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Advancing Timber for the Future Built Environment

Experimental In-Plane Testing of CLT used as Beams and Lintels

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ABSTRACT: The main use of CLT is in floor, wall and roof elements. In these common applications, the load bearing capacity is governed by the "out-of-plane" or "on flat" behaviour of the panels and analytical methods are well-established in the technical literature. Structural lintels, beams, shear walls and floor diaphragms are examples where CLT is loaded "in-plane" or "on edge". The analytical methods for in-plane behaviour are less well-established and performance may vary between manufacturers depending on specific attributes of their products. Compared with other timber products such as glulam or LVL, CLT used in beam applications offers several benefits including improved shear strength, greater resistance to splitting around penetrations and connections, and improved bearing resistance at support. Potential risk areas for in-plane loading of CLT include a comparably lower bending strength which will generally vary between manufacturers. Factors such as lamella thickness and orientation and the strength of different feedstocks are important factors in determining the in-plane strength of CLT and needs to be understood by designers. Greater understanding of the in-plane behaviour of CLT may lead to new market applications for the product in addition to reduced risk of errors in design.

KEYWORDS: timber, CLT, in-plane, beam, lintel, testing

1 – INTRODUCTION

The main use of CLT in building projects is in floor, wall or roof elements. In these applications, the behaviour and load bearing potential of CLT elements is driven by the cross-section stiffness in the out-of-plane direction of the CLT panels in three-layer, five-layer or seven-layer panels.

Situations frequently arise in the design of CLT buildings where the in-plane bending of CLT panels needs to be considered in the design of a structure. Most commonly this occurs where a CLT panel is acting as a beam or lintel. Other situations include CLT in shear walls, floor diaphragm or a wall is acting as a deep beam. In this paper, the focus is on beam and lintel applications typically seen in residential and light commercial applications.

In beam-type, in-plane applications, CLT offers some interesting advantages resulting from its cross-laminated structure including an improved resistance to splitting at supports, around penetrations and connections and improved bearing capacity at supports. While well-established calculation and design methods exist for out-of-plane section properties of CLT which are used for designing walls, floors and roofs, there is comparatively little information available to designers when calculating the in-plane stiffness, bending and shear strength.

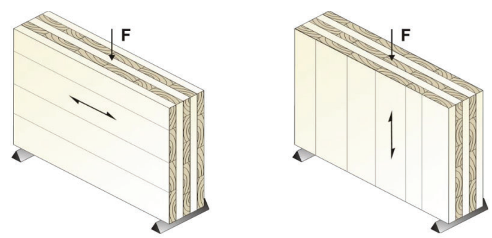

Figure 1 – FP Innovations CLT Handbook 2019 [1]

Due to the typical composition of CLT, the stress state when a CLT is used as a beam is complex and several failure modes need to be considered in the design. Besides the bending stresses, there are three different shear failure modes that need to be taken into consideration [1].

Transverse forces acting in-plane cause shear stresses in the CLT beam cross section. The shear stress distribution can be assumed to be constant over the element thickness. In CLT beams where lamellas within layers are not edge-glued, the thickness is not constant throughout the height of the CLT beam. In cross-sections at unglued joints between the adjacent lamellas, the shear forces can only be transferred by lamellas in the perpendicular direction. Therefore, the shear stresses in the nett cross-sections (at the location of the unglued edge joints) are higher than in the gross cross-sections (between unglued edge joints). The transfer of shear forces between longitudinal and

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transversal lamellas also causes shear stresses in the crossing areas of orthogonally bonded lamellas [6].

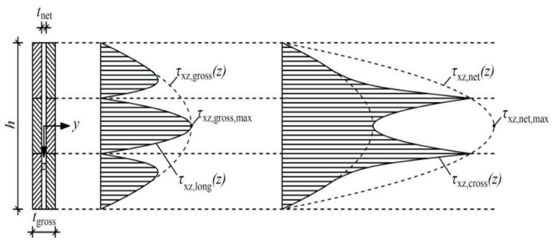

Figure 2 – Distribution of Distribution of shear stresses in the lamellae of a three-layered CLT-beam in cross sections within transversal lamellae: shear stresses $\tau_{xz,long}$ in longitudinal lamellae (left) and shear stresses $\tau_{xz,cross}$ in transversal lamella (right) [6]

By considering the shear stresses in the lamellas and in the crossing areas, three different failure modes exist in CLT beams subjected to shear stresses, as shown below [2], [3].

