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EMBEDMENT STRENGTH OF LVL AND CROSS-BANDED LVL MANUFACTURED FROM BLENDING HARDWOOD AND SOFTWOOD SPECIES

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Abstract: *This paper experimentally evaluates the embedment strength of Laminated Veneer Lumber (LVL) and cross-banded Laminated Veneer Lumber (LVL-C) manufactured from blending spotted gum (Corymbia citriodora subsp. variegata - SPG) veneers with hoop pine (Araucaria cunninghamii - HP) veneers. Nominal 3.0 mm thick veneers were rotary peeled from small diameter (less than 30 cm) native forest sourced SPG logs and commercial plantation grown HP logs. For each species, the veneers were classified into three grades based on their dynamic Modulus of Elasticity (MOE). Six LVL and four LVL-C panels (1.2 m × 0.9 m × 12-ply) were manufactured using four different construction strategies by mixing (i) the number of veneers from each species, (ii) the veneer grades and (iii) the veneer orientations (cross-banding). A total of 240 embedment tests, using three different dowel diameters, were performed using the half-hole test method described in the ASTM D5764-97a. This paper compares (i) the proportional limit strength, 5%-offset embedment strength and maximum embedment strength across the different construction strategies adopted in the study and (ii) discusses the results in terms of load-to-grain angle and dowel diameter. The test results are also compared to the embedment strength prediction equations detailed in the Eurocode 5 to determine their suitability for mixed species LVL products. Overall, the mixed species LVL and LVL-C showed significantly higher embedded strengths than only softwood LVL products. LVL-C samples exhibited a very ductile behaviour for all load-to-grain angles and dowel diameters.*

Keywords: Cross-banded Laminated Veneer Lumber, Embedment strength, Mixed-species LVL

1. INTRODUCTION

Connections with dowel-type fasteners are very common in timber structures and are generally deemed to be the weakest link of the structures (Leijten 1993). These types of connection can either fail in a ductile manner, a brittle manner or a combination of both (Habkirk 2006; Quenneville and Mohammad 2000; Quenneville 2008). To estimate their ductile failure capacity, the European Yield Model (EYM) (Johnsen 1949) forms the basis of the prediction equations in standards, such as the Eurocode 5 (Bristish Standard 2004)and the North American standard (AF&PA 2005), and is considered to be an accurate model (Franke and Quenneville 2011). In this model, the embedment strength is one of the key input parameters to determine the overall connection capacity and is related to the capacity of wood or wood-based products to resist the load induced by a rigid fastener.

The estimation of the embedment strength of various timber species, wood products and fastener types has been extensively studied (Ehlbeck and Werner 1992; Hirai 1989; Hübner 2008; Larsen 1973; Whale et al. 1989; Whale et al. 1986; Wilkinson 1991). This led to various forms of empirical equations been developed. Specifically, Wilkinson (1991) derived equations for the 5% offset bolt diameter embedment strength (ASTM 2013) based on the timber specific gravity and fastener diameter (bolt and nail) from tests performed on seven softwood species and load-to-grain angles of 0^0 (parallel to grain) and 90^0 (perpendicular to grain). These equations were incorporated into the 1997 Edition of the North American National Design Specification for timber construction (NDS) (AF&PA 1997) with a few modifications (Awaludin et al. 2007). Ehlbeck and Werner (1992) proposed equations, for bolts up to 30 mm in diameter, derived from embedment tests performed on European softwood and hardwood species at load-to-grain angles α of 0^0, 30^0, 45^0, 60^0 and 90^0. These equations were adopted in the current version of the Eurocode 5 (Bristish Standard 2004) as stated by Zhou and Guan (2006). In these equations, the embedment strength is evaluated from the characteristic timber density, load-to-grain angle and fastener diameter. Zhou and Guan (2006) found significant discrepancy between the embedment strength predictions between different published models, including above ones.

