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EUCALYPTUS NITENS LAMINATED VENEER LUMBER STRUCTURAL PROPERTIES

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ABSTRACT

Veneer peeled from *Eucalyptus nitens* (Deane et Maiden) Maiden unpruned second logs was segregated into three stiffness classes using an acoustic test. Laminated veneer lumber (LVL) was manufactured using sheets from each stiffness class tested. Strength tests showed that the sheets were successfully segregated by the acoustic stiffness test. The *E. nitens* LVL had strength and stiffness properties which were higher than those of LVL made from New Zealand-grown *Pinus radiata* D.Don veneer.

Keywords: laminated veneer lumber; structural properties; *Eucalyptus nitens*.

INTRODUCTION

Laminated veneer lumber has in recent years become an important wood product for building construction because it has the advantages of uniform engineering properties and dimensional flexibility. The usual manufacturing process is to peel veneer on a rotary lathe to a thickness of 3.2 mm, then dry it, and glue 13 sheets of veneer to make LVL billets. Normally the grain of each veneer layer runs in the long direction of the billet to give maximum strength when edge-loaded as a beam. A plant with a continuous press can make LVL of any length, limited only by transport requirements. Finally, the LVL billets are ripped to the width required. The product has uniform strength properties because natural defects such as knots, slope of grain, and splits have been dispersed throughout the material or have been removed altogether during veneer assembly. In addition, stiffness of individual sheets can be tested by ultrasound and assembled to provide the desired strength properties in the finished material. Laminated veneer lumber has typically been manufactured from softwood species, but in Australia the need to use native forest resources more efficiently has stimulated research on using eucalypts (Ozarska 1999). Various problems have been encountered, for example:

- The veneer produced by high-density eucalypts was difficult to glue because of high levels of extractives;
- In one study of *Eucalyptus obliqua* L'Her. and *E. delegatensis* R.T.Baker growth stress led to end-splits and breakage of sheets of veneer;

- Bending, tension, and compression parallel to the grain were more than twice those for dry sawn timber of the same species.

A resource of *E. nitens*, a low-density species, has been established in New Zealand for local kraft pulp (Bay of Plenty/Taupo region) and export chip (Southland). The species was selected because control of a defoliating beetle *Paropsis charybdis* Stål (Forest Research Institute 1990) led to improved health. There has been no assessment of the suitability of material from young stands for the production of LVL. A peeling and gluing study using New South Wales eucalypts (Wade 1991) included trees from a 36-year-old *E. nitens* natural regrowth stand. Star checking was a problem although the logs were preheated to 60°C. Recovery was low because cores broke up, but it was suggested larger logs might give better results and that the improved glues available subsequently could give better performance.

A stand of 15-year-old *E. nitens* in a Forest Research trial at Golden Downs Forest, Nelson, was used in a comprehensive study of sawn timber and veneer quality (McKenzie, Turner, Shelbourne 2003) and the interrelation of a range of wood properties (McKenzie, Shelbourne, Kimberley, Britton 2003). The second logs were unpruned and would have produced inferior sawn timber but were considered suitable for a trial of LVL manufacture. Details of the stand, logs, and veneer manufacture and testing have been provided by McKenzie, Turner, Shelbourne (2003). Forty trees in the stand were sampled for outerwood density at breast height using 5-mm increment cores and classified as low, medium, or high density; five trees were selected from each density group, giving a total of 15 trees. The peeler logs used to produce veneer for this study were cut from between 7 and 13 m tree height. One log could not be peeled because of severe end-splitting (McKenzie, Turner, Shelbourne 2003, Fig.3) but recovery of full- and part-sheets of veneer from the other 14 logs was 59%. The veneer was assessed for structural plywood (AS/NZS 2269:1994), and sound velocity was measured with a Pundit™, an acoustic device. Density (kg/m^3) × sound velocity^2 (m/s) was used to measure modulus of elasticity (MoE). Most of the veneer sheets (92.5%) failed to achieve the minimum plywood grade because of knots. The analysis of the relationship of modulus of elasticity and other wood properties showed that tree mean modulus of elasticity of veneer sheets, measured sonically with Pundit™, correlated moderately well with modulus of elasticity of clearwood (0.77) and similarly with density, microfibril angle (MFA), and density/microfibril angle ratio. Evaluating or selecting trees for stiffness of veneeer would be feasible with breast-height pith-to-bark cores (McKenzie, Shelbourne, Kimberley, Britton 2003).