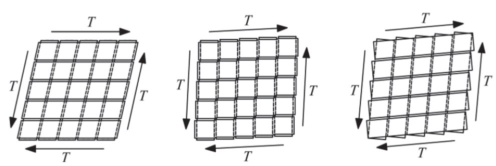

Figure 3 – Failure modes I, II and III in CLT beams subjected to transversal forces in plane direction (from left to right) [6]

Failure mode I is characterised by shear failure parallel to the grain in the gross cross section of a beam. The failure occurs in sections between unglued joints with equal shear stresses in longitudinal layers and transversal layers. Failure mode II is characterised by shear failure perpendicular to the grain in the net cross section of a beam. The failure occurs in sections coinciding with unglued joints with shear stresses only in lamellae perpendicular to the joints. Failure mode III is characterised by shear failure within the crossing-areas between orthogonally bonded lamellae. The failure is caused by torsional and unidirectional shear stresses resulting from the transfer of shear forces between adjacent layers [2],[3].

The purpose of the testing outlined in this paper is to investigate the in-plane failure modes of CLT. Commencing in 2023, XLam has carried out a range of testing both in-house at XLam and Hyne facilities and with external assistance from Griffith University. These tests have included 3- and 5-layer CLT panels (CL3/90 and CL5/140), with depths ranging from 330mm - 450mm, and with outer lamella layers running vertically and horizontally.

A key aim of the current testing has been to identify an approximate limiting span:depth ratio where the failure mode switches from a bending failure to a shear limited failure mode. The testing is also intended to validate calculation methods being developed for bending and shear capacity of XLam CLT to assist structural designers.

2 – METHODOLOGY

Materials:

CL3/90

- External layers: 30 mm thick (XLG1)
- Internal layer: 30 mm thick (XLG2)

CL5/140

- External layers (1 & 5): 32.5 mm thick (XLG1)
- Internal layers (2 & 4): 20 mm thick (XLG2)
- Internal layer (3): 30 mm thick (XLG2)

Table 1 – XLam lamella properties: XLG1 and XLG2

Structural Properties	XLG1	XLG2
Structural Property	External Lamellas	Internal Lamellas
MoE (parallel to grain)	10000 MPa	6000 MPa
Bending Strength (parallel to grain)	17 MPa	10 MPa
Compression Strength (parallel to grain)	18 MPa	15 MPa
Compression Strength (perp. to grain)	10 MPa	8.9 MPa
Tension Strength (parallel to grain)	7.7 MPa	4.0 MPa
Shear Strength (parallel to grain)	2.6 MPa	2.1 MPa
Rolling Shear Strength (perp. to grain)	1.2 MPa	1.2 MPa
Shear Modulus (parallel to grain)	670 MPa	400 MPa
Rolling Shear Modulus (perp. to grain)	45 MPa	29 MPa
Mean density	500 kg/m^3	480 kg/m^3

2.1 4-POINT BENDING TESTS (18×D)

Test Setup:

Two sets of seven beam bending tests with set up in accordance with AS/NZS 4063.1 Section 2.4. Testing was carried out with two different CLT thicknesses (CL3/90 and CL5/140) with outer lamellas horizontal. The failure loads and failure mode type were recorded and bending strength calculated using the AS/NZS 4063.1 method. Load-deflection data was recorded to determine the apparent Modulus of Elasticity (MoE).

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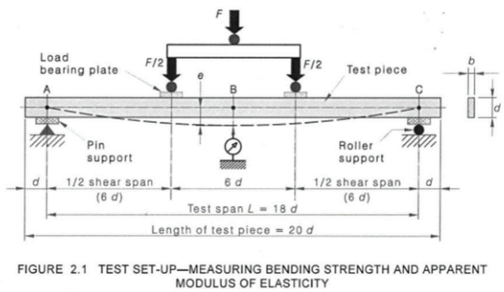

Figure 4 – AS/NZS 4063.1 Section 2.4: 4-point bend test set up

Geometric and Loading Details:

- Span: 5940 mm test span; simply supported
- Depth: 330mm; horizontal outer lamellas

Test samples:

- CL3/90: 330mm deep x 5940mm (7 samples)
- CL5/140: 330mm deep x 5940mm (7 samples)

2.2 3-POINT BENDING TESTS (8×D)

Test Setup:

Four sets of 15 beam shear strength tests with set up in accordance with AS/NZS 4063.1 Section 2.7. Two different CLT thicknesses (CL3/90 and CL5/140) and two different beam depths were tested all with outer lamellas vertical. The failure load and failure mode type were recorded and compared with capacities determined using available calculation methods.

