MECHANICAL IN-PLANE JOINTS BETWEEN CROSS LAMINATED TIMBER PANELS

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ABSTRACT: The construction process of a cross laminated timber building is highly influenced, in terms of time and cost, by the system chosen to joint wall and floor panels. Particularly, when using short width panels, the number of mechanical joints increases: thus on one side improves the global ductility of the whole building but, on the other side, determines undeniable disadvantages in terms of cost and speed of construction.

In this paper results of a testing campaign on mechanical joints between cross laminated timber panels working in the same plane (i.e. vertical joints between wall panels and horizontal joints between floor panels) are presented and discussed, respectively in terms of joint strength, joint stiffness, ease and speed of execution, total cost including the cost of fasteners and that of manpower.

KEYWORDS: Cross laminated timber, panels, screws, nails, strength, stiffness, cost

1 INTRODUCTION

The following report analyses some of the most used types of joints between wooden panel.
The joints under study differ in the edges of the connected elements and in the kind of mechanical connectors used.

Figure 1: A 3 storeys cross laminated building

Two types of panels, three types of edge geometry and six types of fasteners have been tested.

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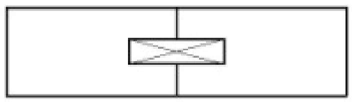
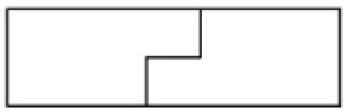
2 MATERIALS AND METHODS

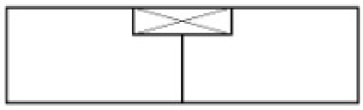
The samples differ in:
- Type of panels
  - 3S - 98mm thickness panel, 3 layers
  - 5S - 98mm thickness panel, 5 layers
- Edge geometry:



A - tenon joints with double groove on the panel edges and a central multi-layered timber panel



B - half-lap joints



C - leaf joints with a groove on the same side of each panel and a connecting multi-layered timber panel

- Type of fasteners:
  - 6mm self drilling screws without washers
  - 6mm self drilling screws with washers
  - 8mm self drilling screws without washers
  - 8mm self drilling screws with washers
  - 3.1mm smooth nails
  - 3.1/3.4 threaded shank nails

Figure 2: *Fasteners used in tests*

2.1 TYPE OF PANELS

The so called "lamination effect" and its influence on the joint strength and ductility is taken into account as well as the importance of the number of panel layers with regards to the geometric configuration of the joint; for instance, in the case of a tenon joint on a 3 layers panel, the execution of a groove in the middle of each panel edge causes the removal of the central cross layer in the jointed area, thus completely erasing the cross lamination effect.

The panels are cross laminated timber composed as follows:

- more then 90% of longitudinal planks are C24 grade, the residual C16 grade (as declared by producers);
- more then 30% of transversal planks are C24 grade, the residual C16 grade (as declared by producer);
- each plank is glued on its face and on the edge without gaps;
- the mean, minimum and maximum densities are, respectively, ρ_m=475kg/m^3, the minimum density ρ_{min}=427kg/m^3 and the maximum ρ_{max}=504kg/m^3 (density was measured on each sample and corrected to 12% moisture content).

2.2 EDGE GEOMETRY

The following three types of edges are the most used in timber panels constructions.

The A-type uses two layers of connections working in series; this is obtained by doubling the number of connectors which, however, have two shear planes each.

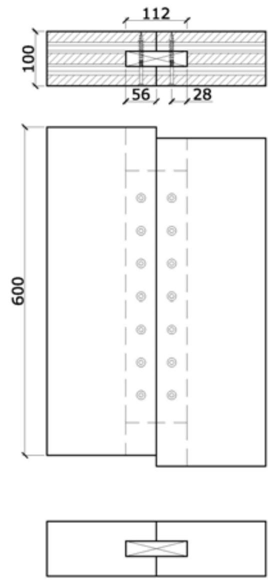


Figure 3: *A-type*

The B-type is the most quick joint because it requires just one layer of connections and does not need the insertion of multi-layered timber panel.

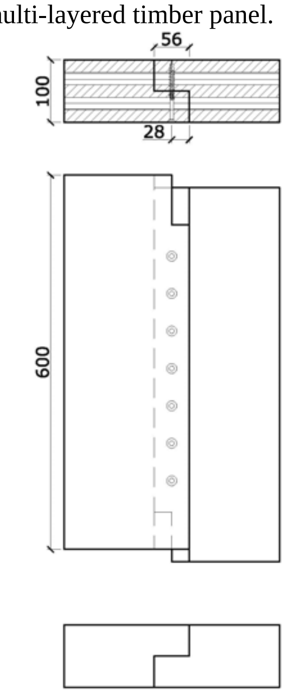


Figure 4: *B-type*

The C-type uses two layers of connectors working in series; this is obtained by doubling the number of connectors but, differently from A-type, each connector has one shear plane only.