METHOD

Manufacture of Laminated Veneer Lumber

Some veneer sheets had stain or decay and there was variation in thickness both between and within sheets (McKenzie, Turner, Shelbourne 2003). For the study, only full-sized veneer sheets were selected which were at least 2.0 mm thick, without any stain, decay, or mould; they were divided into low (< 15 GPa), medium (15–17 GPa), and high (> 17 GPa) stiffness classes based on the Pundit™ assessment. The sheets were redried at the Kinleith plymill to an average moisture content of 8% (range 5% to 10% m.c.). Thirteen veneer sheets of the same stiffness class were laid up, with the top veneer turned over to enable the "tight face" (i.e., the outer side of the sheet as it is peeled) to face to the outside of the billet. Phenolic glue was applied with a curtain spreader. The billets had an open assembly time ranging from 0 to 22 minutes. Pressing temperature was 141°C and the press pressure was 210 psi (1.45 MPa), cold pressing for at least 8 minutes and hot pressing for 20 minutes. Pressure was released in stages hydraulically in about 90 seconds. Excess moisture expansion did not cause any audible explosions, indicating that there were no glue-line failures. Seventeen billets were made up — six of the medium and the low stiffness classes, five of the high stiffness one.

Laminated Veneer Lumber Testing

The *E. nitens* LVL testing procedure was as follows:

- Each LVL billet was ripped at Forest Research to produce twelve 90 × 2400-mm studs.
- All the studs were measured for plank stiffness (MoE_P) (Fig. 1).
- From each LVL billet, alternate studs were tested in bending as a joist (i.e., five per sheet) for bending stiffness (MoE_J) and bending strength (MoR_J) in accordance with AS/NZS 4063:1992 (Fig. 1).

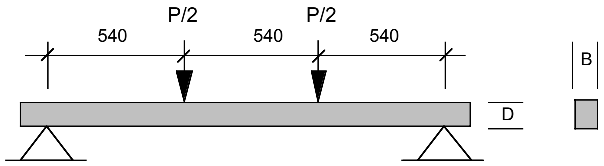

FIG. 1–Bending test configuration

- Other alternate samples (i.e., five per sheet) were tested in tension for tensile strength in accordance with AS/NZS 4063:1992 (Fig. 2). Note the specimen length was shorter than that specified in AS/NZS4063 because of the size of the original billet.

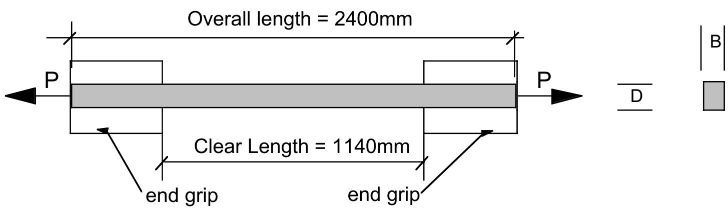

FIG. 2–Tension test configuration

- From the two remaining 90 × 2400-mm studs, two 960-mm-long compression samples were cut. The other compression samples were cut from the undamaged ends of tension studs. Each compression sample was tested for compressive strength in accordance with AS/NZS4063:1993 (Fig. 3).

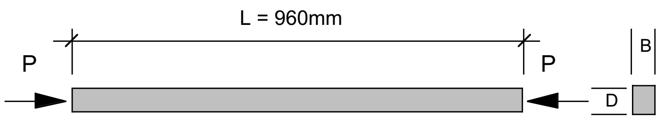

FIG. 3–Compression test configuration

- From the bending samples only, a density block was cut as close to the failure line as possible, for determination of nominal/test density and moisture content. The moisture content was measured using the oven-drying method, with nominal density calculated from the oven-dry weight divided by the volume at test.

A Grade 1 Baldwin Universal test machine was used for the bending tests. The bending specimens were tested on edge under monotonic and third point loading (Fig. 1). The slope of the linear section of the load/deflection data at midspan *vs* load was recorded, until the maximum load was reached; failure usually occurred within 30 to 300 seconds from commencement of loading.