The purpose of this set of tests was to examine the in-plane bending performance of CLT for the critical cases where the outer lamellas are vertical. This is not a preferred configuration from a structural perspective, however it often occurs in CLT designs where large wall panels are adopted that incorporate window and door cutouts.

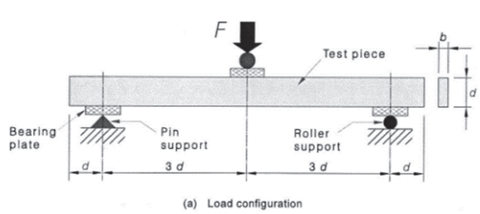

Figure 5 – AS/NZS 4063.1 Section 2.7: 3-point bend test setup

2.2.2 Geometric and Loading Details:

- Span: 2160mm & 2700mm; simply supported
- Depth: 360mm & 450mm; vertical outer lamellas

Test samples:

- CL3/90: 360mm deep x 2160mm (15 samples)
- CL3/90: 450mm deep x 2700mm (15 samples)
- CL5/140: 360mm deep x 2160mm (15 samples)
- CL5/140: 450mm deep x 2700mm (15 samples)

2.3 3-POINT BENDING TESTS (<8×D)

The initial set of 3-point bend tests indicated that the samples were failing in bending and shear failure modes were not being observed. As a result, additional shear tests were carried out for the purpose of determining the approximate span:depth ratio at which shear failure modes become dominant.

Three additional sets (12 samples in each set) were tested following the similar AS/NZS 4063.1 Section 2.7 process but with reduced span:depth ratios of 8:1, 6:1 and finally 4:1. All were CL3/90 panels with horizontal outer lamellas:

- Set 1A (8:1): 360mm deep x 2880mm (12 samples)
- Set 1B (6:1): 360mm deep x 2160mm (12 samples)
- Set 1C (4:1): 360mm deep x 1440mm (12 samples)

3 – STRUCTURAL TESTING

3.1 TEST PROCEDURE

The observed failure loads (F_{ULT}) and corresponding failure mode was recorded. Where data-logging equipment was available for the 4-point bend tests at the Hyne test lab and for 15 samples of the 3-point bend tests carried out by Griffith University, load versus displacement curves were recorded for all test specimens.

AS/NZS 4063.1-2010 Section 2.4.2 was used to calculate the apparent modulus of elasticity for the 4-point bend test samples. The calculated values are based on gross section dimensions.

$$\boldsymbol{E} = \frac{\mathbf{23}}{\mathbf{108}}\left(\frac{\boldsymbol{L}}{\boldsymbol{d}}\right)^{\mathbf{3}}\left(\frac{\Delta\boldsymbol{F}}{\Delta\boldsymbol{e}}\right)\frac{\mathbf{1}}{\boldsymbol{b}}$$

AS/NZS 4063.1-2010 was used to calculate the bending (section 2.4.3) and shear strength (section 2.7) for the test samples. Bending stress and shear strength are again calculated based on gross section properties.

$$f_b = \frac{F_{ULT}\,L}{bd^2} \qquad f_v = \frac{0.75\,F_{ULT}}{b\,d}$$

Apparent Modulus of Elasticity (MoE), bending strength (f_b) and shear strength (f_v) (or shear stress at the point of failure when a bending failure occurs first) were calculated using gross section properties. The reason for using simple gross section properties initially is to establish a baseline performance for in-plane bending of CLT which can later be modified by applying suitable factors to account for nett section and feedstock strength properties.

