Durability of adhesive bonds in cross-laminated timber (CLT) panels manufactured using Irish Sitka spruce

Karol S. Sikora – Annette M. Harte - Daniel O. McPolin

Karol Sikora  |  25th June 2014
Overview

• Opportunities for Irish timber
  – Cross-Laminated Timber (CLT)
• Adhesives for CLT
• Test programme
  – Shear tests
  – Delamination of glue lines test
• Results
• Conclusions
Opportunities for Irish timber
Irish forestry & forest products sector

- €2.2 billion in annual output (in 2012 = 1.3% GDP)
- > 12,000 employed
- Increase from 3903 million m$^3$ in 2011
to 7110 million m$^3$ in 2028 of the supply of roundwood

[IFFPA, 2013]
Opportunities for Irish timber
Uses of Irish Sitka Spruce

[IFFPA, 2013]

Uses of Irish timber in 2012 [in relation to m3]

- Construction/Structural: 33%
- Pallet/packing: 29%
- Square edged fencing: 23%
- Round stakes: 13%
- Other: 2%

graded C16
Opportunities for Irish timber
Cross-Laminated Timber (CLT)

- Made of at least 3 orthogonally bonded layers of timber
- Successive layers of boards placed cross-wise

[archexamhandbook.com]

[Rimetz, 2011]
Adhesives for CLT

- Phenoplast- and aminoplast-adhesives (MUF, PRF)

- **One-component polyurethane adhesives (1K-PUR)**

- Emulsion-polymer-isocyanate adhesive (EPI)
Test programme

- Shear tests

- Delamination test of glue lines between layers
Materials preparation procedure

- Timber conditioning: 3 months: 20 °C & 65% RH
- Timber planing: 30 mm x 94 (or 96) mm
- Thickness tolerance measurements: required : 0.1 mm
- Bonding: 0.1 mm adhesive layer; clamping: 120 min
- Reconditioning: 20 °C & 65% RH
- Cutting
Specimens preparation for shear testing

**Bonding**
- blocks of 4 edge bonded 300 mm long boards
- 0.6 N/mm², 0.8 N/mm², 1.0 N/mm²

**Specimen**
- glue line (or solid wood): 30 mm x 50 mm
- 2 loading directions: · End-grain, · Perpendicular to grain

<table>
<thead>
<tr>
<th>Bonding pressure</th>
<th>0.6 N/mm²</th>
<th>0.8 N/mm²</th>
<th>1.0 N/mm²</th>
<th>Solid wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-grain</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Perp. to g.</td>
<td>36</td>
<td>24</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>
Shear tests results

- Characteristics strength (end-grain) > 3.5 N/mm²
- For solid wood 64% reduction in characteristic strength perpendicular to grain compared to end-grain
  - 74% for 0.6 N/mm²
  - 66% for 0.8 N/mm²
  - 71% for 1.0 N/mm²
Shear tests results

- **Student’s $t$ test:**
  - Comparison with solid wood:

<table>
<thead>
<tr>
<th>P. [N/mm²]</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.-g.</td>
<td>Sig. Dif.</td>
<td>Sig. Dif.</td>
<td>Sig. Dif.</td>
</tr>
<tr>
<td>Perp. to g.</td>
<td>Sig. Dif.</td>
<td>No Sig. Dif.</td>
<td>Sig. Dif.</td>
</tr>
</tbody>
</table>

- Comparison with 1.0 N/mm²

<table>
<thead>
<tr>
<th>P. [N/mm²]</th>
<th>0.6</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.-g.</td>
<td>No Sig. Dif.</td>
<td>No Sig. Dif.</td>
</tr>
<tr>
<td>Perp. to g.</td>
<td>No Sig. Dif.</td>
<td>Sig. Dif.</td>
</tr>
</tbody>
</table>

- Comparison with 1.0 N/mm²

<table>
<thead>
<tr>
<th>Shear strength [N/mm²]</th>
<th>Mean 5-per.</th>
<th>S.D.</th>
<th>Mean 5-per.</th>
<th>S.D.</th>
<th>Mean 5-per.</th>
<th>S.D.</th>
<th>Mean 5-per.</th>
<th>S.D.</th>
<th>Solid wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6 N/mm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8 N/mm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 N/mm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

**End-grain** | **Perpendicular to grain**

College of Engineering & Informatics
Wood failure percentage:
95% specimens ≥ 80 %WF
67% specimens = 100 %WF

