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PULL-OUT RESISTANCE OF SELF-TAPPING SCREWS IN CROSS-LAMINATED TIMBER MADE FROM RADIATA PINE

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Cross-laminated timber (CLT) is now considered a viable alternative to traditional construction materials both in mid-rise and high-rise structures. The structural response of CLT heavily relies on the type of timber used in manufacturing, and this can vary significantly based on the original source for this naturally grown raw material. Spruce has been widely used in Europe for CLT production, but in Australia, locally available radiata pine is used by XLam for the manufacturing of their CLT panels. Self-tapping screws (STS) are typically recommended by CLT manufacturers and are most commonly used in relevant construction due to their high load carrying capacities and easy installation process. VGS STSs produced by Rothoblaas were used to investigate their composite actions when pulled-out from three-layer XLam CLT panels with thicknesses of 105 mm and 135 mm. VGS screws with 11 mm in diameter were inserted both parallel-to-grain and perpendicular-to-grain on the narrow face of the CLT panels as part of the current study. Typical failure modes as well as critical penetration depths were carefully recorded. Obtained results showed significant increase of pull-out capacity as penetration depths were increased for considered cases. However, experimental results also showed some obvious inconsistencies. These observations clearly demonstrate the challenges associated with working naturally grown fibrous materials and highlights the importance of major research on this field.

Keywords: Failure mode, Loading history, Withdrawal strength, Fibrous materials.

1 INTRODUCTION

Cross-laminated timber (CLT) is a relatively new type of engineered timber product which typically consists of an odd number of wood-based layers that are arranged side-by-side and laminated orthogonally using structural adhesives. As a result of its unique crosswise layups, it has been reported to withstand considerable stresses, both out-of-plane and in-plane, making it suitable for various types of construction, especially for mid-rise and even high-rise structures (Karacabeyli and Douglas 2013). CLT was originally developed in Austria and Germany and has ever since been produced by using European wood species, such as spruce. However, due to its inherent naturally anisotropic characteristics, material properties of timber are strongly dependent on the original source used in manufacturing. In Australia, Radiata Pine (Pinus Radiate D. Don) is planted in various states and is considered the major general-purpose timber (Bootle 1983). XLam are one of the major producers of CLT panels in the Asia-Pacific region, and they are using locally available Radiata Pine to manufacture CLT products in Australia (XLam 2017).

Connections in mass timber construction play an essential role in providing stiffness, stability, strength, and ductility to the structure. In CLT buildings, the structural efficiency largely depends on the fastening systems as well as the connection details used to interconnect individual panels and assemblies (Brandner 2016). Traditional dowel-type connectors, such as bolts, dowels, and nails, can be effectively used in connecting panel elements. Self-tapping screws (STS) are most commonly used in relevant construction due to their excellent structural characteristics and easy installation (Loss et al. 2018).

The load carrying capacity of connections, according to Eurocode 5 (BS EN 1995-1-1, 2004), is defined by the resistance of a single connector loaded either axially (F_{ax}) or laterally (F_v) and by their effective number (n_{ef}) to consider in the case of multi-connectors. Therefore, clear knowledge of the carrying capacity of a single connector is crucial, especially when local species are used in manufacturing. As part of the current ongoing research program, this paper will focus on the pull-out (withdrawal) resistance of STSs inserted in the narrow face of Australian radiate pine CLTs. Typical failure modes as well as critical penetration depths were carefully investigated. Characteristic pull-out resistances and withdrawal strengths were carefully investigated and are reported herein to complement further research in the field.

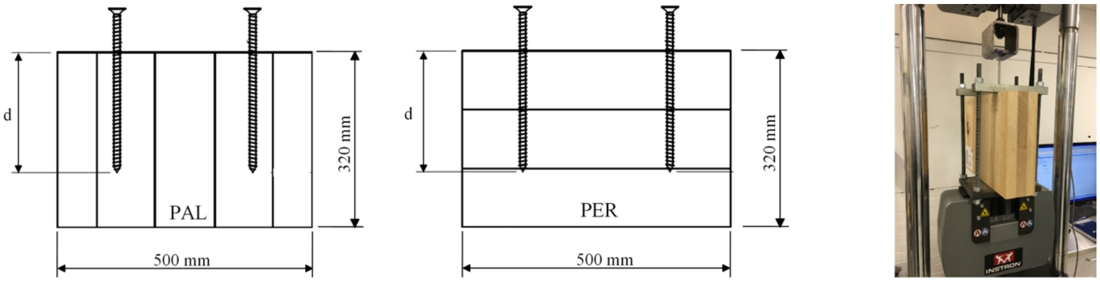
2 EXPERIMENTAL INVESTIGATION

2.1 Material

VGS STSs (11 mm in diameter, VGS11) produced by Rothoblaas were used in the current study. Two types of three-layer XLam commercial CLT panels of 105 mm (CL3/105, 35 mm in each layer) and 135 mm (CL3/135, 45 mm in each layer) thicknesses were used in the testing program.

