Analysis of Full-Scale Fire-resistance Tests of Structural Composite Lumber Beams

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Analysis of Full-Scale Fire-resistance Tests of Structural Composite Lumber Beams

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1. OBJECTIVE

The key objective of this study is to analyze full-scale fire-resistance tests conducted on structural composite lumber (SCL), namely laminated veneer lumber (LVL), parallel strand lumber (PSL) and laminated strand lumber (LSL). A sub-objective is to evaluate the encapsulation performance of Type X gypsum board directly applied to SCL beams and its contribution to fire-resistance of wood elements.

The test data is being used to further support the applicability of the newly developed Canadian calculation method for mass timber elements [1], recently implemented as Annex B of CSA O86-14 [2].

2. TECHNICAL TEAM

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Testing was witnessed by Jason Smart of the American Wood Council (AWC) and representatives from each respective engineered wood product manufacturer, namely Louisiana-Pacific, Weyerhaeuser and Boise Cascade.

Most of the results and discussion presented herein are taken from the test report made by the test facility [3], graciously shared with FPInnovations by AWC staff. Pictures shown in this report are taken from the test report, with the authorization from AWC staff.

3. INTRODUCTION

In recent decades, the wood industry has developed a number of innovative mass timber products. This includes, but is not limited to, structural composite lumber (SCL) products, such as laminated strand lumber (LSL), laminated veneer lumber (LVL) and parallel strand lumber (PSL). SCL products are proprietary in nature and are, for use in Canada, evaluated for conformance by the Canadian Construction Materials Center (CCMC).

All of these have been used in buildings of combustible construction in Canada for some time, especially in residential construction of single and multi-family dwellings. However, a growing interest in using SCL in mass timber (i.e. post & beam) construction has been observed in recent years.

As SCL products are becoming increasingly attractive to designers for use in larger and taller buildings, their fire performance needs to be assessed to facilitate code acceptance and implementation in generic calculation methods. Fire-resistance, flame spread, and combustion properties are, among others, the most important attributes needed to better understand the fire performance of SCL. Some of these properties have been evaluated on a proprietary basis, by their respective manufacturers.

4. BACKGROUND

In the U.S., Chapter 16 of the National Design Specifications (NDS) provides a mechanics-based design method for predicting the structural fire resistance of sawn lumber and glue-laminated timber [4]. The method is applicable to members subjected to axial tension, axial compression and bending. The reference charring rate at 1 hour is assumed to be 1.5 in./hr. (0.635 mm/min) for all products covered within the NDS. Prior to the recently approved 2015 edition, the NDS did not provide specific guidance for evaluating SCL products, leaving designers to either assume SCL has a charring rate equivalent to that of traditional lumber or glue-laminated timber or use the approach with a proprietary charring rate. In attempt to evaluate SCL behaviour in fire conditions, White [5] conducted various fire-resistance tests on SCL elements, namely LVL, LSL and PSL ranging from 41 to 178 mm (1¾ to 7 in.) in width. Thirteen (13) SCL elements were exposed to the standard ASTM E119 [6] time-temperature curve and
subjected to various axial tension load ratios. The observed charring rates and failure times of the tested SCL elements were within the expected range of predicted failure times when using the NDS design procedure. As such, one could argue that current design provisions may be applicable to SCL.

Recently, a preliminary study on SCL beams subjected to bending was performed in an intermediate-scale furnace [7]. The test series evaluated two LSL beams (44.5 and 89 mm in width) and one LVL beam (89 mm in width). When comparing the char depths and charring rates obtained from the test data to those that would be obtained using Annex B of CSA O86-14, it was observed that the calculated char depths and resulting charring rates were somewhat comparable, even with the furnace temperature being higher than the standard time-temperature curve.

It is noted that built-up SCL elements (mechanically-fastened by nails, screws and bolts, for example) do not exhibit the same fire behaviour as that of single SCL elements of similar initial dimensions [8]. It is anticipated that glued built-up SCL members (at job site for example) may also not behave similarly to a solid single SCL element exposed to fire, unless proven otherwise. Moreover, beams manufactured from secondary gluing at the manufacturing facilities would most likely exhibit a similar performance to that of a solid single element having the same overall dimensions, provided the adhesive used for secondary gluing is a structural adhesive meeting all performance standard requirements, such as those for CSA O112.9 and/or CSA O112.10 [9, 10] for use in Canada.

