Fire Resistance of Long Span Composite Wood-Concrete Floor Systems

March 2015

By:
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1 INTRODUCTION

While considerable technical information has been developed on the fire resistance of cross-laminated timber (CLT) assemblies, there are still some fire performance related issues that need to be further tested and investigated to complete a thorough evaluation of CLT assemblies.

CLT construction is becoming more prevalent in Canada and its birthplace, Europe. Canada is yet to reach the same level of acceptance as some European countries, but it is quickly gaining momentum due to its various benefits. These include ease and speed of construction, reduced carbon footprint, and potential cost savings. However, more research is needed for this product to be fully understood, especially in terms of fire performance.

One area that warrants further investigation is timber-concrete composite (TCC) floors (using mass timber products, e.g. CLT and Structural Composite Lumber). In order to be able to span longer distances, which is increasingly desirable for ‘open-concept’ type designs, mass timber plates could be coupled with an additional reinforced concrete topping to provide the necessary strength and stiffness to resist bending stresses and deflections [1, 2]. A TCC system is advantageous because the overall mass is less than that of a sole concrete slab, it reduces vibrations, improves acoustic separation, and construction is simplified by using wood as the concrete form [1].

The UBC Earth Sciences Building used a TCC floor system which consisted of 89 mm thick LSL panels, foam board insulation, a 100 mm concrete topping, and a proprietary Holz-Beton-Verbund (HBV) shear plate, shown in Figure 1. HBV connectors are proprietary perforated steel plates which are epoxied to the timber and are cast into the concrete. This assembly is 50% lighter than a solid concrete floor, and permits spans up to 6.7 m [1].

![Figure 1](image1.png)  
**Figure 1**  
HBV Shear connector in UBC Earth Sciences Building (Courtesy Equilibrium Consulting) [1]

To ensure adequate composite action, shear connectors are needed to transfer forces between the two materials. The wood needs to be mostly loaded in compression parallel to the grain and minimize any compression in the wood perpendicular to the grain. This can be achieved mechanically using screws, or use adhesives to glue a connector to the wood. This also will improve the serviceability of the floor because acoustic performance improves with additional mass. It is anticipated that the inclusion of a
concrete topping above a CLT floor will likely improve fire and acoustic performance. A layer of acoustic insulation can potentially be placed between the wood and the concrete.

FPInnovations has developed a fire resistance calculation methodology [3], which was based on fire resistance testing, according to CAN/ULC-S101 [4], of CLT walls and floors under load. These tests aided in the validation of charring rates. The addition of a concrete topping will likely improve overall fire resistance; however, it is unknown how the presence of shear connectors might impact heat transfer into the specimen.

Similar projects are simultaneously being conducted at the University of British Columbia, Laval University (Québec) and at the Université du Québec à Chicoutimi (UQAC, Qué.) to evaluate the mechanical properties of these types of systems under ambient conditions (normal conditions). The results of these studies have not yet been published.

2 OBJECTIVES

There is a need to evaluate TCC systems under fire conditions to understand how shear connectors will perform and might affect the fire performance and the composite action of the assembly. This project evaluates the fire performance of TCC assemblies based on their structural resistance, integrity and insulation when exposed to a standard fire, as well as how mass timber and concrete interact. This study involves full-scale fire resistance tests on composite wood-concrete floors using two types of shear connectors.

Demonstrating that composite wood-concrete floor systems provide sufficient fire resistance will open many opportunities for these systems, since the introduction of concrete into the assemblies will allow for longer spans. Having the ability to span greater distances (e.g. greater than 9 meters) will diversify the variety of situations in which mass timber assemblies can be used, for example in tall wood buildings. Having mass timber be a competitive product for use in tall buildings will allow for more widespread use of local BC wood products.

The objective is to accurately evaluate how the wood and the concrete materials respond to fire exposure (by evaluating charring rates), but in particular by examining how any metal shear connectors might transfer heat between the materials. The results from these tests could lead to the development of alternate provisions in the fire resistance calculation for mass timber which would specifically address a composite wood-concrete system. A validated calculation methodology can be a useful design tool.