<table>
<thead>
<tr>
<th>p (N/mm²)</th>
<th>100 %WF</th>
<th>95 - 80 %WF</th>
<th>75 - 70 %WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>72%</td>
<td>24%</td>
<td>4%</td>
</tr>
<tr>
<td>0.8</td>
<td>76%</td>
<td>22%</td>
<td>2%</td>
</tr>
<tr>
<td>1.0</td>
<td>56%</td>
<td>33%</td>
<td>11%</td>
</tr>
</tbody>
</table>
Wood failure percentage
Min.: 60 \%WF for 0.8 N/mm\(^2\) pressure and tested perpendicular to grain

- 60\% wood failure loaded perpendicular to grain
- 100\% wood failure loaded perpendicular to grain
- 100\% wood failure loaded at end-grain
Delamination of glue lines test

Clamping
- 3-layer panel of 90 mm (3x 30 mm) x 600 mm x 192 mm
- 0.8 N/mm²

Sample
- 10 specimens
- 105 mm x 96 mm x 90 mm

Vacuum-pressure soak cycle
- submerged in water (~15 °C) » vacuum of ~80 kPa for 30 min
  » pressure of ~550 kPa for 2 h » drying for ~15 h in 70±5 °C
Delamination of glue lines

prEN 16351:2013

**Total delamination** \(\text{Delam}_{\text{tot}}\)

\[
\text{Delam}_{\text{tot}} = \frac{l_{\text{tot,delam}}}{l_{\text{tot,glueline}}} \times 100\%
\]

- \(l_{\text{tot,delam}}\) total delamination length (in mm)
- \(l_{\text{tot,glueline}}\) sum of the perimeters of all glue lines in a delamination specimen (in mm)

**Maximum delamination** \(\text{Delam}_{\text{max}}\)

\[
\text{Delam}_{\text{max}} = \frac{l_{\text{max,delam}}}{l_{\text{glueline}}} \times 100\%
\]

- \(l_{\text{max,delam}}\) maximum delamination length (in mm)
- \(l_{\text{glueline}}\) perimeter of one glue line in a delamination specimen (in mm)
Delamination of glue lines - results

prEN 16351:2013:

- \( \text{Delam}_{\text{tot}} \leq 10\% \) and \( \text{Delam}_{\text{max}} \leq 40\% \) when exceeded

- Lower of the wood failure percentages from two glue lines, \( \text{FF}_{\text{min}} \geq 50\% \)

Minimum wood failure percentage of sum of all split glued areas \( \geq 70\% \)

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>( \text{Delam}_{\text{tot}} ) [%]</th>
<th>( \text{Delam}_{\text{max}} ) [%]</th>
<th>( \text{FF}_{\text{min}} ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.8</td>
<td>33.7</td>
<td>80%</td>
</tr>
<tr>
<td>2</td>
<td>17.6</td>
<td>35.2</td>
<td>75%</td>
</tr>
<tr>
<td>3</td>
<td>27.3</td>
<td>54.2</td>
<td>60%</td>
</tr>
<tr>
<td>4</td>
<td>16.0</td>
<td>32.0</td>
<td>85%</td>
</tr>
<tr>
<td>5</td>
<td>19.5</td>
<td>38.9</td>
<td>70%</td>
</tr>
<tr>
<td>6</td>
<td>21.7</td>
<td>43.7</td>
<td>65%</td>
</tr>
<tr>
<td>7</td>
<td>17.0</td>
<td>34.0</td>
<td>80%</td>
</tr>
<tr>
<td>8</td>
<td>23.1</td>
<td>46.2</td>
<td>65%</td>
</tr>
<tr>
<td>9</td>
<td>19.8</td>
<td>39.6</td>
<td>70%</td>
</tr>
<tr>
<td>10</td>
<td>28.2</td>
<td>56.3</td>
<td>60%</td>
</tr>
</tbody>
</table>

- Delamination occurred in one glue line on one side
- Widths of the narrowest timber elements in each test piece determined depth of delamination
Conclusions

- lowest pressure of 0.6 N/mm$^2$ is sufficient for Irish Sitka spruce in terms of shear strength requirements
- wood percentage failure results for PUR type adhesives are very high with small variations
- shear strength within the required limits
- durability requirements are satisfied
- widths of the narrowest timber elements in CLT test piece determine the size of delamination
Thank you!

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