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STRENGTH CHARACTERIZATION OF OVERLAPPED TIMBER SCREWS

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ABSTRACT: The possibility of transmission of axial forces between self-tapping screws fastened in the opposite faces of a timber element and loaded contrariwise is analysed. The screws are intended to be placed sufficiently close one to another and the threaded shanks overlapped by a suitable length. Experimental tests are conducted, varying type, penetration depth and overlapping length of the screws, to evaluate the actual strength and the type of failure of this fastening technique.

KEYWORDS: Self-tapping screws, Withdrawal capacity, Overlapping length, Withdrawal tests

1 INTRODUCTION

The choice of type and arrangement of steel connections to realize timber joints plays a key-role in the capacity of timber structures.

Full-threaded Self-Tapping Screws (STS) are generally used to strengthen a timber element or to connect two or more timber components of a structure, taking advantage of their high axial strength [1]. The increasing interest in such technique is due to its effectiveness since these screws are fast to be installed and do not always require pre-drilling of the timber element. Examples are available in [2–5].

Recent works confirmed that particular attention must be paid to the design of spacing and edge distance to avoid anticipated brittle failures in the timber element, either for solid wood or laminated timber products (e.g., block shear failure, tension orthogonal to the grain) [6].

The ongoing revision of Eurocode 5 [7], based on detailed works recently published in the literature, aims to provide a design toolbox for the practitioners, which helps them in dealing with the design of modern fasteners with different anchoring materials [8].

To this aim, this work analyses the transmission of axial forces across a glued laminated timber element by means of pairs of STS fastened on the opposite faces, placed sufficiently close one to another and with a suitable overlapping length. The screws are installed with a spacing lower than the one required by current European Code [7]. The aim is to analyse, by means of experimental tests, the increased/decreased capability of transmitting axial forces between the screws through the timber member with such particular arrangement.

2 MATERIALS AND METHODS

Experimental tests were performed at the laboratory of Material testing of the University of Padova exploiting a universal testing machine.

2.1 TEST SETUP

Two couples of the same type of screws (four screws in total per single test) were simultaneously pulled contrarywise by means of a proper symmetric pulling configuration, designed, and realized to avoid possible eccentricities of loads (Figure 1). Two steel C-beams reinforced on both webs and flanges with 100-mm steel plates accommodated specifically designed millings that were able to provide a sufficiently rigid pulling force on the screw's head. Specific washers were designed to fit with the screw's countersunk heads avoiding local damages during the pulling tests. Tests were performed according to the load protocol of EN 26891:1991 [9]. Displacements were measured by placing one potentiometer place in proximity to each of the four screws.

Insertion of the screws close to verticality was assured by predrilling the wooden sample with a 5-mm drill bit up to a depth of 60 mm. Then, STS were pre-installed on the glulam samples, leaving a gap between the head and the surface to allow the positioning of the sample between the supporting U-shape beams. Once in place, a torque wrench was used to tighten the screws and provide direct contact between each of the four screws heads with the tensioning steel frame. Pretension on the STS was avoided through real-time reading of the load cell installed on the testing machine.

In addition, withdrawal tests of single STS according to EN 1382:2016 [10] were taken as reference for comparative purposes (Figure 2).

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A total of 35 tests were performed, 30 of which for testing the overlapping conditions and 5 as reference for the withdrawal capacity. Average and characteristic values of all the main mechanical parameters were calculated according to EN 14358:2016 [11].

Figure 1: *Test setup: load transfer*

Figure 2: *Test setup: withdrawal capacity*

2.2 SPECIMEN CHARACTERISTICS AND MATERIALS

Specimen design aimed to obtained a balanced solution between observing a failure governed by the screws withdrawal and failure due to excessive tension orthogonal to the grain. By varying the overlapping length failure should occur between the two possibilities.