White also evaluated the fire resistance of wood members with directly applied protection [11]. The specimens consisted of Douglas-Fir LVL and Douglas-Fir glulam specimens subjected to tensile stress and were protected with one and two layers of 16 mm (⅝ in.) Type X gypsum board. It was observed from the seven tests protected with a single layer of gypsum board that the improvements ranged from 25 to 40 min with an average value of 33 min. For the three specimens protected with double layers, the improvement ranged from 64 to 79 min with an average value of 72 min. White concluded that times of 30 min for a single layer of 16 mm Type X gypsum board and at least 60 min for a double layer of 16 mm Type X gypsum board can be added to the fire resistance of an unprotected structural wood element to obtain the rating of the protected element.

Full-scale fire resistance tests of cross-laminated timber (CLT) elements protected with Type X gypsum boards also showed similar results [12] where behind a single layer of 16 mm (⅝ in.) protection, 300°C and 600°C were reached at 25 and 45 min, respectively. When using a double layer of 13 mm (½ in.) Type X gypsum board protection, times to reach 300°C and 600 °C were 61 and 86 min (average), respectively.

5. MATERIALS AND METHODS

5.1 Test Furnace

Fire-resistance tests were conducted at Western Fire Center in Kelso (WA). Single beams were placed in the center of the horizontal furnace with insulating lids, replicating a three-sided fire exposure (bottom and sides of beams) as shown in Figure 1.

Fire exposure followed the standard ASTM E119 time-temperature curve, which is similar to that stipulated in CAN/ULC S101 [13].
5.2 SCL Beam Specimens

As mentioned above, LSL, PSL and LVL are proprietary products whose assessment for compliance with the National Building Code of Canada (NBCC) [14] is overseen by the CCMC. For use in Canada, SCL manufacturers need to conform to the CCMC “Technical Guide for Structural Composite Lumber” [15].

The LSL beams were manufactured from wood strands blended with an isocyanate-based adhesive, oriented parallel to the length of the member, formed into mats and pressed to the required thickness [16]. It is assumed that the samples met the manufacturer’s LSL product specification. The LSL beams were 89 mm wide (3½ in.), 241 mm deep (9½ in.) and 4.3 m (168 in.) long and of the 2360Fb-1.55E stress grade. Figure 2a) shows the texture of a LSL product.

The PSL beams were manufactured from wood parallel strands bonded with a phenol-formaldehyde-based adhesive, oriented parallel to the length of the member and fed into a continuous press [17]. It is assumed that the samples met the manufacturer’s PSL product specification. The PSL beam were 89, 133 and 178 mm (3½, 5¼ and 7 in.) wide, 241 mm (9½ in.) deep and 4.3 m (168 in.) long and of the 2950Fb-2.0E stress grade. Figure 2b) shows the texture of a PSL product.

The LVL beams were manufactured from wood veneers bonded with a phenol-formaldehyde adhesive, oriented vertically and running parallel to the length of the member [18]. The finger joints used to manufacture the length of the LVL panels are bonded using a phenol-resorcinol-formaldehyde or a polyurethane emulsion polymer adhesive. Lastly, the LVL panels typically go through a secondary lamination (gluing) for manufacturing thicker LVL panels using an emulsion polymer isocyanate adhesive. It is assumed that the samples met the manufacturer’s LVL product specification. The LVL beams were 89 and 178 mm (3½ and 7 in.) wide, 241 mm (9½ in.) deep and 4.3 m (168 in.) long and of the 3100Fb-2.0E stress grade. Figure 2c) shows the texture of a LVL product.
5.3 Test Configuration and Loading Conditions

All SCL beams were 4.3 m (14 ft.) long specimens placed on 75 mm (3 in.) long steel bearing plates for a design span of 4191 mm (165 in.). The SCL beams were mounted in such a way as to be free to expand or rotate, or both, at their end supports, thus meeting the conditions of “unrestrained assemblies” defined in CAN/ULC S101. Furthermore, the SCL beams met the standard requirement for unrestrained beams exposed to fire of having a clear span not less than 3.7 m (145 in.).