On the other hand, Laminated Veneer Lumber (LVL) and cross-banded Laminated Veneer Lumber (LVL-C) are increasingly been used in structural engineering due their high strength and low variability in material properties allowing longer spans than solid wood products (Stark et al. 2010). A number of studies verified the applicability of the aforementioned empirical equations to LVL and LVL-C (Bader et al. 2016; Franke and Quenneville 2011; Schweigler et al. 2016; Smith et al. 2006). Specifically, Franke and Quenneville (2011) reported that the experimental embedment strength of Radiata Pine LVL, obtained by the 5% offset bolt diameter method and derived from tests performed at various load-to-grain angles and bolt diameters, are close to the strength predictions in the Eurocode 5 (Bristish Standard 2004). They proposed an adjustment to the Eurocode 5 equations based on the experimental results. These results were also confirmed by Schweigler et al. (2016) which found that the embedment strength prediction in the Eurocode 5 approximated well experimental results (with the strength calculated at a 5 mm dowel displacement) carried out on spruce LVL. However, for load-to-grain angles up to 60^o, a 17% overestimation was observed. Likewise, Bader et al. (2016) showed a very good agreement between the experimental embedment strength values of spruce LVL (at load-to-grain angles of 0^0, 45^0 and 90^0 and 5 mm dowel displacement) and predicted values obtained from the Eurocode 5 using the LVL mean density as input value. Regarding LVL-C, very few studies are available on the embedment strength of this product. Kobel et al. (2014) investigated the embedment strength of beech LVL and LVL-C following the tensile test method in the Bristish Standard (2007). They concluded that the Eurocode 5, using the average density of the LVL-C in the equations, underestimates the experimental embedment strength of the LVL-C by up to 7%. The LVL-C showed a more ductile behaviour than the LVL.

However, while the embedment strength of laminated veneer lumbers has been investigated in the literature, it has been limited to single-species products, and investigations on LVL-C are scarce. The extent to which the embedment strength design equations in international design specifications are applicable to mixed-species LVL and LVL-C (i.e. manufactured from blending different wood species) has not been looked at. As such, the key objective of this work is to experimentally evaluate the embedment strength and behaviour of mixed-species LVL and LVL-C, both manufactured from Spotted gum (*Corymbia citriodora subsp. variegate* - SPG) and Hoop pine (*Araucaria cunninghamii* - HP) veneers. These test results would both form essential data to verify the accuracy of the embedment strength design equations in international design specifications and serve as benchmark data for numerical models. In this paper, embedment tests have been performed at load-to-grain angles α of 0^0, 30^0, 60^0 and 90^0, with dowel diameters of 12 mm, 16 mm and 20 mm, on three different types of mixed-species LVL and LVL-C samples and one HP LVL for comparison purposes. First, this paper presents the different construction strategies used in the manufacturing of the samples and the test methodology. Second, the test results are discussed in terms of the slip modulus, the proportional limit strength, 5%-offset embedment strength and maximum embedment strength.

Finally, the experimental embedment strength results are compared to the prediction equations in the Eurocode 5.

2. MATERIALS AND METHODS

2.1. Construction strategies (Material)

In total, six 12-ply LVL and four 12-ply LVL-C panels were manufactured from blending spotted gum (SPG) with hoop pine (HP) veneers (Table 1). The veneers were nominal 3.0 mm thick and rotary peeled from small diameter (less than 30 cm) native forest sourced SPG logs and commercial plantation grown HP logs. Four different construction strategies, derived from the optimisation model described in Nguyen et al. (2018), were used to manufacture the panels. The strategies uses the veneer grades defined in Nguyen et al. (2018) and which are solely based on the value of the veneer dynamic Modulus of Elasticity (MOE). These grades are referred to as “Low”, “Medium” and “High” and are termed “H_L”, “H_M” and “H_H” for the SPG hardwood species and “S_L”, “S_M” and “S_H” for the SP softwood species (Nguyen et al. (2018)). The construction strategies are given in Fig.1 and are:

- Strategy LVL_1 consists of a reference LVL only manufactured from HP veneers, all veneers with a dynamic MOE greater than 13.1 GPa (high grade).
- Strategy LVL_2 consists of mixed-species LVL with veneers of different grades.
- Strategy LVLC_1 consists of mixed-species LVL-C with two HP cross-banded veneers and two high graded (MOE ≥ 23.7 GPa) SPG veneers on each face.
- Strategy LVLC_2 is similar to LVLC_1 but with different graded veneers.

LVL_2 and LVLC_2 were manufactured from the exact same veneer sheets (cut in two) to compare the performance of mixed-species LVL to mixed-species LVL-C. Note that three different panels were planned to be manufactured for each construction strategy, however, two panels (one for Strategy LVLC_1 and one for Strategy LVLC_2) experienced gluing problems during the manufacturing process and were disregarded.

