology, especially in veneer manufacture and gluing, will probably be required in the current work.

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