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POTENTIAL FOR HIGH-STIFFNESS ENGINEERED WOOD PRODUCTS FROM *Eucalyptus fastigata*

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ABSTRACT: Adopting alternative species, such as some fast grown hardwoods may provide an opportunity to utilize existing manufacturing capability to produce greater volumes of high stiffness engineered wood products. In this study laminated veneer lumber was produced from 23-year-old *Eucalyptus fastigata* in a commercial radiata pine mill. The resource gave very good stiffness results, with the lowest stiffness logs producing an average veneer stiffness well in excess of typical radiata pine stiffness levels (average 14 GPa across all the veneer produced, compared to 10 GPa for radiata). Property testing to the relevant New Zealand standards showed boards met or exceeded LVL13 grades for all properties except shear. Subsequent testing indicated that the low shear performance was the result of surface deactivation, due to lengthy delays during the processing, and not a particular property of the wood or the adhesive system. While the trial objectives of increased veneer stiffness were met, there is scope to improve the manufacturing process, and to understand the performance of LVL manufactured under production conditions, rather than in a scientific trial which involved delays and frequent manual handling of veneers.

KEYWORDS: Engineered wood products, Eucalyptus, Hardwoods, Laminated veneer lumber, Mechanical properties

1 – INTRODUCTION

Increasing use of timber in demanding applications such as multi-storey timber buildings highlight the need for wood products that have enhanced mechanical properties compared to traditional sawn timber. When producing structural sawn timber, the location of the board within the stem (distance from pith, height up tree) has an impact on the mechanical properties, resulting in boards having a range of strength and stiffness values. Additionally, defects such as knots mean that the mechanical properties of the wood can vary considerably along a single board. This variability results in the whole board structural properties being lowered to the properties of a proportion of the board, and consequently only being suitable for lower value uses [1].

Engineered wood products (EWPs) such as laminated veneer lumber (LVL) provide options for enhancing the mechanical properties compared to solid wood. EWP manufacturing typically involves measuring the stiffness of each component (e.g. veneer) and sorting these according to stiffness. This can be used either to ensure uniform mechanical properties across all the finished products, or it can be used to segregate the highest stiffness components and to use them to make premium products with enhanced mechanical properties. Utilising higher stiffness timber means it is possible to design with longer spans, or smaller cross sections. This can allow less material to be used in a particular application or enable wood to be used in applications like wide door lintels, where the long spans mean that other materials such as steel might otherwise have been required. For many softwood plantation resources the proportion of higher stiffness material is relatively low, so this limits the volume of high-performance material that can be produced. For example, given the distribution of board stiffness values for 27-year-old radiata pine grown in the central North Island of New Zealand [2], less than 5% of boards could be expected to have average MOE values above 11GPa.

In order to produce larger volumes of wood products with enhanced mechanical properties, a shift to a new wood resource may be required. Eucalyptus species grow quickly and produce high-stiffness timber from a young age [3]. Eucalyptus species have been grown in New Zealand in fibre-managed plantations for many years and

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thus provides an opportunity for producing higher stiffness wood products, compared to what would be possible with the typical New Zealand structural timber resource. While in New Zealand most eucalyptus is grown for short-fibre pulp production, but there is potential to utilise a small proportion of this wood resource for higher value products, such as veneer. Previous studies have shown that eucalypt veneers can be used in combination with plantation softwood veneers to produce hybrid products with enhanced mechanical properties, and no apparent gluing issues [4, 5]. During LVL manufacture, veneers can be arranged strategically to provide strength and stiffness exactly where required (e.g. outer faces of a beam). This means that in order to produce higher performance EWPs small amounts of high stiffness veneer could be combined with the existing resource. This would mean that the volume of high stiffness wood required would be small, and thus to produce meaningful volumes of high-performance EWPs would not require a large change to the forest resource, or the processing operations. *Eucalyptus fastigata* (H.Deane & Maiden) is grown in small but consistent volumes in the central North Island of New Zealand with areas of forest sufficient for ongoing harvests of 50-100 ha/p.a. of 16+ year old trees, and much larger planted areas for younger trees [6].