The results from these tests will also provide fundamental information to supplement CLT research that is currently underway at FPInnovations [5] and would allow for potential implementation of CLT in the BCBC as an additional structural building system. The tests provide insights into new alternative advanced wood-based floor systems that can be used to enhance the serviceability of wood-based floors, especially for longer spans using CLT and traditional laminated wood.
This research can help designers make the case for permitting long span wood-concrete composite floor systems in BC, which might otherwise not be permitted due to a lack of fire performance information. The results of this study, and continued efforts by FPInnovations, also provide engineers and designers with the tools necessary to create fire safe designs using composite wood-concrete floor systems.

Several of the photos in this report were captured by NRC staff, when this is the case it is indicated in the photo.

3 TECHNICAL TEAM

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4 PROCEDURES AND RESULTS

Two full-scale composite wood-concrete assemblies were evaluated for fire resistance. The performance of how the systems performed as a whole, and specifically how the shear connectors transferred heat between the materials is investigated. The two assemblies were:

- 5-ply, 175 mm CLT, 89 mm concrete topping, with self-tapping screws at 45º
- Screw laminated 2x8 (38 mm x 184 mm), 89 mm concrete topping, with steel truss plates

Self-tapping screws for use as shear connectors is considered to be a simple method, whereas using truss plates for shear connectors is a more non-traditional application (although some research has been done on this system in the past). There is minimal existing research into the structural effectiveness of truss plates, and other similar plate type shear connectors for TCCs [6, 7].

The assemblies were simultaneously exposed to the standard CAN/ULC-S101 [4] on the full-scale furnace at the National Research Council of Canada fire laboratory in Ottawa, ON. Each assembly was instrumented with thermocouples during construction so that charring rates and depth of char could be calculated and heat transfer could be assessed.

4.1 Assembly Construction

Both assemblies were constructed and instrumented at the FPInnovations laboratory in Québec City, QC. Each sample measured 1829 x 4800 mm (6’ x 15’ 9/12”).
4.1.1 CLT-concrete

The CLT was a 5-ply, 175 mm thick, E1 stress grade, conforming to ANSI/PRG-320 [8]. Self-tapping wood screws, 180 mm (7") long, (WFC-T-T40-Ø8x180/100) were drilled into the specimen at 45°. The entire thread, measuring 100 mm (4"), was drilled into the CLT. 89 mm (3 ½") of concrete was poured on top on the assembly, having a compressive strength of 30 MPa after 28 days. The compression resistance values during curing are given in Appendix I. Steel mesh was included for shrinkage reinforcement but no tensile reinforcement was provided in the concrete. A design drawing of the assembly is shown in Figure 2. The panel during construction prior to the concrete being poured is shown in Figure 3 a). Detailed construction drawings can be found in Appendix II.

![Figure 2](image_url)

Figure 2  Design drawing of CLT-concrete floor

Along the 1829 mm (6') width the screws were spaced at 102 mm (4") in the centre and 51 mm (2") from the edges. In the long direction screws were spaced 406 mm (16") in the centre and 165 mm (6.5") from either end. Screws were angled away from the centerline, parallel to the length of the panel, as seen in Figure 3 b).

The concrete surface, CLT-concrete interface, and the CLT exposed surface are shown in Figure 3 c), d), and e), respectively.
Figure 3  CLT-concrete panel during construction
4.1.2 Laminated wood-concrete

The (2x8) laminated wood-concrete specimen consisted of nominal 2x8 SPF No.2 lumber boards that were held together in ‘beams’ of 5 boards. Ultimately 9 beams made up the whole assembly. Each beam used 180 mm (7”) self-tapping screws (WFR-T-T30-\(\phi\)6x180/64) to attach the boards together. Two rows of screws, each 38 mm (1½”) from the edges of the board, were spaced every 610 mm (24”), the same pattern was used on the opposite side of the beam, but staggered by 305 mm (12”). The screws were driven at a 45º angle.

