Producing High-stiffness LVL from Eucalyptus fastigata: Part 3. LVL production and mechanical properties

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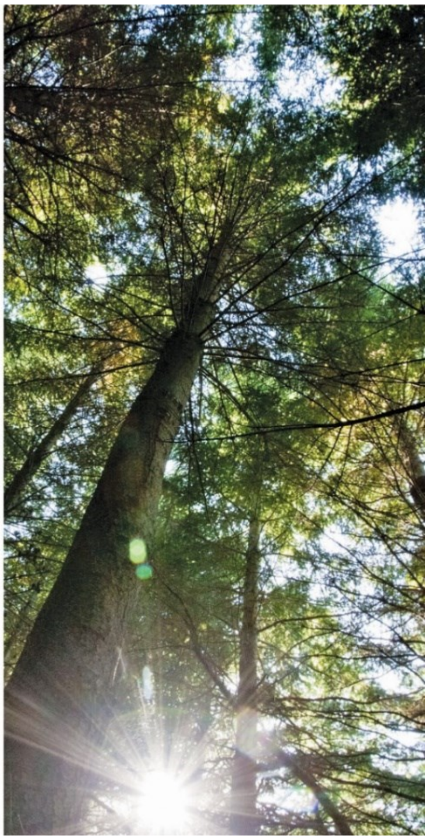

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EXECUTIVE SUMMARY

Laminated veneer lumber (LVL) has been produced in a commercial radiata pine mill (JNL Wairarapa) using veneers from 23-year-old *Eucalyptus fastigata*. The veneers were glued using one of the glue formulations commercially used by the mill, to produce 24 LVL panels (1.2 x 2.4m), 40mm thick. Six of the panels were produced from veneers of known density and stiffness and the veneers for these were sorted to ensure the widest possible range of average stiffness values between these panels. The remaining panels were produced from veneers grouped according to their log-stiffness class (low, medium or high stiffness).

Mechanical testing of the LVL found that:

- With the exception of shear strength, the 95x40 *E. fastigata* LVL overall achieved the LVL 13 grade as limited by Bending Stiffness, with the other strength properties meeting or exceeding the highest LBL16 grade.
- Shear strength both on edge and on flat were very low.
- Poor glue spread was found to be an issue along with the showing a lot of splitting and fracturing along the, this issue needs further exploration.
    - Further exploration using veneers cut from solid timber and then laminated to produce an LVL ‘similar’ product showed high shear strength. This suggests that the poor shear behaviour is a result of the processing conditions, rather than a characteristic of this species.
- Accurate measurement of veneer stiffness was found to be a very good predictor of final bending stiffness but not that reliable in predicting the strength properties.
- It is estimated that the LVL would produce 30% LVL16 and 70% LVL13. This compares with Radiata pine LVL commonly falling into LVL8, 10, 11 & 13 grades.

We recommend future work on this product focussing on understanding and mitigating the causes of poor shear behaviour. This to identify if improved processing with minimal handling, and no re-drying could reduce splitting in veneers, and improve shear properties.

INTRODUCTION

Juken New Zealand (JNL) wanted to find a way of producing veneers with a higher average stiffness than is typical for radiata pine. Many eucalypt species have comparatively high stiffness timber, even in relatively young trees, so eucalyptus veneer provides a potential avenue for producing high stiffness products from New Zealand grown trees.

Background

In this study, 23 year old *Eucalyptus fastigata* trees were peeled into veneers at JNL Wairarapa, and subsequent measurements confirmed that the veneers had a significantly higher average stiffness than radiata pine (average of 14.3GPa, compared to 9.9GPa for radiata pine). The veneer peeling trial, and subsequent veneer properties have been reported separately (Sargent, et al., 2020; Sargent & Riley, 2020). The veneers were slower to dry than radiata pine, and had some issues with end splitting, but otherwise peeled well.

Previous gluing trials by Hexion found that the plywood tolerant A bond glue normally used at JNL glued the *E. fastigata* veneers successfully, so it was planned to produce LVL at JNL to confirm that the veneers could be glued well, and to provide material to evaluate in terms of the Australian, New Zealand standard AS/NZS4357:2006 the structural properties of the 95x40 *E. fastigata* LVL. The LVL will also be included in separate framing durability tests for SWP (both untreated and boron treated LVL are being tested).

METHODS

LVL Production

Drying veneers

The veneers had been stored indoors at Scion for over 1 year and were at around 7% moisture content (MC). Typical moisture contents for pressing LVL is 3-4% MC, so the veneers needed to be re-dried prior to shipping to JNL Wairarapa for pressing.

The veneers were trimmed to 2.4m long to fit into the two large Scion kilns for drying. The veneers were stacked in layers of three veneers followed by a layer of fillets. The veneers were dried at 90°C/50°C (EMC 2%) for 5 days. This was expected to equilibrate the veneers to 2-3% MC.

Layup

Following drying, the veneers were stacked in layup order. 90 veneers had known stiffness and density values, from Metriguard validation measurements (Sargent & Riley, 2020). These veneers were sorted into five stiffness classes (high, med-high, medium, med-low, low) and these were sorted into six sets of 11 veneers, to give an expected range of panel stiffness values from 19.7GPa to 10.7GPa (Table 1). Each set of 11 veneers were colour coded on the ends, so they were easy to distinguish during the trial. A further 12 sheets of veneer of known stiffness were available as spares.

