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# EVALUATING FIRE PERFORMANCE OF NAIL-LAMINATED TIMBER: INFLUENCE OF GAPS

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EVALUATING FIRE PERFORMANCE OF NAIL LAMINATED TIMBER: INFLUENCE OF GAPS

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# 1. INTRODUCTION

Nail-laminated timber (NLT) is a mass timber element that has many potential applications for use in larger and taller wood buildings; it is commonly used in construction of floors and can also be used in the construction of vertical shafts, such as for elevators and exit stairs. It is simple to construct, uses a large volume of low-grade readily-available lumber, and is as cost competitive as other prefabricated mass timber elements. The recent publication of Canadian and American editions of the NLT design guide [1] [2] provide guidance on how to design and construct with NLT; however, these documents provide limited details in regards to fire performance.

NLT is recognized as solid wood construction in Appendix D-2.4 of the National Building Code of Canada (NBCC) [3]; however, significant knowledge gaps exist related to its fire performance. The basis for the assigned fire resistance ratings for solid wood assemblies in the NBCC is unknown; a review of North American research yielded no data to directly support these ratings. This lack of data, also demonstrates a lack of understanding of how NLT chars when exposed to fire.

NLT essentially consists of sawn lumber boards nailed together. Natural defects in lumber (such as cupping, twisting, etc.) result in gaps forming between the boards. It is unclear how these gaps might affect overall fire performance of an assembly. Gaps can also be a function of changes in moisture content, where, as lumber dries after installation shrinkage occurs which could lead to further appearance of gaps. Construction can be included in design to account for shrinkage. There is a need to better understand how gaps influence the rate of charring in NLT assemblies.

# 2. OBJECTIVE

The objective of this work is to generate fire performance data for NLT assemblies to address gaps in technical knowledge. This project aims to study how the size of gaps between NLT boards might affect charring of an assembly and its overall fire performance. This research will support designers and builders in the use of mass timber assemblies in larger and taller buildings, by ensuring fire safe designs.

# 3. TECHNICAL TEAM

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# 4. PROCEDURE

Two horizontal intermediate-scale tests were conducted to investigate how gaps between NLT boards affect charring rates. Testing was conducted at QAI Laboratories in Vancouver, BC. In both tests, gaps were induced between the boards to replicate spaces that might occur during construction or due to shrinkage. Assemblies were exposed to a standard fire as prescribed in CAN/ULC-S101 [4]. The tests included:

Test 1: Exposed 2x6 NLT floor with 15.9 mm (⅝ in.) plywood and 15.9 mm (⅝ in.) Type X gypsum board, variable gap spacings

Test 2: Exposed 2x8 NLT floor with 12.7 mm (½ in.) plywood, 2 mm gaps between boards, 101 mm (4 in.) copper penetration

Both assemblies were constructed with 76 mm (3 in.) smooth shank galvanized nails installed in one row staggered 175 mm (7 in.) o.c., 20 mm from the top and bottom edge. 76 mm (3 in.) nails are recommended in the Canadian NLT Design Guide [1] for ease of construction.

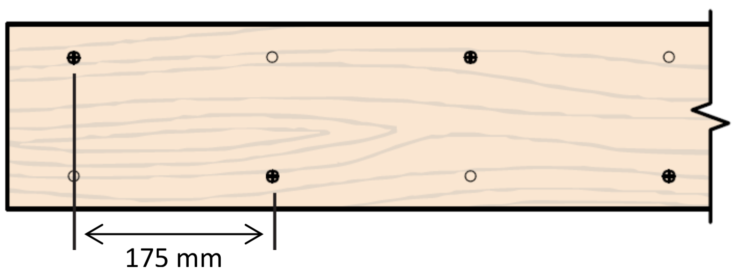
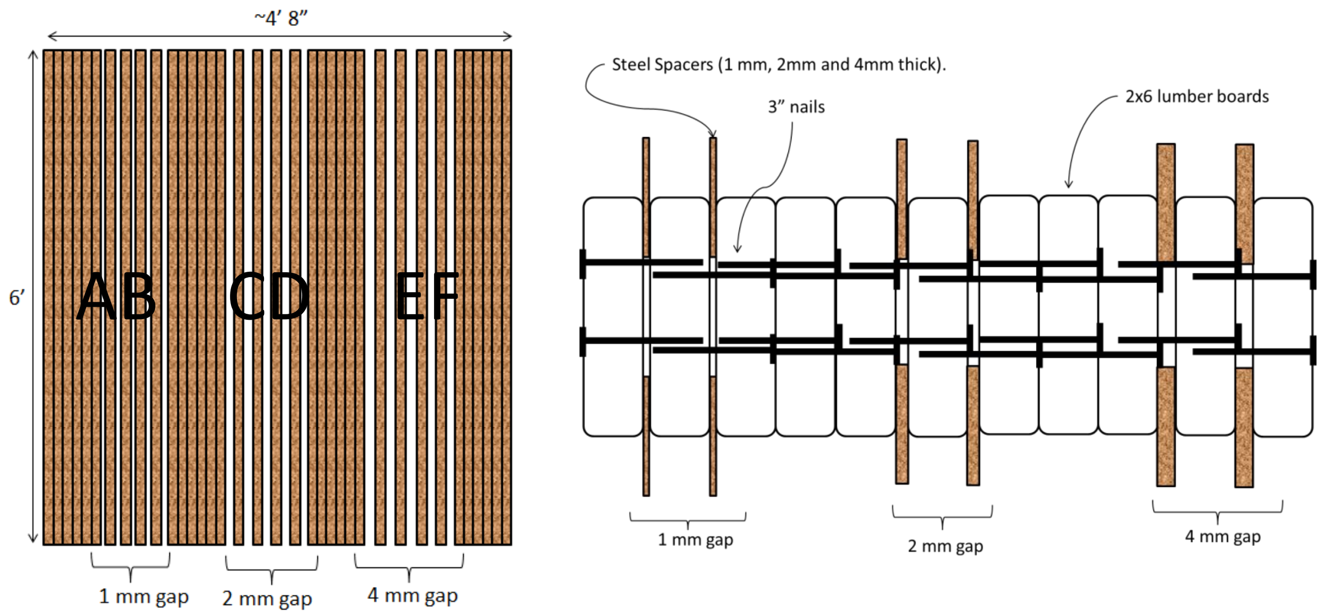



Figure 1. Example of nailing pattern [1]

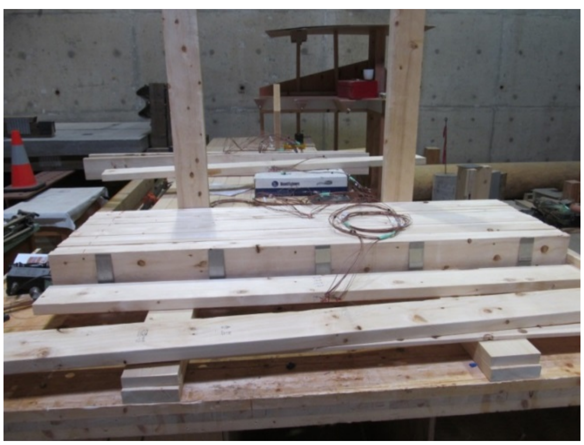
## 4.1 Test 1

Test 1 evaluated a nominal 2x6 (38 mm x 140 mm) NLT floor with three sizes of gap spacings. 15.9 mm (⅝ in.) plywood and 15.9 mm (⅝ in.) Type X gypsum boards were installed on the unexposed side to limit the flow of air and hot gases through the assembly. Metal spacers were used to induce gaps between boards: 1 mm, 2 mm, and 4 mm wide. The plan for board spacing and method of construction is shown in Figure 2. There were five gaps induced for each specified width. Five spacers were placed between each board to keep the space continuous the length of the boards. The spacers were kept in place during construction and removed prior to shipping to the test laboratory. The construction of the assembly is shown in Figure 3. The spacing of the boards prior to the test is shown in Figure 4. The assembly measured 1.42 m (4 ft. 8 in.) x 1.83 m (6 ft.); the surface exposed to fire measured 1.25 m (4 ft 2 in.) x 1.3 mm (4 ft. 4 in.). The size of the furnace was 1.52 m (60 in.) x 1.52 m (60 in.) x 1.32 m (52 in.) deep. The NLT boards were parallel with the long dimension of the furnace.