2.2 Pull-out Testing

The CLT panels were cut into smaller blocks (500 mm x 320 mm). To meet the requirements for minimum spacing, end and edge distance, and other boundary conditions (Ringhofer et al. 2018), two STSs were inserted vertically into the middle layer of each panel based on the panel type, i.e., parallel-to-grain insertion (PAL) and perpendicular-to-grain insertion (PER), as illustrated in Figure 1(a). Detailed sample configurations are shown in Table 1. Designation of samples used in Table 1 refers to panel type—insertion orientation (PAL/PER) and penetration depth.



(a) Sample configuration (b) Test setup

Figure 1. Sample configuration and test setup for pull-out tests.

Samples were centrally placed and fixed by the base rigs; a custom designed bracket was used to connect the screw head and the loading rig, ensuring a precise and effective setup, which is shown in Figure 1(b). Load was introduced by a 100 kN INSTRON universal testing machine with a displacement control at a rate of 0.5 mm/min for all tested samples.

Table 1. Details of test samples.

Sample designation	Penetration depth (mm)	Insertion direction	Number of samples
CL3/105-PER/PAL-100	100	Perpendicular/Parallel	3/3
CL3/105-PER/PAL-150	150	Perpendicular/Parallel	3/3
CL3/105-PER/PAL-175	175	Perpendicular/Parallel	2/2
CL3/135-PER/PAL-100	100	Perpendicular/Parallel	3/3
CL3/135-PER/PAL-150	150	Perpendicular/Parallel	2/2
CL3/135-PER/PAL-175	175	Perpendicular/Parallel	1/1

3 RESULTS AND DISCUSSION

Key results obtained from tested specimens are summarized in Table 2. F_{max} is the maximum load recorded from the testing machine. f_{max} is the maximum stress at failure obtained by

$$f_{ax} = \frac{F_{ax}}{d \cdot \pi \cdot l_{ef}} \tag{1}$$

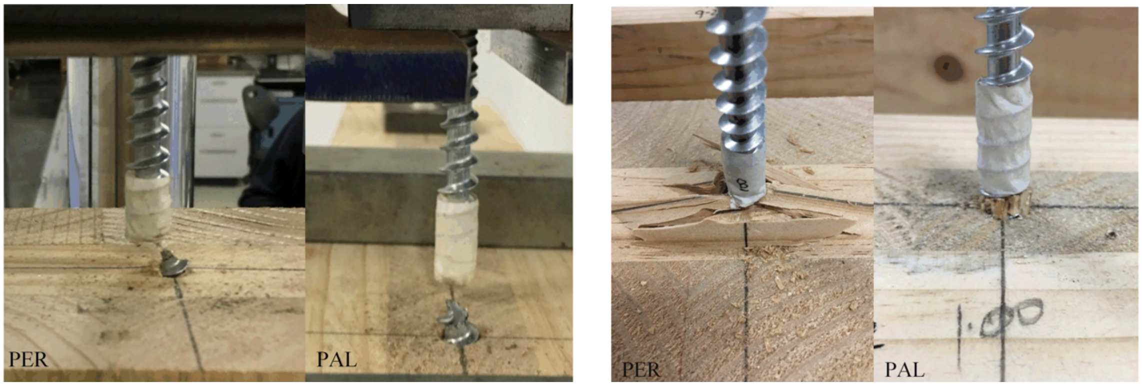
where d is the diameter of the screw's outermost thread, and l_{ef} presents the penetration length of the threaded part.

Table 2. The main results and failure modes obtained from the tests.