For the tension tests, only maximum load was recorded under monotonic loading in the tension tester, with failure usually occurring within a period of 30 to 60 seconds from commencement of loading.

The Baldwin Universal test machine was also used for the compression tests. Load/deflection data and maximum load were recorded under monotonic loading, and failure usually occurred within a period of 30 to 300 seconds from commencement of loading.

RESULTS

Testing and derived characteristic strength properties (Appendix 1) are summarised in Table 1 for the combined sample (All LVL) and the three stiffness groups (high, medium, and low). The characteristic properties can be compared with the grade characteristic values in Table 2 (NZS 3603:1993; AS1720-1989).

The following characteristics were observed.

- Overall the LVL has high stiffness and extremely high strength.
- When assessing the properties of LVL using the formulae in AS/NZS4063 it is not uncommon to find the characteristic strengths are higher than the average strengths. This is because of the very low coefficient of variation of LVL, which has a significant effect in the formula. Several LVL manufacturers have raised questions over the suitability of these formulae for LVL. If *E. nitens* LVL were to be commercially produced, the published strength properties would not be based on the characteristic values in Table 1 but would be significantly lower.
- On the basis of MGP grade, the “All LVL” achieved MGP 12 limited by stiffness. The strengths exceeded the grade values by a factor of 2.2 (approx). The high-stiffness group achieved MGP 15, again limited by stiffness.
- On an “F” grade basis, the “All LVL” achieved F17 as limited by stiffness. The strengths exceeded the grade values by a factor of 1.4 (approx). The high-stiffness group achieved F22, again limited by stiffness.
- One benefit of LVL is seen here with the *E. nitens* LVL having a low coefficient of variation. For instance, for stiffness it is approx. 10%, which compares with solid wood at 20–30%.
- The sort into high-, medium-, and low-stiffness groups has been very effective, as seen by the distinct differences in structural performance between groups.

TABLE 1–Statistical summary of the structural test results

	All LVL	Percentage of total LVL volume		
		Low group 35	Medium group 35	High group 30
Bending Stiffness tests as a joist				
Characteristic stiffness (GPa)	14.2	12.7	14.0	16.6
Average (GPa)	14.3	11.9	14.7	16.6
Standard deviation (GPa)	2.3	1.0	1.6	0.6
Coefficient of variation (%)	16	8	11	4
5th percentile (GPa)	11.0	10.4	13.0	15.7
Minimum (GPa)	10.2	10.2	12.8	15.7
Bending Strength tests as a joist				
Characteristic strength (MPa)	67.3	61.6	62.3	103.4
Average (Mpa)	82.2	69.2	84.4	96.3
Standard deviation (MPa)	14.5	7.4	13.3	5.9
Coefficient of variation (%)	18	11	16	6
5th percentile (MPa)	60.0	57.4	70.2	85.3
Minimum (MPa)	54.3	54.3	55.3	81.8
Tension Strength tests				
Characteristic strength (MPa)	40.6	40.6	39.2	66.0
Average (MPa)	58.2	44.9	58.8	73.5
Standard deviation (MPa)	15.9	5.3	15.9	9.2
Coefficient of variation (%)	27	12	27	12
5th percentile (MPa)	39.0	35.3	39.9	58.2
Minimum (MPa)	34.3	34.3	39.4	56.5
Compression Strength tests				
Characteristic strength (MPa)	54.3	52.6	54.3	60.9
Average (MPa)	52.4	48.8	52.4	56.8
Standard deviation (MPa)	4.9	2.9	4.6	3.5
Coefficient of variation (%)	9	6	9	6
5th percentile (MPa)	45.0	42.9	45.5	49.9
Minimum (MPa)	41.0	41.0	42.3	48.5
Assigned MGP grade	MGP 12	MGP 12	MGP 12	MGP 15
Assigned "F" grade	F17	F14	F17	F22

- The high stiffness of this LVL suggests this product could be used in specific design situations where stiffness is critical. Using this material to replace No.1 Framing (MoE = 8 GPa) would be wasteful.
- The high stiffness of the *E. nitens* veneers suggests that if they were used in combination with lower stiffness *P. radiata* veneers a net gain in stiffness could be realised.