3.2 RESULTS: 4-POINT BENDING (18×D)

3.2.1 Apparent MoE

Table 2 – Apparent MoE

Sample #	Apparent Modulus of Elasticity (AS 4063.1:2010 – Section 2.4.2)	
	CL3/90 x 330 deep beam test (MPa)	CL5/140 x 330 deep beam test (MPa)
1	7732	7240
2	7398	7493
3	6985	7005
4	6695	7266
5	7191	7316
6	7358	7352
7	7313	7250
Mean.	7240	7270
5th percentile	6630	7000

Figure 6 – 4-point bend test set up

3.2.2 Bending and Shear

Table 3 – CL3/90 x 330mm deep beam (18×D)

Sample	CL3/90 x 330 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	47.3	Bending	70.2	28.6	23.7	1.19
2	39.7	Bending	59.0	24.0	19.9	1.00
3	43.5	Bending	64.6	26.1	21.8	1.10
4	35.7	Bending	53.0	21.7	17.9	0.90
5	32.0	Bending	47.5	19.4	16.0	0.81
6	39.3	Bending	58.4	23.8	19.7	0.99
7	37.8	Bending	56.1	22.9	18.9	0.95
Mean	39.3	-	58.4	23.8	19.7	0.99
5%	31.7	-	47.1	19.3	15.9	0.80

Figure 7 – Typical being failure in bending tests

Table 4 – CL5/140 x 330mm deep beam (18×D)

Sample	CL5/140 x 330 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	54.4	Bending	80.8	21.2	27.2	0.88
2	62.5	Bending	92.8	24.4	31.2	1.01
3	62.6	Bending	93.0	24.4	31.3	1.02
4	83.5	Bending	124.0	32.5	41.7	1.36
5	75.9	Bending	112.7	29.56	37.9	1.23
6	78.7	Bending	116.9	30.7	39.3	1.28
7	68.1	Bending	101.1	26.5	34.0	1.11
Mean	69.4	-	103.0	27.0	34.6	1.13
5%	53.6	-	79.5	20.9	26.8	0.87

Figure 8 – CL5/140 x 330 deep beam (18×D) sample with cracking in internal lamella

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3.3 RESULTS: 3-POINT BENDING (8×D)

3.3.1 Bending and Shear

Table 5 – CL3/90 x 360mm deep (8×D)

Sample	CL3/90 x 360 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	99.5	Bending	53.7	18.4	49.8	2.30
2	64.2	Bending	34.7	11.9	32.1	1.49
3	99.9	Bending	53.9	18.5	50.0	2.31
4	67.9	Bending	36.7	12.6	34.0	1.57
5	61.2	Bending	33.0	11.3	30.6	1.42
6	54.3	Bending	29.3	10.1	27.2	1.26
7	69.3	Bending	37.4	12.8	34.7	1.60
8	72.3	Bending	39.0	13.4	36.2	1.67
9	80.7	Bending	43.6	14.9	40.4	1.87
10	63.7	Bending	34.4	11.8	31.9	1.47
11	47.7	Bending	25.8	8.8	23.9	1.10
12	55.9	Bending	30.2	10.4	28.0	1.29
13	65.6	Bending	35.4	12.1	32.8	1.52
14	64.9	Bending	35.0	12.0	32.5	1.50
15	86.0	Bending	46.4	15.9	43.0	1.99
Mean	70.2	-	37.9	10.5	35.1	1.63
5%	45.9	-	24.8	8.5	23.0	1.06

Table 6 – CL3/90 x 450mm deep (8×D)

Sample	CL3/90 x 450 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	91.4	Bending	45.2	9.9	45.7	1.69
2	106.0	Bending	52.5	11.5	53.0	1.96
3	98.3	Bending	48.7	10.7	49.2	1.82
4	85.3	Bending	42.2	9.3	42.7	1.58
5	103.8	Bending	51.4	11.3	51.9	1.92
6	104.1	Bending	51.5	11.3	52.1	1.93
7	117.0	Bending	57.9	12.7	58.5	2.17
8	97.0	Bending	48.0	10.5	48.5	1.80
9	121.8	Bending	60.3	13.2	60.9	2.26
10	116.4	Bending	57.6	12.6	58.2	2.16
11	84.7	Bending	41.9	9.2	42.4	1.57
12	110.5	Bending	54.7	12.0	55.3	2.05
13	106.0	Bending	52.5	11.5	53.0	1.96
14	107.5	Bending	53.2	11.7	53.8	1.99
15	81.3	Bending	40.2	8.8	40.7	1.51
Mean	102.1	-	50.5	11.1	51.0	1.89
5%	82.5	-	40.8	9.0	41.3	1.53