For the shear connectors between the wood and the concrete, 254 x 127 mm (10” x 5”) conventional steel truss plates (MT-20) were pressed into either side of the beam at 610 mm (24”) intervals o.c., being 267 mm (10.5”) from either end. 76 mm (3”) of the truss plates were pressed into the wood; a close up view of the truss plate is shown in Figure 5 a).

Once the wood assembly construction was complete, as shown in Figure 5 b), 89 mm (3½”) of 30 MPa concrete was poured on top of the specimen. As with the CLT-concrete assembly, steel mesh was included for shrinkage reinforcement but no tensile reinforcement was provided in the concrete. The finished concrete surface is shown in Figure 5 c), and the laminated wood surface (once installed in the furnace) is shown in Figure 5 d).

As is typical of visually-graded lumber boards, not all were perfectly straight and some had imperfections, is highlighted in Figure 5 e).

Detailed construction drawings can be found in Appendix III.

![Design drawing of laminated wood-concrete assembly](image-url)
a) Close up view of truss plate

b) Laminated wood assembly before concrete pour

c) Concrete surface

d) Laminated wood-concrete assembly from inside the furnace

e) Typical imperfections in lumber boards

Figure 5  Laminated wood-concrete assembly during construction
4.1.3 Instrumentation

Both assemblies were instrumented with Type K thermocouples to capture temperature profiles within the wood components, at the shear connectors, and within the concrete. Five locations were selected for each set of thermocouples, as detailed in Figure 6.

![Figure 6 Location of thermocouples](image)

Five thermocouples were embedded at each location at depths of 35 mm, 70 mm, 105 mm (which correspond to laminates in the CLT), then at the wood-concrete interface, 175 mm for the CLT assembly and 184 mm for the laminated wood assembly. The depths are illustrated in Figure 7. At locations #1-4, a thermocouple was also placed in contact with the shear connector (i.e., screw or truss plate) and epoxied in place. At location #5, one thermocouple was placed mid-depth into the concrete, at 45 mm. Thermocouples were also installed on the unexposed side of the assemblies at each location.

Deflection measurements were taken at (or near) locations #2 and #4, as well as along the plane of #1 and #3 but at the centerline (mid-span).
4.2 Fire Testing

The assemblies were tested on March 11th, 2015. The two assemblies were installed side-by-side on the full-scale furnace at NRC in Ottawa. A layer of fibrefrax was placed between the two assemblies to prevent any smoke leakage, as shown in Figure 8 a); the edges of the assemblies were also protected using fibrefrax.

Lifting anchor bolts were installed for ease of transportation. Once installed on the furnace these anchors were removed and sealed with a firestop sealant, shown in Figure 8 b) and c). The unexposed surface prior to loading is shown in Figure 8 d).

A 2.4 kPa load was applied uniformly to both specimens. This load represents a typical live load that could be expected for an office area (for floors above the first storey) according to the National Building Code of Canada (NBCC) [9]. This loading condition also covers typical 1.9 kPa residential live loads.
The assemblies were exposed to the standard CAN/ULC-S101 fire curve, as is illustrated in Figure 9. The average furnace temperature was within 1% total error of the standard fire curve, which is within the tolerance limit of 5% as specified in CAN/ULC-S101 for tests lasting longer than 2 h.
When the test first started localized burning was evident at the edge of the laminated wood assembly and some smoke escaped into the lab (Figure 10 a)). This was early in the test, while the furnace pressure was still stabilizing. This may have indicated some airflow through the laminated wood boards at the edges. An account of test observations is given in Appendix IV.

During the test it was sometimes difficult to differentiate between the observations of the two assemblies. The entire wood surface, of both assemblies, was engulfed in flames. In some instances charred wood was observed falling off, but it is unknown exactly which assembly it fell from. This is one of the drawbacks of testing two assemblies simultaneously. Another disadvantage of this method is that once one assembly failed it is very difficult, if not impossible, to continue to test the other specimen to failure.