Tests involved the use of carbon steel fully-threaded STS fastened to glulam timber samples. Three key parameters were considered in the definition of the test campaign, namely:

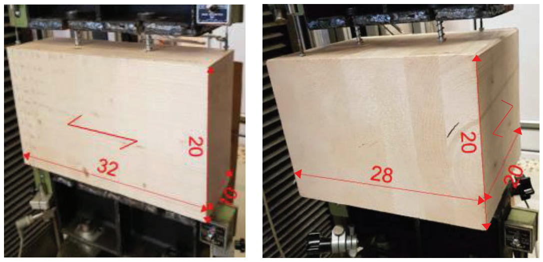
- dependency on the overlapping length of the STSs l_o: reference values were 60, 100 and 140 mm or *6d*, *10d* and *14d*;
- dependency on the total penetration length of the STSs l_{eff}: reference values were 130, 150 and 170 mm;
- Alignment between each couple of STS: parallel or perpendicular to the grain direction.

Although the screw's nominal diameter *d* should was potentially an essential variable to be analysed, it was not included in the parametric test: a fixed nominal diameter equal to 10 mm was considered as a good compromise to investigate the load transmission phenomenon while keeping the dimensions of the timber specimens sufficiently small to be manipulated in the testing machine while respecting the provisions on minimum edge distances reported in Eurocode 5 [7]. In detail, dimensions equal to 32x10x20 cm and 28x20x20 cm were chosen for the test in the parallel and perpendicular to grain screws layout (Figure 3). Spacing between the two opposite facing screws was set at a constant value of *2d* = 20 mm. All glulam specimens were cut from two beams having a cross-section of 20 x 28 cm and a certified strength class equal to GL24h [12]. At the age of the tests, all specimens were correctly dried, and each wood sample was assessed with a pin-type digital hygrometer; an average moisture content of 13.97% was measured, thus slightly above the reference value of 12.00%. Wood density was also extrapolated by weighting and measuring each sample, resulting in an average value equal to 431.59 Kg/m³.

Details on specimen nomenclature and relative characteristics are reported in Table 1.

Table 1: *Specimen characteristics*

Specimen ID	140-0	140-90	100-0	100-90	60-0	60-90	W
Number of tested samples	5	5	5	5	5	5	5
Wood element dimensions (cm)	9x32x20h	20x28x20h	9x32x20h	20x28x20h	9x32x20h	20x28x20h	20x20x20h
STS alignment (°)	0	90	0	90	0	90	-
Total length L (mm)	200	200	180	180	160	160	180
Effective length L_{eff} (mm)	170	170	150	150	130	130	150
Overlapping length L_{ov} (mm)	140	140	100	100	60	60	-
Mean density (Kg/m³)	441.39	434.17	424.46	415.22	434.39	444.62	426.88
Moisture content (%)	15.41	12.69	14.75	12.97	15.36	13.68	12.93



(a) (b)

Figure 3: Geometry of the Glulam samples for overlapping parallel (a) and perpendicular to grain (b)

2.3 ANALYTHICAL CALCULATION

Values of the experimental resistance were compared with the analytical load bearing capacity. For the comparison, both the equation reported in the homologation document of the producer [13]:

$$F_{ax,\alpha,Rk} = n_{ef} \cdot k_{ax} \cdot f_{ax,k} \cdot d \cdot l_{ef} \cdot (\frac{\rho_k}{350})^{0,8} \quad (1)$$

and the one included in Eurocode 5 [7] were used:

$$F_{ax,\alpha,Rk} = \frac{n_{ef} \cdot f_{ax,k} \cdot d \cdot l_{ef}}{1{,}2cos^2\alpha + sin^2\alpha} \cdot (\frac{\rho_k}{\rho_s})^{0,8} \quad (2)$$

In the computation, the characteristic withdrawal parameter $f_{ax,k}$ and the factor k_{ax} were respectively set equal to 10.5 N/mm² and 1.0 according to [13]. The characteristic tensile load bearing capacity of the steel $f_{tens,k}$ was equal to 25kN [13].
Finally, the characteristic strength orthogonal to the grain $f_{t90,k}$ for the timber necessary to compute the load capacity $F_{t,90,k}$ of the specimen was set equal to 0.5N/mm².