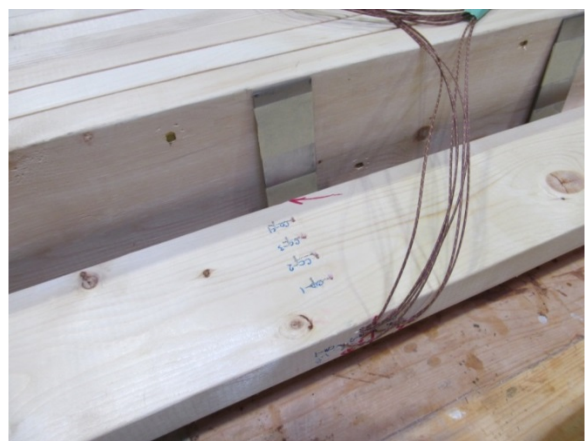



a) b)

Figure 2. Layout of gap spacing for Test 1. 2x6 NLT



a) installation of spacers



b) installation of thermocouples on outside of boards

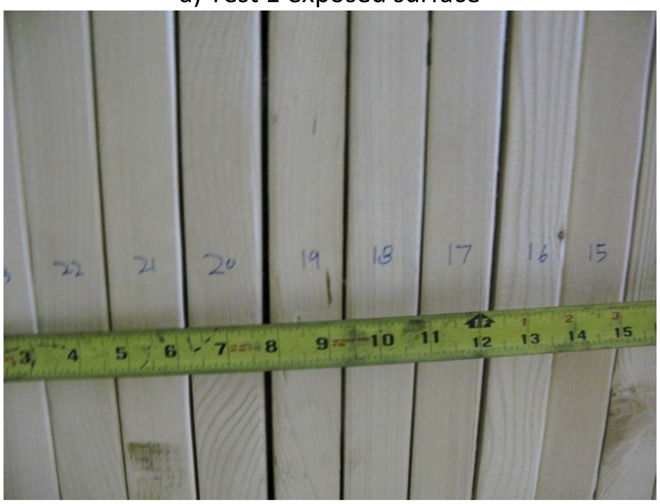
c) completed assembly

d) assembly on furnace before test

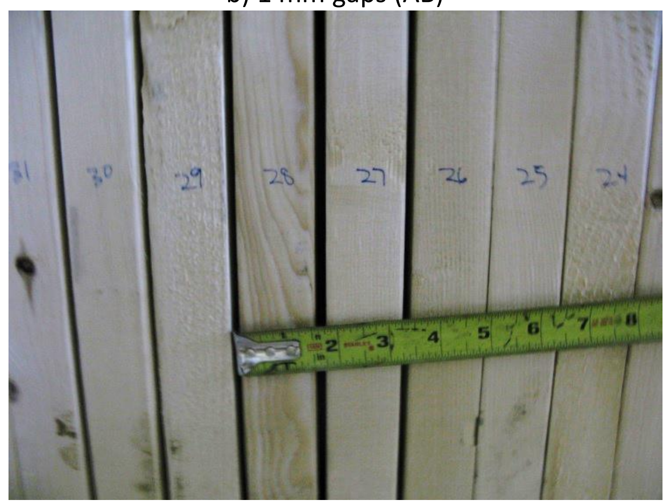
Figure 3. Construction of Test 1 assembly

a) Test 1 exposed surface

b) 1 mm gaps (AB)



c) 2 mm gaps (CD)



d) 4 mm gaps (EF)

Figure 4. Gap spacing in Test 1

### 4.1.1 Instrumentation

18 fiberglass insulated thermocouples (Type G/G-24-KK) were installed at various depths and at each interface (i.e., between the NLT and the plywood, and between the plywood and gypsum board) for each spacing in Test 1; for a total of 54 thermocouples. At 25, 50, 75, and 125 mm, thermocouples were installed either in the centre of a board or on the board face (within the gap). All were located at mid-span. The thermocouples were installed in and between the two inner boards of each gap spacing. These boards were labelled AB for the 1 mm gap, CD for the 2 mm gap and EF for the 4 mm gap (layout given in Figure 2); AB was located near the furnace door and EF was at the back of the furnace near the exhaust. 'M' denotes thermocouples that were installed in the middle of boards and 'O' denotes thermocouples that were installed on the outside of boards, in the gap. The thermocouple layout and labels are given in Figure 5.

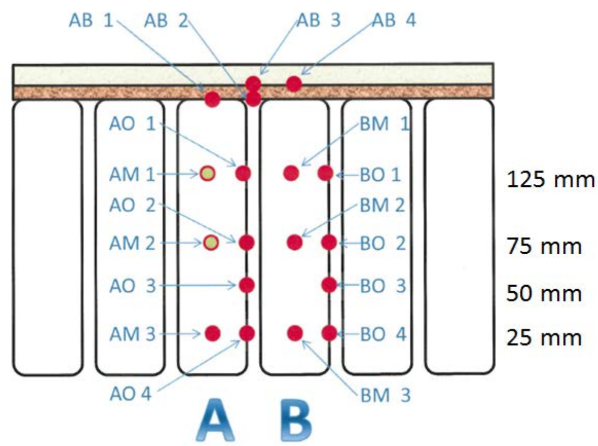



Figure 5. Thermocouple layout for Test 1

## 4.2 Test 2

Test 2 evaluated a nominal 2x8 (38 mm x 184 mm) NLT with 2 mm gaps and a metallic through-penetration. 12.7 mm (½ in.) plywood was installed on the unexposed side. The goal of the second test was to verify the performance of an appropriate allowable spacing, determined from Test 1, over a larger area and to evaluate the performance of a 100 mm (4 in.) copper penetration within a 152 mm (6 in.) opening. Figure 6 shows the layout of the assembly and the locations of the thermocouples. The construction of the assembly is shown in Figure 7. The assembly measured 1.42 m (4' 8") x 1.83 m (6'). QAI Laboratories updated their furnace equipment prior to the second test; the size of the furnace was 1.78 m (70 in.) w x 1.91 m (75 in.) h x 1.32 m (52 in.) deep. The NLT boards were parallel with the long dimension of the furnace.

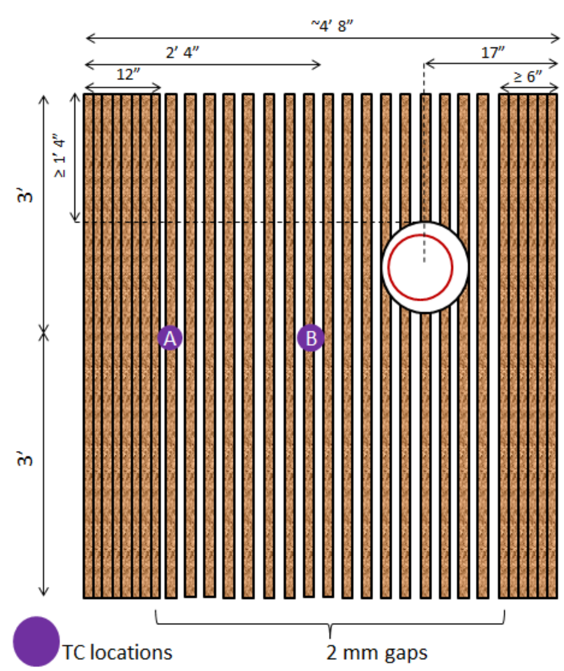


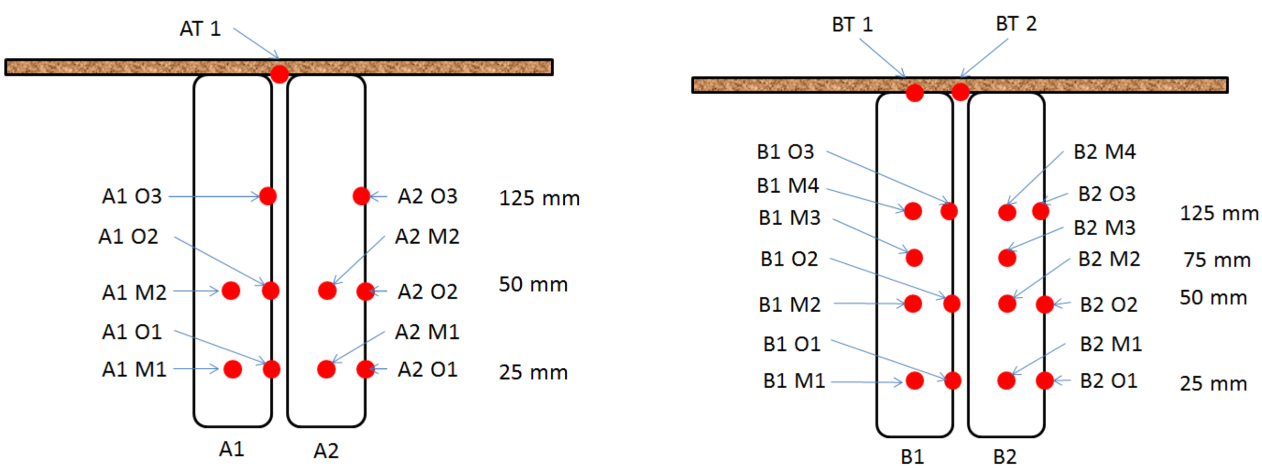

Figure 6. Layout of Test 2. 2x8 NLT with penetration

a) b)