Small pieces, presumably of the CLT assembly were observed to start falling off at 1 h, which became more prominent after 80 to 110 min. Just after 3 h 20 min smoke was noted at the seam between the two assemblies due to the difference in deflection between the two. Shortly after, the rate of deflection in the CLT assembly began to rise quickly, which ultimately lead to the failure of the assembly at 3 h 34 min (214 min). The laminated wood assembly had not yet failed, but the test was stopped due to flames protruding up between the two specimens.
a) Burning noted at edge of laminated wood assembly early in the test

b) 2 h 54 min into test

Figure 10  During the test

After the test the frame was removed from the furnace, shown in Figure 11 a) and b). Flaming of the wood ceased as the assemblies were no longer exposed to the heat source, shown in Figure 11 c) and d), which also provides an indication of the condition of the assemblies prior to extinguishing with a hose for the CLT and laminated wood assemblies, respectively. This procedure can exert high forces which cause any loose, charred pieces to fall off. The condition of the assemblies after the tests is discussed in more detail in Section in 4.2.1 and 4.2.2.
4.2.1 CLT-Concrete Assembly

It was evident that the first three layers had fallen off of the CLT assembly (based on observations of pieces falling off during the test), as had the majority of the fourth layer, although some pieces of the fourth layer were still intact, see Figure 11 c).

The panel had deflected until structural failure was reached; see Figure 12 a). When the frame was lifted off the furnace the assembly was still intact, although a clear crack had formed in the concrete near the centerline, Figure 12 b). Shortly after extinguishing the assembly, the remaining concrete could no longer carry its self-weight and it collapsed out of the frame and fell to the floor, shown in Figure 12 c) and d). This behaviour may potentially have been avoided if tensile reinforcement had been provided in the concrete.
The temperature profiles measured in the wood are shown in Figure 13; the unexposed temperatures remained at ambient throughout the duration of the test suggesting adequate insulation performance of the assembly. Temperatures behind the first ply in the CLT began to gradually increase around 15 min. Based on thermocouple data, the first ply of the CLT was charred shortly after 1 h, when temperatures reached roughly 300°C. After this point temperatures grew more quickly until they matched the furnace temperature around 90 min. It is understood that by this point the first layer had fallen off.

The second layer had charred by 105 min and likely began to fall off after 120 min, when pieces were observed falling off. The third layer was fully charred after 150 min, and presumably started to fall off around 180 min, also consistent with observations during the test.
Temperatures at the wood-concrete interface increased on average only 20°C, and merely 5°C at mid-depth in the concrete. However, the thermocouples at the concrete interface that were directly attached to the shear connector increased by 93°C. This indicates that heat was conducted up through the screw, from the tip to the head. The tip of the screws were essentially level with the face of the 4th ply, at 105 mm. The temperatures measured at the screws began to gradually increase once temperatures exceeded 100°C at 105 mm. As the third layer begun to fall off, a steeper rate of temperature increase was noted at the screws, likely as the third layer fell off the tips of the screws became fully exposed to the furnace and therefore temperatures increased more rapidly. Despite this temperature increase, there was negligible heat transfer into the concrete.

In order to assess when charring had occurred, conservative temperature criteria, which have been used in other projects [10], were adopted. When either an average temperature rise of 250°C or a single point temperature rise of 270°C was reached, the wood was deemed to be charred. These criteria are in line with the generally accepted concept that wood chars at 300°C.

The time that the charring criteria were reached are summarized in Table 1. The average and single point criteria were both met within 3 min of each other. The time at which 300°C was reached was also assessed and was determined to provide the same results as the single point increase of 270°C. The
overall charring rate was calculated for each depth (using the time when the single point criteria was reached). Initially the charring rate was 0.52 mm/min which is slightly less than the commonly used 0.65 mm/min charring rate for CLT [3]. For the subsequent plies, the charring rate increased to 0.71 and 0.68 mm/min, namely due to heat delamination of the adhesive (i.e. fall-off of charred layers exposing fresh wood underneath to char faster than usual). This increase in charring rate was also observed during full-scale fire resistance tests of CLT assemblies, which resulted in developing the stepped charring model in both the US and CDN Chapter 8 of the CLT Handbook [3, 11].