Table 1. Expected stiffness values for panels made from veneers of known stiffness

Sheet number	Stiffness distribution	Expected GPa
1	Highest stiffness	19.3
2	Medium-high stiffness	15.5
3	Medium stiffness	12.3
4	High outer, low inner	13.1
5	Med-high outer, med-low inner	13.4
6	Lowest stiffness	10.7

The remainder of the veneers were sorted according to whether they came from high-, medium- or low stiffness logs. These were also colour coded to show which stiffness group they belonged to.

The veneers were all block stacked, wrapped tightly in tarpaulins and freighted to JNL Wairarapa around one week prior to the trial date.

Panel pressing

The veneers were made into 11-ply LVL (nominal 45mm thick) using JNL's plywood tolerant A bond glue formulation (Bruce, 2020). The glue mix did not have boron added, but there was a risk of carry-over from boron still within the system. According to JNL staff "Unfortunately we have only some control over the time is takes to use up the MCAT9555 glue mixes before swapping to a non MCAT9555 glue mix for the trial." (boron free glue). Boron testing on an LVL cross-section immediately after pressing showed no, or very minor presence of boron.

The press parameters were chosen to ensure the veneers heated slowly to avoid blowouts and to ensure the press time was long enough to get the centre of the panels to 100°C. A thermocouple was inserted into one panel to confirm that the centre was heated sufficiently. Full pressing and gluing parameters can be found in the trial plan in the Appendix.

While JNL has a 40 panel multi-daylight press, the veneers were pressed in two loads. A second press load also provided the opportunity to address any issues found in the first press load. However, both press loads finished successfully.

Following pressing, the panels were ripped to 95 mm wide boards and returned to Scion.

Mechanical testing

Testing Schedule

Scion carried out the tests listed in Table 2 on the 95x40 *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.

Table 2. 95x40 *E. fastigata* LVL testing schedule.

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

Mechanical Test Methods

1. 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. The Scion Grade 1 Baldwin Universal test machine was used for the bending tests.
2. The tension strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006. The Scion tension test machine was used for the tension tests.
3. The compression strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006. The Scion Grade 1 Baldwin Universal test machine was used for the compression tests.
4. The rail shear strength specimens were tested to destruction in accordance with AS/NZS4357.2:2006. 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.
5. The strength and stiffness data were analysed in accordance with AS/NZS4357.3:2006 and AS/NZS4063.2:2010.

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.

In addition to the mechanical testing 12 lengths of LVL were used in framing durability tests. These will be reported separately.

RESULTS

LVL Production

Trimming the veneers so they fitted into the kiln removed the worst of the end splitting present in the veneers. The drying proceeded normally, and the veneers were stacked in lay-up order for shipping without causing too much additional damage to the veneers. Veneers which had full thickness splits were discarded, as these could not easily be fed through the glue spreader.

The veneers were freighted to JNL on schedule and were stored indoors until the trial date, ensuring they would not pick up too much moisture.

Figure 1. Colour coded veneer sheets are fed into the glue spreader

Feeding the eucalypt veneers through the glue spreader was more challenging than radiata veneers due to their brittle nature, and several veneer layers had to be assembled from broken strips.

The conservative press schedule which had been chosen for the eucalypt veneers led to core temperatures well above 100°C for over 12 min (Figure 2). Both press loads completed without encountering any issues (e.g. blown panels).

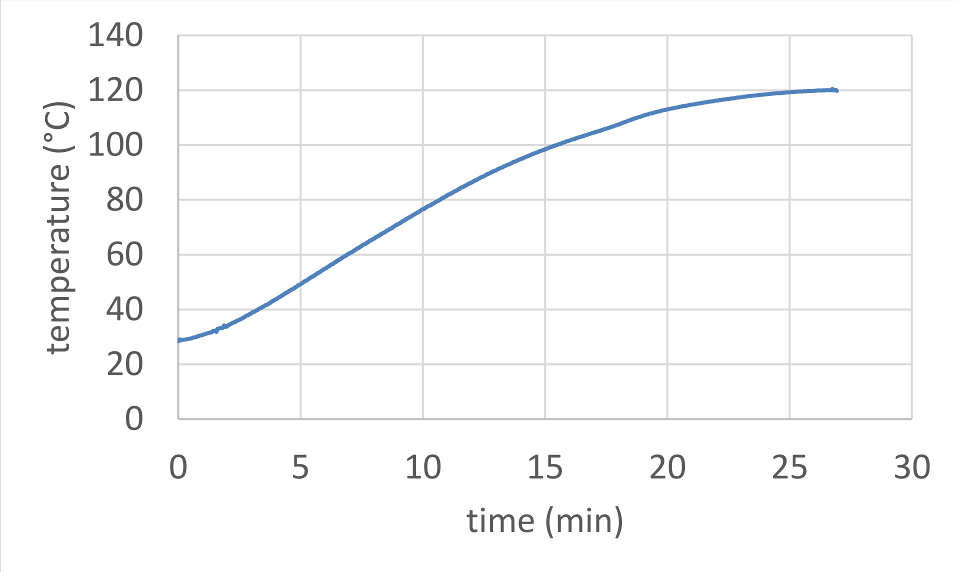

Figure 2. Core temperature profile of eucalypt LVL during hot pressing

Almost all the veneers were made into LVL panels, with 24 panels being made in total, including all 6 panels with veneers of known stiffness and density. After the boards were returned to Scion it was found that the LVL panels were only around 40mm thick, and it is suspected that the veneers were peeled to 4.1mm thick, when 4.5mm is typical for LVL productions. The dry veneers were around 3.99mm thick, and with the expected radial shrinkage for E. fastigata of 3% (*Farm Forestry timbers - Eucalyptus*), this would give a green veneer thickness of around 4.1mm.