Figure 7. Construction on Test 2 assembly. Installation of spacers

### 4.2.1 Instrumentation

Fiberglass insulated thermocouples (Type G/G-24-KK) were installed at two mid-span locations (location A and B) in the NLT panel in Test 2 at depths of 25, 50, 75, and 125 mm and at the plywood interface. 11 thermocouples were installed at location A, 305 mm (1 ft.) from the door of the furnace; 16 thermocouples were installed at location B at the centre of the panel. The location and labelling of these thermocouples is shown in Figure 8.




a) b)

Figure 8. Thermocouple installation locations for Test 2.

### 4.2.2 Penetration

A nominal 100 mm (4 in.) Type L copper pipe was installed in a 155 mm (6 in.) diameter hole with a 12.7 mm (½ in.) offset. The hole was centred between 4 boards. The annular space was packed with mineral wool until flush with top and bottom faces of the NLT. The annular space above the mineral wool was filled with firestop sealant until flush with the top of the plywood (12.7 mm depth). The penetration details are shown in Figure 9, images of the completed assembly are shown in Figure 10.

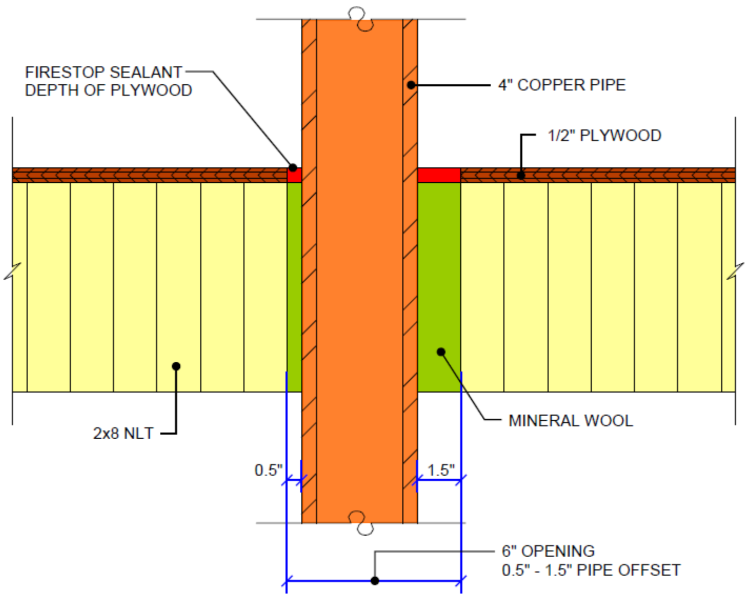



Figure 9. Penetration through NLT. Prepared by GHL Consultants Ltd.

a) penetration through NLT

b) assembly installed on furnace

Figure 10. Test 2 assembly in furnace

The penetration was instrumented with thermocouples in accordance with CAN/ULC-S115 [5]. This included on the copper pipe 25 mm (1 in.) from the firestop (FS 1), mid-way between the pipe and CLT on the firestop (FS 2), at the interface of the CLT and the firestop (FS 3), and a minimum of 100 mm (4 in.) from the opening of the penetration (FS 4).

# 5. RESULTS

## 5.1 Test 1

The 2x6 NLT panel with 1 mm, 2 mm, and 4 mm gaps was tested on June 5, 2018. Moisture content readings averaged 8.5% across the sample. The test report from QAI Laboratories can be found in Appendix I. The assembly was exposed to a standard fire for 1 h 30 min. There was some smoke leakage through the assembly in the beginning of the test, but it was mostly confined to where thermocouple wires exited the assembly, images during the test can be found in Figure 11. Once firestop sealant was added at these locations smoke leakage subsided.

The times when thermocouples reached 300°C, to indicate when the wood had charred for each gap spacing, are given in Table 1. The values for the 1 mm and 2 mm gap were similar; charring extended up to 75 mm in the gap (but not in the middle of the board). The temperatures in the 4 mm gap consistently reached 300°C the fastest, which charring reaching 125 mm within the gap. The table also includes the maximum temperatures reached. Up to 75 mm in the gap, temperatures were generally similar (within +/- 150°C) for each of the gap spacings. Beyond this depth the maximum temperature generally increased with greater gap spacing. The maximum temperature reached on the unexposed side of the assembly was 75°C.

Table 1. Time to reach 300°C and maximum measured temperatures in Test 1

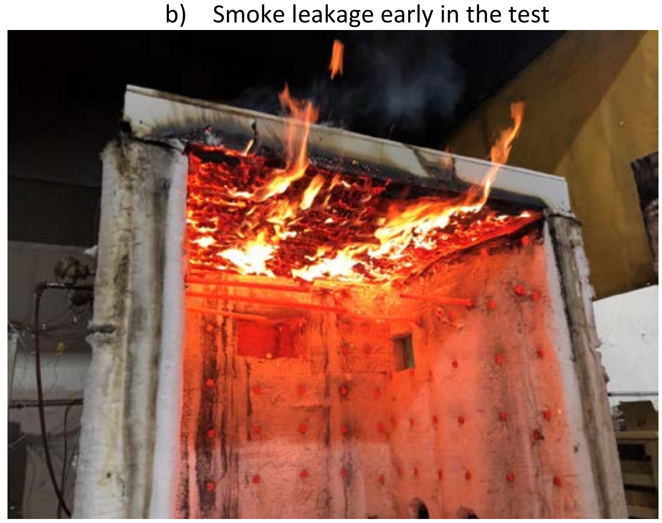
| Depth | Location | 1 mm Gap | | 2 mm Gap | | 4 mm Gap | |
|---|---|---|---|---|---|---|---|
| | | Time to 300°C (min) | Max (°C) | Time to 300°C (min) | Max (°C) | Time to 300°C (min) | Max (°C) |
| **25 mm** | **O** | 20.6 | 834.0 | 18.0 | 823.0 | 16.5 | 860.0 |
| | **M** | 53.4 | 722.0 | 59.0 | 721.0 | 37.7 | 796.0 |
| **50 mm** | **O** | 49.1 | 765.0 | 55.6 | 708.0 | 33.3 | 806.5 |
| **75 mm** | **O** | 81.6 | 554.0 | 70.1 | 622.0 | 56.8 | 680.5 |
| | **M** | - | 192.0 | - | 276.0 | 88.5 | 337.5 |
| **125 mm** | **O** | - | 86.0 | - | 273.0 | 86.4 | 411.5 |
| | **M** | - | 83.0 | - | 81.0 | - | 107.0 |

Notes: M denotes middle (embedded), O denotes outside (in gap)

a) Wood surface burning

b) Smoke leakage early in the test

c) Later in the test no smoke leakage



d) NLT surface at end of test

Figure 11. Images during testing

The average temperature measurements for thermocouples embedded within the wood are illustrated in Figure 12. Each depth is denoted by a different line style. The thermocouples at the CD location (2 mm gap) were not reading data at the beginning of the test. The data acquisition system was reset 15 min into the test and data was received again at 16 min 30 s; there is a gap in data during this time. DO1 malfunctioned as did EO4 near the end of the test, this data was not included in the plot. The average temperature measurements for thermocouples within the gaps are illustrated in Figure 12. This similar trend between both plots is that temperatures were higher in the 4 mm gap, and temperatures were similar between the 1 mm and 2 mm gaps.