2.2. Test Samples and Test Set-up

24 test samples were cut from each panel to assess the embedment strength under load-to-grain angles α of 0^o, 30^o, 60^o and 90^o, and three different dowel diameters of 12 mm, 16 mm and 20 mm. The test set-up is illustrated in Fig. 2 and follows the half-hole embedment strength recommendations in the ASTM (2013). Tests were repeated twice per configuration and panel. All specimens had nominal height and width of 85 mm and 120 mm, respectively, to comply with the recommendations in the ASTM (2013). A half-hole of diameter equal to the diameter of the investigated dowel was drilled in the middle of one of the 120 mm edges, as shown in Fig. 2(a). A steel dowel was positioned in the half-hole and driven in displacement control, at a rate of 1.0 mm/min, using a 100 kN capacity INSTRON 5980 universal testing machine. The bottom of the samples was positioned on a fixed platen while a steel block was positioned on top of the dowel and loaded through a top platen (Fig.2(b)) mounted on a spherical seat so as to apply a uniform pressure to the dowel. The dowel displacement relative to the bottom platen was recorded as the average of two laser transducers, symmetrically positioned on each side of the sample, and attached to the bottom platen. Two aluminium plates were glued to the dowels and offered flat targets to the transducers, as shown in Fig. 2(c). The tests were stopped when either brittle failure occurred, and the load dropped significantly or when the dowel displaced by 8 mm, whichever comes first. High strength steel dowels (Grade 8.8) were used.

All specimens were conditioned at 20°C and 65% relative humidity before testing. Selected samples were weighted immediately after testing to determine the moisture content at the time of testing following the oven dry methodology specified in the Australian and New Zealand standard AS/NZS 1080.1 (AS/NZS 2012). The number of tested specimens, measured average moisture content and measured average density of all construction strategies, are given in Table 1.

Table 1: Number of panels and tested samples, moisture content and density of all construction strategies

Group name	No. of Panels	No. of specimens	Average moisture content (%)		Average density (kg/m3)	
			Mean	COV	Mean	COV
LVL_1	3	72	13.5$^{(1)}$	2.7%	628$^{(2)}$	2.6%
LVL_2	3	72	12.5$^{(1)}$	3.3%	780$^{(2)}$	1.5%
LVLC_1	2	48	12.5$^{(1)}$	1.7%	778$^{(2)}$	1.8%
LVLC_2	2	48	12.5$^{(1)}$	2%	770$^{(2)}$	2.1%

$^{(1)}$: Moisture content measured on 12 samples for each strategy.

$^{(2)}$: Density measured on all samples of each strategy.

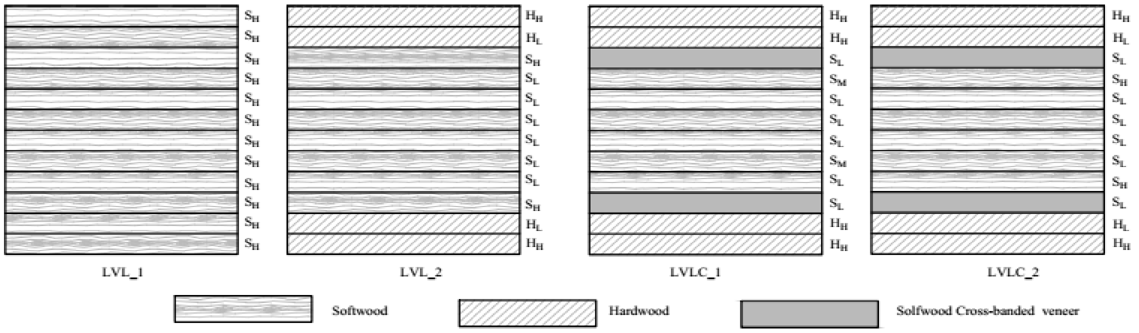

Figure 1. Construction strategies of LVL and LVL-C (Note that for each species, the grades are referred to as "Low", "Medium" and "High". They are termed "H_L", "H_M" and "H_H" for the SPG hardwood species and "S_L", "S_M" and "S_H" for the SP softwood species Nguyen et al. (2018)).