Figure 9 – Typical failure mode in CL3/90 x 450 deep beam (8×D) sample with vertical outer lamellas

Table 7 – CL5/140 x 360mm deep (8×D)

Sample	CL5/140 x 360 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	104.1	Bending	56.2	12.4	52.1	1.55
2	115.9	Bending	62.6	13.8	58.0	1.72
3	78.3	Bending	42.3	9.3	39.2	1.17
4	56.1	Bending	30.3	6.7	28.1	0.83
5	84.5	Bending	45.6	10.1	42.3	1.26
6	79.5	Bending	42.9	9.5	39.8	1.18
7	104.3	Bending	56.3	12.4	52.2	1.55
8	92.2	Bending	49.8	11.0	46.1	1.37
9	58.0	Bending	31.3	6.9	29.0	0.86
10	54.0	Bending	29.2	6.4	27.0	0.80
11	86.2	Bending	46.5	10.3	43.1	1.28
12	90.1	Bending	48.7	10.7	45.1	1.34
13	97.2	Bending	52.5	11.6	48.6	1.45
14	82.0	Bending	44.3	9.8	41.0	1.22
15	74.2	Bending	40.1	8.8	37.1	1.10
Mean	83.8	-	45.2	10.0	41.9	1.25
5%	54.9	-	29.7	6.5	27.5	0.81

Figure 10 – Bending failure mode in CL5/140 x 360 deep beam (8×D) sample with vertical outer lamellas (view from beam soffit)

Table 8 – CL5/140 x 450mm deep (8×D)

Sample	CL5/140 x 450 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	90.0	Bending	60.8	8.6	45.0	1.07
2	103.7	Bending	70.0	9.9	51.9	1.23
3	92.7	Bending	62.6	8.8	46.4	1.10
4	94.1	Bending	63.5	9.0	47.1	1.12
5	94.1	Bending	63.5	9.0	47.1	1.12
6	85.2	Bending	57.5	8.1	42.6	1.01
7	97.4	Bending	65.7	9.3	48.7	1.16
8	96.0	Bending	64.8	9.1	48.0	1.14
9	124.6	Bending	84.1	11.9	62.3	1.48
10	124.5	Bending	84.0	11.9	62.3	1.48
11	80.3	Bending	54.2	7.6	40.2	0.96
12	69.3	Bending	46.8	6.6	34.7	0.83
13	84.1	Bending	56.8	8.0	42.1	1.00
14	82.7	Bending	55.8	7.9	41.4	0.98
15	111.0	Bending	74.9	10.6	55.5	1.32
Mean	95.3	-	64.3	9.09	47.7	1.13
5%	70.7	-	47.7	6.7	35.4	0.84

3.4 RESULTS: 3-POINT BENDING (<8×D)

3.4.1 Bending and Shear

Table 9 – Set 1A: CL3/90 x 360mm deep (8×D)

Sample	CL3/90 x 360 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	103.0	Bending	55.6	19.1	51.5	2.38
2	102.4	Bending	55.3	19.0	51.2	2.37
3	120.7	Bending	65.2	22.4	60.4	2.79
4	82.4	Bending	44.5	15.3	41.2	1.91
5	88.3	Bending	47.7	16.4	44.2	2.04
6	132.4	Bending	71.5	24.5	66.2	3.06
7	91.2	Bending	49.2	16.9	45.6	2.11
8	77.5	Bending	41.9	14.4	38.8	1.79
9	157.0	Bending	84.8	29.1	78.5	3.63
10	87.3	Bending	47.1	16.2	43.7	2.02
11	102.4	Bending	55.3	19.0	51.2	2.37
12	85.3	Bending	46.1	15.8	42.7	1.97
Mean	102.5	-	55.3	19.0	51.2	2.37
5%	65.5	-	35.4	12.2	32.8	1.51

Figure 11 – Set 1A sample showing bending failure near mid span

Table 10 – Set 1B: CL3/90 x 360mm deep (6×D)