3 RESULTS AND DISCUSSION

Table 2 reports in summary the maximum pulling load F_{max} obtained from each test as well as average and characteristic values $F_{test,m}$ and $F_{test,k}$.
Three failure modes were evidenced during the experimental tests: screw withdrawal, wood failure for tension orthogonal to the grain or rolling shear. Results shows that for both l_{ov} equal to 100 and 140 mm, when STS were arranged parallel to the grain, force transmission could be mostly ensured thus avoiding the premature splitting of wood. In both configurations, in eight out of ten trials failure was governed by the withdrawal of the STS. The only difference observed was was that for the higher l_{ov}, failure was due to rolling shear rather than tension orthogonal to the grain.
For the lowest l_{ov} of 60 mm, failure on the timber side was mostly happening. This explains why tests on configuration 60-90, namely the ones with the smallest transfer capability, were interrupted before the completion of the series (Table 2).

3.1 LOAD VS. DISPLACEMENT CURVES

Figure 4 reports the curves obtained from the withdrawal tests of the STS according to EN 1382:2016 [10].
Figure 5, Figure 6 and Figure 7 show the load vs. displacement curves obtained from the tests of specimens with l_{ov} equal to 60, 100 and 140 mm respectively. Load refers to a couple of STS, i.e., the total load measured from the load cell divided by two. Displacement is the average displacement calculated from the four potentiometers.

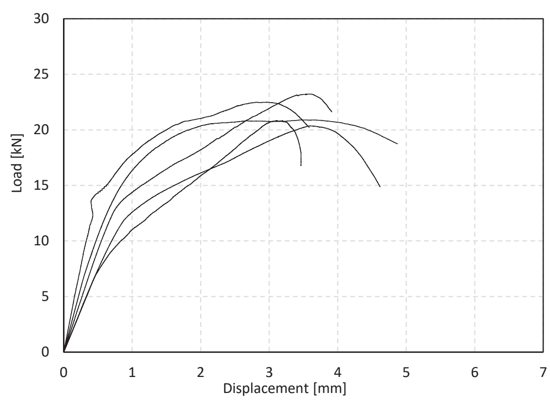


Figure 4: Load vs. displacement curves of the withdrawal tests according to EN 1382:2016 [10]

The seldom presence of a red cross at the end of a curve indicates that failure ended with premature failure of the

Table 2: Values of F_{max} and corresponding failure mode obtained from each test: W = withdrawal failure, T = tension orthogonal to the grain failure, R = rolling shear failure

		l_{ov} = 60 mm			l_{ov} = 100 mm			l_{ov} = 140 mm		
		F_{max} [kN]	Failure Mode	$F_{test,m}$ [kN]	$F_{test,m}$ [kN]	Failure Mode	F_{max} [kN]	F_{max} [kN]	Failure Mode	$F_{test,m}$ [kN]
0°	Test 1	18,57	W	17,62 kN	21,25 kN	W	20,27	25,56	W	27,96 kN
	Test 2	16,74	T			W	21,07	29,23	W	
	Test 3	18,91	T	$F_{test,k}$	$F_{test,k}$	W	20,38	29,23	W	$F_{test,k}$
	Test 4	14,44	T	12,57 kN	17,65 kN	W	23,80	29,59	W	23,52 kN
	Test 5	19,46	T			W	20,70	26,18	W	
90°	Test 1	19,04	T	$F_{test,m}$	$F_{test,m}$	T	23,14	26,74	R	$F_{test,m}$
	Test 2	20,08	T	19,56 kN	21,94 kN	W	18,73	24,97	W	26,10 kN
	Test 3	-	-			T	24,34	25,49	W	
	Test 4	-	-		$F_{test,k}$	W	20,73	27,22	W	$F_{test,k}$
	Test 5	-	-		16,49 kN	W	22,79	27,20	R	23,52 kN

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wood. As a reference, theoretical limits computed for the withdrawal capacity $F_{ax,Rk}$ of the STS and the resistance of timber orthogonal to the grain $F_{t,90,k}$ are also plotted. Additionally, By observing the curves, it emerges the sudden brittle behaviour of wood failure which clearly anticipates the withdrawal of the STS, and that opposes to the typical smooth curve that characterizes failure due to withdrawal.