The data in Table 1 were converted into kilograms and centimetres for the units of the Japanese Agricultural Standard (JAS). The assigned JAS LVL grades in Table 3 have been derived from the JAS structural classifications (McKenzie, Turner, Shelbourne 2003) which are presented in Table 4. For assigning a JAS grade:

(1) The average modulus of elasticity must be equal to or above the specified value;

TABLE 2–Characteristic grade stresses for 45-mm thickness ranked in order of bending stiffness (ASTM1720-1989; NZS 3603:1993)

Grade	Bending stiffness (GPa)	Bending strength (MPa)	Tension strength (MPa)	Compression strength (MPa)	Shear strength (MPa)
MGP 6*	6.0	10.0	4.0	19.0	2.5
F4	6.1	13.0	6.5	9.7	1.5
No. 2 Framing†	6.1	13.0	7.7	9.7	1.5
F5	6.9	16.2	8.2	12.1	1.8
F7	7.9	20.4	10.3	15.3	2.1
MGP 8*	8.0	14.0	6.3	20.0	4.0
No. 1 Framing	8.0	17.7	10.6	20.9	3.8
F8	9.1	25.4	13.0	19.5	2.5
MGP 10	10.0	19.0	8.9	24.0	5.0
Engineering	10.5	27.7	16.5	25.7	3.8
F11	10.5	32.5	16.6	24.8	3.1
F14	12.0	41.3	21.1	30.1	3.7
MGP 12	12.7	28.0	15.0	29.0	6.5
CHH hySPAN LVL‡	13.2	42.0	27.0	34.0	4.5
F17	14.0	50.0	26.0	40.0	4.3
NITENS LVL (All)	**14.2**	**67.3**	**40.6**	**54.3**	**Not tested**
MGP 15	15.2	41.0	23.0	35.0	9.1
F22	16.0	65.0	35.0	50.0	5.0

* Proposed new New Zealand MGP grades
† Assumed equal to F4 as no grade stresses exist for No. 2 Framing.
‡ As presented in the Carter Holt Harvey hySPAN literature (CHH 1988)

TABLE 3–Structural test results converted to JAS grades for "Structural Laminated Veneer Lumber"

	All LVL	Percentage of total LVL volume		
		Low group 35	Medium group 35	High group 30
Bending stiffness tests				
Average (1000 kgf*/cm^2)	146	121	150	169
Minimum (1000 kgf/cm^2)	104	104	131	160
Bending strength tests				
Average (kgf/cm^2)	838	706	861	982
Minimum (kgf/cm^2)	554	554	564	834
Tension strength tests				
Average (kgf/cm^2)	594	458	600	750
Minimum (kgf/cm^2)	350	350	402	576
Compression strength tests				
Average (kgf/cm^2)	534	498	534	579
Minimum (kgf/cm^2)	418	418	431	495
Assigned JAS Grade	120E-450	120E-450	140E-525	160E-600

* kgf = kilograms force

(2) The minimum modulus of elasticity of any sample must be equal to or above the specified value;

(3) The minimum bending strength of any sample must be equal to or above the specified value.

The JAS grades (SIS-24 1993) assigned according to this procedure are noted at the bottom of Table 3.

The following points are noted (Tables 3 and 4):

- The "All LVL" sample achieved the JAS grade of 120E-450, i.e., an average Young's modulus of 120 (1000kgf/cm^2) and bending strength of 450 kgf/cm^2.
- The high-stiffness group rated a JAS of 160E-600, i.e., an average Young's modulus of 160 (1000kgf/cm^2) and bending strength of 600 kgf/cm^2.

Laminated veneer lumber made from New Zealand-grown *P. radiata* commonly achieves stiffness classifications of 80E and 100E.