2.3. Evaluation Method

For each test, the load-displacement curve is used to evaluate the following characteristics (ASTM 2013), also summarised in Fig 3:

- The stiffness or slip modulus K, defined as the slope of the linear part of the curve and calculated herein between 15% and 40% of the maximum load.
- The proportional limit load F_{prop}, defined as the point when the load-displacement curve deviates from the initial linear (elastic) portion of the curve.
- The maximum load F_{max} corresponding to either the ultimate load or the load at a displacement of 5 mm, which comes first.
- The yield load $Fe_{5\%}$ corresponding to the load at which a line of stiffness K and offset by 5% of the bolt diameter from the linear part of the load-deformation curve intersects this curve. Note that $Fe_{5\%}$ is taken herein as the maximum load F_{max} if the yield load is found at a displacement greater than the one corresponding to F_{max}.

The yield proportional limit $f_{h,prop}$, the 5%-offset embedment strength $f_{h,5}$ and the maximum embedment strength $f_{h,max}$ are reported herein and calculated from F_{prop}, $Fe_{5\%}$ and F_{max}, respectively, and the measured thickness of the samples and dowel diameter.

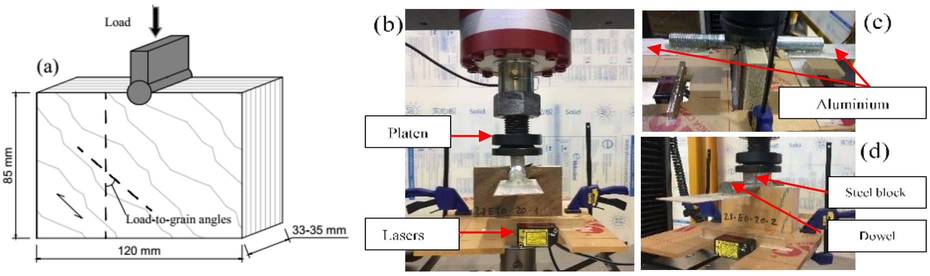

Figure 2. Test set-up (a) schematic view and (b-d) photos

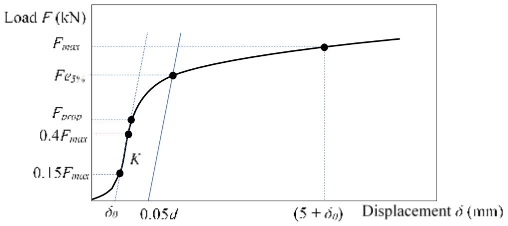

Figure 3. Evaluation methods for embedment strength

3. RESULTS AND DISCUSSION

3.1. Test results

3.1.1. Load-displacement curves

Fig.4 presents typical load-displacement curves for the four groups of LVL and LVL-C, a 12 mm diameter dowel, and all investigated load-to-grain angles. Generally, the load-displacement curves presented different behaviours relative to the load-to-grain angles, dowel diameters and construction strategies:

- For the HP only LVL (LVL_1), two main load-displacement behaviours were observed (Fig. 4(a)): (i) for α = 0^o and 30^o, the curves show an almost perfectly elasto-plastic behaviour with the plastic load being of the same order of magnitude for the two values of α, and (ii) for α = 60^o and 90^o, a linear hardening is encountered after the elastic region, with the hardening being more pronounced for α = 90^o. Such behaviour were also observed in Hwang and Komatsu (2002) and Franke and Quenneville (2011).
- For mixed-species LVL (LVL_2) in Fig. 4(b), a different behaviour to LVL_1 was observed. The load-displacement curves typically reached a plateau for all load-to-grain angles and dowel diameters until sudden failure eventually occurred with various ranges of plastic deformations. Larger plastic deformations were observed for α = 60^o and 90^o than for α = 0^o and 30^o.
- The LVL-C specimens showed a very ductile behaviour (Fig 4(c-d)) and their performance was dependant on the load-to-grain angle. For α = 0^o and 30^o, after reaching the maximum load, the load was observed to decrease almost linearly while for α = 60^o and 90^o, a perfect plastic behaviour was somewhat noticed.