A bonding test was performed by JNL staff, but this did not give conclusive results, the veneer splintered into small 'matchsticks' which made it impossible to assess whether there was glueline failure or wood failure.

Mechanical Test Results

Strength and Stiffness

The characteristic strength and stiffness properties have been calculated using the calculations and procedures set out in AS/NZS4357.3:2006 & AS/NZS4063.2:2010. These calculations rely on having a minimum of 30 test specimens.

Table 3 shows the characteristic strength and stiffness values for the 95x40 *E. fastigata* LVL.
Table 4 lists the proposed characteristic values for the LVL grades
Table 5 shows a statistical summary of strength and stiffness data.

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

95x40 *E. fastigata* LVL	**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 4. Proposed LVL grades from DZ ASNZS1720.1

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 (Connection Design) 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

Table 5. E. fastigata Strength and Stiffness Statistical Summary as Tested

Strength Property	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	Moisture content %
Average	14.39	64.12	49.25	63.11	3.32	2.96	688.5	6.39
Minimum	12.79	46.25	40.46	54.17	2.43	2.06	638.6	5.97
Maximum	17.65	81.25	69.20	75.89	4.31	3.91	768.9	7.24
Range	4.86	35.00	28.75	21.73	1.88	1.85	130.3	1.27
STDev	1.44	8.18	7.58	4.98	0.48	0.48	36.3	0.39
CoV%	10.02%	12.76%	15.40%	7.89%	14.46%	16.33%	5.27%	6.17%
Count	30	30	30	30	30	30	30	30

Observations

- With the exception of shear strength, the 95x40 *E. fastigata* LVL overall achieved the LVL 13 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.
- Shear strength on edge and on flat were very low failing to achieve the lowest characteristic value of 3.5MPa. Please refer to the section 'Inspection of the Shear' test specimens on page 12.
- The characteristic density at test is considerably higher that the in Table 4.

Figures 3 shows the relationship between bending stiffness (MoE) and bending stiffness (MoE) for the thirty pieces tested. As reasonably expected there is a positive relationship between stiffness and strength.

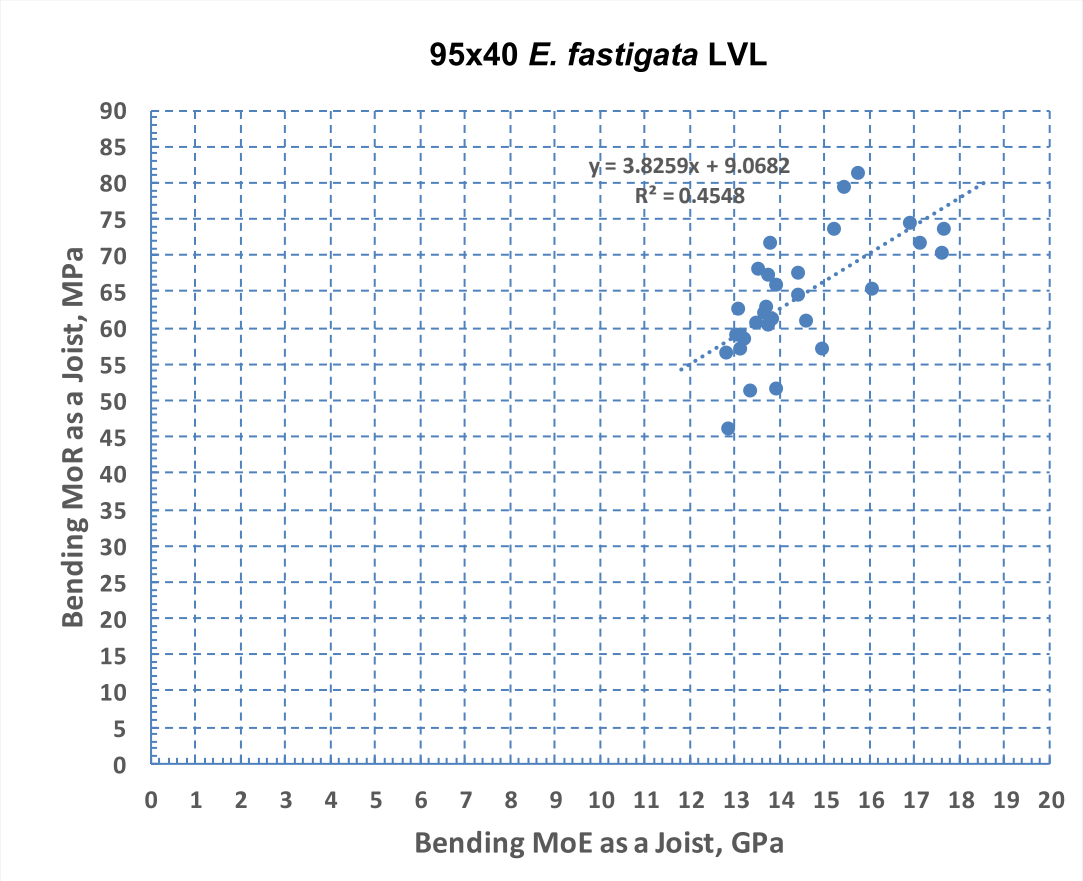

Figure 3. Bending stiffness (MoE) vs Bending Strength (MoR)

The following Figures 4 - 9 show average veneer stiffness versus the six strength properties measured. Average veneer stiffness is defined as the numerical average of all the veneers in the LVL billet. Plotted on these figures are regression coefficients and characteristic values for the LVL grades (Table 4).