Each SCL beam was loaded with two (2) hydraulic rams centered 1702 mm (67 in.) from each other and 1283 mm (50½ in.) from the beam extremities (i.e. at 1245 mm (49 in.) from center of supports) as illustrated in Figure 3. Each ram had a metal bracing cuff/saddle 25 mm (1 in.) deep which provided lateral support to the SCL beams, preventing out-of-plane buckling of the compressive edge. Neglecting the beam’s self-weight; the factored bending moment ($M_f$ in kNm) for such a loading condition can be calculated per Equation 1.

$$M_f = \alpha_L \cdot \left( \frac{P}{2} \right) \cdot a = \alpha_L \cdot \left( \frac{P}{2} \right) \cdot 1.245 \cdot 0.623 \cdot \alpha_L \cdot P \leq M_r$$

(1)

Where $P$ is the applied load from the hydraulic ram (kN) and $a$ is the distance from either loading point to closest end supports (1.245 m) and $\alpha_L$ is taken as either 1.5 for normal design or 1.0 for fire design.

Each beam was loaded to various percentages of the assigned allowable stress design (ASD) bending moment, calculated according to the NDS. Target load levels were 25%, 50% and 100% of ASD bending moment. Prior to testing, all beams were also conditioned to 20°C and 65% relative humidity for over a month at an APA facility. As explained in the test report, the hydraulic rams were calibrated prior to testing to correlate the pressure in the hydraulic rams to the applied load; however, the actual applied load resulted in being approximately 15% greater than the target loads.

Table 1 provides the loading conditions and load ratios, when using limit states design (LSD) and CSA O86-14 design procedures under normal (ambient) design. The load values shown in Table 1 are the actual loads applied to the SCL beams and incorporate the 15% increased loading. Lastly, deflection of the beams was measured with a linear voltage displacement transducer (LVDT) located at mid-span over the center of the beams.
Table 1 – Loading conditions based on CSA O86 design procedures

<table>
<thead>
<tr>
<th>SCL Stress Grade</th>
<th>Width (mm)</th>
<th>$C_B$ (a)</th>
<th>$K_L$ (a)</th>
<th>$M_r$ (b) (kN·m)</th>
<th>Load, $P$ (kN)</th>
<th>$M_f$ (c) (kN·m)</th>
<th>Load Ratio (LSD) (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 LSL 1.55E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>24.1</td>
<td>19.2</td>
<td>18.0</td>
</tr>
<tr>
<td>2 LSL 1.55E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>24.1</td>
<td>19.2</td>
<td>18.0</td>
</tr>
<tr>
<td>3 PSL 2.0E</td>
<td>133</td>
<td>6.2</td>
<td></td>
<td></td>
<td>44.2</td>
<td>23.8</td>
<td>22.2</td>
</tr>
<tr>
<td>4 LSL 1.55E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>24.1</td>
<td>19.2</td>
<td>18.0</td>
</tr>
<tr>
<td>5 PSL 2.0E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>58.9</td>
<td>16</td>
<td>14.9</td>
</tr>
<tr>
<td>6 PSL 2.0E</td>
<td>178</td>
<td>4.7</td>
<td></td>
<td></td>
<td>31.3</td>
<td>16.8</td>
<td>15.7</td>
</tr>
<tr>
<td>7 LVL 2.0E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>62.6</td>
<td>68.2</td>
<td>63.7</td>
</tr>
<tr>
<td>8 LVL 2.0E</td>
<td>178</td>
<td>4.7</td>
<td></td>
<td></td>
<td>62.6</td>
<td>68.4</td>
<td>63.9</td>
</tr>
<tr>
<td>9 LVL 2.0E</td>
<td>178</td>
<td>4.7</td>
<td></td>
<td></td>
<td>31.3</td>
<td>16.8</td>
<td>15.6</td>
</tr>
<tr>
<td>10 LVL 2.0E</td>
<td>89</td>
<td>9.3</td>
<td></td>
<td></td>
<td>29.4</td>
<td>31.4</td>
<td>29.4</td>
</tr>
</tbody>
</table>

(a) Slenderness ratio ($C_B$) and lateral stability factor ($K_L$) calculated per sections 7.5.6.3 & 7.5.6.4 of CSA O86-14.
(b) Factored bending moment resistance ($M_r$) determined per section 15.2 of CSA O86-14.
(c) Factored applied bending moment ($M_f$) determined from Equation 1, for normal design.
(d) Taken as the ratio of the factored bending moment to the factored bending resistance, multiplied by 100.

5.4 Type X Gypsum Board

In attempt to evaluate the additional fire-resistance time that encapsulation materials could provide when directly applied to SCL beams, some specimens were initially protected by 16 mm (⅝ in.) Type X gypsum boards, as shown in Figure 1b) and detailed in Table 2.