This type turned out as the less efficient joint among those tested. However, it is not possible to use this type of joint for the three layers panels, because of the reasons given in §2.1.

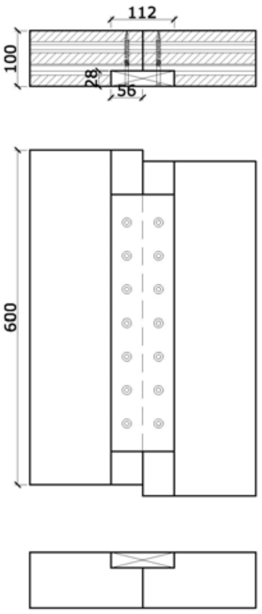


Figure 5: C-type

2.3 TYPE OF FASTENERS

Tests on screwed joints, with and without washers, and on nailed ones, with smooth and threaded shank nails, were carried out in order to put into evidence the rope effect.

Tests on two very different types of fasteners, screws and nails, were made to point out the differences in terms of strength, stiffness, simplicity and velocity of construction, costs.

Screws were auto-drilling screws made of steel f_u = 1000N/mm^2 (not tested but declared by the producer).

Nails were made with steel f_u = 600N/mm^2 (not tested but declared by the producer).

3 SHEAR TESTS AND DATA PROCESSING

3.1 TEST ARRANGEMENT

The tests was carried out by an hydraulic testing machine with 200kN of capacity in load control, according to EN 26891.

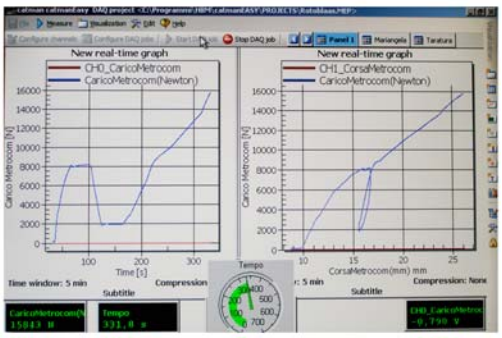


Figure 6: Loading protocol

The measurement of slip was carried out using linear transducers placed near the slip surface on booth faces of each sample.

Figure 7: Test arrangement

3.2 DATA PROCESSING

3.2.1 Density

The density was measured on each sample and corrected to 12% moisture content according to EN384.

3.2.2 Strength

The values of F_{max} were corrected according to “method 2” of EN 28970, using the following formula:

$$F_{corr} = F_{\max}\left(\frac{\rho_k}{\rho_{12}}\right)^c \quad (1)$$

where: ρ_k=350kg/m^3 is the characteristic density of C24, ρ is the measured density corrected to 12% moisture content and c=0.5.

Since this correction is made with respect to the characteristic density of wood, the characteristic strength value F_k has been calculated as mean of the F_{corr} values obtained from each homogeneous group of samples:

$$F_k = \text{mean}(F_{cor}) \quad (2)$$

3.2.3 Stiffness

The stiffnesses K_{ser} e K_u are calculated from the load-slip curves according to EN 26891 using the same value of F_{max} for each group of homogeneous samples and placing $F_{max} = F_k$

4 TESTS IN PLACE

Experments in a construction site are carried out in order to evaluate the working time with screws and nails.

Tests were carried outo only with:

- 8mm self drilling screws without washers

- 3.1/3.4 threaded shank nails

Tests were carried out fixing the panels both in horizontal and vertical position.

Screws and nails are placed by means of an electric screwerand and a pneumatic nailer respectively.

Figure 8: *Screwing in horizontal position*

Figure 9: *Screwing in vertical position*

Figure 10: *Nailing in horizontal position*

Tests were carried out fixing the panels both in horizontal and vertical position.

The time to charge the pneumatic nailer was measured and considered in the evaluations.

5 RESULTS

5.1 MECHANICAL VALUES

The results are compared with values calculated according to EN 1995 “Eurocode 5” and explained in Table 1 e 2.