Sample	CL3/90 x 360 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	109.9	Bending	39.6	13.6	55.0	2.54
2	138.3	Bending	49.8	17.1	69.2	3.20
3	139.3	Bending	50.1	17.2	69.7	3.22
4	105.9	Bending	38.1	13.1	53.0	2.45
5	150.0	Bending	54.0	18.5	75.0	3.47
6	120.7	Bending	43.5	14.9	60.4	2.79
7	123.6	Bending	44.5	15.3	61.8	2.86
8	115.8	Bending	41.7	14.3	57.9	2.68
9	137.3	Bending	49.4	17.0	68.7	3.18
10	153.0	Bending	55.1	18.9	76.5	3.54
11	100.1	Bending	36.0	12.4	50.1	2.32
12	137.3	Bending	49.4	17.0	68.7	3.18
Mean	127.6	-	45.9	15.8	63.8	2.95
5%	100.2	-	36.1	12.4	50.2	2.32

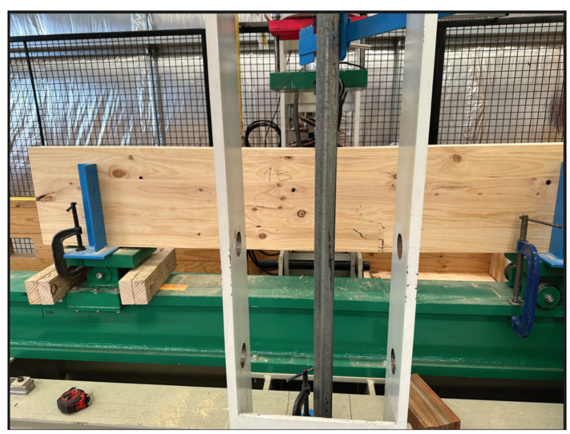

Figure 12 – Set 1B sample showing bending failure near mid span

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Table 11 – Set 1C: CL3/90 x 360mm deep (4×D)

Sample	CL3/90 x 360 deep beam test					
	F_{ult} (kN)	Failure Mode	Moment at failure (kNm)	Bending stress at failure (MPa)	Shear at failure (kN)	Shear stress at failure (MPa)
1	166.8	Shear	39.0	13.4	83.4	3.86
2	215.8	Shear	50.5	17.3	107.9	5.00
3	235.4	Shear	55.1	18.9	117.7	5.45
4	190.3	Shear	44.5	15.3	95.2	4.41
5	180.5	Shear	42.2	14.5	90.3	4.18
6	159.9	Shear	37.4	12.8	80.0	3.70
7	235.4	Shear	55.1	18.9	117.7	5.45
8	191.3	Shear	44.8	15.4	95.7	4.43
9	215.8	Shear	50.5	17.3	107.9	5.00
10	215.8	Shear	50.5	17.3	107.9	5.00
11	201.1	Shear	47.1	16.1	100.6	4.66
12	214.8	Shear	50.3	17.2	107.4	4.97
Mean	201.9	-	47.3	16.2	101.0	4.67
5%	163.1	-	38.1	13.1	81.6	3.78

Figure 13 – Set 1C sample showing shear failure

3.3 KEY OBSERVATIONS

3.3.1 4-Point Bending

The CL3/90 x 330 deep samples showed an average apparent MoE of 7240 MPa. The CL5/140 x 330 deep samples showed a very similar an average apparent modulus of elasticity of 7270 MPa. As noted in the methodology, MoE values are calculated considering gross section properties. All samples in the 4-point bending tests had horizontal outer lamellas.

The 4-point bending samples all failed in bending. Failure usually initiated from a knot or finger joint near the midspan of the beams. In some samples the bending failure was associated with a failure of the internal layer (see Figure 8) in the wood fibre of the first internal lamella adjacent to the glue line. It appears that this may be secondary cracking which occurs after the initial bending failure on the outer lamella as load is re-distributed.

Based on gross section properties: The CL3/90 x 330mm deep samples had a characteristic bending strength of 19.3 MPa. The CL5/140 x 330mm deep samples had a slightly higher characteristic bending strength of 20.9 MPa. Shear stresses were relatively low at the point bending failure occurred.