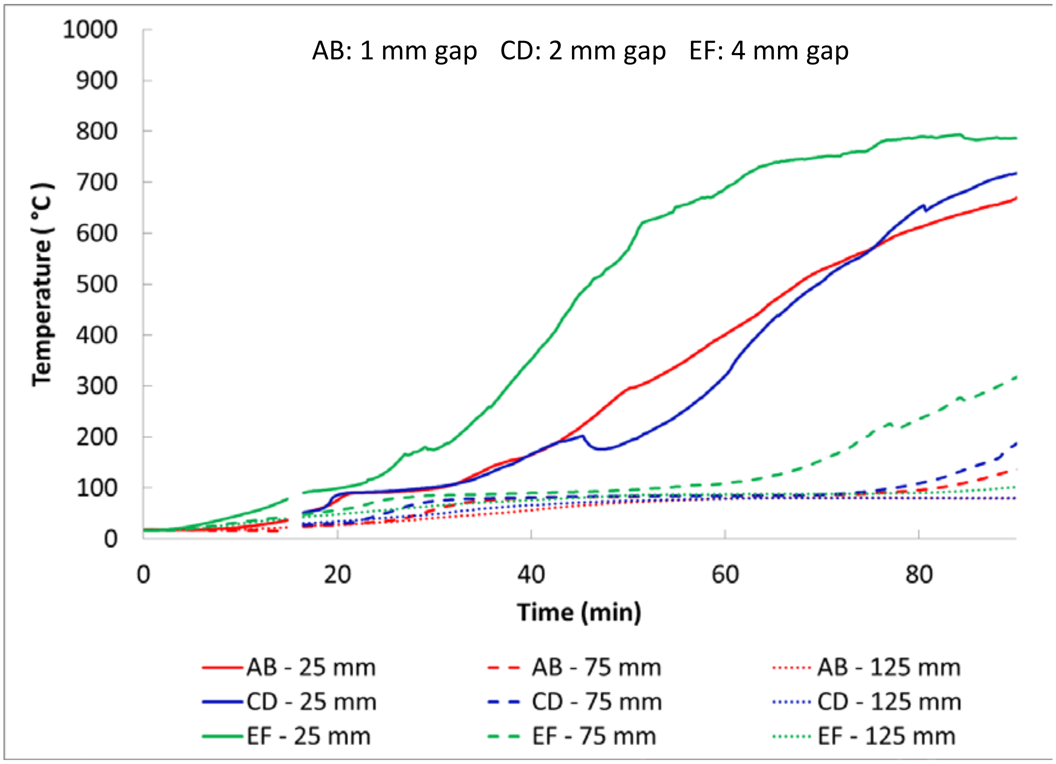



Figure 12. Test 1. Temperature measurements within wood members

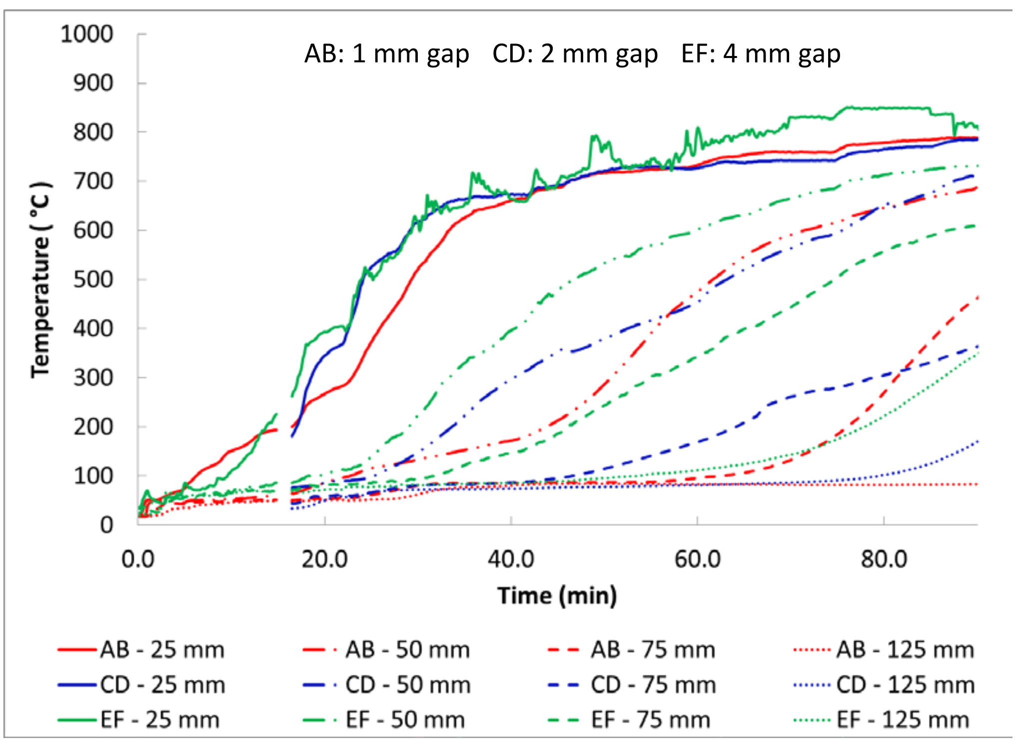



Figure 13. Test 1. Temperature measurements within gaps

The calculated charring rates, based on the times that the embedded thermocouples reached 300°C, are presented in Table 2. The charring rates in the 1 mm and 2 mm gap were both below 0.5 mm/min. The charring in the 4 mm gap was initially 0.66 mm/min (in line with charring rate design values for solid timber of 0.65 mm/min [6]), but then increased to 0.86 mm/min once the char front reached 75 mm.

Table 2. Charring rates in Test 1

| Depth | Charring rate (mm/min) | | |
|---|---|---|---|
| | 1 mm Gap | 2 mm Gap | 4 mm Gap |
| **25 mm** | 0.47 | 0.42 | 0.66 |
| **75 mm** | - | - | 0.86 |
| **125 mm** | - | - | - |

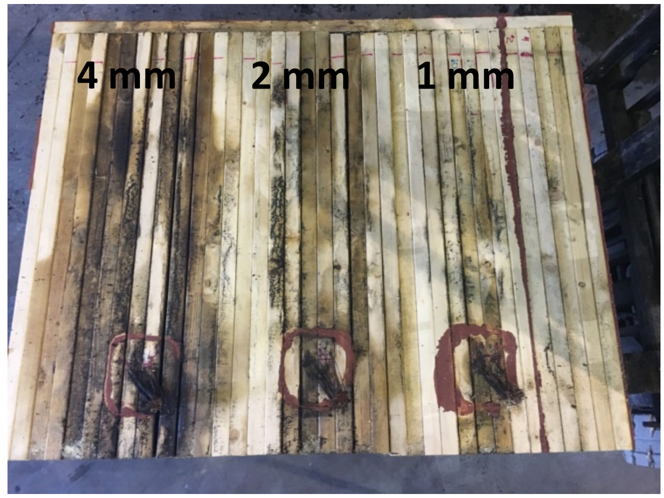
None of the thermocouples at the plywood or gypsum board interfaces exceeded 85°C. The maximum temperatures at these interfaces are given in Table 3. The values are consistent for all gap spacings. The temperatures in the gap were also very close to the temperatures measured between the NLT and plywood. This suggests that if gaps are sufficiently small, heat transfer in the gap is limited. Also combustion cannot occur if there is a lack of oxygen in the gap; having protection of the unexposed side prevents airflow that might permit more combustion within the gaps.

Table 3. Maximum temperatures reached at plywood and gypsum board

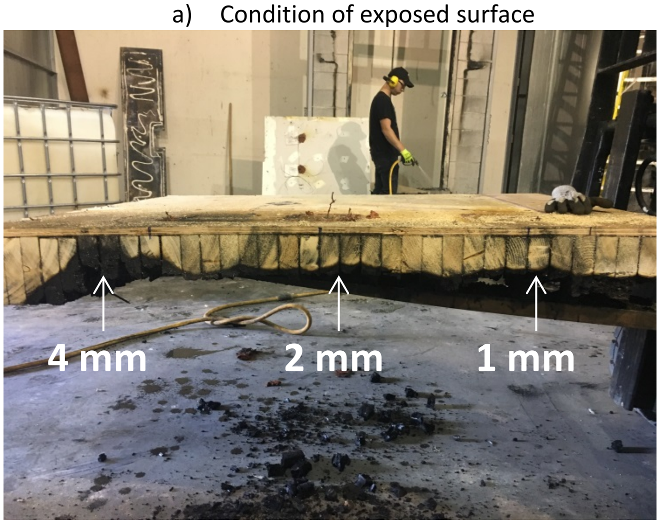
| Location | | Maximum Temperature (°C) | | |
|---|---|---|---|---|
| | | 1 mm Gap | 2 mm Gap | 4 mm Gap |
| **NLT/plywood** | **In gap** | 68.0 | 75.0 | 81.0 |
| | **Behind NLT** | 82.0 | 79.0 | 83.0 |
| **Plywood/GB** | **In gap** | 69.0 | 59.0 | 70.0 |
| | **Behind NLT** | 55.0 | 60.0 | 69.0 |

After the test the assembly was removed from the furnace and was taken apart to assess its condition at the different gap spacings, depicted in Figure 14. When removed from the furnace, it was apparent that the assembly was in the worst condition in the location of the 4 mm gaps; the 1 mm and 2 mm gap locations appeared similar. The plywood and gypsum board were removed, and again the worst condition was in the location of the 4 mm gap, with the most prominent evidence of smoke staining and/or water penetration. The assembly was cut at mid-span, which demonstrated that charring had extended deeper into the assembly at the 4 mm gap. Several of the boards were pulled apart to further confirm. The residual depths at each gap spacing were 55 mm for the 1 mm gap, 60 mm for the 2 mm gap, and 41 for the 4 mm gap. These values are consistent in demonstrating that greater charring occurred in the 4 mm gap.