- As clarification 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.
- As clarification the characteristic strength values are broadly based on a fifth percentile value, which will result in this case of virtually all the test values falling above the characteristic grade value.

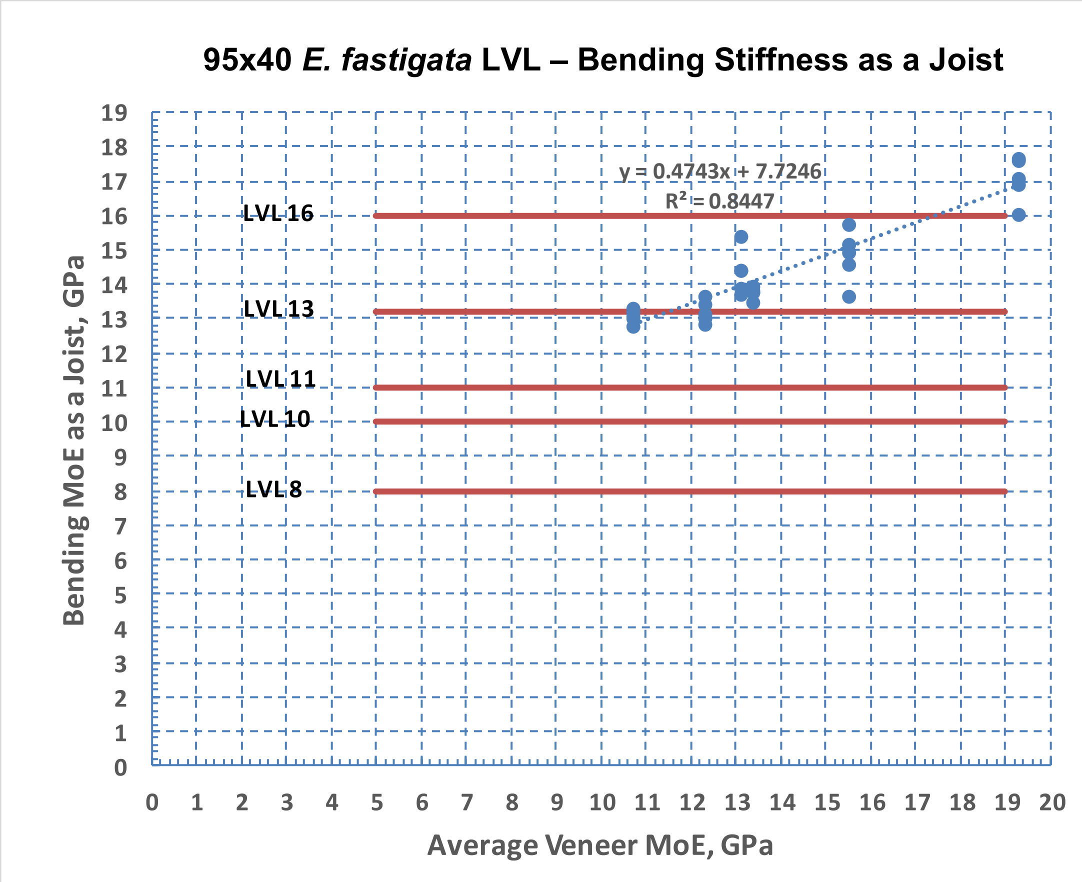

Figure 4. Average Veneer MoE vs LVL MoE

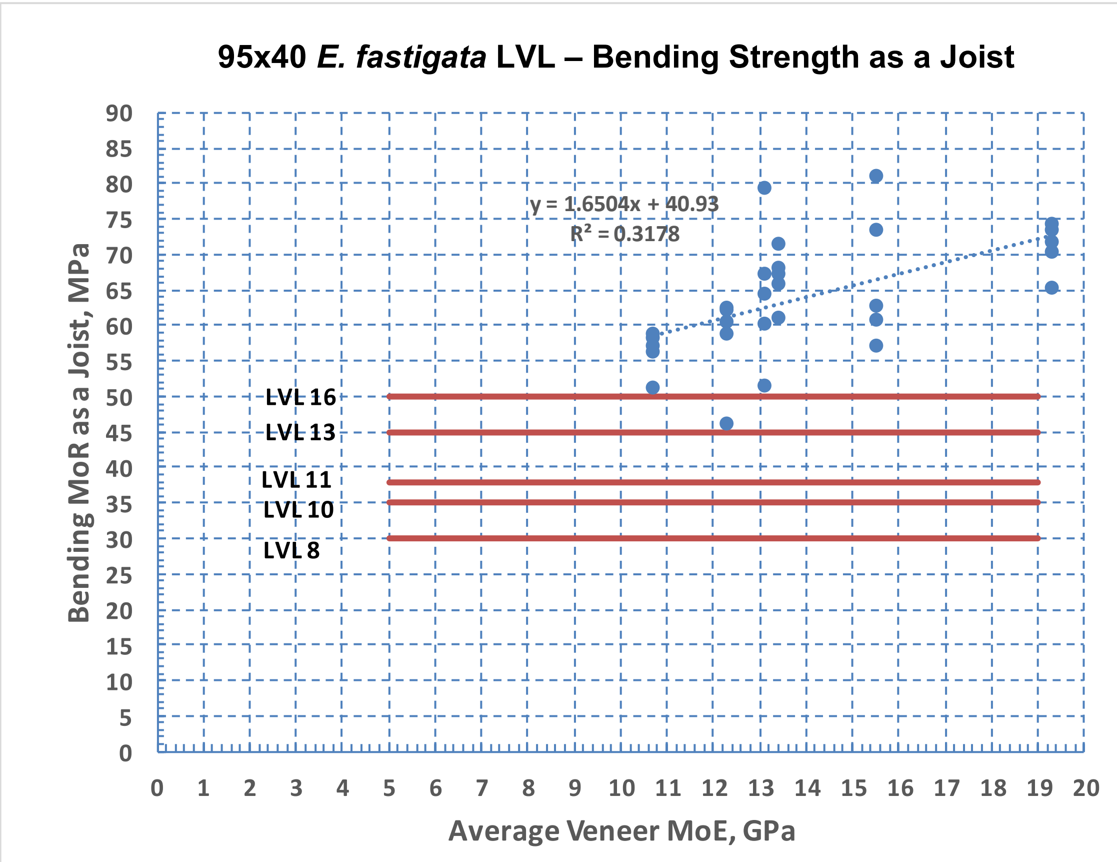

Figure 5. Average Veneer MoE vs Bending strength as a Joist

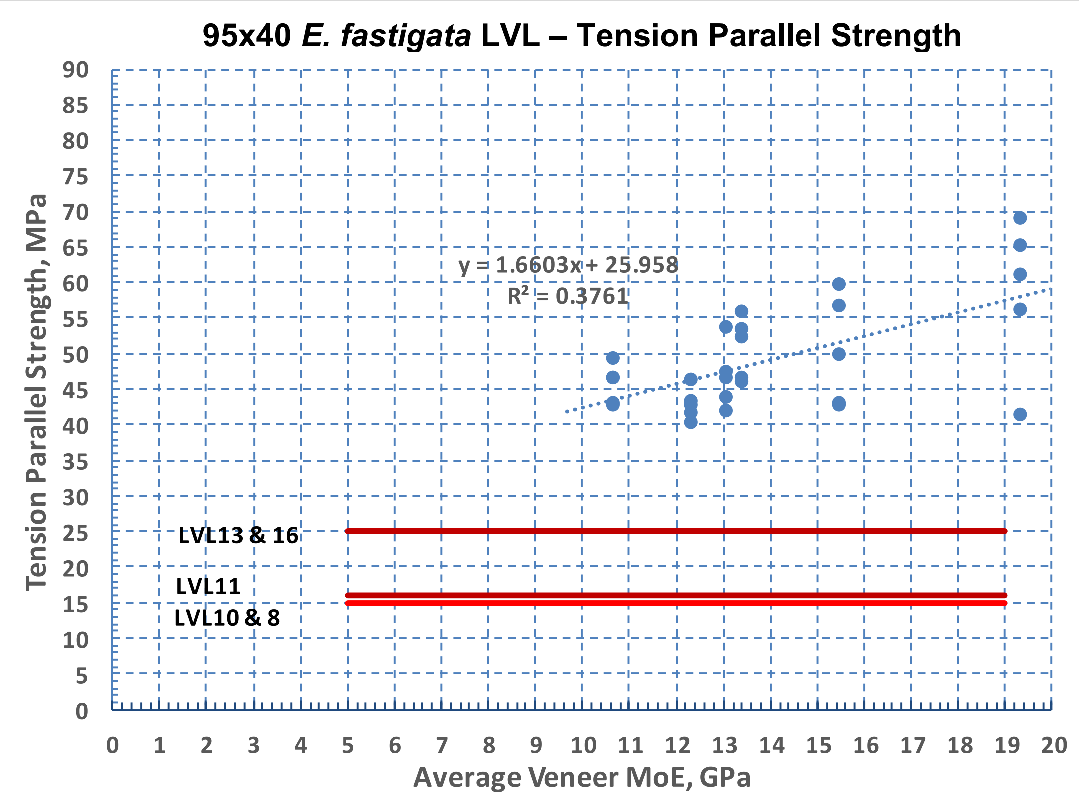

Figure 6. Average Veneer MoE vs Tension strength

