Performance of Mass Timber Construction in Fire

Christian Dagenais, Eng., M.Sc. – FPInnovations

Mass Timber (CLT) Research Workshop
November 3rd, 2015 – Madison (WI), USA
Outline

- Fire-Resistance
- Surface Flammability
- Fire Stops and Service Penetrations
- Compartment Fires
- Conclusion
Fire-Resistance of CLT

- Full-scale testing in accordance with ULC S101 / ASTM E119 (joint FPI/NRC Test Program)
  - Charring rate
  - Fire performance of adhesive (PUR)
  - Calculation procedure for US and Canadian standards
- Additional full-scale tests were also conducted with wood industry partners and CLT manufacturers
## Fire-Resistance of CLT

### Table 1 – Fire resistance test results (Dagenais 2014)

<table>
<thead>
<tr>
<th># Plies</th>
<th>ANSI/APA PRG 320 Stress Grade</th>
<th>Thickness (in)</th>
<th>Gypsum Board Protection</th>
<th>Superimposed Load</th>
<th>Failure Time</th>
<th>Type of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WALL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>E2</td>
<td>4 1/2</td>
<td>2 x 1/2” Type X</td>
<td>22,818 lb/ft</td>
<td>1 h 46 min</td>
<td>R</td>
</tr>
<tr>
<td>5</td>
<td>E1</td>
<td>6 7/8</td>
<td>Unprotected</td>
<td>22,818 lb/ft</td>
<td>1 h 53 min</td>
<td>E</td>
</tr>
<tr>
<td>5</td>
<td>V2</td>
<td>4 1/8</td>
<td>Unprotected</td>
<td>4,934 lb/ft</td>
<td>57 min</td>
<td>R</td>
</tr>
<tr>
<td>3 [1]</td>
<td>E1</td>
<td>4 1/8</td>
<td>Unprotected</td>
<td>20,214 lb/ft</td>
<td>32 min</td>
<td>R</td>
</tr>
<tr>
<td>5 [2]</td>
<td>E1</td>
<td>6 7/8</td>
<td>1x 5/8” Type X (both sides)</td>
<td>8,702 lb/ft</td>
<td>3 h 06 min</td>
<td>R</td>
</tr>
<tr>
<td>5 [3]</td>
<td>E1</td>
<td>6 7/8</td>
<td>2 x 5/8”</td>
<td>30,767 lb/ft</td>
<td>3 hr 39 min</td>
<td>R</td>
</tr>
<tr>
<td><strong>FLOOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>E2</td>
<td>4 1/2</td>
<td>2 x 1/2” Type X</td>
<td>56 psf</td>
<td>1 h 17 min</td>
<td>[4]</td>
</tr>
<tr>
<td>5</td>
<td>E1</td>
<td>6 7/8</td>
<td>Unprotected</td>
<td>246 psf</td>
<td>1 h 36 min</td>
<td>E</td>
</tr>
<tr>
<td>3</td>
<td>V2</td>
<td>4 1/8</td>
<td>1 x 5/8” Type X</td>
<td>50 psf</td>
<td>1 h 26 min</td>
<td>R</td>
</tr>
<tr>
<td>5</td>
<td>V2</td>
<td>6 7/8</td>
<td>1 x 5/8” Type X</td>
<td>169 psf</td>
<td>2 h 04 min</td>
<td>E</td>
</tr>
<tr>
<td>7</td>
<td>V2</td>
<td>9 3/8</td>
<td>Unprotected</td>
<td>305 psf</td>
<td>2 h 58 min</td>
<td>R</td>
</tr>
<tr>
<td>5 [3]</td>
<td>E1</td>
<td>6 7/8</td>
<td>3 1/2” Glass Fiber Insulation 5/8” Resilient Channels 1 x 5/8” Type X</td>
<td>196 psf</td>
<td>2 h 08 min</td>
<td>R</td>
</tr>
</tbody>
</table>

*R—Structural Failure, E—Integrity Failure


Fire-Resistance of CLT

- Timber-Concrete Composite Floors
  
  FRR > 3½ hrs

NLT  

CLT
Fire-Resistance of CLT

- CLT can exhibit significant fire-resistance
- Charring rate similar to mass timber, but...
  - 0.65 mm/min (one-dimensional)
  - Stepped charring model (i.e. not constant throughout)
  - Influenced by the adhesive and thickness of laminates
    - More studies are required on adhesives exposed to fire
- Failure modes are different from walls to floors
  - Buckling (P-Δ effects) vs. Integrity between panels
    - Fire integrity can easily be resolved using flooring/topping
Surface Flammability

- Full-scale testing in accordance with ULC S102 and ASTM E84
  - Tests conducted with AWC and CLT/SCL manufacturers
- Mass timber behaves as thermally-thick solids (vs. thermally-thin)
- Exhibit lower FSI when compared to traditional interior wood finish materials
Surface Flammability
## Surface Flammability