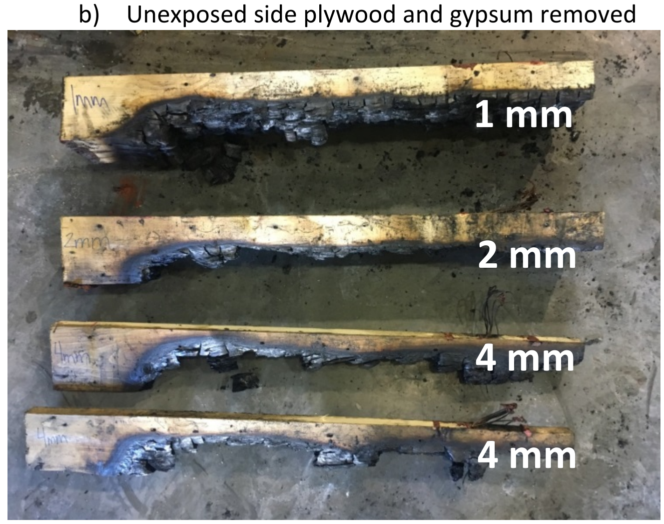
a) Condition of exposed surface




b) Unexposed side plywood and gypsum removed




c) Profile of assembly cut at mid-span




d) Charring of boards at each gap spacing

Figure 14. NLT assembly after the test

## 5.2 Test 2

Test 2, evaluating a 2x8 NLT with 2 mm spacing between boards and a 100 mm (4 in.) copper penetration, was conducted on September 19, 2018. Moisture content readings across the assembly averaged 8.9%. The QAI Laboratories report is provided in Appendix II. The assembly was exposed to a standard fire for 2 h. Light smoking around the penetration was evident early in the test. The firestop around the penetration charred approximately 20 min into the test. The assembly during the test is shown in Figure 15.


a) penetration during test

b) surface during the test

c) unexposed side during the test

d) assembly removal after the test

Figure 15. Test 2 assembly during test

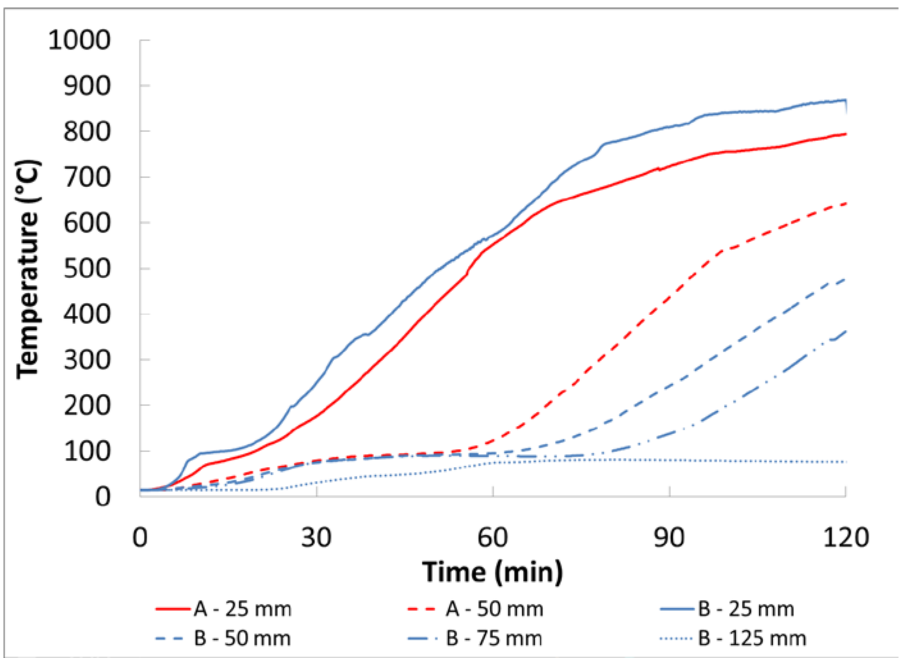
The times when thermocouples reached 300°C, to indicate when the wood had charred, and their maximum values are given in Table 4. Charring reached 50 mm at location A, and reached 75 mm at location B. There was some variability in the time that 300°C was reached, in particular at the 50 mm depth. The maximum temperature reached on the unexposed side of the assembly was 66°C.

Table 4. Time to reach 300°C and maximum measured temperatures

| Depth | Location | A Time to 300°C (min) | A Max (°C) | B Time to 300°C (min) | B Max (°C) |
|---|---|---|---|---|---|
| 25 mm | O | 25.8 | 853 | 24.2 | 897 |
| | M | 40.8 | 794 | 32.7 | 869 |
| 50 mm | O | 60.8 | 741 | 57.7 | 734 |
| | M | 78.2 | 642 | 83.5 | 621 |
| 75 mm | O | / | / | / | / |
| | M | / | / | 112.2 | 364 |
| 125 mm | O | - | 100 | - | 82 |
| | M | / | / | - | 82 |

Notes: M denotes middle (embedded), O denotes outside (in gap).
/ TCs not installed at that depth, - criteria not reached

The temperature profiles for thermocouples embedded within the wood (M) and within the gaps (O) are provided in Figure 16 and Figure 17 respectively. Location A temperatures are shown in red and location B in blue. Each depth is denoted by a different line style. The temperatures within the boards were similar at 25 mm, but deviated at 50 mm; the temperatures within the gaps were nearly identical.




Note: Data was removed from A-25 mm from TC A1-M1 after 88 min because it malfunctioned

Figure 16. Temperature measurements at thermocouple locations embedded within wood members

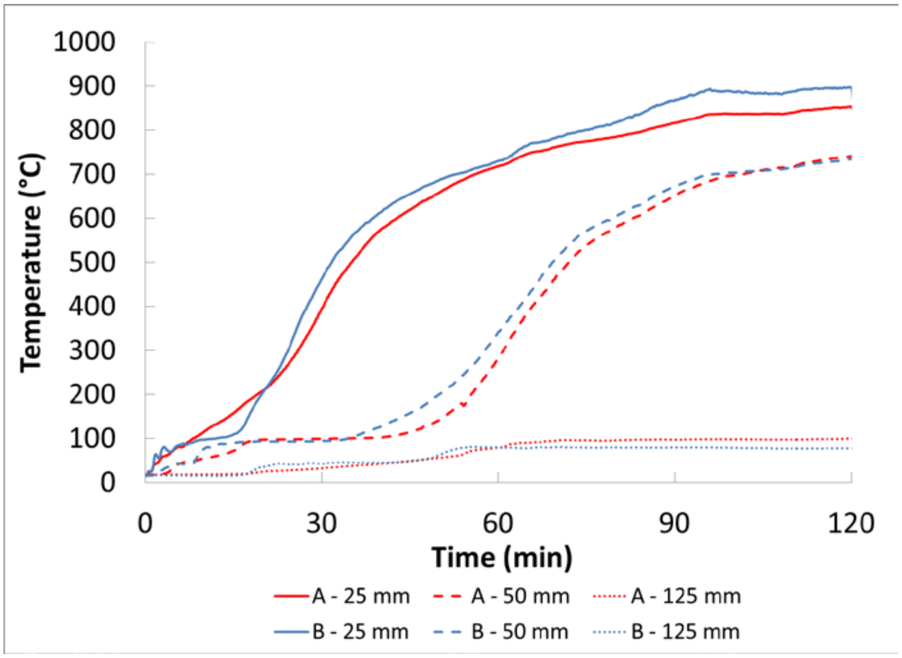



Figure 17. Temperature measurements in spaces between boards

The charring rates for each thermocouple depth were calculated using the time that the thermocouples in the middle of the boards reached 300°C. The charring rates are presented in Table 5 for both thermocouple locations. These charring rates were generally less than the accepted design value of 0.65 mm/min identified in CSA-O86 [6] for solid timber. Charring was faster, 0.76 mm/min, at the 25 mm depth at location B, which was closer to the back of the furnace (near the exhaust).