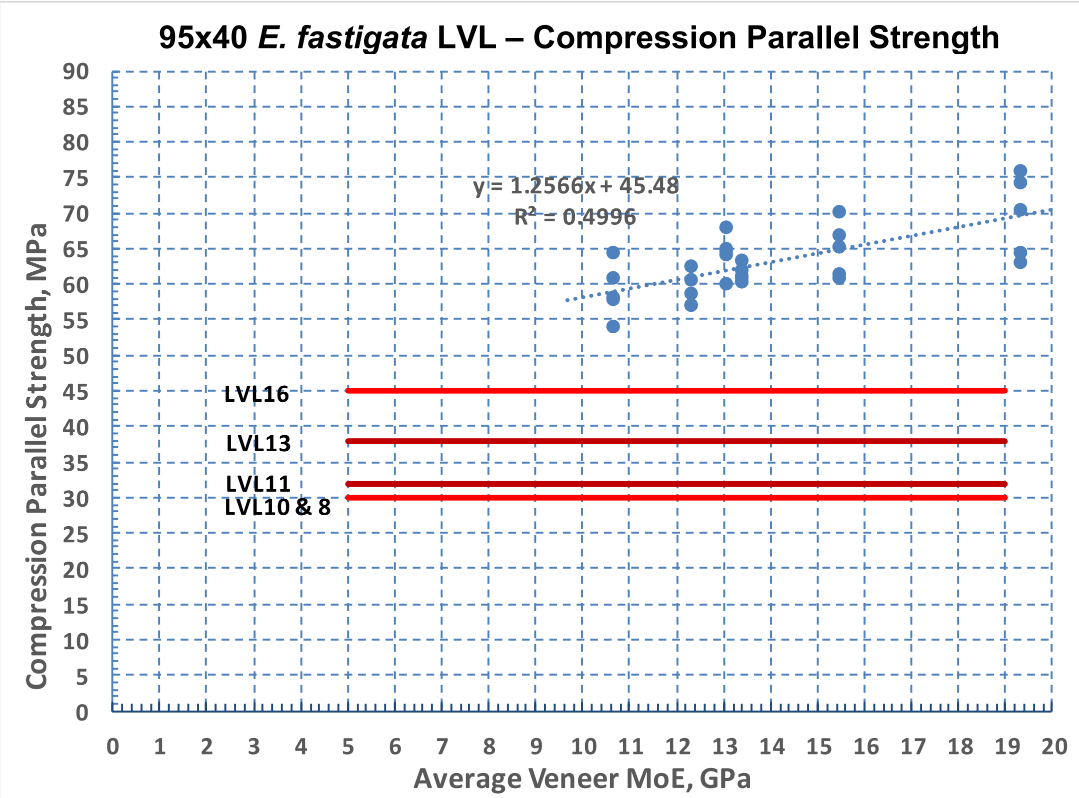

Figure 7. Average Veneer MoE vs Compression strength

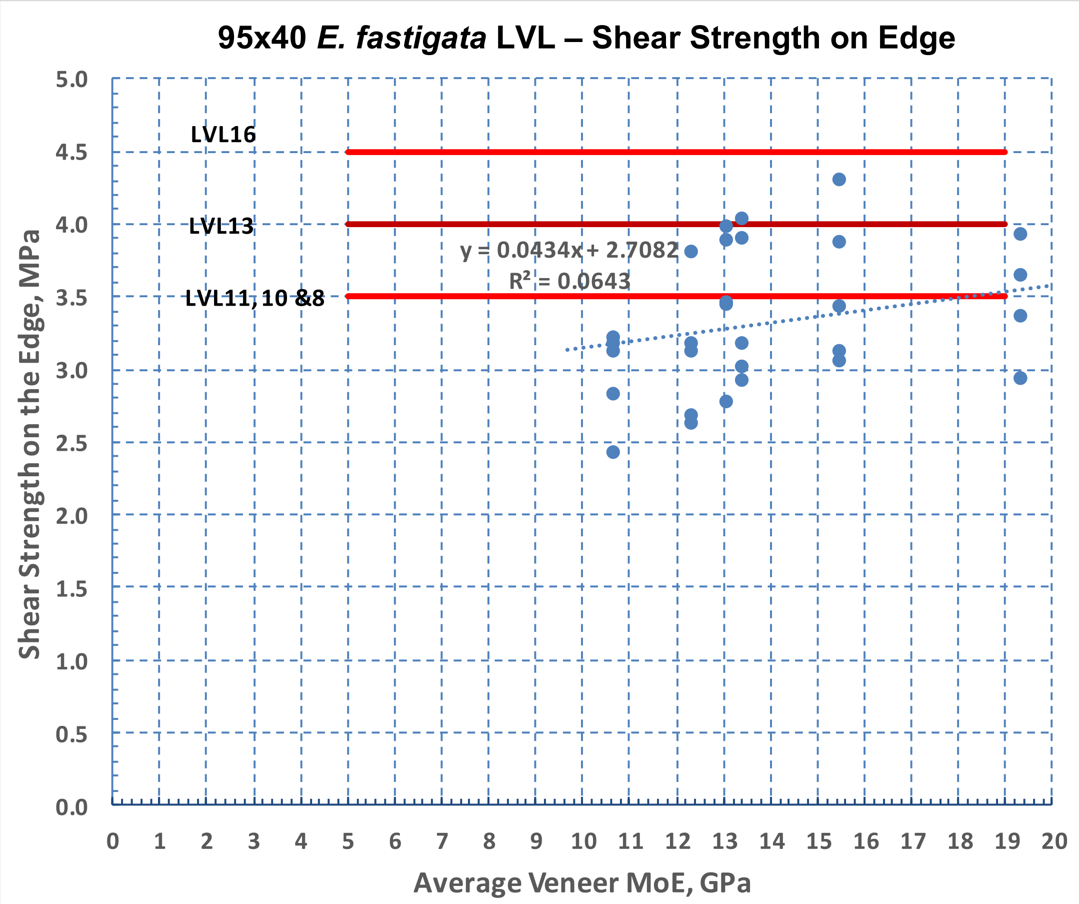

Figure 8. Average Veneer MoE vs Shear strength on edge

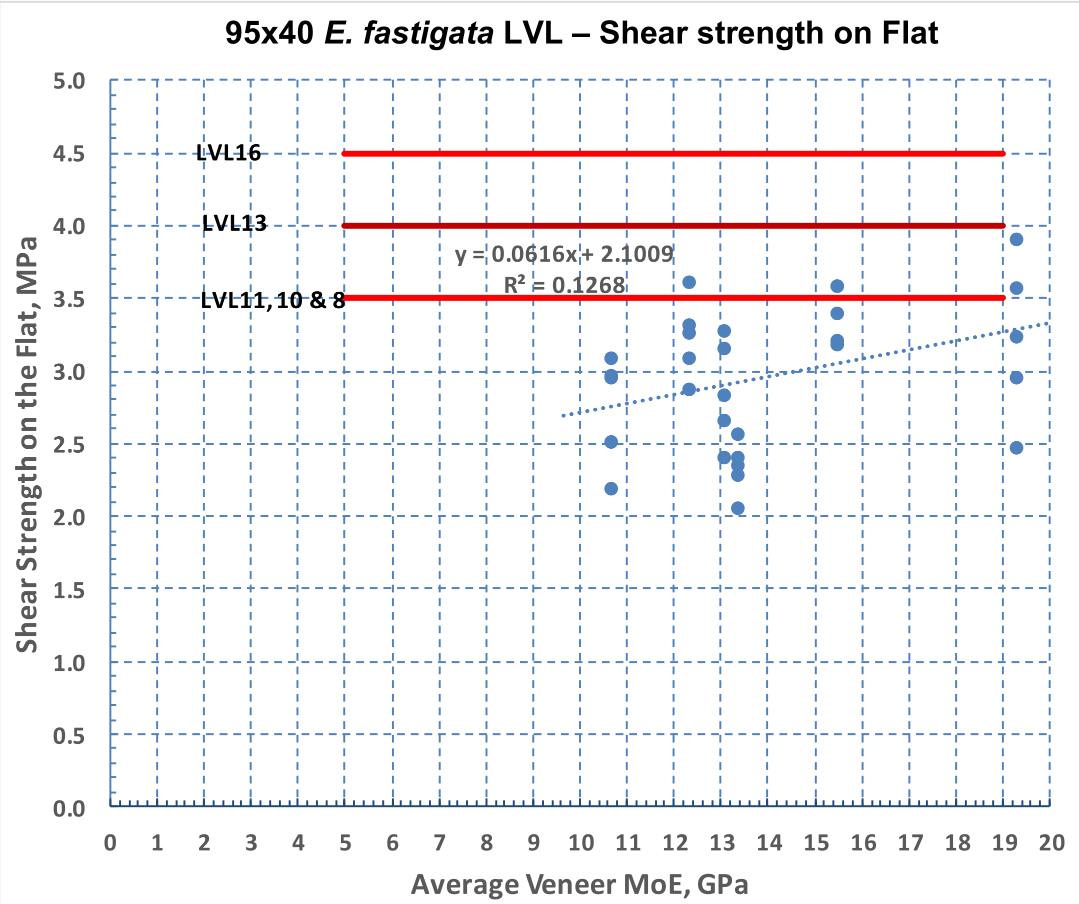

Figure 9. Average Veneer MoE vs Shear strength on the flat

Inspection of the Shear test specimens

The following Figure 10 from a shear on the flat specimen shows the patchy nature of the glue bond applied to the face of the veneers, the glue appears as a series of blobs rather than being evenly spread over the surface. Increasing the spread rate of glue would possibly have reduced this issue (B. Smith, *pers. comm.*).

Figure 10. Poor glue spread on veneers

This should have negatively impacted the shear on the flat results however the magnitude of this effect is difficult to assess.

The following Photo 2 from a shear on the edge specimen the glue dripping into the cracks in the LVL, if there were no cracks the glue lines would just appear as a series of lines.

Figure 11. Evidence of splits within the veneers

As noted earlier cracks would negatively impact the shear on the edge results however the magnitude of this effect is difficult to assess.

SECONDARY SHEAR INVESTIGATION.

Following discussion in was agreed that small shear exploratory trail be undertaken, the goal of trial was to make 'perfect' LVL to understand whether or not fastigata has a shear issue. The trial was as follows'

1. Cut flat sawn 3mm thick laminates from the solid wood fastigata held in stock.
2. Laminate using Resorcinol glue to produce five AS.NZS4357 shear flat and five shear edge test specimens

The following Table 6 & 7 show the shear test data for the additional shear tests.