Table 1  Time charring criteria were reached for CLT-concrete assembly

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time average Δ 250°C reached (min)</th>
<th>Time single point Δ 270°C reached (min)</th>
<th>Charring rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 mm</td>
<td>69</td>
<td>67</td>
<td>0.52</td>
</tr>
<tr>
<td>75 mm</td>
<td>109</td>
<td>106</td>
<td>0.71</td>
</tr>
<tr>
<td>105 mm</td>
<td>156</td>
<td>154</td>
<td>0.68</td>
</tr>
<tr>
<td>Interface</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Interface - screw</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mid-depth in concrete</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.2.2  Laminated Wood-Concrete Assembly

The laminated wood-concrete assembly did not reach failure; the test was stopped because the CLT-concrete assembly had failed structurally. The entire exposed face of the laminated wood assembly was charred, some of which had fallen off and some remained in place, Figure 11 d). In some locations the depth of char that remained in place was as much as a few inches deep. Most of the loose char fell off when the assembly was extinguished, shown in Figure 14 a). Upon closer investigation, most of the wood had charred, with roughly 50 mm (2”) remaining, depicted in Figure 14 b) (for reference the truss plate was embedded 76 mm (3”) into the wood). Most of the laminating screws appeared to still be in place (Figure 14 c); the heads of the screws were driven in at 38 mm (1.5”) which indicates that at least this depth of wood was still intact.
Temperature profiles of the (2x8) laminated wood-concrete assembly are presented in Figure 15. Temperatures at 35 mm began to increase after 15 min and had reached the charring temperature criteria shortly after 60 min. Once 800°C was reached, the rate of temperature rise decreased, i.e. the line became more horizontal on the graph. This is to be expected as the temperatures were approaching the furnace temperature. During this period, temperatures remained approximately 100°C lower than the furnace temperature, indicating that likely the charred wood remained in place.

75 mm into the wood temperatures began to gradually increase after 45 min, once 100°C was reached the rate of temperature rise increased. Charring was reached at 75 mm after 130 min. Temperatures at 105 mm followed a similar profile and had charred after approximately 180 min.
Temperatures at the interface increased 16ºC, and at the truss plate shear connector by 64ºC. This indicates that the truss plate was conducting heat up its cross-section; however this did not affect the temperature at the surrounding interface on into the concrete any significant amount. Mid-depth into the concrete temperatures rose by merely 10ºC. Temperatures at the shear connector gradually increased at roughly the same rate until the end of the test. Unexposed temperature rise varied between 3-9ºC.

![Temperature profiles within the (2x8) laminated wood-concrete assembly](image)

**Figure 15** Temperature profiles within the (2x8) laminated wood-concrete assembly

Table 2 summarizes the times at which the charring temperature criteria were reached. The overall charring rates were subsequently calculated and found to be between 0.56 and 0.58 mm/min. As opposed to the increased charring rate observed from the CLT-concrete assembly due to fall-off effect, the charring rates of the 2x8 laminated assembly remained fairly constant throughout the test duration.
Table 2  Time charring criteria were reached for (2x8) laminated wood -concrete assembly

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time average Δ 250°C reached (min)</th>
<th>Time single point Δ 270°C reached (min)</th>
<th>Charring rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 mm</td>
<td>67</td>
<td>62</td>
<td>0.56</td>
</tr>
<tr>
<td>75 mm</td>
<td>134</td>
<td>130</td>
<td>0.58</td>
</tr>
<tr>
<td>105 mm</td>
<td>189</td>
<td>181</td>
<td>0.58</td>
</tr>
<tr>
<td>interface</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>shear connector</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mid-depth in concrete</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.2.2.1 Deflection

After initial preloading, deflection was less than 1 mm for both assemblies. The highest deflections were consistently measured along the centerline for both assemblies, as would be expected. Initially the laminated wood assembly was deflecting very slightly more than the CLT assembly, however after 3 h this changed when the rate of deflection of the CLT-concrete assembly began to increase, ultimately until failure.