Table 5. Charring rates in Test 2

| Depth | Charring rate (mm/min) | |
|---|---|---|
| | A | B |
| **25 mm** | 0.61 | 0.77 |
| **50 mm** | 0.64 | 0.60 |
| **75 mm** | - | 0.67 |
| **125 mm** | - | |

None of the thermocouples at the plywood interface exceeded 100°C. The maximum temperatures at these interfaces are given in Table 6. The temperature in the gap was consistent with the thermocouple behind the NLT board, again confirming that if gaps are sufficiently small then significant heat transfer does not occur up the gap.

Table 6. Maximum temperatures reached at plywood interface in Test 2

| Location | | Maximum Temperature (°C) | |
|---|---|---|---|
| | | A | B |
| NLT/plywood | In gap | 97 | 73 |
| | Behind NLT | / | 76 |

After the test a cross-section was cut to evaluate the depth of charring. The residual depth of the section varied between 85 to 100 mm, due to corner rounding. This roughly translates to a charring rate of 0.70 mm/min, not including corner rounding.

a) cut at mid-span b) residual depth of section

Figure 18. Residual depth, Test 2

### 5.2.1 Penetration

The copper penetration was instrumented with thermocouples to determine its firestop rating. The firestop remained in the opening during the test without permitting the passage of flames to the unexposed side, indicating that a 2 h F-rating was achieved. Temperatures at FS 1 exceeded 181°C, therefore the firestop did not achieve a T-rating. The temperature profiles for thermocouples on the firestop are shown in Figure 19. The condition of the opening and firestop after the test are shown in Figure 20. From the unexposed side, it was evident that the firestop had charred, but charring did not progress to the surrounding wood.

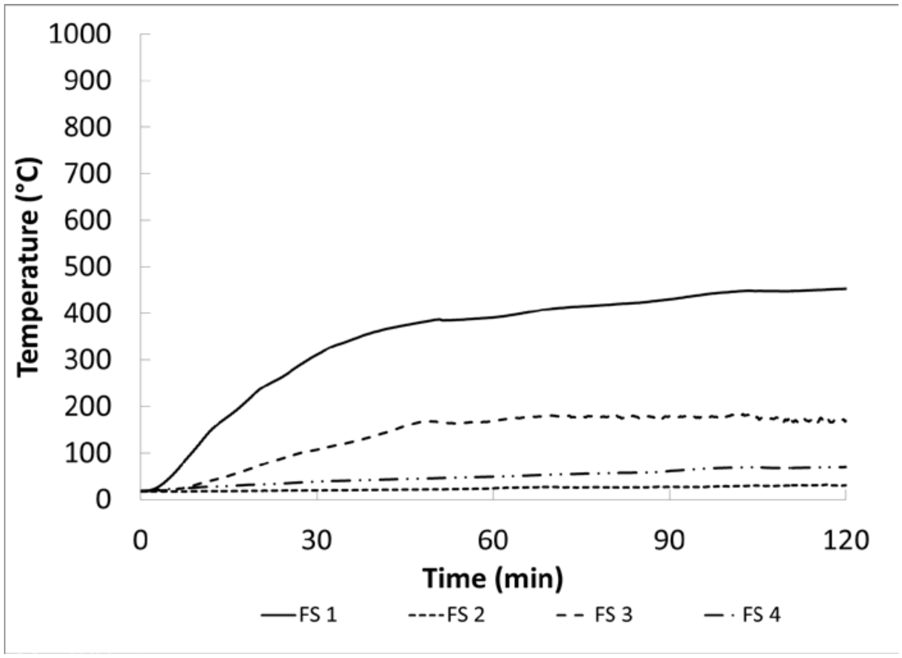



Figure 19. Penetration temperature measurements

a) unexposed side

b) exposed side

Figure 20. Condition of firestop after Test 2

# 6. DISCUSSION

These two tests demonstrated that charring of NLT is complex when gaps are present between the boards. NLT does not directly follow a simple one-dimensional charring model. One-dimensional charring refers to charring strictly perpendicular to the plane of the assembly. Due to planing of lumber and gaps between boards corner rounding takes place.

In Test 1, varying the size of the gap from 1 mm to 2 mm did not have a significant impact; similar charring rates, time to reach 300°C and maximum temperatures were measured at thermocouples of the same depth and location. The charring rates for the 1 mm and 2 mm gap did not exceed the typical design value of 0.65 mm/min for solid timber, which suggests that these sizes of gaps do not adversely affect the overall fire performance of the assembly. Increasing the size of the gap to 4 mm did have an impact on increasing the charring rate. At the 75 mm depth, the measured charring rate was 0.86 mm/min which is faster than design values. Gaps should be limited to no more than 2 mm.

The charring rates in Test 2 were faster than in Test 1, and varied based on the depth of the thermocouple. This further confirms that variability in NLT construction results in variability in its charring rates. All of the charring rates in the 2 mm gaps were less than 0.80 mm/min and the residual depth suggested an overall charring rate of 0.77 mm/min.

In both tests faster charring rates occurred at the locations that were closest to the back of the furnace, which was near the exhaust. There was not a significantly noticeable difference in the furnace temperature near the back of the furnace in either test, however air flow towards the exhaust could have had an impact on the charring rates.

Section 16.2.5 in the National Design Specification (NDS) for Wood Construction [7] accounts for the effects of limited exposure of the sides of timber decks (between boards) by using a char rate equivalent to 33% of the effective char rate. The results from these tests suggest this would be a conservative approach for NLT where gaps are not more than 2 mm.

It was challenging to ensure the width of the gaps were maintained at the specified width. The spacers used to induce the gaps were removed before transportation of the assembly, so it is possible that boards could have shifted, which could have contributed to some variability in results. In practice, the width and location of gaps in NLT can be unpredictable. Appropriate quality control measures should be followed to ensure that gaps sizes do not exceed 2 mm. This includes suitable selection of boards (avoiding boards with deformation) and monitoring moisture content to limit shrinkage after boards are installed.

The amount of shrinkage for a 30% change in moisture content (green to dry conditions) is approximately 5% radially and 7% tangentially [8]. Whether radial or tangential shrinkage takes place is dependent on where the board was cut from the tree (how it is positioned relative to growth rings), which varies, so shrinkage perpendicular to grain can be taken as the average of these, at 6%. A 6% change in dimension of a 38 mm (nominal 2x) board is 2.3 mm (approximately 1 mm on either side), leaving a 2-3 mm gap between boards (1 mm from either side). This is based on a 30% change in moisture content which is unlikely. The NBCC requires that lumber be no more than 19% MC at installation. As such, a change in moisture content less than 19% is more realistic, which would reduce the size of the shrinkage gap. This scenario figures boards are initially tightly pressed together. If a gap was pre-existing due to natural defects in boards, then shrinkage would increase the size of that gap.

In both tests, in all gap spacings evaluated, the temperature in the gap at the plywood did not exceed 100°C. This indicates that although gaps are present, heat does not extend up the full length of the gap, as temperatures at the back of the gap stayed well below that of the furnace. The width of the gaps was not sufficient enough to permit significant heat transfer into the space. A lack of oxygen within the gaps may prevent combustion from occurring within the space. This is evidence to support that the inclusion of intentional construction gaps in mass timber may not have a significant impact on fire performance of mass timber assemblies, so long as the unexposed side is well protected to prevent burn-through.

In a study evaluating 38 mm and 64 mm thick timber butt-joint decking, it was evident that gaps up to 2 mm can be common between decking boards due to shrinkage as a result in moisture content change after installation, and imperfections in milling of tongue and grooves can increase the size of those gaps [9]. Unloaded floors exposed to an ASTM E119 [10] fire, displayed one-dimensional charring rates of the boards between 0.65 and 0.9 mm/min based on measurements of residual char depth after the tests. Flame-through occurred at the gaps between boards at 1458 and 272 s, whereas when an OSB backing was used, flame-through occurred later (exceeding 3000 s), regardless of spacing. This is further evidence to suggest that protection on the unexposed side limits flame-penetration.