When using a single layer, the gypsum board was fastened using 57 mm (2¼ in.) No.6 Type S drywall screws spaced at 300 mm (12 in.) on center and placed 25 mm (1 in.) from the edges of the SCL beams. When using 2 layers of gypsum board, the Type S screws were staggered 150 mm (6 in.) apart from those of the base layer and again placed at 25 (1 in.) from the edges of the SCL beams. In both situations, joints and screw heads were neither taped nor covered with gypsum compound. Figure 4 shows the installation detail. Test specimens no. 8 and 10 were each instrumented with two (2) thermocouples, located at mid-span, one at the bottom of the beam and the other on the side, to measure the temperature profile at the interface between the SCL beams and the directly applied gypsum board.
Table 2 – Gypsum board protection

<table>
<thead>
<tr>
<th>SCL Stress Grade</th>
<th>Width (mm)</th>
<th>Type X Gypsum Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LSL 1.55E</td>
<td>89</td>
</tr>
<tr>
<td>2</td>
<td>LSL 1.55E</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>PSL 2.0E</td>
<td>133</td>
</tr>
<tr>
<td>4</td>
<td>LSL 1.55E</td>
<td>89</td>
</tr>
<tr>
<td>5</td>
<td>PSL 2.0E</td>
<td>89</td>
</tr>
<tr>
<td>6</td>
<td>PSL 2.0E</td>
<td>178</td>
</tr>
<tr>
<td>7</td>
<td>LVL 2.0E</td>
<td>89</td>
</tr>
<tr>
<td>8</td>
<td>LVL 2.0E</td>
<td>178</td>
</tr>
<tr>
<td>9</td>
<td>LVL 2.0E</td>
<td>178</td>
</tr>
<tr>
<td>10</td>
<td>LVL 2.0E</td>
<td>89</td>
</tr>
</tbody>
</table>

According to the new provisions of CSA O86-14, the assigned fire-resistance duration calculated in accordance with Annex B can be increased by the following times when Type X gypsum board protection is used:

a) 15 min when one layer of 12.7 mm (½ in.) Type X gypsum board is used;
b) 30 min when one layer of 15.9 mm (⅝ in.) Type X gypsum board is used; or
c) 60 min when two layers of 15.9 mm (⅝ in.) Type X gypsum boards are used.

Annex B of CSA O86-14 also stipulates that the values given above only apply where the fasteners used to attach the gypsum board penetrate the wood element a minimum of 25 mm (1 in.) and are spaced a maximum of 300 mm (12 in.) on center and each length of gypsum board is attached by a minimum of two rows of fasteners that are off-set by half the fastener spacing if row spacing is less than 300 mm. The screws used in this test series meet the screw depth and spacing requirements as they penetrate the SCL beams by 41 mm (single layer) and 25 mm (double layer) and are spaced at 300
mm on center. However, as mentioned previously, joints and screw heads were neither taped nor covered with gypsum compound, which is another requirement from Annex B.

6. RESULTS

Table 3 presents the test results with respect to test duration (time to failure, \( t_f \)) and calculated failure times per Annex B of CSA O86. All of the SCL beams failed beyond the predicted failure times.