The maximum deflection for the CLT assembly prior to failure was 7.5 cm, but this quickly increased to 21 cm after structural failure. The maximum deflection in the 2x8 assembly was 3 cm at the end of the test. A plot of deflection during the test is shown in Figure 16.
4.2.2.2 Comparison of Results

The CLT-concrete assembly was the first to reach failure. Early on in the test it was clear that temperatures were rising more quickly in the CLT, and that ultimately the CLT assembly reached higher temperatures, which can be attributed partially to fall-off of the layers. A comparison of the temperature profiles is shown in Figure 17. For each depth, higher overall temperatures were measured in the CLT assembly. The CLT assembly also exhibited faster rates of temperature rise, once roughly 100ºC was reached at each depth in the wood.

![Figure 17 Comparison of temperature profiles](image)

Despite the variations in temperatures throughout the majority of the test, the charring rate for the first 35 mm of wood was similar for both assemblies, i.e. around 0.55 mm/min. Over greater depths, the total charring rate increased for the CLT assembly, but maintained essentially constant for the laminated wood assembly. This can be attributed to wood on the 2x8s staying in place and CLT laminates falling off once fully charred.

After 3 h it became apparent that deflections in the CLT assembly were more significant than the laminated wood assembly. Because more wood had charred in the CLT assembly its structural capacity was reducing more quickly. Eventually the concrete was carrying the bulk of the load, until it structurally failed. The non-homogenous cross-section of a CLT also affects its residual bending stiffness as soon as a layer in the strength direction is charred. The laminated 2x8 has a homogenous cross-section that reduces almost linearly with time.
The overall temperature rise at the wood-concrete interface at the location of a shear connector was higher for the screws by 30ºC, even though the truss plates projected further down into the wood and have a greater overall surface area. This is likely more attributed to the wood remaining in place on the laminated wood assembly than the superior performance of the truss plate. A summary of temperature rise at certain locations is given in Table 3.

<table>
<thead>
<tr>
<th>Location</th>
<th>CLT</th>
<th>2x8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Interface - shear connector</td>
<td>93</td>
<td>64</td>
</tr>
<tr>
<td>Mid-depth in concrete</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Both the laminated wood-concrete and CLT-concrete assemblies withstood a standard fire exposure in excess of 3 h when a 2.4 kPa load was applied. Although this was not specifically a test to determine the fire resistance rating of the assemblies, these results indicate that in a building conforming to NBCC residential or office loading conditions at least 2 h of fire resistance could be expected from these assemblies (which is the requirement for tall buildings). Overall, both shear connectors performed very well in terms of limiting heat transfer into the concrete and did not make any evident significant impact on the overall fire performance of the assemblies.

5 CONCLUSION AND RECOMMENDATIONS

Two timber concrete composite (TCC) floor assemblies were simultaneously exposed to a standard CAN/ULC-S101 [4] fire with a 2.4 kPa applied load. The main objective was to observe the overall fire performance of the composite specimens and to assess the impact that any shear connectors might have on heat transfer into the assembly. The test was conducted at the NRC fire laboratory in Ottawa, ON.

One assembly consisted of a 5-ply CLT and 89 mm (3½”) of concrete, which used self-tapping wood screws driven in at 45º as shear connectors. The other assembly consisted of a series of nine screw laminated 2x8 ‘beams’, where each beam combined five boards of lumber. Conventional truss connector plates were pressed into either side of the ‘beams’ to act as shear connectors into the 89 mm (3½”) of concrete.

Temperatures were measured throughout the assemblies during the test, as were deflections across the unexposed surface. The CLT-concrete assembly began rapidly deflecting after 3 h of exposure, until a structural failure was ultimately reached after 3 h 34 min. The laminated wood-concrete assembly had, in comparison, minimal deflections. Due to the nature of testing two assemblies simultaneously, the test was halted once the CLT assembly had failed and therefore the laminated wood assembly did not reach failure. This is one limitation of simultaneous assembly testing, as is having difficulty in differentiating which assembly to attribute visual observations to, such as char fall-off.

