Bending behaviour of massive and aerated timber floors

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Cross Laminated Timber (CLT) floors

- Uniform mechanical and hygroscopic behaviour
- Low self-weight (timber: 450, RC: 2500, steel: 8000 [Kg/m³])
- Possibility of prefabrication, reduction of building time
- Good seismic behaviour
CLT floors heterogeneities

- **“Low” heterogeneities**

  ![Image of low heterogeneities](http://www.techniwood.fr/)

  (Hochreiner et al. 2013)

- **Stronger heterogeneities: floors with regularly spaced boards**

  ![Image of strong heterogeneities](http://www.techniwood.fr/)

  (Zhou, 2013)
Contents

- Low heterogeneities
  - Modelling, validation and parameter study

- Stronger heterogeneities
  - Experimental campaign
    - Bending tests – structure scale
    - Material characterization – small scale
  - Simplified and advanced modelling
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Low heterogeneities: modelling

- Equivalent layer model, continuous or discontinuous
- Exact 3D analytical solution for composites in bending (Pagano, 1969)
- Failure criterion for wood (van Der Put, 1982)
- Point-wise dominant failure mode = \( \max(\frac{\sigma_1}{f_I}, \ldots, \frac{\tau_{zn}}{f_{zn}}) \)

Elastic displacements and stresses

Panel’s failure load and failure mode
Low heterogeneities: validation

(Hochreiner et al. 2013)

- Good agreement between the predicted and actual panel’s global stiffness and variation of failure modes (Franzoni et al, 2015)

- Each layer model is consistent with the corresponding edge-gluing regime

- Gluing the lateral boards slightly increases panel’s stiffness (about 8%) but introduces also an additional failure mode

- The discontinuous model gives a better prediction of global load carrying capacity
New orientation for transverse layers

- Influence on bending behaviour of varying transverse layers’ orientation

(Chen, 2011)
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Stronger heterogeneities

Lighter (high-rise buildings) and more acoustically efficient CLT floors

→ Stronger heterogeneities: periodic voids within the panel

(http://www.techniwood.fr/)

Influence on CLT floor’s bending behaviour?
Stronger heterogeneities – 4 points bending tests

- Measuring system: vertical and horizontal LVDTs
- Bending deflection \( (u) \) and absolute rotation at supports \( (\phi) \)

\[
\begin{align*}
\phi &= \frac{H_{z_2} - H_{z_1}}{t} \\
\frac{u}{u} &= U - U_1 \\
E_I &= \text{Effective bending stiffness} \\
G_A &= \text{Shear stiffness} \\
\text{Ratio shear deflection / bending deflection}
\end{align*}
\]
Stronger heterogeneities – 4 points bending tests

- Classical (massive) CLT panels and regularly spaced ones
- Two ratios wood/void: 2/3 and 1/3

<table>
<thead>
<tr>
<th></th>
<th>CLT</th>
<th>Panobloc®</th>
<th>Panobloc®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slenderness ratio L/h</td>
<td>46.5</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Wood/void ratio</td>
<td>-</td>
<td>2/3</td>
<td>1/3</td>
</tr>
<tr>
<td><strong>Total wood volume fraction</strong></td>
<td>1.0</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Failure load [kN]</td>
<td>75</td>
<td>68</td>
<td>34</td>
</tr>
<tr>
<td>Bending Stiffness [kNm²]</td>
<td>890</td>
<td>3400</td>
<td>1950</td>
</tr>
<tr>
<td>Shear/Bending deflection [%]</td>
<td>3.0</td>
<td>17</td>
<td>27</td>
</tr>
</tbody>
</table>
Stronger heterogeneities – 4 points bending tests

➤ Failure modes:

Massive CLT panel: ductile longitudinal compressive cracks before tensile failure

*Panobloc® 1/3*, more spaced: rolling shear failure of transverse boards

*Panobloc® 2/3*, less spaced: tensile failure of bottom boards
Stronger heterogeneities: material characterization