LVL was manufactured from *E. fastigata* in a radiata pine LVL mill, to understand the properties of the veneers and LVL and to assess the feasibility of producing a high-stiffness eucalyptus product using existing manufacturing operations.

2 – PROJECT DESCRIPTION

Twenty pruned *E. fastigata* trees were harvested from the Marlborough region of New Zealand's South Island. From these, 13m^3 of logs were evaluated for stiffness, then peeled in the JNL Masterton site, and the stiffness of each veneer measured with a Metriguard 2800DME grader. A subset of 90 veneers had their stiffness and density re-measured by hand to confirm the accuracy of the Metriguard measurements. Following laboratory gluing trials, the veneers were re-dried and pressed into LVL panels. The mechanical properties of 30 LVL boards were assessed according to AS/NZS4357.2:2006 [7].

3 – EXPERIMENTAL SETUP

3.1 LVL PRODUCTION

The trees were sourced from a small stand of 23-year-old *E. fastigata*, that had managed to produce high-value sawlogs (pruned to 8m, thinned to 350 stems per hectare). Following harvesting, log scaling was performed to assess the logs against the peeler log specifications supplied by JNL. In-specification logs were delivered to JNL's Masterton site where they were segregated into three stiffness groups according to acoustic velocities measured with a Hitman Director HM220. Logs were peeled without preheating and the dried veneers were sorted according to the log stiffness grouping. The Metriguard 2800DME grader was re-calibrated by the manufacturer prior to the trial, using existing veneers of known stiffness and density. The Metriguard data was collected for each log stiffness group. Additionally, Metriguard data for a typical day of radiata pine production was supplied for comparison. An attempt was made to calibrate the Camsensor visual grader, but it was not able to reliably detect knots in the *E. fastigata* veneers. Visual grading data was not a key part of the trial, so it was decided not to make further attempts to improve the calibration, and to not collect visual grading data.

The dried veneers were returned to Scion in Rotorua where the stiffness of 90 veneers (30 randomly selected from each log stiffness group) was confirmed by measuring the sheet densities and measuring the ultrasonic time of flight to estimate stiffness. The density and stiffness of each log stiffness group were compared to the overall population of Metriguard measurements for that log stiffness group.

Trials were performed by Hexion New Zealand to assess the gluing performance against AS/NZS 4357.0:2005 [8] using existing phenolic glue formulations used by JNL Masterton. From these results, one of the existing glue formulations met the requirements of the standard and it was chosen for LVL production. Veneers were re-dried and returned to JNL to be pressed into 11-ply LVL panels. The veneers that had been manually stiffness tested were sorted into six stiffness classes, with average MOE of each class ranging from 21 GPa to 10.5 GPa. The veneers were laid up into in different combinations to give 6 panels (each 1200 x 2400mm) with a wide range of stiffness properties, to be used for downstream testing. Three panels each contained veneers from one single stiffness class (e.g. a panel made solely from veneers from the lowest stiffness class) and three panels used veneers from a mix of stiffness classes, with the stiffest veneers always making up the outer layers of the panel. The remaining veneers were laid up randomly within their log stiffness groups. The panels were ripped to 95x40 mm wide boards and returned to Scion.

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3.2 TESTING SCHEDULE

Scion carried out the tests listed in Table 1 on 30 boards of the 95x40 mm *E. fastigata* LVL produced from the veneers of known stiffness. This ensured a wide spread of wood properties (e.g. density, stiffness) between test specimens and enabled comparisons to be made between the actual LVL properties and those predicted by the stiffness of the individual veneers. The boards were stored in Scion's Timber Engineering laboratory prior to testing, to allow the boards to condition and equilibrate.

Table 1. 95x40 E. fastigata LVL testing schedule.