Confidential
Temperature profiles were relatively similar for the first hour of testing, after which the laminated-wood assembly began to demonstrate better performance. This was defined by lower peak temperatures reached at each thermocouple depth, reduced rates of temperature rise at each depth, and longer periods of initial heating at depths of 70 and 105 mm. The better overall performance of the laminated-wood assembly is attributed, in part, to the ability of the charred wood to remain in place for long periods and to its homogenous cross-section (i.e. no cross-plies affecting the bending stiffness). For CLT assemblies, typically once a layer is fully charred it will fall off when the charring front reaches a glue-line. The advantage of the laminated wood assembly is that the 2x8s used in construction are continuous across their depth, therefore taking advantage of the propensity for wood to char.

The use of shear connectors between the wood and the concrete had little or no observable impact on transferring heat into the concrete. While the shear connector temperature did increase at the wood-concrete interface, there was minimal temperature rise at other locations at the interface and even less mid-depth into the concrete. This indicates that the type of shear connector has negligible impact on heat transfer into the assembly. In these tests, both shear connector methods extended into the wood roughly 76 mm (3"). If a shear connector were to extend deeper into the wood portion of an assembly, it may not benefit as greatly from being protected by the wood and would therefore have a longer opportunity to increase in temperature.

Further fire testing of other assembly configurations is suggested to verify the findings in this project. In particular, a full-scale fire resistance test, of a singular assembly, would be beneficial in acquiring an actual fire resistance rating for an assembly. This type of test report could be used by designers to demonstrate the ability of an assembly to achieve a 2 h fire resistance rating, as would be required in a tall wood building, according to the NBCC.
6 REFERENCES


APPENDIX I
Compressive Resistance of Concrete during Curing
### Renseignements généraux

- **Entrepreneur:** 
- **Sous-traitant:** 
- **Fournisseur:** 
- **Usine:** 
- **Mélange:**

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<th>N°</th>
<th>Date d'échantillonnage</th>
<th>Endroit du prélèvement</th>
<th>Essais sur béton plastique</th>
<th>Essais sur béton durci</th>
<th>Remarques</th>
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### Spécification n° 1

- **Dossier:** B-0006949-1
- **Réf. client:**
- **Rapport n°:** 1
- **Rev. 15-02-12**
- **Page 1 de 1**

**Remarques**

Méthode d’échantillonnage : Par le client

(*) L’astérisque indique un affaissement mesuré après ajout de SUPERPLASTIFIANT.

**Préparé par:** Chantal Ouellet, chef laboratoire  
**Date:** 2/12/2015

**Approuvé par:** Michel Buron  
**Date:** 2/13/2015

EQ-09-EM-234 rev. 00 (06-03)
APPENDIX II
Construction Drawings for CLT-concrete Assembly
I. Sketches for construction of CLT-Concrete Composite Slab (Assembly 1)

Concrete: 30MPa compressive strength, including steel mesh for shrinkage reinforcement

CLT: 6’ by 16’ 5-ply Nordic CLT (Grade E1)

Connectors: WFC-T-T40-8x180/100 self tapping screws drilled at 45°. The entire thread (i.e., 100mm or 4”) is to be drilled into the CLT.

Original design was for 16’ long panels, however this was reduced to 15’ 9” to conservatively accommodate the furnace. The drawings shown in this appendix are for the full 16’ length, however 1.5” was cut from either end.
APPENDIX III
Construction Drawings for Laminated Wood-Concrete Assembly
II. Sketches for construction of 2x8Lumber-Concrete Composite Slab (Assembly 2)

Original design was for 16’ long panels, however this was reduced to 15’-9” to conservatively accommodate the furnace. The drawings shown in this appendix are for the full 16’ length, however 1.5” was cut from either end.