Axial – parallel to grain and rolling shear tests

<table>
<thead>
<tr>
<th>Axial Tests</th>
<th>n</th>
<th>Mean [Mpa]</th>
<th>COV [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{L(t+c)}$</td>
<td>21</td>
<td>12700</td>
<td>17.2</td>
</tr>
<tr>
<td>$f_{L,t}$</td>
<td>10</td>
<td>85</td>
<td>17.3</td>
</tr>
<tr>
<td>$f_{L,c}$</td>
<td>8</td>
<td>51</td>
<td>6.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shear Tests</th>
<th>n</th>
<th>Mean [Mpa]</th>
<th>COV [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{ZN}$</td>
<td>7</td>
<td>110</td>
<td>25</td>
</tr>
<tr>
<td>$f_{ZN}$</td>
<td>9</td>
<td>1.7</td>
<td>17</td>
</tr>
</tbody>
</table>
Contents

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  - Modelling and validation
  - Investigation on CLT design properties

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Stronger heterogeneities: modelling

Stronger heterogeneities – simplified and advanced modelling

- Classical CLT floor comparison:
  - Equivalent-layer model for low heterogeneities (discontinuous)
  - Two design methods: shear analogy (Kreuzinger, 1999) and gamma method (EN, 2004)

<table>
<thead>
<tr>
<th>Massive CLT</th>
<th>Gamma method</th>
<th>Shear analogy</th>
<th>Equivalent layer - discontinuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure load</td>
<td>-</td>
<td>-</td>
<td>+5%</td>
</tr>
<tr>
<td>Bending stiffness</td>
<td>-7%</td>
<td>-7.5%</td>
<td>-5.5%</td>
</tr>
<tr>
<td>Shear deflection</td>
<td>-8%</td>
<td>+7%</td>
<td>+5.5%</td>
</tr>
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</table>
Stronger heterogeneities – simplified and advanced modelling

- Aerated timber floors: simplified and advanced approaches

- **Simplified**: reducing the mechanical properties by the wood volume fractions

- **Advanced**: periodic homogenization scheme handled by a high-order plate theory (Lebée and Sab, 2012)

Ex. Wood volume fraction of Panobloc 2/3 $\rightarrow$ 0.4

$\rightarrow$ Modulus $E_L^* = E_L \cdot 0.4 \ldots$

$\rightarrow$ Strength $f_{L,t}^* = f_{L,t} \cdot 0.4 \ldots$
## Stronger heterogeneities: modelling

### Stronger heterogeneities – simplified and advanced modelling

<table>
<thead>
<tr>
<th><strong>Panobloc® 2/3</strong></th>
<th>Shear analogy*</th>
<th>Equivalent layer – discontinuous*</th>
<th>Periodic homogenization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure load</td>
<td>-</td>
<td>+40%</td>
<td>In progress</td>
</tr>
<tr>
<td>Bending stiffness</td>
<td>+7.5%</td>
<td>+7%</td>
<td>+6%</td>
</tr>
<tr>
<td>Shear deflection</td>
<td>-73%</td>
<td>-60%</td>
<td>+8.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Panobloc® 1/3</strong></th>
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<td>-</td>
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<tr>
<td>Bending stiffness</td>
<td>+8%</td>
<td>+9%</td>
<td>+7.5%</td>
</tr>
<tr>
<td>Shear deflection</td>
<td>-84%</td>
<td>-76%</td>
<td>+6%</td>
</tr>
</tbody>
</table>

* = mechanical properties reduced by the wood volume fraction
Conclusion – Low heterogeneities

- Reliable modelling: 3D solution + equivalent layer + failure criterion
- Low influence on global behaviour of edge-glued layers
- Low favourable impact of changing transverse layers’ orientation
Conclusion – Strong heterogeneities

Need of an advanced modelling to predict the shear effects

On going work → Modelling of strength and failure modes, parameter studies

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<td>Total wood volume fraction</td>
<td>1.0</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>550</td>
<td>-60%</td>
<td>-75%</td>
</tr>
<tr>
<td>Failure load [kN]</td>
<td>200</td>
<td>-65%</td>
<td>-83%</td>
</tr>
<tr>
<td>Bending Stiffness [kN m²]</td>
<td>8500</td>
<td>-60%</td>
<td>-75%</td>
</tr>
<tr>
<td>Shear/Bending deflection [%]</td>
<td>10</td>
<td>+70%</td>
<td>+170%</td>
</tr>
</tbody>
</table>
References


DIN 4074-1:2012-06 Sortierung von Holz nach der Tragfähigkeit, Nadelschnittholz

EN 338:2010 Structural timber—strength classes