<table>
<thead>
<tr>
<th>Wood and Wood-Based Products</th>
<th>Flame Spread Rating</th>
<th>Smoke Developed Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lumber, not less than 19 mm (3/4”) in thickness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>65</td>
<td>n.d.</td>
</tr>
<tr>
<td>Sitka</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Western</td>
<td>100</td>
<td>n.d.</td>
</tr>
<tr>
<td>Spruce</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Composite Lumber (SCL)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSL</td>
<td>Min. 89 mm (3½”) on flat</td>
<td>35</td>
</tr>
<tr>
<td>LVL</td>
<td>Min. 140 mm (5½”) on edge</td>
<td>35</td>
</tr>
<tr>
<td>LSL</td>
<td>Min. 89 mm (3½”) on flat</td>
<td>70</td>
</tr>
<tr>
<td><strong>Cross-Laminated Timber (CLT)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLT</td>
<td>E1 Stress Grade (min. 105 mm)</td>
<td>35</td>
</tr>
<tr>
<td>V2 Stress Grade (min. 99 mm)</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>
Fire Stops and Service Penetrations

- **INTEGRITY** and **CONTINUITY** of fire separations are fundamental for achieving/providing the expected level of compartmentation
  - Penetrations and junctions are to be firestopped (tested per CAN/ULC S115 / ASTM E814)
Fire Stops and Service Penetrations

- Junctions evaluated per CAN/ULC S115
  - Floor-to-wall (sealant on unexposed side)
  - Floor-to-wall (sealant on exposed side)
  - Wall-to-Floor (sealant on both sides)
  - Floor-to-Floor
  - Stair landings

→ FT-rating of 1 to 2 hours
Fire Stops and Service Penetrations

- 6 penetrations tested per CAN/ULC S115 → F-rating of 1½ hrs.
Fire Stops and Service Penetrations

- Fire stopping provided at unexposed surface (fire stopping at exposed surface may also be required)
- Thermal insulation
- Through-penetrating item with enough clearance as to not touch the mass timber
- Fire stopping provided around through-penetrating item, up to an appropriate depth/thickness to account for anticipated/calculated charring of mass timber
Compartment Fires

- Compartment fire tests from 2011-2014
Compartment Fires

- Compartment fire tests from 2011-2014
  - Scenarios where CLT is 100% exposed
    - Contribution to fire growth
  - Scenarios where CLT is partially-exposed
    - Burnout of fuel content, depending on exposed face configurations
  - Scenarios where CLT is fully protected
    - Burnout of fuel content

Compartment Fires

- Compartment fire tests from 2011-2014
  - Evaluation of combustible and noncombustible construction subjected to natural fires
    1. CLT: 2 x Type C (½ in.)
    2. CLT: 2 x Type C (½ in.)
    3. CLT: fully exposed
    4. Wood-Frame: 1 x Type C (½ in.)
    5. Wood-Frame: 2 x Type C (½ in.)
    6. Cold-Formed Steel Frame: 1 x Type C (½ in.)

Compartments Fires

- Compartments fire tests from 2011-2014
Compartment Fires

- Mid-Rise Research Consortium (NRCC/CWC/FPI)
  - 3-Storey Apartment Unit, no sprinklers
Compartment Fires

- Mid-Rise Research Consortium (NRCC/CWC/FPI)
  - Duration: 185 min.
  - No structural failure
  - No fire spread beyond compartment boundaries
  - Fire dynamics similar to that of a compartment of noncombustible construction
  - CLT performed better than CFS apartment test
Compartment Fires

- Fire tests in support of a TWB in Quebec City
  - Exposed CLT in vertical shaft
  - Encapsulated CLT in room of fire origin
  - Gypsum board around fire-rated door
  - 45-min fire-rated door (vs. 20 min.)
  - Tested at NRCC laboratory
  - Funded by Quebec Government (MFFP)
Compartment Fires

- Fire tests in support of a TWB in Quebec City
Compartment Fires

- Fire tests in support of a TWB in Quebec City
  - Test conducted for 2 hours
    - Per NBCC for noncombustible construction
  - No fire penetration through walls/floor/ceiling
  - Very little charring on exposed CLT shaft wall
  - No charring/smoke inside CLT shaft
  - Reports (French/English) and video (French) available at:
Conclusion

- CLT detailing can provide for highly fire-resistance rated compartmentation in buildings
- Test results showed the effectiveness of the encapsulation approach in delaying contribution of wood structural members to fires
- Inherent fire performance of CLT makes it suitable for sound alternative solutions
- Design methods and guides are readily available
Acknowledgements

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Thank you!
Christian Dagenais, Eng., M.Sc.
Scientist – Serviceability & Fire Performance
Advanced Building Systems
christian.dagenais@fpinnovations.ca

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