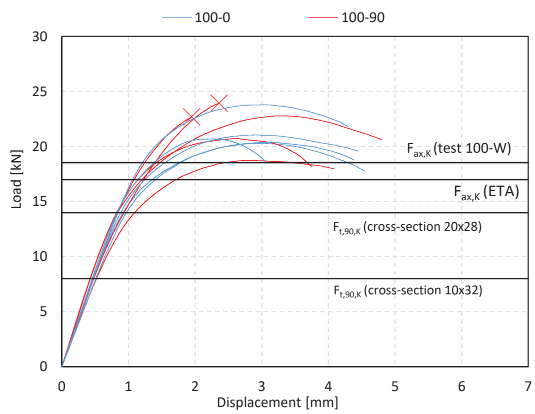

Figure 5: *Load vs. displacement curves with l_{ov} = 60mm*

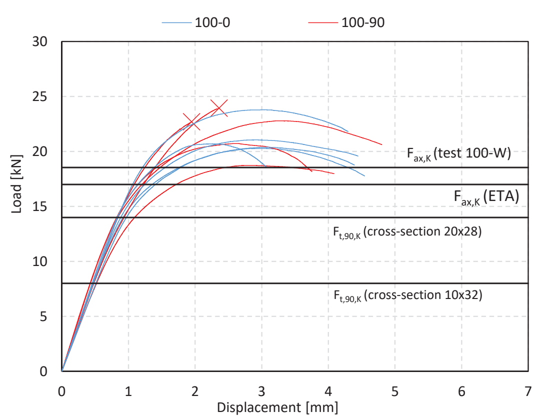

Figure 6: *Load vs. displacement curves with l_{ov} = 100mm*

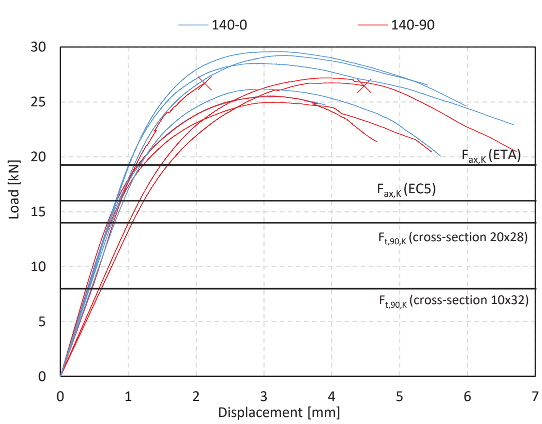

Figure 7: *Load vs. displacement curves with l_{ov} = 140mm*

3.2 FORCE COMPARISON

Figure 8 summarizes the results in terms of characteristic load bearing capacity between analytical and experimental values extrapolated for the three different values of l_{ov}.

The intermediate overlapping length (l_{ov} = 100 mm) can be retained the reference point from where to start comparing the data as the comparison includes also the reference values of $F_{ax,Rk}$ *(test W)* obtained from the withdrawal tests. In this configuration, the joint was almost able to completely exploit the capacity of the STS without incurring into premature brittle failure of the wooden medium. Comparable values of $F_{test,k}$, $F_{ax,Rk}$ (ETA) and $F_{ax,Rk}$ (Test) demonstrates it.

This phenomenon gains more evidence for the configuration analysing the maximum overlapping length (l_{ov} = 140 mm) were $F_{test,k}$ was consistently higher the $F_{ax,Rk}$ calculated from the homologation document (+22.1%). On the opposite, the lowest overlapping length (l_{ov} = 60 mm), did not allow a sufficient load transmission between the couple of STSs, as can be seen by comparing the $F_{test,k}$ with the $F_{ax,Rk}$ calculated from the homologation document (-14.7%).