Test	Specimen Size (mm)
Bending $MoE_{apparent}$ & MoR as a joist	95x40x1900
Tension parallel	95x40
Compression parallel	95x40
Rail Shear as a joist (on edge)	ex 95x40
Rail Shear as a plank (on flat)	ex 95x40

The bending strength and stiffness specimens were tested as a joist (load parallel to glue lines) to destruction in accordance with AS/NZS4357.2:2006 [7]. The Scion Grade 1 Baldwin Universal test machine was used for the bending tests.

The tension strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006 [7]. The Scion tension test machine was used for the tension tests.

The compression strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006 [7]. The Scion Grade 1 Baldwin Universal test machine was used for the compression tests.

The rail shear strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006 [7]. The Scion Grade 1 Weidemann Universal test machine was used for the rail shear tests. Shear strength on the edge is defined as having the shear plane perpendicular to the glue lines and hence passing through every veneer. Shear strength on the flat is defined as having the shear plane parallel to the glue lines and passing through one to two veneers.

The strength and stiffness data were analysed in accordance with AS/NZS4357.3:2006 [9] and AS/NZS4063.2:2010 [10]. All the testing was completed in the Timber Engineering laboratory of Scion, Rotorua, New Zealand. The testing was carried out over the period 21 June - 30 July 2021.

Testing revealed poor shear results from the LVL, prompting an additional experiment where *E. fastigata* timber was sawn into 3mm thick 'veneers' and these glued immediately using Resorcinol glue to produce 10 rail shear strength specimens (approximate dimensions 31.5 mm thickness, 55 mm width, 300 mm length). As above, shear testing was performed on edge and on the flat according to AS/NZS4357.2 [7]. While these samples were produced via a very different process to peeling veneers, it is assumed that the surface properties of the dried, sawn sections would be sufficiently similar to peeled veneer to mimic the gluing behaviour of fresh veneers. The shear strength from these specimens is thus assumed to be representative of veneers that were freshly peeled and dried prior to gluing.

4 – RESULTS

From the $42m^3$ of logs harvested, $13m^3$ were suitable for peeling. The main reasons for rejection of logs were sweep, end splitting, and diameter (i.e. too large or too small). Logs were peeled without preheating and presented few issues during peeling, although end splitting in the logs did produce splits in many of the veneers. Anecdotally, mill staff were concerned that the level of end splitting would limit the commercial viability of *E. fastigata* veneers. Unfortunately, the lack of visual grading data made it impossible to quantify the level of end splits present immediately after peeling and drying. The nature of the trial meant frequent manual handling of the veneers which substantially increased the likelihood of end splits compared to what would be expected in normal production conditions. Drying of the veneers was slower than for radiata pine, and two passes through the veneer dryer were required, even after the dryer speed was reduced to increase drying time.

Overall recovery of trimmed veneer was 60% of the peelable volume, or 43% of the total volume of logs. This ignores the presence of end splits, as these could not be meaningfully quantified. These recoveries correspond to a stand recovery of $67m^3$ trimmed veneer per hectare of forest.

Metriguard stiffness values for the three log classes are compared to values for radiata pine in Fig. 1. All three log stiffness groups produced veneer that was, on average, much stiffer than radiata pine. Average Metriguard stiffness values for the high, medium and low stiffness logs were 17, 15 & 13 GPa respectively, compared to an average for radiata pine of 10 GPa. 80% of the *E. fastigata* veneers are at or above 12GPa compared with 20% for radiata pine veneers 12 GPa, Fig. 1.