## 6.1 Penetration

A 100 mm (4 in.) copper penetration was installed in a 150 mm (6 in.) opening, with a 12.7 mm (½ in.) offset. The penetration was installed following the same method as has been successfully used to achieve 2 h F-ratings through CLT assemblies [11]. The results from this test were similar to results in the previous CLT fire stopping study, and confirm that for penetrations in NLT, filling the annular space with mineral wool, and finishing the opening with 12.7 mm (½ in.) firestop caulking prevents the passage of flame through the opening. This firestop system likely will provide similar results for other types of mass timber assemblies.

# 7. CONCLUSION

Natural imperfections in sawn lumber can result in spaces between NLT boards during manufacturing and/or during their service life. When installed on site, lumber can undergo shrinkage due to changes in moisture content which can further widen these spaces. Two intermediate scale tests were conducted on NLT assemblies to assess what impact gap spacing between boards had on charring rates. Both assemblies were exposed to a standard fire and instrumented with thermocouples to evaluate charring. Test 1 evaluated a 2x6 NLT assembly with gaps of 1 mm, 2 mm, and 4 mm, having 15.9 mm plywood and 15.9 mm Type X gypsum board on the unexposed side. The assembly was exposed to fire for 1.5 h. The 1 mm and 2 mm gap performed similarly in terms of charring of the boards. Increased charring rates were observed where 4 mm gaps were used.

In Test 2, a 2x8 NLT with 2 mm gaps between all of the boards and 12.7 mm plywood on the unexposed side was evaluated. Faster charring rates were observed in Test 2 compared to the measurements in the 2 mm gap in Test 1. Generally all of the charring rates in the 2 mm gaps were below 0.65 mm/min, except in location B in Test 2 where charring was not more than 0.80 mm/min. This could be a result of intrinsic variability in NLT; defects in lumber at this location could have resulted in a larger gap which led to increased charring.

Test 2 included a 100 mm copper penetration in a 150 mm hole with a 12.7 mm offset to evaluate the performance of the firestop. Mineral wool was packed into the opening and the last 12.7 mm (the depth of the plywood) was filled with firestop caulking. The assembly was exposed to fire for 2 h. The firestop prevented the passage of flames through the assembly for the duration of the test and achieved a 2 h F-rating in accordance with CAN/ULC-S115.

Following the tests, the assemblies were taken apart to observe the degree of char. It was apparent in Test 1 that a greater amount of charring had occurred at the boards with the 4 mm gaps. In Test 2 the depth of char was consistent, with corner rounding apparent at the edges of boards.

In both tests, temperature measurements within the gap at the plywood stayed below 100$^{o}$C in all gap spacings. This indicates that the width of the gaps was not sufficient to permit significant heat transfer into the space. If construction gaps are intentionally used between assemblies, so long as the gap is small enough, it may not have a significant impact on the overall fire performance of a mass timber assembly, so long as appropriate protection is provided on the unexposed side to limit airflow.

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[3] "National Building Code of Canada," Canadian Commission on Building and Fire Codes. National Research Council Canada, Ottawa, ON, 2015.

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[11] L. Ranger, C. Dagenais, C. Lum and T. Thomas, "Fire Performance of Firestops, Penetrations, and Fire Doors in Mass Timber Assemblies," in *World Conference in Timber Engineering*, Seoul, South Korea, 2018.

# APPENDIX I

QAI Test Report – Test 1 – 2x6 NLT with 1 mm, 2 mm, and 4 mm gaps

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3980 North Fraser Way
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604.527.8378 ph. | 604.527.8368 fx.

**CLIENT:** **FPInnovations**
580 Booth St.
Ottawa, ON
K1A 0E4

| Test Report No: T895-8 | Date: July 24, 2018 |
|---|---|

**SAMPLE ID:** Nail Laminated Timber (NLT) floor/ceiling assembly with various gap sizes between members.

**SAMPLING DETAIL:** The FPInnovations NLT floor/ceiling assembly was constructed and submitted directly by the client. The test assembly was not independently selected for testing.

**DATE OF RECEIPT:** Samples were received at QAI on June 5, 2018 in good condition.

**TESTING PERIOD:** June 25, 2018.

**AUTHORIZATION:** QAI Test Proposal Number 18MB05222R1, signed and dated on May 25, 2018, by Sylvain Gagnon.

**TEST PROCEDURE**: Tested on a small scale to the time temperature and general requirements of the following standard with the deviations from the test standard found on page 5:

- CAN/ULC S101-14, *Standard Methods of Fire Endurance Tests of Building Construction and Materials* (CAN/ULC S101).
- ASTM E119-16a, *Standard Test Methods for Fire Tests of Building Construction and Materials* (ASTM E119).

**TEST RESULTS:** The tested FPInnovations NLT floor / ceiling assembly detailed on page 3 of this report met the requirements for a 1 hour non-load bearing fire resistance rating when tested with the deviations found on page 5.

**Prepared By**

**Scott Leduc, EIT**
Project Manager

**Signed for and on behalf of**
**QAI Laboratories, Ltd.**

**Matt Lansdowne**
Director of Engineering

# Table of Contents

## Introduction:

This report documents the fire testing conducted by QAI Laboratories Ltd. for FPInnovations of a NLT floor / ceiling assembly with various gap sizes between the members.

Testing was performed on a reduced test assembly, following the time temperature curve outlined in CAN/ULC S101 and ASTM E119 with the deviations noted on Page 5.

## Test Description:

**Table 1:** Test Assembly Description

| COMPONENT | DESCRIPTION | |
|---|---|---|
| **Assembly** | Overall Size: | 1.83 m (72 in.) length x 1.42 m (56 in.) width x 171 mm (6.75 in.) thickness. |
| | Type: | Nail Laminated Timber (NLT) floor/ceiling assembly. |
| **Framing** | Type: | No. 2 SPF wood studs nail laminated. |
| | Size: | 38 mm x 232 mm (Nominal 2 in. x 6 in.) |
| | Gap Spacing: | The assembly was split into 3 sections each consisting of a different spacing of the wood members. The AB section consisted of 1 mm gaps, the CD section consisted of 2 mm gaps and the EF section consisted of 4 mm gaps. |
| | Fasteners: | 102 mm (4 in.) smooth shank nails placed in two rows top and bottom spaced 178 mm (7 in.) OC. |
| **Subfloor** | Type: | Plywood. |
| | Thickness: | 16 mm (5/8 in.) |
| | Fasteners: | No. 8 Wood screws. |
| **Unexposed Sheathing** | Type: | CGC Sheetrock Brand Firecode X, Type X gypsum panels. |
| | Thickness: | 16 mm (5/8 in.) |
| | Fasteners: | No. 6 x 32 mm (1-1/4 in.) coarse thread drywall screws spaced 305 mm (12 in.) OC |

## Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 60 in. in height, 60 in. in width, and 52 in. in depth.

Temperatures within the furnace were monitored using four thermocouples. The temperatures are controlled by adjusting fuel to the furnace burners to conform to the time/temperature curve specified by the test standards. Temperature measurements are recorded by a Keithley 2750 data acquisition unit (ID# DMM1) which passes the readings to a computer for graphical display and storage.

54 thermocouples were placed at various locations inside and between the studs as well as below and above the subfloor and on the unexposed face of the test assembly. See Appendix figure 3 for detailed locations.

One pressure tap is installed along the longitudinal center line of the test assembly. The pressure tap is attached and monitored by Setra model 264 pressure transducers (ID# Pressure T3). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

**Figure 1:** Burners Fired in the Furnace

## Test Conditions:

The FPInnovations floor/ceiling assembly outlined on page 3 was supported by the walls of the furnace. A ceramic fiber gasket was used to maintain an air tight seal between the furnace and the floor/ceiling assembly.

The pressure of the furnace was monitored throughout the test.

Prior to the fire endurance test the test assembly was placed on top of the furnace, the front panel was moved into place and the burners were ignited. The fire endurance test was initiated immediately after igniting the burners. The temperature inside the furnace was controlled to follow the standard time/temperature curve within the limits described in the test standard.

## Deviations from the Test Standard:

The intent of this test was for R&D purposes to compare the difference between various gap sizes between the wood members in an NLT floor/ceiling assembly. Since the assembly was less than 16.8 $m^2$ (181 $ft.^2$), it did not meet the required assembly size for the test standards.