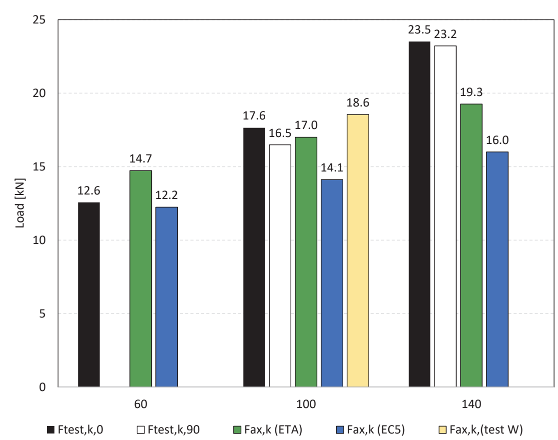

Figure 8: *Comparison of the analytical and experimental load bearing capacity for different l_{ov}*

3.3 FORCE TRANSMISSION IN WOOD

Specimens involving a withdrawal failure were cut along the vertical plane containing the couple of STSs for a detailed visual inspection. Figure 9 and Figure 10 shows the different behaviour of the wood grain in case of STS arrangement parallel and perpendicular to the grain respectively. In the first case, it can be observed how the couple of screws involve the wood fibres between them which, given the short distance, worked in predominant shear. Observing the wood fibres near the screws but on the opposite direction it is also clear the length of the fibres involved in the resisting model during the screws withdrawal.

In the second case, it is clear how no transfer between the overlapping length is visible. The orthogonal alignment of the wood fibres does not allow any interaction between the screws and force transmission is given only by the wooden medium, leading to frequent premature of the

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timber element when splitting resistance is lower than the screws withdrawal capacity.

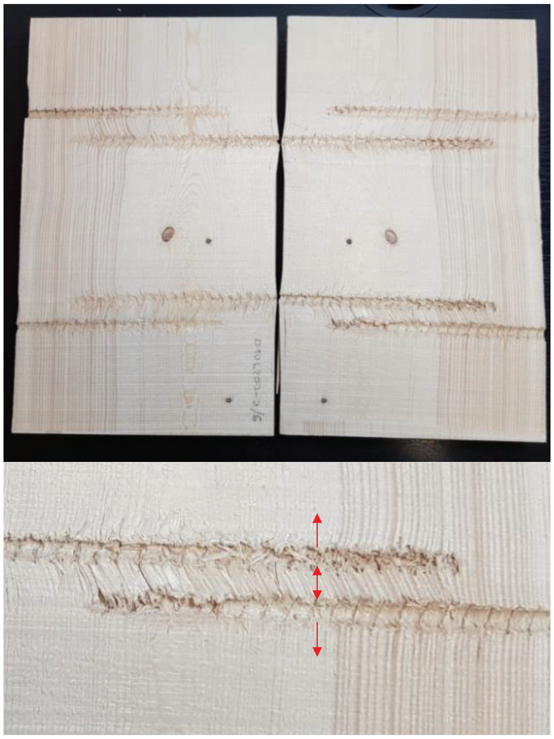

Figure 9: *Inspection of wood grain deformation on specimen 140-0/5 after withdrawal failure*

Figure 10: *Inspection of wood grain deformation on specimen 100-90/5 after withdrawal failure*

4 CONCLUSIONS

In this work, the possibility of transmitting axial forces between screws through the timber element, by partially overlapping the threaded parts was analysed.

Results from experimental tests, varying both the penetration and the overlapping length, showed that only a balanced configuration between effective penetration length (i.e., withdrawal capacity) and overlapping length allowed to transmit high axial forces without incurring into brittle failures of the wooden medium.

Future works may extend the studied configurations to different screws nominal diameters, different spacing between the opposed screws and possibly different screws as well.

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