<table>
<thead>
<tr>
<th>SCL Stress Grade</th>
<th>Width (mm)</th>
<th>Type X Gypsum Board</th>
<th>Load Ratio (LSD) (^{(d)})</th>
<th>Time to Failure, ( t_f ) (min:sec)</th>
<th>Calculated Time to Failure (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 LSL 1.55E</td>
<td>89</td>
<td>-</td>
<td>75%</td>
<td>34.8</td>
<td>18</td>
</tr>
<tr>
<td>2 LSL 1.55E</td>
<td>89</td>
<td>1 x 16 mm (% in.)</td>
<td>74%</td>
<td>73.6</td>
<td>18 + 30 = 48</td>
</tr>
<tr>
<td>3 PSL 2.0E</td>
<td>133</td>
<td>-</td>
<td>50%</td>
<td>66.0</td>
<td>47</td>
</tr>
<tr>
<td>4 LSL 1.55E</td>
<td>89</td>
<td>2 x 16 mm (% in.)</td>
<td>74%</td>
<td>113.9</td>
<td>18 + 60 = 78</td>
</tr>
<tr>
<td>5 PSL 2.0E</td>
<td>89</td>
<td>-</td>
<td>100%</td>
<td>25.7</td>
<td>15</td>
</tr>
<tr>
<td>6 PSL 2.0E</td>
<td>178</td>
<td>-</td>
<td>25%</td>
<td>119.1</td>
<td>83</td>
</tr>
<tr>
<td>7 LVL 2.0E</td>
<td>89</td>
<td>-</td>
<td>50%</td>
<td>33.4</td>
<td>21</td>
</tr>
<tr>
<td>8 LVL 2.0E</td>
<td>178</td>
<td>2 x 16 mm (% in.)</td>
<td>102%</td>
<td>139.4</td>
<td>42 + 60 = 102</td>
</tr>
<tr>
<td>9 LVL 2.0E</td>
<td>178</td>
<td>-</td>
<td>102%</td>
<td>49.9</td>
<td>42</td>
</tr>
<tr>
<td>10 LVL 2.0E</td>
<td>89</td>
<td>1 x 16 mm (% in.)</td>
<td>50%</td>
<td>71.2</td>
<td>21 + 30 = 51</td>
</tr>
</tbody>
</table>

According to the test report, the fire exposure for all SCL beams were within the tolerance limits stipulated in ASTM E119 and CAN/ULC S101, ranging from 0.2% to 2.0%.

7. DISCUSSION

7.1 Mechanics-based Calculation Methods

The SCL design charring rates given in Annex B of CSA O86-14 are to be taken as 0.65 mm/min and 0.70 mm/min for one-dimensional charring and notional charring respectively. It is noted that these rates are applicable to only wood-based SCL products (e.g. bamboo is typically not considered as a wood-based material). Moreover, a strength adjustment factor of 1.25 (\( K_{fi} \)) is recommended to convert from the specified strength to mean design value, which is based on quality control data provided by SCL manufacturers [1].

The predicted failure times given in Table 3 are based on SCL beams exposed on 3 sides and without explicitly considering corner rounding effects, thus using a notional charring rate of 0.70 mm/min. It can be observed from Table 3 and Figure 5 that the Annex B calculation method provides conservative predictions when compared to all test results. The comparison shows that current fire resistance design provisions for sawn and glulam lumber are acceptable for SCL products, while being conservative (especially for longer fire exposures). Figure 6 shows the residual cross-section of some SCL beams after scrapping the charred layer, clearly showing the corner rounding effect. Additional pictures from the fire-resistance tests can be found in Appendix I.
Figure 5. Comparison between predicted failure times and test data

Figure 6. Reduced cross-sections of SCL beams (credit: [3])

7.2 Type X Gypsum Board Performance

Encapsulation is a fundamental approach to fire protection of all structural materials, including steel, concrete and wood. Encapsulation relates to the use of materials for protecting the structural elements to mitigate the effects of the fire on the structural elements, in such way that any effects of the combustible structural elements on the fire severity can be delayed.

Typically, encapsulation materials protect the substrate from thermal degradation and from ignition. The delay of the onset of charring can be determined as the time when the exposed face of the SCL beams
reaches 300°C, provided the gypsum board remains in place (i.e. attached to the SCL beams). Fall-off time of gypsum board is typically assumed as the time when temperatures behind the gypsum board reach 600°C. Table 4 summarizes the additional times given by the Type X gypsum board encapsulation, when compared a reference unprotected SCL beam.

Table 5 provides the individual and average times at which thermocouples located at the interface between the gypsum board and the SCL beams reached 300°C and 600°C for specimens no. 8 and 10. Figure 7 and Figure 8 show the temperature profiles recorded during these two (2) tests.

### Table 4 – Encapsulation performance of Type X gypsum board

<table>
<thead>
<tr>
<th>SCL Stress Grade</th>
<th>Width (mm)</th>
<th>Type X Gypsum Board</th>
<th>Time to Failure, $t_f$ (min)</th>
<th>Additional time provided by encapsulation (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LSL 1.55E</td>
<td>89</td>
<td>-</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>1 x 16 mm (% in.)</td>
<td>73</td>
<td>+39</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2 x 16 mm (% in.)</td>
<td>113</td>
<td>+79</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>LVL 2.0E</td>
<td>89</td>
<td>-</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>1 x 16 mm (% in.)</td>
<td>71</td>
<td>+38</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LVL 2.0E</td>
<td>178</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>8</td>
<td>2 x 16 mm (% in.)</td>
<td>139</td>
<td>+90</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5 – Thermal performance of Type X gypsum board