Table 6: *Shear on edge test results*

Lab No:	Client Ref:	Thickness (b): (mm)	Width (d) (mm)	length (l) (mm)	Max load (N)	Shear failure	Shear Stress (MPa)
288109	1.00	31.59	54.88	299	84243	yes	8.65
288110	2.00	31.61	54.93	300	91820	yes	9.39
288111	3.00	31.74	54.95	300	104731	yes	10.67
288112	4.00	31.51	54.96	300	80684	yes	8.28
288113	5.00	31.58	55.08	300	58804	yes	6.02

Table 7: *Shear on flat test results*

Lab No:	Client Ref:	Thickness (b): (mm)	Width (d) (mm)	Length (l) (mm)	Max load (N)	Shear failure	Shear Stress (MPa)
288114	1.00	31.57	54.29	300	66621	yes	6.83
288115	2.00	31.75	54.80	300	59658	yes	6.08
288116	3.00	31.66	54.83	299	82890	yes	8.50
288117	4.00	31.79	55.28	299	91886	yes	9.38
288118	5.00	31.78	54.79	300	81154	yes	8.26

Comparing Tables 6 & 7 to Table 4 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*.

CONCLUSIONS

The production of LVL from *E. fastigata* veneers worked well in terms of mill production, with only minor adjustments required to the typical radiata pine parameters (e.g. conservative press schedule to prevent blowouts). There were potentially some issues with veneer splitting and bonding quality, but it is likely that further refinement of the process would overcome these.

The key results from the mechanical testing are as follows:

- Accurate measurement of veneer stiffness is very good predictor of final bending stiffness as indicated by an R^2 of 0.8431.
- Veneer stiffness is not that reliable in predicting the strength properties.
- Based on bending stiffness, bending strength, tension and compression strengths (excluding shear) it is estimated that the 95x40 *E. fastigata* LVL would produce 30% LVL 16 and 70% LVL13. Radiata pine LVL commonly falls into LVL8, 10, 11 & 13 grades
- The bending, tension and compression strengths exceed the characteristic grade values.
- As noted earlier the shear strengths in both orientations fall below the characteristic grade values, the issue needs further exploration as it could be a function of multiple handling and drying the veneers have been exposed to resulting in some veneer degradation or it could be a characteristic of *E. fastigata* LVL.
- The secondary shear investigation informs us that it should be possible to achieve the LVL shear properties in *E. fastigata.*

Overall, this study has shown that it is possible to produce high stiffness veneers and LVL from *E. fastigata* using existing production facilities in New Zealand. There are some outstanding issues around veneer splitting and shear strength properties of the LVL. It is likely that these were exacerbated by the conditions required in the trial (repeated manual handling of veneers, multiple drying cycles, and likely over-drying), so further work would be required to understand the extent of these issues under normal production conditions.

ACKNOWLEDGEMENTS

Jamie Agnew, Bruce Davy and Robin Parr assisted with the veneer sorting and drying. Ross Anderson (Scion) assisted with developing the LVL production trial plan. Brendan Smith, Chris Wenden and Mark Orange at JNL assisted with planning the LVL production trial. Terri Forlong from Hexion assisted with the LVL production trial.

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APPENDICES

Appendix 1: Trial plan

E. fastigata **LVL MILL TRIAL – JNL, Wairarapa**
April 2021

AIM

To produce a single press load of 45mm thick LVL from existing *Eucalyptus fastigata* veneers. LVL with a range of mechanical properties (stiffness) will be produced by selecting veneers from known log stiffness classes. Products will be used for mechanical and durability testing at Scion.

ACHIEVEMENTS

10 – 20 panels of 1.2 x 2.4 m LVL, produced from veneers of known log stiffness classes (Scion to supply veneers in correct order for layup). Panels ripped into 45x93mm LVL.

DATE

22-April 2021. The veneer will need to be redried at Scion for around 1 week immediately prior to the trial.

PRODUCTS

45x93 mm structural LVL, ripped to width but not moulded.

DOCUMENTATION

Gluing performance report for *E. fastigata* veneer from Hexion (SWP-T103).

TRIAL STEPS

Veneer drying

Veneers will be supplied dried to ~ 3% MC by Scion

Glue mixing

JNL to provide their standard adhesive. This is Hexion “Tolerant A bond plywood resin”, as specified in Hexion report SWP-T103.

No glueline treatment to be used.

Lay up

4 types of veneer will be used for lay-up. These are veneers from low, medium and high density logs as well as six charges of veneers with individually measured stiffnesses. Veneers are colour-coded by group, and Panels will be made exclusively from a single colour code. Veneers with the individual measurements will be laid-up at Scion; all other veneers will be laid-up on-site.

Around 250 veneers are available in total, i.e. a maximum of 20 11-ply panels can be produced.

Glue spread is 180gsm, as recommended by Hexion

Pressing

The following press schedule will be used

- Veneer MC 3 – 4%
- Glue spread 180gsm
- Open Assembly Time: 10 minutes
- Cold Press Time: 10-15 minutes
- Cold Press Pressure: 9kgf/cm2
- Closed assembly Time: 10 minutes
- Hot Press Temperature: 150°C

- Hot Press Time: 28 minutes (measure centre glue line temperature, ensure it reaches 100°C)
- Hot press pressure: 12kgf/cm2
- Hot press low pressure time: 3 minutes

This is a conservative schedule to ensure sufficient curing time and to reduce the risk of steam blows.

Cutting

Panels to be ripped to 93 mm wide. No moulding. No docking of panel ends (this would remove colour coding).

Transport

Identify/hold stickers on trial packs for shipment to Rotorua.

Scion to organise shipping if required.