TABLE 4–JAS structural LVL classifications (SIS-24 1993)

Classification of Young's modulus of bending	Young's modulus of bending (1000 kgf/cm^2)		Bending strength (kgf/cm^2)		
	Average	Minimum	Grade-specials	Grade-1	Grade-2
180E	180	155	675	580	485
160E	160	140	600	515	430
140E	140	120	525	450	375
120E	120	102	450	385	320
100E	100	85	375	320	270
80E	80	70	300	255	215

Cumulative Frequency Comparisons

Nominal density, the density calculated from the oven-dry weight (Nominal) and the volume at test (density at test), is shown in Fig. 4. The stiffness of a structural member, say a beam, is expressed as the load required to deflect the member a given amount. So that beams of different sizes can be compared with each other on a common basis, the stiffness of the wood is quantified as its modulus of elasticity (Fig. 5), MoE or E value for short. This is usually measured in Gigapascals (GPa). Bending stress in the section calculated at the point of maximum load is the modulus of rupture (MoR) (Fig. 6). The tensile section calculated at the point of maximum load is the tensile stress (Fig. 7). The compression stress section calculated at the point of maximum load is compressive stress (Fig. 8).

Where possible the following additional data have been included in Fig. 4 to Fig. 8 for comparative purposes only.

- Data from LVL made from *P. radiata* grown in the South Island of New Zealand (unpubl. data).
- Data from LVL made from *P. radiata* grown in Kaingaroa Forest, North Island, New Zealand.