3.3.2 3-Point Bending (8×D)

All samples in the 8×D 3-point bending tests had vertical outer lamellas. The short span beam tests in AS/NZS 4063.1 (section 2.7) are intended for determining shear strength, however due to the persistence of bending failure modes, gross section bending strength was also calculated at the failure load so results could be compared with the original 4-point bending tests. MoE was not calculated for the 3-point bending tests. At 8×D, all samples failed in bending. The shear stresses present in the beams at the time the bending failures occurred were relatively low for the CL3/90 and CL5/140 thick samples.

As expected, the gross section bending strength of the CL3/90 beams with vertical lamellas was significantly lower than similar samples with horizontal lamellas. The 360mm and 450mm deep samples had gross section characteristic bending strengths of 8.5 MPa and 9.0 MPa respectively. 330mm deep 4-point bending tests with horizontal lamella test samples showed bending strengths of 19.3 MPa. The 360mm deep short span samples (< 8×D also with horizontal lamellas) showed bending strength 12.2 MPa – 13.1 MPa. It should be noted however, that the applied AS/NZS 4063.1 Section 2.4 method for calculating bending strength is not strictly applicable to the short span tests and the calculated bending strength may not be accurate.

Similarly, the gross section bending strength of the CL5/140 beams with vertical lamellas was significantly lower than similar samples with horizontal lamellas. 360mm deep and 450mm deep CL5/140 sample results showed gross section characteristic bending strengths of 6.5 MPa and 6.7 MPa respectively, compared with the 330mm deep CL5/140 horizontal lamella test samples at 20.9 MPa.

3.3.3 3-Point Bending (<8×D)

All short span beam samples were 360mm deep CL3/90 beams with horizontal outer lamellas. The aim of this series of tests was to observe the point at which the dominant failure mode of in-plane loaded beams may switch from bending mode to a shear mode as the span to depth ratio is reduced.

At 8×D and 6×D all samples failed in bending originating at midspan from either a knot or finger joint. At the time of the bending failure, average shear stresses in the beams were 2.37 MPa and 2.95 MPa for 8×D and 6×D samples respectively.

At 4×D the samples all failed in shear. The study by Boggian et al [4] showed similar failure modes in CLT beams tested at similar span to depth ratios. Samples showed significant crushing at the load application point followed by shear failure. The characteristic shear strength for the 4×D samples was 3.53 MPa

For the samples that failed in bending (8×D and 6×D samples), the gross section characteristic bending strengths were similar at 12.2 MPa and 12.4 MPa respectively. For the 4×D samples which failed in bending, 13.1MPa was observed. This may indicate that the 4×D samples were close to failing in bending at the point when shear failure occurred, however as noted earlier, the bending strengths calculated with AS/NZS 4063.1 methods may not be accurate at very short span/depth ratios and 3-point bending. Repeating the bending strength calculation for point load on a simply supported beam instead of the AS/NZS 4063.1calculation gives a bending stress of 18.3 MPa, close to the 19.3 MPa bending strength observed in the 4-point bend test for the similar-sized CL3/90 samples.

3.4 RESULTS DISCUSSION

An increased shear strength is an advantage for timber beams, for example, in beams with large penetrations, locations where higher bearing strength is desirable, an increased resistance to splitting in high shear zones and around connections. With relatively high shear strength compared to bending strength, in many practical cases the in-plane capacity of CLT beams will tend to be limited by bending capacity of the cross section. Bending failures appear to be dominant down to span to depth ratios of approximately 4:1 for the panel types investigated.

The XLam CLT range has lower strength feedstock (XLG2) on the inner lamellas. This will have an effect on the overall strength of the cross section and needs be considered when calculating the in-plane bending strength. Comparing CL5/140 samples with vertical lamellas and horizontal lamellas is an interesting case. Correcting for the nett section geometry and proportioning material strength seems may be necessary to explain the differences between the two orientations. Research Flaig and Blass [3] has shown that the shear strength of a CLT beam is affected not only by the material strength and gross cross section dimensions but also by the ratio of the thickness of the longitudinal and the transversal layers, by the dimensions of the cross-sections of the individual laminations, and by the number of laminations.