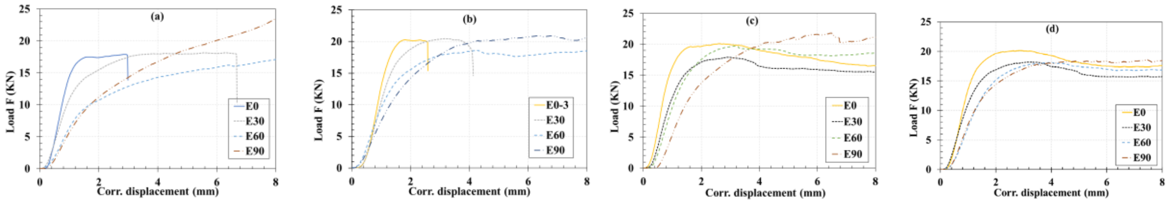

Figure 4. Typical load-displacement curves for a 12 mm diameter dowel (a) LVL_1, (b) LVL_2, (c) LVLC_1 and (d) LVLC_2.

3.1.2. Embedment Strength Results

Table 2 provides the average embedment stiffness and strength values (out of four to six tests per construction strategy) for each dowel diameter, load-to-grain angle and construction strategy. The following remarks can be drawn from the table:

- For LVL-C, the average stiffness value for all dowel diameters and $\alpha = 0^o$ was 31%, 56% and 63% higher than the one for load-to-grain angles $\alpha = 30^o$, 60^o and 90^o, respectively. Due to the anisotropic material properties, these values became 33%, 71% and 92% for the LVL. A similar trend was also reported in Franke and Quenneville (2011) for radiata pine LVL samples.
- Typically, the 5%-offset embedment strength $f_{h,5}$ and maximum embedment strength $f_{h,max}$ decreased with increasing load-to-gran angle. The maximum embedment strength $f_{h,max}$ was less dependent on the value of the load-to-grain angle than $f_{h,5}$. To illustrate, the average value of $f_{h,5}$ decreased by 19.7% between $\alpha = 0^0$ and 90^o for LVLC_1 and a 16 mm dowel whereas $f_{h,max}$ only decreased by 13.7%.
- The 5% offset embedment strengths for $\alpha = 60^o$ and 90^o were typically within 5% of each other for all dowel diameters.
- The average embedment strengths $f_{h,5}$ and $f_{h,max}$ of mixed-species LVL (LVL_2) were observed to be 20% and 12% higher on average than the ones of the HP only LVL (LVL_1), respectively. The embedment strengths of mixed-species LVL were found to be typically of the same order of magnitude of the embedment strengths of LVL-C, which is contradictory to the study by Kobel et al. (2014) carried out on tensile embedment tests.
- For all investigated configurations, the embedment strengths were typically higher for samples tested with a 16 mm dowel than for samples tested with either a 12 mm or 20 mm dowel. The lowest embedment strengths were generally encountered for the 20 mm dowel, which agrees with result in Franke and Quenneville (2011).
- For all bolt diameters, loading angles and construction strategies, the average ratios $f_{h,5}/f_{h,prop}$ and $f_{h,5}/f_{h,max}$ were 1.71 and 1.90, respectively.
- The COV corresponding to the yield proportional limit $f_{h,prop}$ can be large (up to 20.3%) due to the nature of this criteria in which the point when the load-displacement curve deviates from the initial linear region may vary significantly from one curve to another.

3.2. Eurocode 5 predictions

Table 2 includes a comparison of the mean test values with the predicted embedment strength $f_{h,EC}$ using Equations (8.31) to (8.33) of the Eurocode 5 (Bristish Standard 2004). The embedment strength $f_{h,EC}$ at a load-to-grain angle α is calculated as,

$$f_{h,EC} = \frac{f_{h,0,k}}{k_{90}\sin^2\alpha + \cos^2\alpha} \qquad (1)$$

where the characteristic embedment strength $f_{h,0,k}$ at a load-to-grain angle $\alpha = 0^o$ is obtained as,

$$f_{h,0,k} = 0.082(1-0.01\mathrm{d})\rho_k \qquad (2)$$

and k_{90} for LVL as,

$$k_{90} = 1.30 + 0.015d \qquad (3)$$

In Equations (2-3), d is the dowel diameter (in mm), ρ_k the characteristic timber density (in kg/m^3). For comparison purpose in Table 2, the average densities values reported in Table 1 for both LVL and LVLC samples were used as input value for ρ_k in Equation (2). Table 2 shows that:

- For all load-to-grain angles and a 16 mm dowel diameter, the Eurocode 5 equations typically underestimate the 5%-offset embedment strength $f_{h,5}$ (by up to 14.5%).
- For the 12 mm and 20 mm dowels, for load-to-grain angles of α = 0^o and 30^o, $f_{h,5}$ was found to be up to 23% and 17% lower than the estimated embedment strength $f_{h,EC}$, respectively. Similarly, for load-to-grain angle of α = 90^o and a 20 mm dowel diameter, $f_{h,5}$ is up to 18% lower than $f_{h,EC}$.
- The experimental embedment strengths for the HP only LVL (LVL_1) are closer to the predicted values given by Eurocode 5 than the ones for mixed-species LVL (LVL_2) with the average difference being 3.2% for the former and and 5.0 % for the latter. For the mixed-species, the average difference between the experimental 5% offset embedment strength $f_{h,5}$ and the estimated embedment strength $f_{h,EC}$ is about 3%.

Table 2: Test results for all tested configurations

Group	***d* *(mm)***	**α (º)**	**Stiffness (kN/mm)**	**$f_{h,prop}$ (MPa)**		**$f_{h,5}$ (MPa)**		**$f_{h,max}$ (MPa)**		**$f_{h,EC}$ *(MPa)***	**$f_{h,5}/f_{h,prop}$**	**$f_{h,max}/f_{h,prop}$**	**$f_{h,EC}/f_{h,5}$**
				Mean	**COV**	**Mean**	**COV**	**Mean**	**COV**				
LVL_1	12	0	20.59	31.4	3.5%	43.1	3.3%	43.8	4.3%	45.3	1.40	1.39	1.05
		30	14.34	20.8	5.9%	36.1	3.5%	43.0	4.1%	40.5	1.70	2.07	1.12
		60	9.70	16.4	5.3%	27.6	4.6%	37.6	3.5%	33.3	1.70	2.29	1.21
		90	7.28	17.6	9.3%	29.0	9.1%	40.9	9%	30.6	1.60	2.32	1.06
	16	0	28.96	29.1	18.4%	50.5	4.9%	50.9	4.6%	43.3	1.70	1.75	0.86
		30	21.16	21.5	4.1%	39.4	5.0%	46.1	4.7%	38.1	1.80	2.14	0.97
		60	12.12	16.4	4.4%	29.7	5.9%	36.9	5.5%	30.8	1.80	2.25	1.04
		90	9.48	15.7	9.7%	28.3	7.5%	36.9	9.9%	28.1	1.80	2.35	0.99
	20	0	33.38	31.3	8.8%	38.3	5.3%	38.3	5.3%	41.2	1.20	1.22	1.08
		30	23.78	21.5	10.3%	32.7	5.8%	33.6	7.6%	35.8	1.50	1.56	1.09
		60	16.18	15.6	11.5%	29.1	6.3%	32.0	8.4%	28.4	1.90	2.05	0.98
		90	11.56	14.5	4.1%	27.1	5.3%	33.3	5.5%	25.7	1.90	2.30	0.95
LVL_2	12	0	23.76	33.2	7.3%	47.1	3.5%	47.2	3.3%	56.3	1.40	1.42	1.20
		30	17.28	27.9	15.1%	45.1	3.7%	47.3	4.4%	50.3	1.60	1.70	1.12
		60	12.53	20.9	7.4%	38.1	3.3%	43.8	3.0%	41.4	1.80	2.10	1.09
		90	9.71	20.5	3.2%	36.9	3.7%	47.7	2.7%	38.0	1.80	2.33	1.03
	16	0	31.51	43.1	13.3%	56.7	2.8%	56.7	2.8%	53.7	1.30	1.32	0.95
		30	23.71	30.3	10.8%	47.2	3.4%	49.0	2.7%	47.3	1.60	1.62	1.00
		60	15.00	20.5	5.2%	40.1	7.7%	44.1	9.2%	38.2	2.00	2.15	0.95
		90	12.26	19.1	4.6%	37.1	2.8%	43.7	3.8%	34.9	1.90	2.29	0.94
	20	0	36.84	37.3	7.3%	41.5	3.6%	41.5	3.6%	51.2	1.10	1.11	1.23
		30	25.91	29.9	8.4%	39.3	4.5%	39.4	4.8%	44.5	1.30	1.32	1.13
		60	17.05	17.2	4.9%	34.3	4.1%	35.1	3.8%	35.3	2.00	2.04	1.03
		90	14.25	16.5	9.6%	34.2	7.5%	36.8	8.5%	32.0	2.10	2.23	0.94
