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.

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
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 than 90% of longitudinal planks are C24 grade, the residual C16 grade (as declared by producers);
- more than 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, $\rho_m=475\,\text{kg/m}^3$, the minimum density $\rho_{\text{min}}=427\,\text{kg/m}^3$ and the maximum $\rho_{\text{max}}=504\,\text{kg/m}^3$ (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.

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.

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.
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 $f_u = 1000\text{N/mm}^2$ (not tested but declared by the producer).

Nails were made with steel $f_u = 600\text{N/mm}^2$ (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.

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

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

where: \(\rho_k = 350\text{kg/m}^3\) is the characteristic density of C24, \(\rho\) 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 $F_{\text{corr}}$ values obtained from each homogeneous group of samples:

$$F_k = \text{mean}(F_{\text{corr}})$$

3.2.3 Stiffness

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

4 TESTS IN PLACE

Experiments in a construction site are carried out in order to evaluate the working time with screws and nails. Tests were carried out 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 screwer and a pneumatic nailer respectively.

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.

<table>
<thead>
<tr>
<th>Type of joints</th>
<th>Type of fasteners</th>
<th>n. of samples</th>
<th>Fk EC5 [N]</th>
<th>Fk tests [N]</th>
<th>increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
<td>3.1mm smooth nails</td>
<td>2</td>
<td>1420</td>
<td>2220</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>3.1/3.4 threaded shank nails</td>
<td>3</td>
<td>1610</td>
<td>2750</td>
<td>71%</td>
</tr>
<tr>
<td></td>
<td>3.1mm smooth nails</td>
<td>3</td>
<td>1420</td>
<td>2690</td>
<td>89%</td>
</tr>
<tr>
<td></td>
<td>3.1/3.4 threaded shank nails</td>
<td>3</td>
<td>1610</td>
<td>2710</td>
<td>68%</td>
</tr>
<tr>
<td>A5</td>
<td>6mm self drilling screws</td>
<td>3</td>
<td>3300</td>
<td>5200</td>
<td>58%</td>
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<tr>
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<td>6mm self drilling screws with washers</td>
<td>2</td>
<td>3300</td>
<td>4850</td>
<td>47%</td>
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<tr>
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<td>8mm self drilling screws</td>
<td>4</td>
<td>4390</td>
<td>6100</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>3.1/3.4 threaded shank nails</td>
<td>4</td>
<td>860</td>
<td>2130</td>
<td>148%</td>
</tr>
<tr>
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<td>3</td>
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<td>5380</td>
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<tr>
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<td>5390</td>
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<td>3320</td>
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<td>2</td>
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<td>5770</td>
<td>29%</td>
</tr>
<tr>
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<td>2</td>
<td>4490</td>
<td>6000</td>
<td>34%</td>
</tr>
<tr>
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<td>3320</td>
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<td>6000</td>
<td>34%</td>
</tr>
<tr>
<td>C3</td>
<td>3.1mm smooth nails</td>
<td>3</td>
<td>855</td>
<td>1970</td>
<td>30%</td>
</tr>
<tr>
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<td>3.1/3.4 threaded shank nails</td>
<td>6</td>
<td>850</td>
<td>1850</td>
<td>118%</td>
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<tr>
<td></td>
<td>8mm self drilling screws</td>
<td>4</td>
<td>2570</td>
<td>3960</td>
<td>54%</td>
</tr>
<tr>
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<td>3</td>
<td>3740</td>
<td>5140</td>
<td>37%</td>
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<tr>
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<td>3.1/3.4 threaded shank nails</td>
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<td>850</td>
<td>1980</td>
<td>133%</td>
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<tr>
<td></td>
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<td>4</td>
<td>1605</td>
<td>3060</td>
<td>91%</td>
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<tr>
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<td>2535</td>
<td>3740</td>
<td>48%</td>
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<tr>
<td></td>
<td>8mm self drilling screws</td>
<td>3</td>
<td>2570</td>
<td>4000</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>8mm self drilling screws with washers</td>
<td>2</td>
<td>3740</td>
<td>4410</td>
<td>18%</td>
</tr>
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</table>

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

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### Table 2: Comparison between tests and EC5 values in terms of stiffness ($K_{\text{EC5}}/K_{\text{ser}}=0.667$ for EC5 values)

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

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

<table>
<thead>
<tr>
<th></th>
<th>screws</th>
<th>nails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal assembly time</td>
<td>94 s</td>
<td>27 s</td>
</tr>
<tr>
<td>Vertical assembly time</td>
<td>299 s</td>
<td>71 s</td>
</tr>
<tr>
<td>Horizontal assembly cost</td>
<td>3.53 €</td>
<td>0.75 €</td>
</tr>
<tr>
<td>Vertical assembly cost</td>
<td>4.96 €</td>
<td>1.07 €</td>
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</table>

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

<table>
<thead>
<tr>
<th></th>
<th>screws</th>
<th>nails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal assembly time</td>
<td>57 s</td>
<td>16 s</td>
</tr>
<tr>
<td>Vertical assembly time</td>
<td>183 s</td>
<td>43 s</td>
</tr>
<tr>
<td>Horizontal assembly cost</td>
<td>2.16 €</td>
<td>0.46 €</td>
</tr>
<tr>
<td>Vertical assembly cost</td>
<td>3.03 €</td>
<td>0.65 €</td>
</tr>
</tbody>
</table>

---

Figure 11: All the samples after the tests
Table 5: Comparison, in terms of cost, between screwed joints and nailed joints (C-type, 5 layers)

<table>
<thead>
<tr>
<th></th>
<th>Screws</th>
<th>Nails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Screws</td>
<td>135 s</td>
<td>36 s</td>
</tr>
<tr>
<td>Threaded Shank Nails</td>
<td>331 s</td>
<td>98 s</td>
</tr>
<tr>
<td>Horizontal Assembly Cost</td>
<td>5.10 €</td>
<td>1.03 €</td>
</tr>
<tr>
<td>Vertical Assembly Cost</td>
<td>7.16 €</td>
<td>1.46 €</td>
</tr>
</tbody>
</table>

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 between 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.

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 parameters, as the thickness 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.

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Last but not least, special tanks to Dott. Paolo Burato and the other Technician of Trees and Timber Institute for the precious assistance.

REFERENCES


Figure 12: C-type sample after the test