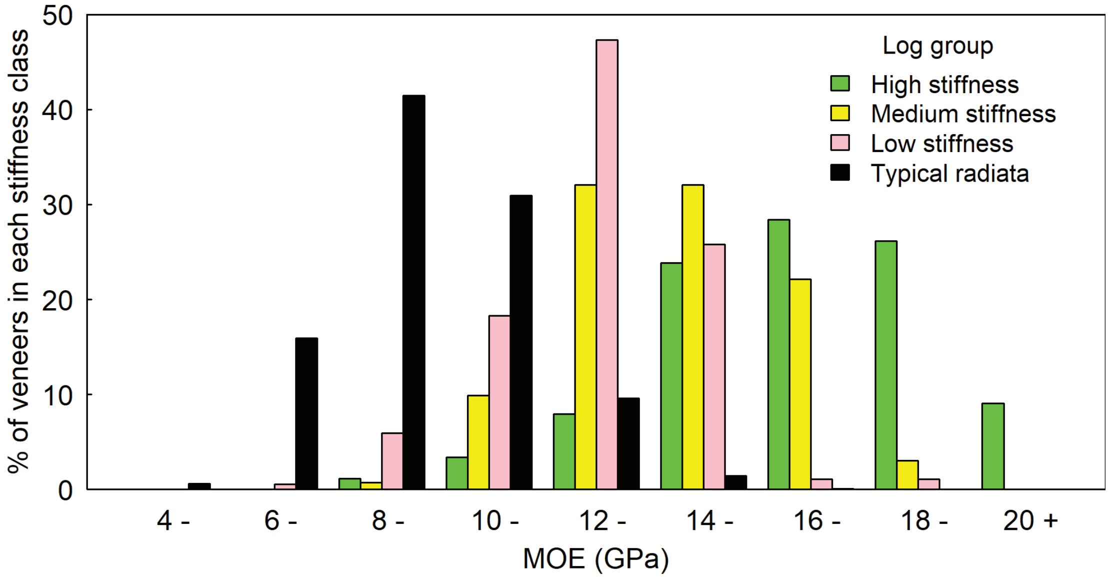

Figure 1. Stiffness distribution of veneers from each log stiffness group, plus typical radiata pine values for comparison.

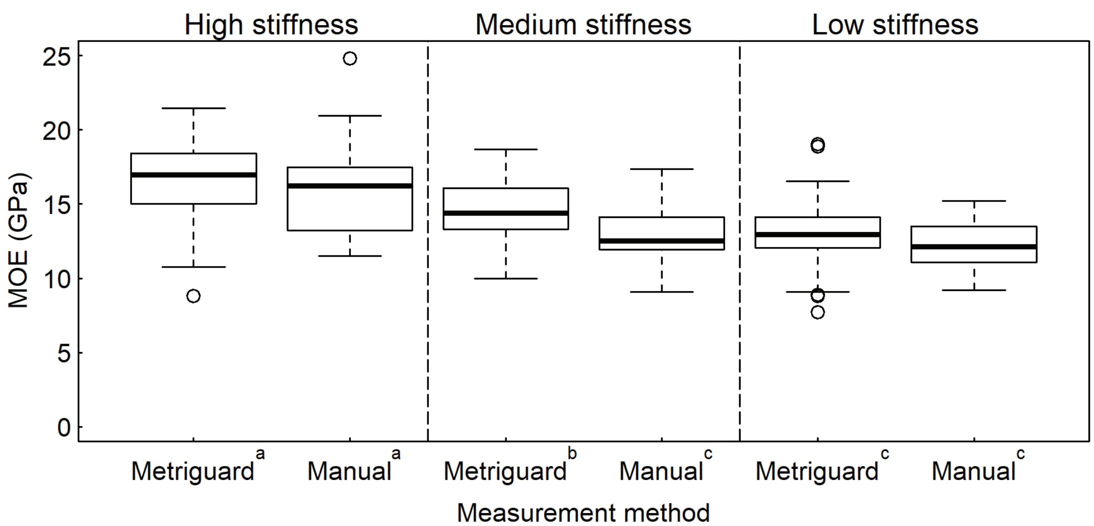

Figure 2. Metriguard measurements compared to acoustic stiffness measured manually for a subset of the veneers from each log stiffness group

Manually determined acoustic stiffness values are compared to the population of Metriguard stiffness values for each log stiffness group in Fig. 2. Because the manual measurements quantify sheet properties like density directly, they are assumed to be more accurate than the Metriguard measurements. The manual measurements are, on average, slightly lower than the Metriguard measurements, but this is only significant for the medium stiffness logs. While this indicates the Metriguard measurements may have been over-predicting the stiffness of the veneers, the manual *E. fastigata* measurements are still well above what would normally be expected for radiata pine (Average 14.4 GPa, compared to 9.9 GPa for radiata pine).