LVLC_1	12	0	25.27	31.7	2.%	49.2	5.4%	50.8	5.6%	56.1	1.60	1.60	1.14
		30	18.54	22.6	11.9%	44.1	7.7%	47.0	6.7%	50.1	2.00	2.08	1.14
		60	14.41	22.5	3.1%	40.8	6.3%	46.5	6.3%	41.3	1.80	2.07	1.02
		90	12.53	22.6	10.7%	40.5	8.2%	50.1	8.3%	37.9	1.80	2.22	0.93
	16	0	31.94	37.2	9.3%	56.7	7.1%	58.5	8%	53.6	1.50	1.57	0.95
		30	24.05	29.8	9.7%	50.1	6.3%	53.5	9.1%	47.2	1.70	1.80	0.94
		60	16.84	21.5	7.9%	41.6	6.8%	45.9	9.4%	38.1	1.90	2.13	0.92
		90	15.78	21.5	7.4%	40.7	5.5%	50.5	7.4%	34.8	1.90	2.35	0.86
	20	0	36.41	37.6	2.5%	46.1	6.1%	46.2	5.8%	51.0	1.20	1.23	1.11
		30	25.87	31.5	15.1%	42.6	9.8%	43.0	8.2%	44.4	1.40	1.37	1.04
		60	20.22	18.5	2.7%	35.6	2.7%	37.4	2.2%	35.2	1.90	2.02	0.99
		90	18.80	17.9	4.9%	37.6	3.6%	40.5	3.7%	31.9	2.10	2.26	0.85
LVLC_2	12	0	22.31	29.4	11.7%	45.7	4.3%	47.9	4.2%	55.6	1.60	1.63	1.22
		30	17.34	22.1	6.3%	42.5	5.2%	46.3	4.6%	49.6	1.90	2.10	1.17
		60	13.00	21.3	3.2%	38.0	5.8%	43.9	5.3%	40.9	1.80	2.06	1.08
		90	12.49	20.2	1.9%	36.9	1.1%	45.7	3.2%	37.6	1.80	2.26	1.02
	16	0	32.93	33.8	10.5%	55.5	3.1%	57.3	2.3%	53.1	1.60	1.70	0.96
		30	23.39	26.2	7.1%	47.1	3.4%	50.9	1.5%	46.8	1.80	1.94	0.99
		60	16.71	21.2	8.5%	40.5	7.4%	44.8	9%	37.8	1.90	2.11	0.93
		90	16.22	19.9	4.8%	38.5	4.9%	45.2	6.5%	34.5	1.90	2.27	0.90
	20	0	32.72	33.9	9.2%	44.0	4.9%	44.1	4.9%	50.5	1.30	1.30	1.15
		30	23.44	25.6	20.3%	40.0	2.2%	40.9	3.2%	44.0	1.60	1.60	1.10
		60	20.32	18.5	9.5%	35.6	5%	36.9	4.2%	34.9	1.90	1.99	0.98
		90	19.05	16.5	4.7%	34.2	5.6%	37.3	6.8%	31.6	2.10	2.26	0.92
										Average	**1.71**	**1.90**	**1.03**
										CoV (%)	**14.82**	**19.68**	**9.7**

CONCLUSION

The embedment strength of mixed-species LVL and LVL-C was investigated in the paper for four different manufacturing strategies, four load-to-grain angles and three dowel diameters. The samples were manufactured from blending native forest sourced spotted gum veneers with commercial plantation grown hoop pine veneers. Results showed that the average 5% offset and maximum embedment strengths $f_{h,5}$ and $f_{h,max}$ of mixed-species LVL (LVL_2) were respectively 20% and 12% superior to the ones of the reference LVL solely manufactured from hoop pine veneers. For all dowel diameters and load-to-grain angles, the load-displacement curves of LVL-C samples showed a more ductile behaviour than the ones of LVL samples. LVL-C samples were observed to fail in only wood fibres crushing, whereas both wood fibres crushing and splitting shear modes were encountered in LVL samples. The embedment strength prediction equations detailed in the Eurocode 5 accurately predicted the experimental 5% offset embedment strength values of mixed species LVL and LVL-C products with an average predicted to experimental ratio of 1.03.

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