After factoring the results for nett section properties in the span direction, the CL3/90 4-point bending strength samples have an approximate characteristic bending strength of 29.0 MPa. This is somewhat higher than XLam XLG1 feedstock characteristic bending strength of 17 MPa. One possible contributing factor may be that the XLG1 is graded using an “on flat” testing method which reflects the major loading direction for CLT walls and floors. In general, timber specimens tested “on flat” tend to have lower strength compared to testing “on edge” that is typical for grading framing timbers for example. Another factor that may contribute to the higher observed strength is the group effect where multiple members in parallel have a strengthening effect (for example AS1720.1 Section 2.4.5). The adjacent transverse layers may also provide a strengthening or load sharing effect which benefits the layers oriented in the span direction. A similar result was noted for the CL5/140 beams.

The beams considered in this study ranged between 330mm and 450mm. This covers a reasonable range of practical situations seen in residential or light commercial CLT projects. In some cases, depths shallower than those tested may occur. XLam is carrying out a range of tests on shallow beams in the range of 200/240/300mm deep to investigate if there is a reduction in bending strength or strength becomes more variable as depth is reduced below a certain level due. This could potentially occur due to strength reducing effect of knots or unglued edge joints becoming more significant as beam size reduces. It should be noted that when CLT beam sections are cut from larger CLT billets, the location of un-glue lamella edge joints is typically not a parameter that can be controlled in production.

The in-plane bending stiffness, bending strength and shear strength will vary between different manufacturers on account of the lamella strength properties and layer thicknesses. The general structural performance for standard CLT layups (3-, 5- and 7-layer panels with alternating lamella orientations) is expected to be similar. The general rules such as those presented in FP Innovations CLT Handbook [1] provide general guidelines.

There are several in-plane shear calculation methods available in the literature. Some of these are relatively

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complex and not straightforward to apply in design. A more user-friendly calculation method for in-plane strength following a similar approach to the AS 1720.1 method for in-plane calculation of plywood (AS 1720.1 Section 5.5) could be a potential approach for the in-plane design of CLT. This approach could be modified to account for variations between different manufacturers by implementing appropriate factors .

4 – CONCLUSIONS

While the main use for CLT is in wall, floor and roof elements where out-of-plane performance is the predominant behaviour, CLT has an opportunity to be applied as beam or lintel elements, taking advantage of high shear and bearing strengths, reasonable stiffness and the ability to leverage production volume capability of CLT manufacturing processes.

This study has aimed to increase understanding of the in-plane behaviour of CLT using a range of 4-point and 3-point bending tests.

Key conclusions for this study include:

- **Stiffness:**
  - For the samples tested CLT beam stiffness can be estimated considering gross section properties and MoE of 7200 MPa.
  - Verifying this figure for other CLT panels such as thicker 5-layer panels and 7-layer panels is recommended.
  - In some applications a more accurate determination of in-plane shear deformation may be required.
- **Bending and Shear Strength:**
  - Outer lamella orientation is critical in calculating bending strength. Generally, vertically oriented lamellas are best to be avoided particularly in 3-layer panels unless the span is short and loading is low.
  - Applying correction factors to the gross section to account for nett section properties in the span direction and proportioning lamella material strengths seems to give a conservative estimate of bending strength when failure stresses are compared to feedstock characteristic strength.
  - Shear strength of XLam CLT beams is relatively high compared to bending strength and would generally not be a limiting factor in many designs. A simple calculation using the gross section and characteristic shear strength determined from testing (3.8 MPa) would appear to give a conservative result. Further testing to confirm that this adequately covers the shear Type III failure mode may be needed.
- **Critical Span to Depth Ratios:**
  - CLT beams with span:depth ratio > 4:1 tend to show a bending failure mode.
  - CLT beams with span:depth ratio < 4:1 tend to show a shear failure mode.
  - The limits are an approximate guide only and based on a relatively limited set of tests. The results may vary for different panel types, lamella orientation and/or different manufacturers. Verifying this figure for other CLT panels such as thicker 5-layer panels and 7-layer panels is also recommended.
- **Future Work:**

XLam is developing a design methodology for the in-plane design of XLam CLT. A strategy under consideration is to apply reduction factors to the gross section to correct for nett section geometry and proportioning of material strengths for the different lamellas. The aim is to develop a calculation approach for the design CLT beams and lintels that is simple to use for designers, gives a conservative strength and stiffness calculation and is consistent with current industry practices in Australia and New Zealand.

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