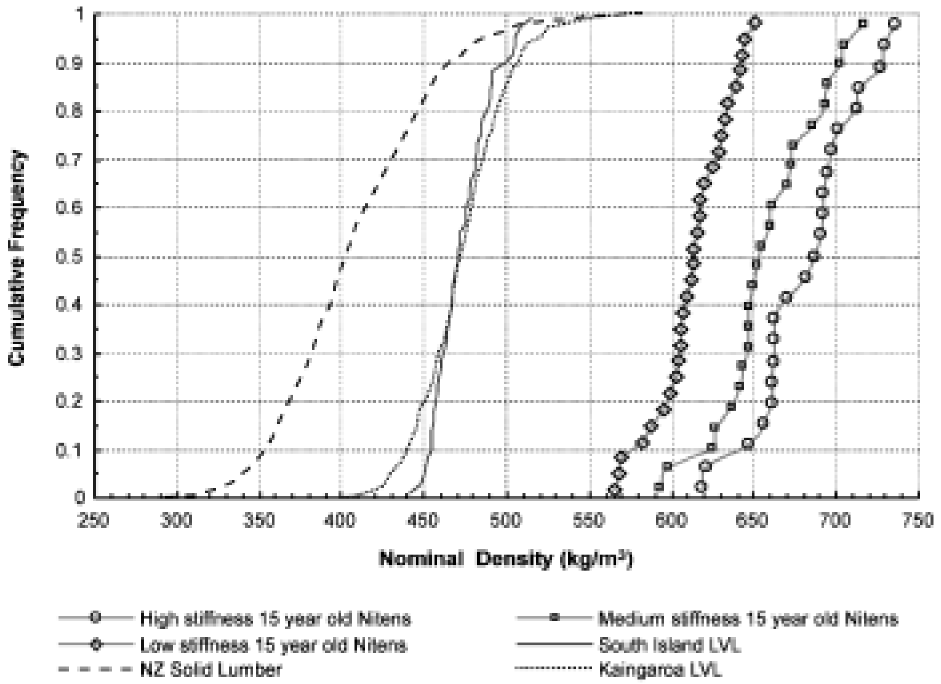

FIG. 4–Nominal density comparison

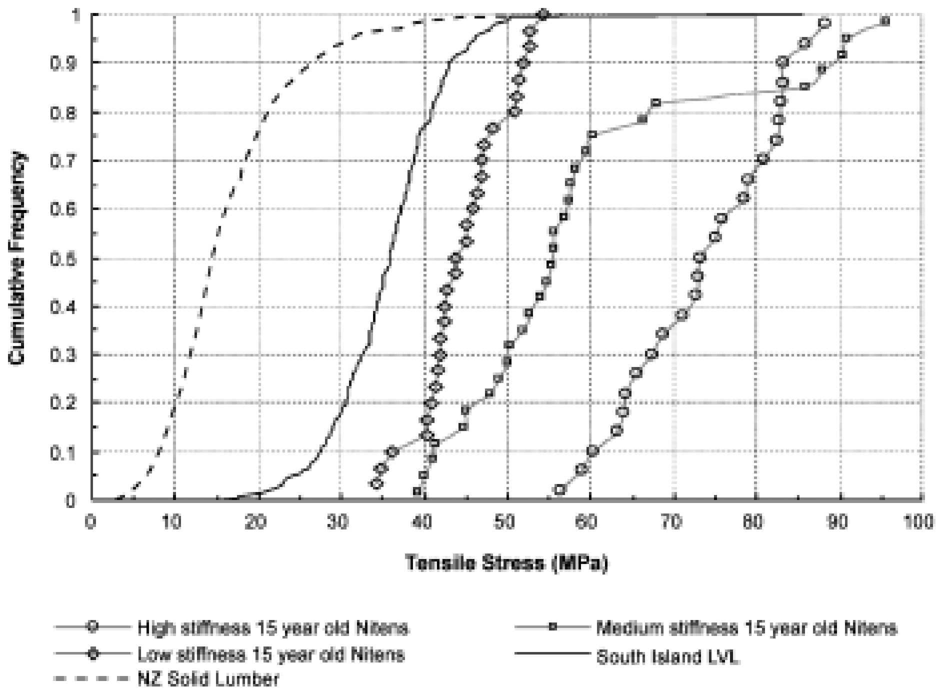

FIG. 5–Modulus of elasticity comparison

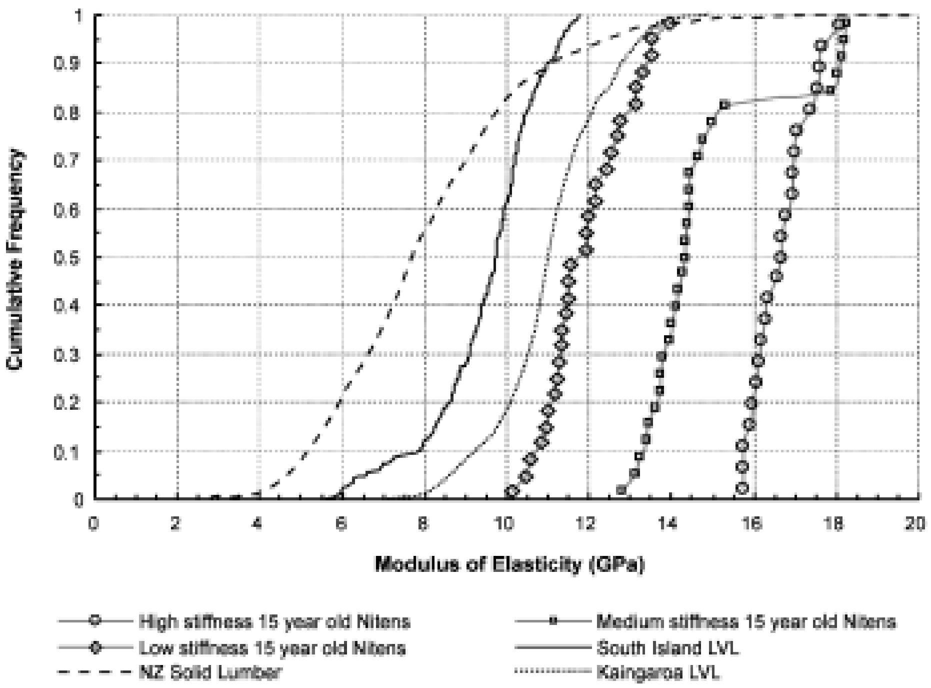

FIG. 6–Modulus of rupture comparison

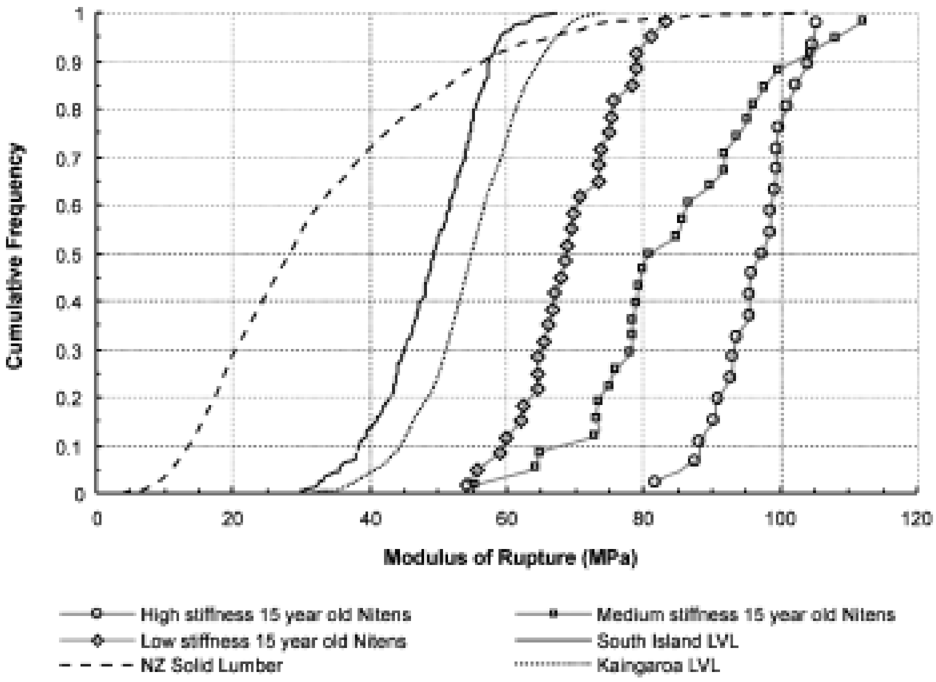

FIG. 7–Tensile stress comparison

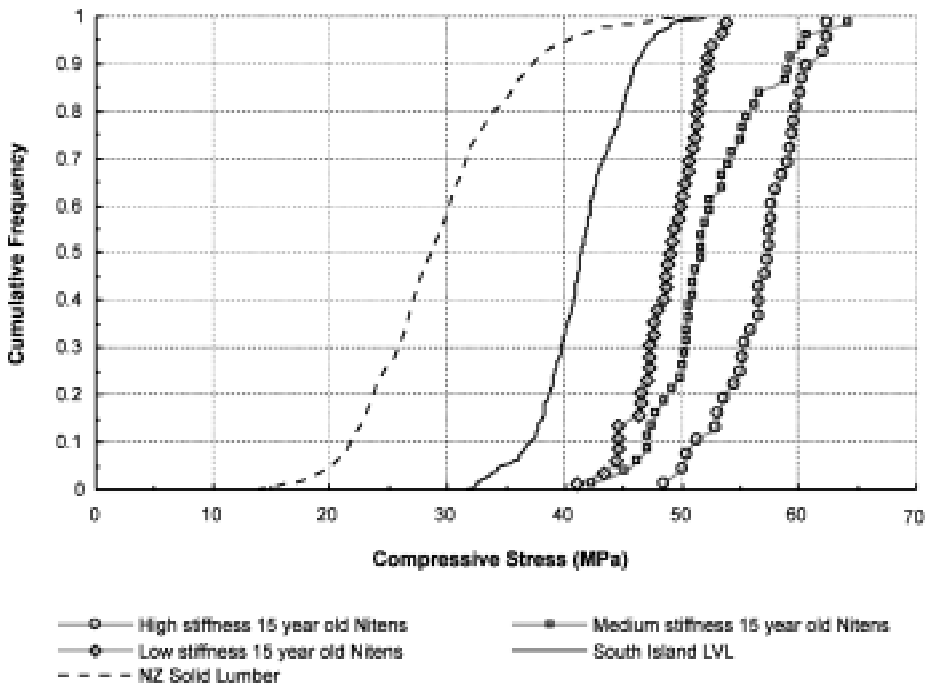

FIG. 8–Compression stress comparison

- In-grade solid wood data representing a collection of "new crop" data from several sites around New Zealand, in the 90 × 45-mm size cut of log (i.e., all grades combined).

The nominal density comparison is intended only to indicate the general differences. Laminated veneer lumber contains significant quantities of glue and has been compressed during manufacturing processes; this increases the measured density, thus making direct comparisons with sawn lumber invalid.