Type of joints	Type of fasteners	n. of samples	F_k EC5 [N]	F_k tests [N]	increase
A3	3.1mm smooth nails	2	1420	2220	56%
	3.1/3.4 threaded shank nails	3	1610	2750	71%
A5	3.1mm smooth nails	3	1420	2690	89%
	3.1/3.4 threaded shank nails	3	1610	2710	68%
	6mm self drilling screws	3	3300	5200	58%
	6mm self drilling screws with washers	2	3300	4850	47%
	8mm self drilling screws	4	4390	6100	39%
B3	3.1/3.4 threaded shank nails	4	860	2130	148%
	6mm self drilling screws	3	2030	5380	65%
	6mm self drilling screws with washers	3	2960	5390	82%
	8mm self drilling screws	3	3320	6440	94%
	8mm self drilling screws with washers	2	4490	5770	29%
B5	3.1/3.4 threaded shank nails	4	860	2180	53%
	6mm self drilling screws	3	2030	3930	94%
	8mm self drilling screws	3	3320	4670	41%
	8mm self drilling screws with washers	2	4490	6000	34%
C3	3.1mm smooth nails	3	855	1970	30%
	3.1/3.4 threaded shank nails	6	850	1850	118%
	8mm self drilling screws	4	2570	3960	54%
	8mm self drilling screws with washers	3	3740	5140	37%
C5	3.1/3.4 threaded shank nails	3	850	1980	133%
	6mm self drilling screws	4	1605	3060	91%
	6mm self drilling screws with washers	2	2535	3740	48%
	8mm self drilling screws	3	2570	4000	56%
	8mm self drilling screws with washers	2	3740	4410	18%

Table 1: *Comparison between tests and EC5 values in terms of strength*

Type of joints	Type of fasteners	K_{ser} EC5 [N]	K_{ser} [N] tests	K_u EC5 [N]	K_u [N] tests	K_u/K_{ser} tests
A3	3.1mm smooth nails	710	1322	473	754	0.570
	3.1/3.4 threaded shank nails	710	856	473	566	0.661
A5	3.1mm smooth nails	710	859	473	652	0.759
	3.1/3.4 threaded shank nails	710	823	473	575	0.699
	6mm self drilling screws	1535	1512	1023	1217	0.805
	6mm self drilling screws with washers	1535	1445	1023	1130	0.782
	8mm self drilling screws	2095	2843	1397	2402	0.851
B3	3.1/3.4 threaded shank nails	710	221	473	173	0.783
	6mm self drilling screws	1535	952	1023	657	0.690
	6mm self drilling screws with washers	1535	745	1023	574	0.770
	8mm self drilling screws	2095	2833	1397	1656	0.585
	8mm self drilling screws with washers	2095	3677	1397	2113	0.575
B5	3.1/3.4 threaded shank nails	710	451	473	238	0.528
	6mm self drilling screws	1535	1094	1023	726	0.664
	8mm self drilling screws	2095	1880	1397	1435	0.763
	8mm self drilling screws with washers	2095	3149	1397	2206	0.700
C3	3.1mm smooth nails	355	602	235	286	0.475
	3.1/3.4 threaded shank nails	355	361	235	274	0.759
	8mm self drilling screws	1047	897	698	726	0.809
	8mm self drilling screws with washers	1047	1280	698	946	0.739
C5	3.1/3.4 threaded shank nails	355	340	235	238	0.700
	6mm self drilling screws	768	439	512	443	1.009
	6mm self drilling screws with washers	768	614	512	530	0.863
	8mm self drilling screws	1047	998	698	779	0.780
	8mm self drilling screws with washers	1047	888	698	715	0.805

Table 2: *Comparison between tests and EC5 values in terms of stiffness (K_u/K_{ser}=0.667 for EC5 values)*

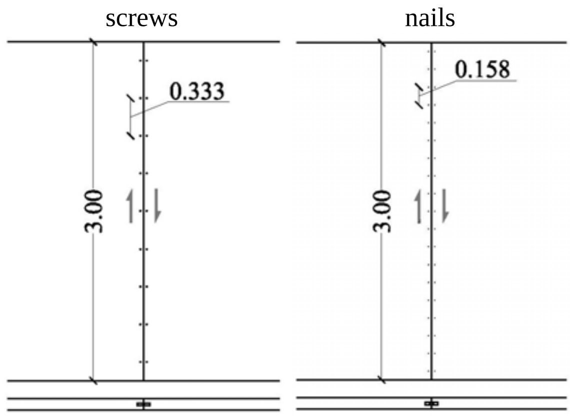
Figure 11: *All the samples after the tests*

5.2 COSTS OF JOINTS

The cost analysis was carried out using:

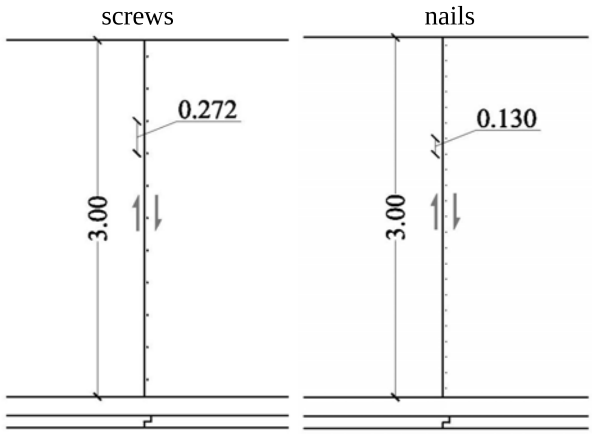
- € 0.16 for each screw
- € 0.015 for each ring nail
- € 25.00 for each working hour

The comparison is made with respect to the same total strength of the joints (50kN).



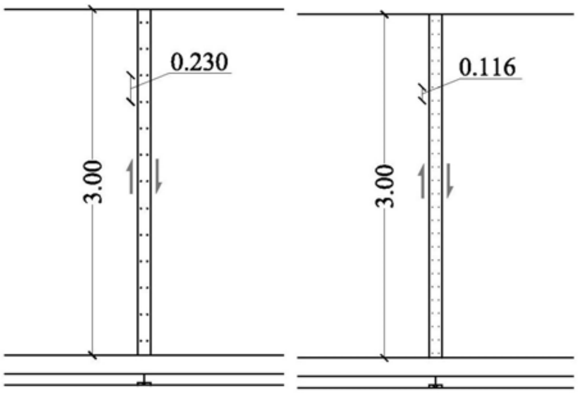
	9x2 8mm self drilling screws	**19x2** 3.1/3.4 threaded shank nails
Horizontal assembly time	94 s	27 s
Vertical assembly time	299 s	71 s
Horizontal assembly cost	3.53 €	0.75 €
Vertical assembly cost	4.96 €	1.07 €

Table 3: *Comparison, in terms of cost, between screwed joints and nailed joints (A-type, 5 layers)*



	11 8mm self drilling screws	**23** 3.1/3.4 threaded shank nails
Horizontal assembly time	57 s	16 s
Vertical assembly time	183 s	43 s
Horizontal assembly cost	2.16 €	0.46 €
Vertical assembly cost	3.03 €	0.65 €

Table 4: *Comparison, in terms of cost, between screwed joints and nailed joints (B-type, 5 layers)*



	13x2 8mm self drilling screws	**26x2** 3.1/3.4 threaded shank nails
Horizontal assembly time	135 s	36 s
Vertical assembly time	331 s	98 s
Horizontal assembly cost	5.10 €	1.03 €
Vertical assembly cost	7.16 €	1.46 €

Table 5: *Comparison, in terms of cost, between screwed joints and nailed joints (C-type, 5 layers)*

6 CONCLUSIONS

6.1 MECHANICAL PROPERTIES

Because of the small number of samples, the following considerations are only an hypothesis.

6.1.1 Comparison between screwed joints with and without washers

The comparison betwen screwed joints with and without washers in A and B-type shows no significative differences due to rope effect. This is probably because of the very short thread zone: the presence of washer induce the rope effect at the beginning of loading, the rope effect induces a rapid and brittle withdrawal failure which nullifies the rope effect itself.
The presence of rope effect is appreciable in C-type because of the major penetration of the threaded zone in the second wood.

Figure 12: *C-type sample after the test*

6.1.2 Comparison between test results and calculated value of strength

The comparison between test results and calculated values according to EN 1995 shows that, due to the cross laminated effect, test results are more then 1.5 times higher then the calculated ones.
This fact is in accordance with [1]

6.1.3 Comparison between test results and calculated value of stiffness

In many cases the differences between test results and values calculated according to EN 1995 are significant.
This is probably due to the very large estimate made by the EN 1995 formulae which do not take in to account many parametrers, as the tickness of the wooden elements and the type of steel used for of the fasteners.

6.2 COSTS

The in-place tests show that nailed joints are very cheap in comparison with screwed ones.
The cheapest is nailed type-B joint, although the difference between the three types of nailed connection is very small.

ACKNOWLEDGEMENT

This work was sponsored by: Binderholz GmbH Austria, Sistem Costruzioni S.r.l. Italy, Rothoblaas S.r.l. Italy, Trees and Timber Institute IVALSA CNR Italy, which gave us for free materials, manufacture and test laboratory.
Special tanks to Eng. Marco Pio Lauriola for the scientific supervision.
Last but not least, special tanks to Dott. Paolo Burato and the other Technician of Trees and Timber Institute for the precious assistance.

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