Sample designation	F_{max} (kN)	f_{max} (MPa)	Failure modes
CL3/105-PER-100-1	16.45	4.76	Withdrawal
CL3/105-PER-100-2	28.00	8.10	Withdrawal
CL3/105-PER-100-3	24.03	6.95	Withdrawal
CL3/105-PAL-100-1	19.68	5.69	Withdrawal
CL3/105-PAL-100-2	18.56	5.37	Withdrawal
CL3/105-PAL-100-3	16.79	4.86	Withdrawal
CL3/105-PER-150-1	28.19	5.44	Withdrawal
CL3/105-PER-150-2	40.65	7.84	Tensile rupture
CL3/105-PER-150-3	38.38	7.40	Tensile rupture
CL3/105-PAL-150-1	35.79	6.90	Withdrawal
CL3/105-PAL-150-2	41.21	7.95	Tensile rupture
CL3/105-PAL-150-3	27.98	5.40	Withdrawal
CL3/105-PER-175-1	40.71	6.73	Tensile rupture
CL3/105-PER-175-2	41.05	6.79	Tensile rupture
CL3/105-PAL-175-1	40.44	6.69	Tensile rupture
CL3/105-PAL-175-2	41.87	6.92	Tensile rupture
CL3/135-PER-100-1	25.74	7.45	Withdrawal
CL3/135-PER-100-2	21.23	6.14	Withdrawal
CL3/135-PER-100-3	20.79	6.02	Withdrawal
CL3/135-PAL-100-1	16.11	4.66	Withdrawal
CL3/135-PAL-100-2	16.29	4.71	Withdrawal
CL3/135-PAL-100-3	22.65	6.55	Withdrawal
CL3/135-PER-150-1	34.97	6.75	Withdrawal
CL3/135-PER-150-2	38.77	7.48	Tensile rupture
CL3/135-PAL-150-1	40.29	7.77	Tensile rupture
CL3/135-PAL-150-2	35.64	6.88	Withdrawal
CL3/135-PER-175	40.75	6.74	Tensile rupture
CL3/135-PAL-175	37.81	6.25	Tensile rupture

3.1 Failure Modes

Figure 2 shows the typical failure modes observed for the tested samples; Figure 2(a) shows the tensile rupture of the screw shank, whilst Figure 2(b) shows withdrawal failure. Failure types for each tested sample are listed in Table 2.



(a) Rupture failure of screw (b) Withdrawal failure

Figure 2. Typical failure mode of pull-out test.

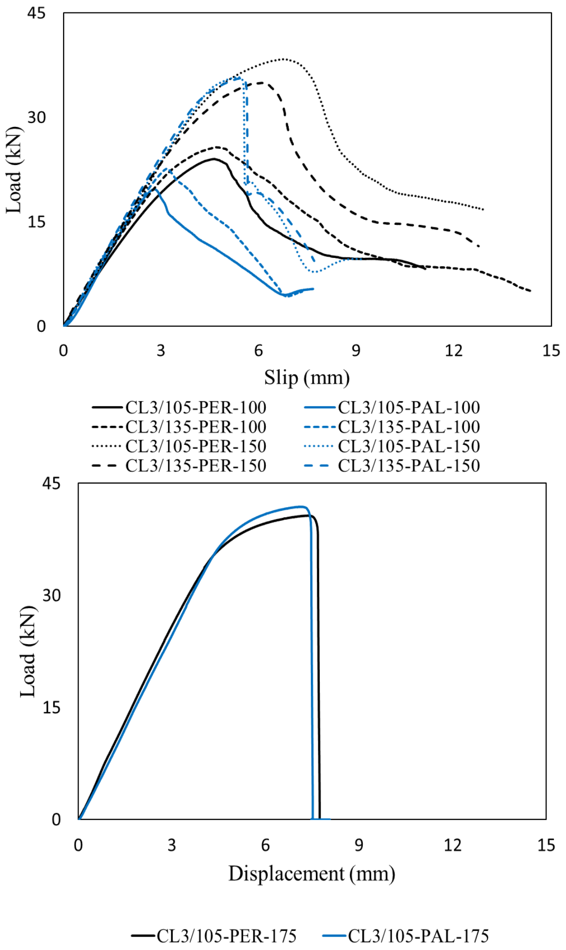
Obtained results indicated some patterns in the failure modes of STSs based on insertion orientations, i.e., tearing of adjacent fibers when inserted perpendicular to timber grains (PER) and column-like pull-out of timber components when inserted parallel to the grains (PAL). This is due to the fact that, for PAL samples, shear stress generated in the local timber areas surrounding the screw threads and adjacent timber grains were easily pulled-out due to shear failure along the entire screw threads once the limits were exceeded. On the contrary, for PER samples, wood fibers failed under a combined shear and tensile strength perpendicular-to-grain states. But critical penetration depths seemed to be approximately 150 mm regardless of panel type and thickness of layer.