STEP 1: CONSTRUCTION OF NINE (9) IDENTICAL TIMBER BEAMS

Each beam consists of:
- 2x8 SPF lumber boards 16’ in lengths – Five units
- 10x5 Truss Plates MT-20 – 16 units
- WFR-T-T30-6x180/64 Self tapping screws – 32 units

TRUSS PLATE DETAIL - 10x5 Truss Plates MT-20
Dimensions shown are from center-to-center
SELF TAPPING SCREW DETAIL - WFR-T-T30-6x180/64 Self tapping screws (staggered pattern)
STEP 2: ATTACHING OF THE NINE (9) IDENTICAL BEAMS WITH CROSSED SELF TAPPING SCREWS (WFR-T-T30-6x140/64) (driven at 45° in between every truss plate as shown)
STEP 3: CONCRETE POUR
3 ½” Concrete slab with 30MPa minimum compressive strength

MATERIAL REQUIREMENTS (for Assembly 2)

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<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY</th>
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<tr>
<td>2x8 SPF Lumber elements 16' in length</td>
<td>45</td>
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<tr>
<td>10x5 MT-20 Truss plates</td>
<td>144</td>
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<tr>
<td>WFR-T-T30-6x180/64 Self tapping screws</td>
<td>288</td>
</tr>
<tr>
<td>WFR-T-T30-6x140/64 Self tapping screws</td>
<td>144</td>
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<tr>
<td>30MPa Concrete</td>
<td>6 ft³</td>
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APPENDIX IV
Test Observations
<table>
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<tr>
<th>Time</th>
<th>Observations</th>
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<tbody>
<tr>
<td>0:00</td>
<td>Start time approximately 10:50 AM</td>
</tr>
<tr>
<td>0:01</td>
<td>Smoke escaping through assembly into lab</td>
</tr>
<tr>
<td>0:02</td>
<td>Furnace burners turn off to account for fast initial temperature due to exposed wood. Burning noted at edge of laminated wood assembly. Potentially location where air can leak through assembly</td>
</tr>
<tr>
<td>0:07</td>
<td>Crack sound heard</td>
</tr>
<tr>
<td>0:13</td>
<td>Slightly greater deflection noted for laminated wood assembly ~ 1.4 mm</td>
</tr>
<tr>
<td>0:32</td>
<td>~60°C at 35 mm in CLT assembly ~90°C at 35 mm in laminated wood assembly</td>
</tr>
<tr>
<td>0:42</td>
<td>~57°C at 70 mm in CLT assembly</td>
</tr>
<tr>
<td>0:47</td>
<td>~100°C at 35 mm in CLT assembly</td>
</tr>
<tr>
<td>1:00</td>
<td>~240°C at 35 mm in laminated wood assembly</td>
</tr>
<tr>
<td>1:02</td>
<td>Piece of CLT appears to be falling off (delaminating) ~300°C at 35 mm in laminated wood assembly at two thermocouples</td>
</tr>
<tr>
<td>1:04</td>
<td>Small pieces falling off</td>
</tr>
<tr>
<td>1:07</td>
<td>Larger piece of CLT fell</td>
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<tr>
<td>1:15</td>
<td>~300-450°C at 35 mm in laminated wood assembly</td>
</tr>
<tr>
<td>1:20</td>
<td>Small pieces falling off</td>
</tr>
<tr>
<td>1:40</td>
<td>Small pieces falling off</td>
</tr>
<tr>
<td>1:55</td>
<td>Small pieces falling off</td>
</tr>
<tr>
<td>2:10</td>
<td>~100°C at 105 mm in CLT assembly</td>
</tr>
<tr>
<td>2:30</td>
<td>Small pieces falling off</td>
</tr>
<tr>
<td>2:36</td>
<td>Some larger pieces falling off</td>
</tr>
<tr>
<td>3:15</td>
<td>Some pieces falling off. CLT deflection is now greater than the laminated wood assembly</td>
</tr>
<tr>
<td>3:27</td>
<td>Smoke/steam is seen at the seam between the two assemblies</td>
</tr>
<tr>
<td>3:30</td>
<td>Can visually see difference in deflection between the two assemblies, greater for CLT</td>
</tr>
<tr>
<td>3:32</td>
<td>Pieces falling off, smoke at seam</td>
</tr>
<tr>
<td>3:32</td>
<td>Structural failure of CLT assembly. Laminated wood has not yet reached failure.</td>
</tr>
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