It can be seen (Fig. 4–8) that:

- The sorting of the veneers to produce the three stiffness groups of LVL (high, medium, and low) has been very successful, as indicated by the clear separation between the groups.
- All the *E. nitens* LVL groups had higher stiffness and strength than the typical North Island and South Island *P. radiata* LVL.
- The variation in strength and stiffness was significantly smaller than in solid sawn timber.
- The extremely high strength of the *E. nitens* LVL is immediately apparent in the fifth percentile value (used in the determination of characteristic strength). It could be argued that the high strength is not often used in that many structural elements will become stiffness limited before reaching the strength limit.
- The effect of location is apparent — the North Island LVL from medium- to high-density sites performed better than the South Island material from low-density sites.

CONCLUSIONS

Veneer from the heavily branched, unpruned, second logs of 15-year-old *E. nitens* was used successfully for LVL. Although visual grading indicated that most of the veneer was not suitable for construction plywood, it produced LVL with high stiffness and extremely high strength, achieving MGP 12 or F17 as limited by stiffness. Testing veneer acoustically with Pundit™ gave a useful estimate of modulus of elasticity, enabling the veneer to be sorted into stiffness classes.

The LVL had better strength and stiffness properties than that made from *P. radiata* grown in either the North or the South Island of New Zealand. The *E. nitens* LVL overall achieved the JAS grade of 120E-450, with the high-stiffness group rising to 160E-600. The high stiffness of the *E. nitens* veneers suggests that, if used in combination with lower stiffness *P. radiata* veneers, a net gain in stiffness could be realised. The level of decay associated with branches in New Zealand-grown trees needs further study as decay could have a severe impact on strength properties.

ACKNOWLEDGMENTS

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APPENDIX 1

DATA EVALUATION EQUATIONS FOR LIMIT STATE CODES

1.1 Characteristic strength is calculated by the following equation:

$$R_k = \left[1 - \left[\frac{2.7V_R}{\sqrt{n}}\right]\right] R_{0.05}$$

where:

V_R = coefficient of variation of the measured data
n = sample size
$R_{0.05}$ = fifth percentile value of measured data

1.2 The normalised characteristic strength is calculated by the following equation:

$$R_{k,norm} = \frac{1.35}{\Phi} \frac{R_k}{(1.3 + 0.7V_R)}$$

where:

Φ = capacity factor specified in the limit state code
(for timber, poles, and glulam $\Phi = 0.8$)

1.3 The characteristic modulus of elasticity (E_k) is given by the smaller of the following two equations:

$$E_k = \left[1 - \left[\frac{0.7V_E}{\sqrt{n}}\right]\right] E_{mean}$$

or

$$E_k = 1.5\left[1 - \left[\frac{2.7V_E}{\sqrt{n}}\right]\right] E_{0.05}$$

where:

E_{Mean} = average value
$E_{0.05}$ = fifth percentile value
V_E = coefficient of variation of the data

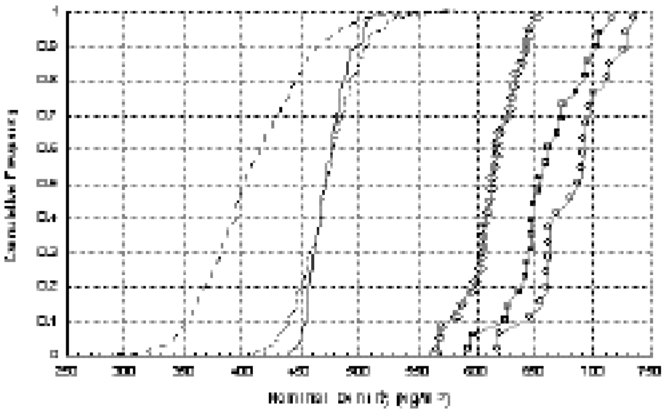
1.4 The coefficients of variation V_R and V_E are given by the following equations:

$$V_R = \frac{1}{X_{mean}} \sqrt{\frac{\sum_{i=1}^{n} (X_i - X_{mean})^2}{n - 1}} \quad \text{or} \quad Cov = \frac{Stdev}{mean}$$

where

$$X_{mean} = \frac{1}{n} \left[\sum_{i=1}^{n} X_i\right]$$

X_i = sample values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