3.2 Load-Displacement Behavior

Typical load versus slip curves are shown in Figure 3.

Figure 3(a) shows the withdrawal behavior of tested samples for the CL3/105 and CL3/135 panels. Initially, all samples showed somewhat similar linear increase in load resistance, albeit STSs inserted perpendicular to the grain, i.e., PER curves exhibited obvious nonlinear load-deformation behavior up to the maximum load followed by a mildly descending stage when compared against those showed by their PAL counterparts, in which STSs were inserted parallel to the grains.

Figure 3(b) illustrates the tensile rupture behavior of the CL3/105 samples with 175 mm penetration depths. Obtained load-deformation curves closely match that of the high carbon steels used for manufacturing STS. At this penetration, the interfaces between the screw's threads and the timber grains were strong enough to allow the screws to develop full strength against withdrawal, and therefore, screw shanks were the weakest sections and eventually failed due to tensile stress. A mean value of 40.18 kN was obtained from the current tests, which closely matches with the characteristic tensile capacity of 38 kN for VGS11 screws as reported by the manufacturer Rothoblaas (2019).

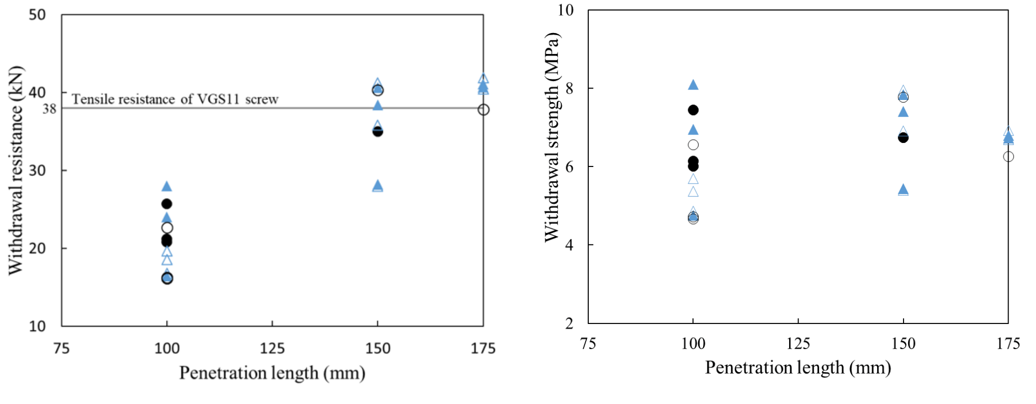


(a) Typical withdrawal curves (b) Typical tensile rupture curves

Figure 3. Typical load vs slip/displacement curves of tested samples.

3.3 Comparison

Figure 4 illustrates the details of the test outcomes. Based on the analysis and aforementioned loading histories, some general observations may be summarized:



(a) Penetration length *vs* withdrawal capacity (b) Penetration length *vs* withdrawal strength

Figure 4. Details of test outcomes.

(1) Overall, withdrawal resistances obtained for PER samples were higher than those of the PAL samples. Panel type, i.e., 105 mm vs 135 mm thickness representing different lamella, did not seem to have any significant effect on the withdrawal resistance; this phenomenon is more pronounced in PAL samples;

(2) The pull-out resistance increased as penetration depths were increased. Obtained results indicated that an increase of 50 mm in penetration depth, i.e., difference between 100 mm and 150 mm, resulted in a remarkable increase of withdrawal resistance by 59%, whilst the effects on withdrawal strength was only 6%.

4 CONCLUSION

This paper aimed at investigating pull-out responses of Rothoblaas VGS11 STSs when used for a new type of heterogeneous CLT produced by XLam in Australia. Tearing failure of adjacent fibers were observed when STSs were axially pulled out perpendicular-to-grain, whilst column-like pull out of timber components occurred when used parallel-to-grain. Based on the considered cases, the critical penetration depth seemed to be approximately 150 mm. Mean withdrawal strength of 6.3 MPa was obtained for current combination of sample configurations, but inconsistencies were obvious and clearly indicated the need for additional research in the field to exploit the full potential of XLam CLTs when used in conjunction with Rothoblaas STSs.

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