Mechanical test results for the LVL boards are shown in Table 2 and the corresponding LVL grades from NZS/AS 1720.1 are shown in Table 3. [11]. For all properties except shear, all boards met the LVL 13 grade, and 30% of boards met the LVL 16 grade. Shear strength did not meet the standard for any grade. Poor shear results were likely a result of poor gluing performance caused by surface inactivation of the veneers, due to the long time period (approx. 1.5 years) between peeling and gluing the veneers. This was a combination of constraints of the trial, and disruption due to the Covid-19 pandemic. Under normal operation the time between peeling and gluing would be very short (a matter of days).

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Table 2. AS/NZS4357.3:2006 Characteristic Strength Properties as Tested

	Bending Stiffness MoE Joist GPa	Bending Strength MoR Joist MPa	Tension Parallel Strength MPa	Compression Parallel Strength MPa	Shear Strength on edge MPa	Shear Strength on flat MPa	Density at test kg/m^3
Characteristic Values	14.21	50.03	37.18	55.78	2.51	2.10	727
Indicated LVL grade	LVL13	LVL16	LVL16	LVL16	Reject	Reject	

Table 3. LVL grades from AS/NZS1720.1

Grade	Bending Strength (f'b) MPa	Compression Strength (f'c) MPa	Tension Strength (f't) MPa	Shear Strength (f's) MPa	Compression Perp to grain (f'p) MPa	Bending Stiffness (average) GPa	Average Density kg/m^3	Characteristic Density kg/m^3
LVL 16	50	45	25	4.5	10	16.0	600	480
LVL 13	45	38	25	4.0	10	13.2	600	480
LVL 11	38	32	16	3.5	10	11.0	570	480
LVL 10	35	30	15	3.5	10	10.0	540	480
LVL 8	30	30	15	3.5	10	8.0	480	480

With the exception of shear strength, the 95x40mm *E. fastigata* LVL overall achieved the LVL13 grade as limited by Bending Stiffness. Bending strength just exceeded the LVL16 value whereas tension and compression strengths comfortably exceeded the characteristic value of the highest grade LVL16. The characteristic density at test is considerably higher than the values in Table 4. Shear strength on edge and on flat were very low failing to achieve the lowest characteristic value of 3.5 MPa. Additional shear strength testing was performed to confirm if these low values were typical of this species or caused by the processing conditions used.

Fig. 3 shows measured MOE for each LVL sample, compared to average veneer stiffness for that particular LVL billet. Average veneer stiffness is defined as the numerical average of all the veneers in the LVL billet. Plotted on Fig. 3 are regression coefficients and characteristic values for the LVL grades (from Table 3). The characteristic stiffness value is broadly based on an average value, which will result in some test values falling above and below the characteristic grade value. There is a good correlation between individual veneer stiffness and the stiffness of the LVL. All measured samples achieved LVL13 grade, with, around 30% achieving the LVL16 grade. Radiata pine typically achieves LVL8 and LVL10 grades, although veneers can be sorted to produce small volumes of LVL11 grade.

The results from additional shear testing are shown in Tables 4 & 5. While there are not sufficient data points to calculate characteristic values from these, comparing these values to Table 3 shows the shear strengths to be well in excess of the code requirements which points to it being possible to achieve good shear strength in *E. fastigata*. This indicates that the poor shear properties in the LVL were an artefact of the experimental design, rather than an issue specific to the gluing of *E. fastigata*. This result does need to be confirmed by further mill trials which minimise the delays between peeling and gluing.