<table>
<thead>
<tr>
<th>SCL Stress Grade</th>
<th>Width (mm)</th>
<th>Type X Gypsum Board</th>
<th>Time to Reach 300°C (min)</th>
<th>Time to Reach 600°C (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>LVL 2.0E</td>
<td>178</td>
<td>2 x 16 mm (% in.)</td>
<td>73/73 (73)</td>
</tr>
<tr>
<td>10</td>
<td>LVL 2.0E</td>
<td>89</td>
<td>1 x 16 mm (% in.)</td>
<td>29/27 (28)</td>
</tr>
</tbody>
</table>

(1) Values are $T_{C1}/T_{C2}$ (average).
It can be seen from the measured times that CSA O86-14 assigned times for directly applied Type X gypsum board are conservative. The observed times are also greater than those found by White [11] as well as Osborne et al. [12]. It is assumed that at that temperature (300°C), wood has started to char. However, since the gypsum board protection is still in place, the charring rate is reduced due to a lower heat transfer within each component. As such, an inherent conservatism is implied in the 30 and 60 minutes additional time as it does not account for the slower charring until the thermal protection
actually falls. Therefore, greater time duration could be assigned to the fire-resistance contribution of 16 mm (% in.) Type X gypsum board directly applied to wood members.

Assuming an additional time of 40 min per layer of 16 mm Type X gypsum boards, as demonstrated in this test series, the predicted failure times are still on the conservative side, while being slightly more accurate when compared to test results (Figure 9). A time duration of 40 min is also consistent with current provisions given in the Component Additive Method (CAM) for light-frame wood assemblies and detailed in Appendix D-2.3 of the NBCC as well as Section 721.6 of the International Building Code (for use in the U.S.) [19]. The CAM clearly explains that the assigned times for protective membranes are based on their ability to remain in place during fire tests and are not to be confused with the rating of membranes determined on a temperature rise limit set forth in standard fire-resistance tests.

![Figure 9. Comparison of gypsum board performance (30 vs. 40 min per layer)](image)

It is suggested that a harmonization of additional times between wood assemblies (i.e. light-frame, post-and-beam or mass timber plates as well as Canada-US) be made so that designers can rely on a single source of information, regardless of the type of building system and/or the applicable building code.

As such, the times given in the CAM, assigned to Type X gypsum board, should be used throughout (i.e. 25 min for a 13 mm Type X and 40 min for a 16 mm Type X). Based on Harmathy's rules of fire endurance [20], double layers of 13 and 16 mm would afford respectively at least 50 and 80 min of additional fire resistance, which is also consistent with those observed in this test series and test data from Osborne et al. [12]. The values of 40 and 80 min for single and double layers of 16 mm Type X gypsum board are also consistent with those observed in this test series.
7.3 Implementation of SCL in “Heavy Timber Construction”

The NBCC defines “heavy timber construction” as a special type of combustible construction (typically of post-and-beam construction) in which a certain degree of fire safety is attained by placing limitations on the minimum sizes of structural elements and on the thickness and composition of floors and roofs as well as eliminating concealed spaces (see Table 3.1.4.7 of Part 3 of Division B of the NBCC. This type of construction is allowed to be used where combustible construction is permitted and is not required to have a fire-resistance rating greater than 45 minutes. Furthermore, the NBCC recognizes the inherent fire-resistance of this type of construction by allowing its use in many applications in lieu of noncombustible construction.

As of its 2010 edition, only solid sawn and glue-laminated timbers are recognized as heavy timber construction. While one may argue that SCL would fit within this category, SCL is not explicitly cited in the NBCC. As such, prescriptive language for SCL should be added in the NBCC, similarly to the provisions given for solid and glue-laminated timber. Table 6 provides minimum dimensions that would be acceptable in heavy timber construction, based on SCL manufacturing dimensions closest to those already deemed acceptable for solid and glue-laminated timbers. It is noted that only single pieces of SCL elements would be acceptable (i.e. mechanically-fastened build-up SCL members meeting the minimum dimension requirements would not be suitable for use in heavy timber construction due to their different behaviour when exposed to fire). Also, the 2015 edition of the IBC will provide prescriptive language to recognize SCL members to be used in Type IV construction (heavy timber construction) and will provide similar minimum dimensions as those shown below.