Table 4: Shear on edge test results – Additional samples

Sample #	Max load (N)	Shear failure	Shear Stress (MPa)
1	84243	yes	8.65
2	91820	yes	9.39
3	104731	yes	10.67
4	80684	yes	8.28
5	58804	yes	6.02

*Table **5:** Shear on flat test results – Additional samples*

Sample #	Max load (N)	Shear failure	Shear Stress (MPa)
6	66621	yes	6.83
7	59658	yes	6.08
8	82890	yes	8.50
9	91886	yes	9.38
10	81154	yes	8.26

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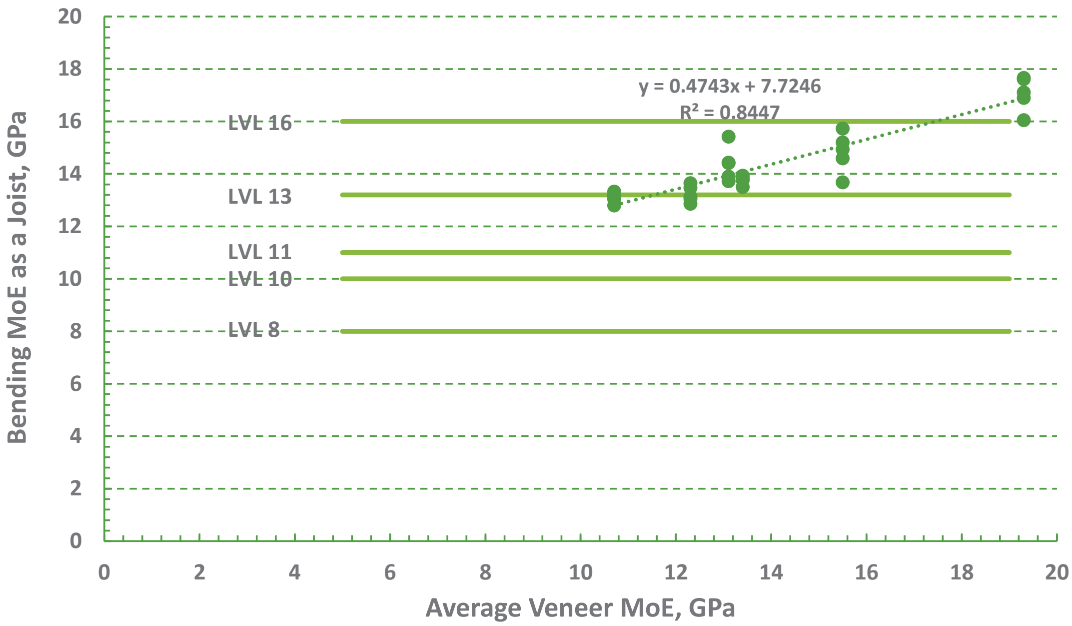

Figure 3. Measured LVL stiffness as a function of the average stiffness of the individual veneers

6 – CONCLUSION

This project has shown that it is possible to produce high-stiffness veneers from fast grown *E. fastigata* in a mill that normally processes radiata pine. The 23-year-old trees were within the typical range of harvest ages for radiata pine and produced veneers with a much higher average stiffness (14 GPa, compared to 10 GPa for radiata pine). End splitting was evident in many of the veneers, but the experimental design made it difficult to assess how much of an issue this would be under normal production settings. Mechanical testing of LVL made from the *E. fastigata* veneers showed excellent mechanical properties for all properties except shear. Excluding the shear results, all specimens tested met the New Zealand LVL13 grade, and 30% met the LVL16 grade. Radiata pine is typically produced in LVL8 and LVL10 grades, but small volumes of LVL11 are possible. Additional shear testing using freshly cut wood surfaces achieved good shear results, suggesting that the poor shear performance was due to delays between peeling and gluing, not because of a specific issue with *E. fastigata.* It is recommended that this work be repeated, minimising delays between peeling and gluing to better understand gluing performance. Additional work could also look at the gluing performance of hybrid materials combining *E. fastigata* and radiata pine. This would allow very small volumes of *E. fastigata* to be combined with the existing resource to produce high stiffness products.

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