<table>
<thead>
<tr>
<th>Supported Assembly</th>
<th>Structural Element</th>
<th>Solid Sawn (width x depth) (mm)</th>
<th>Glue-Laminated (width x depth) (mm)</th>
<th>Structural Composite Lumber (width x depth) (mm)</th>
<th>Round (diameter) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>roofs only</td>
<td>Columns</td>
<td>140 x 191</td>
<td>130 x 190</td>
<td>133 x 191</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Arches supported on the tops of walls or abutments</td>
<td>89 x 140</td>
<td>80 x 152</td>
<td>89 x 140</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Beams, girders and trusses</td>
<td>89 x 140</td>
<td>80 x 152</td>
<td>89 x 140</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Arches supported at or near the floor line</td>
<td>140 x 140</td>
<td>130 x 152</td>
<td>133 x 140</td>
<td>-</td>
</tr>
<tr>
<td>floors, floors plus roofs</td>
<td>Columns</td>
<td>191 x 191</td>
<td>175 x 190</td>
<td>178 x 191</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Beams, girders, trusses and arches</td>
<td>140 x 241 or 191 x 191</td>
<td>130 x 228 or 175 x 190</td>
<td>133 x 241 or 178 x 191</td>
<td>-</td>
</tr>
</tbody>
</table>

Lastly, for consistency with glue-laminated timber manufacturing requirements given in paragraph 4.3.1.2 of Division B, a new clause should be added for referencing ASTM D5456 [21], similar to those found in CSA O86-14. The language could be as follows:

**4.3.1. Structural Composite Lumber**

1) Structural composite lumber products shall be manufactured to, and evaluated in accordance with ASTM D5456, “Standard Specification for Evaluation of Structural Composite Lumber Products.”
8. CONCLUSION AND RECOMMENDATIONS

This study aimed at evaluating the structural fire-resistance of select SCL beams. It compared their predicted failure time when using the newly developed Canadian calculation method for mass timber elements implemented as Annex B of CSA O86-14. A sub-objective was to evaluate the encapsulation performance of Type X gypsum board directly applied to SCL beams.

Fire-resistance tests were conducted on 10 SCL beam configurations. Single beams were placed in the center of the horizontal furnace with insulating lids, replicating a three-sided fire exposure, which followed the ASTM E119 and CAN/ULC S101 time-temperature curve. Each SCL beam was loaded with two (2) hydraulic rams equipped with a metal bracing cuff/saddle to provide lateral support to the SCL beams, preventing out-of-plane buckling of the compressive edge. The SCL beams were evaluated under various load ratios.

All of the SCL beams failed beyond the predicted failure times when calculated from Annex B of CSA O86-14, thus suggesting that the current provisions are acceptable for SCL products, while being conservative.

When compared to other research projects described in this test report, the measured encapsulation performance of 16 mm (⅝ in.) Type X gypsum board is consistent. The time to reach 300°C at the interface between the gypsum board base layer and the SCL beams (called encapsulation performance) ranged from 27 to 29 min when using a single layer, and 73 min when using a double layer. The time to failure of the protective membranes (taken as the time to reach 600°C at the interface) ranged from 47 to 55 min when using a single layer and 93 to 117 min when using a double layer. The latter times are typically used to increase the fire-resistance of an assembly by adding the protective membrane failure time to the fire-resistance of an initially unprotected element.

It is suggested that a harmonization of additional times between wood assemblies (i.e. light-frame, post-and-beam or mass timber plates as well as Canada-US) be made so that designers can rely on a single source of information, regardless of the type of building system and/or the applicable building code. As such, additional times of 25 and 50 min should be assigned to single and double layers of 13 mm Type X gypsum board respectively. When using 16 mm Type X gypsum board, additional times of 40 and 80 min should be assigned to single and double layers respectively.

Lastly, as SCL products behave similarly to solid sawn timber when exposed to fire, it is suggested that prescriptive code language be implemented in the NBCC with respect to minimum dimensions to be used and recognized in heavy timber construction. However, only single pieces of SCL elements (i.e. cross-sections of solid elements) would be acceptable (i.e. mechanically-fastened build-up SCL members meeting the minimum dimension requirements would not be suitable for use in heavy timber construction due to their different behaviour when exposed to fire).
9. REFERENCES

Appendix I

Pictures from the SCL Fire Test Series (credit: [3])
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