## Test Results:

### Observations

The following observations were taken over the duration of the fire test:

**Table 2:** Test Observations

| Test Time (min) | Unexposed | Exposed |
|---|---|---|
| 0:32 | | Ignition. |
| 12:32 | | Heavy flaming. |
| 30:00 | No changes. | |
| 60:00 | No changes. | |
| 90:30 | Test discontinued. | |

### Flaming and Penetration

No flaming occurred on the unexposed face of the test assemblies, and no through penetrations or openings were observed during the fire test.

### Unexposed Temperature Rise

The maximum allowable single point temperature of 325°F above the initial ambient temperature was not reached. The maximum allowable average temperature of 250°F above the initial ambient temperature was not reached.

The FPInnovations NLT floor/ceiling assembly met the unexposed temperature rise requirements for a 1-hour fire resistance rating.

## Conclusions:

QAI performed testing in accordance with CAN/ULC S101 and ASTM E119, with the deviations found on page 5; on an NLT floor/ceiling assembly as described in table 1.

The test assembly evaluated by QAI and outlined in this report, met the requirements of CAN/ULC S101 and ASTM E119 when tested with the deviation found on page 5.

# APPENDIX A

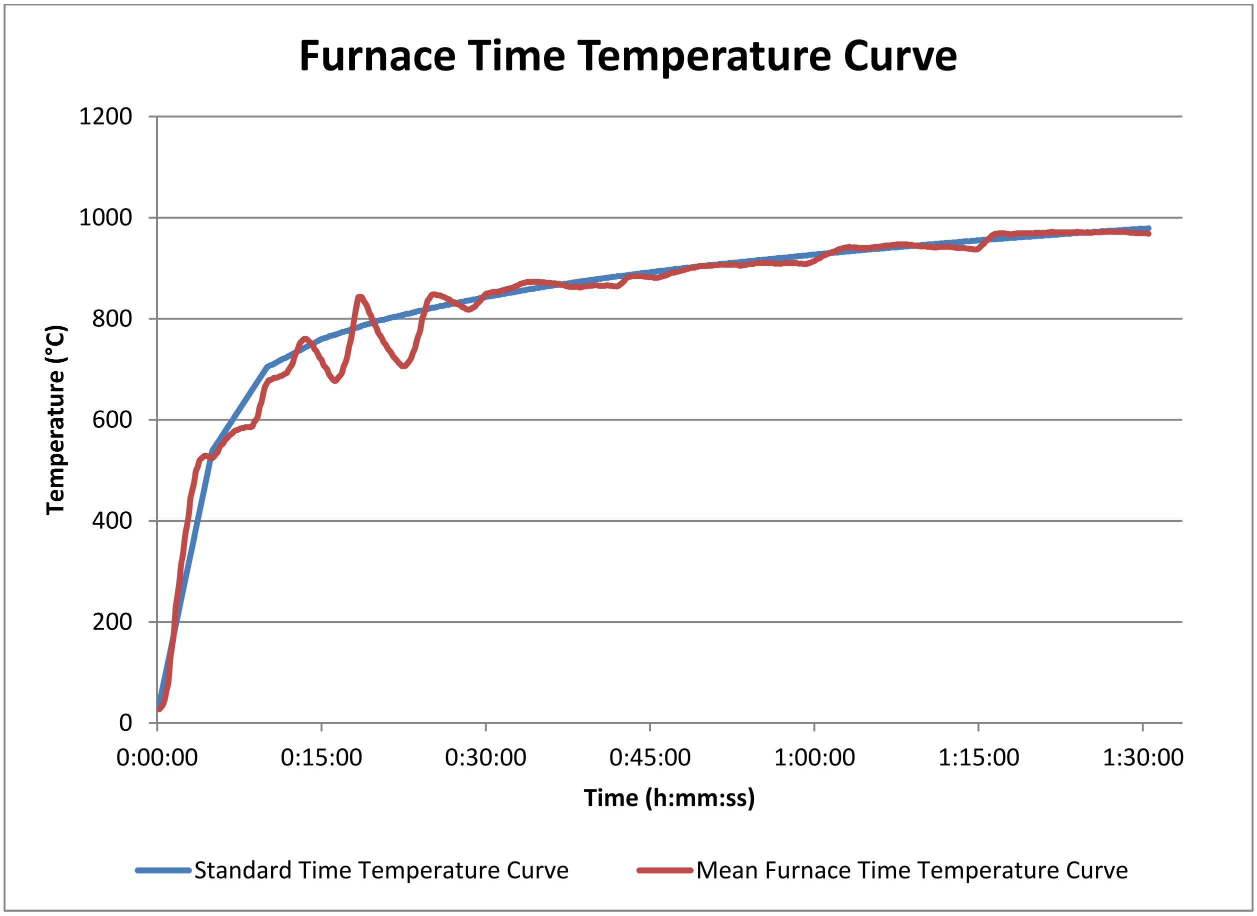


**Figure 2:** Time Temperature Curve

Boards are labeled A,B,C,D,E,F with the corresponding number pattern referencing thermowire position. M or O references middle or outside of board and the numbers reference depth. Thermowire on the plywood is simply labeled with the board numbers they are above and numbered for position

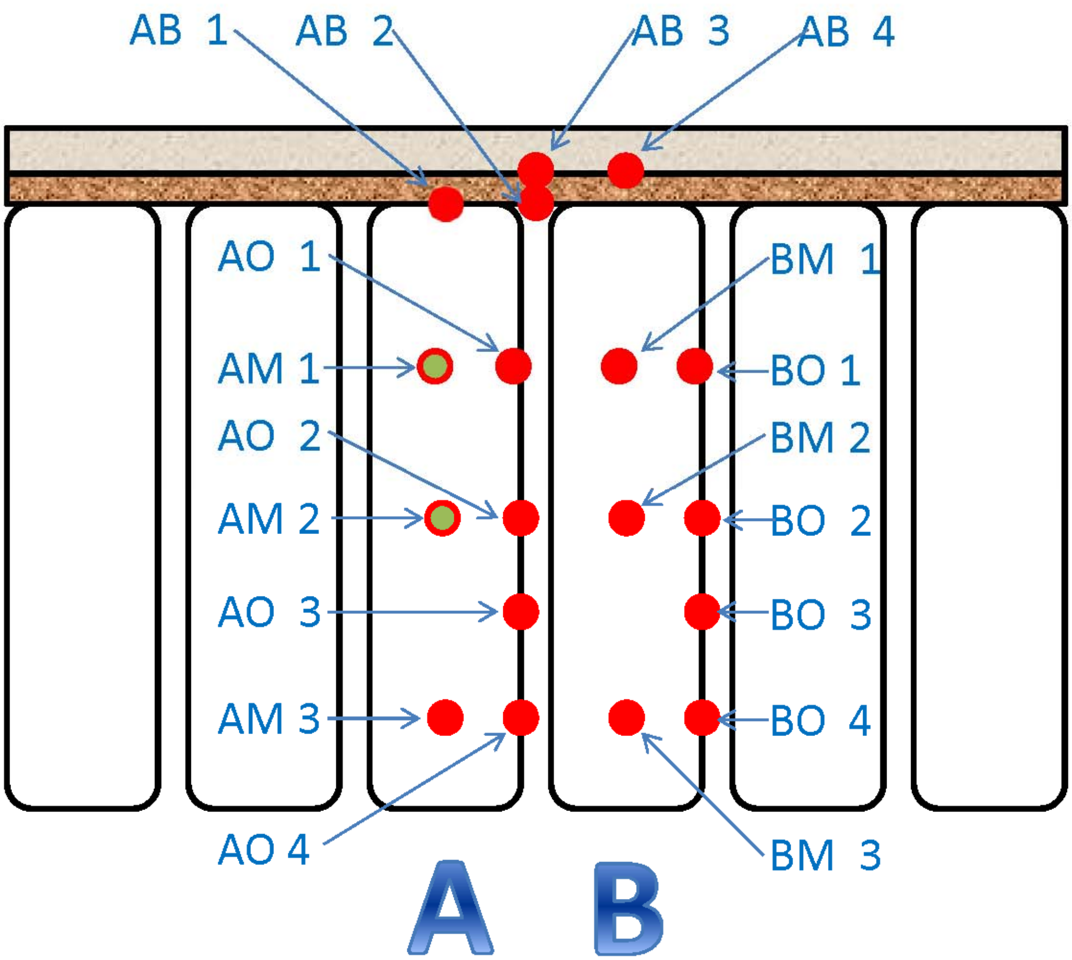


**Figure 3:** Unexposed Thermocouple Locations

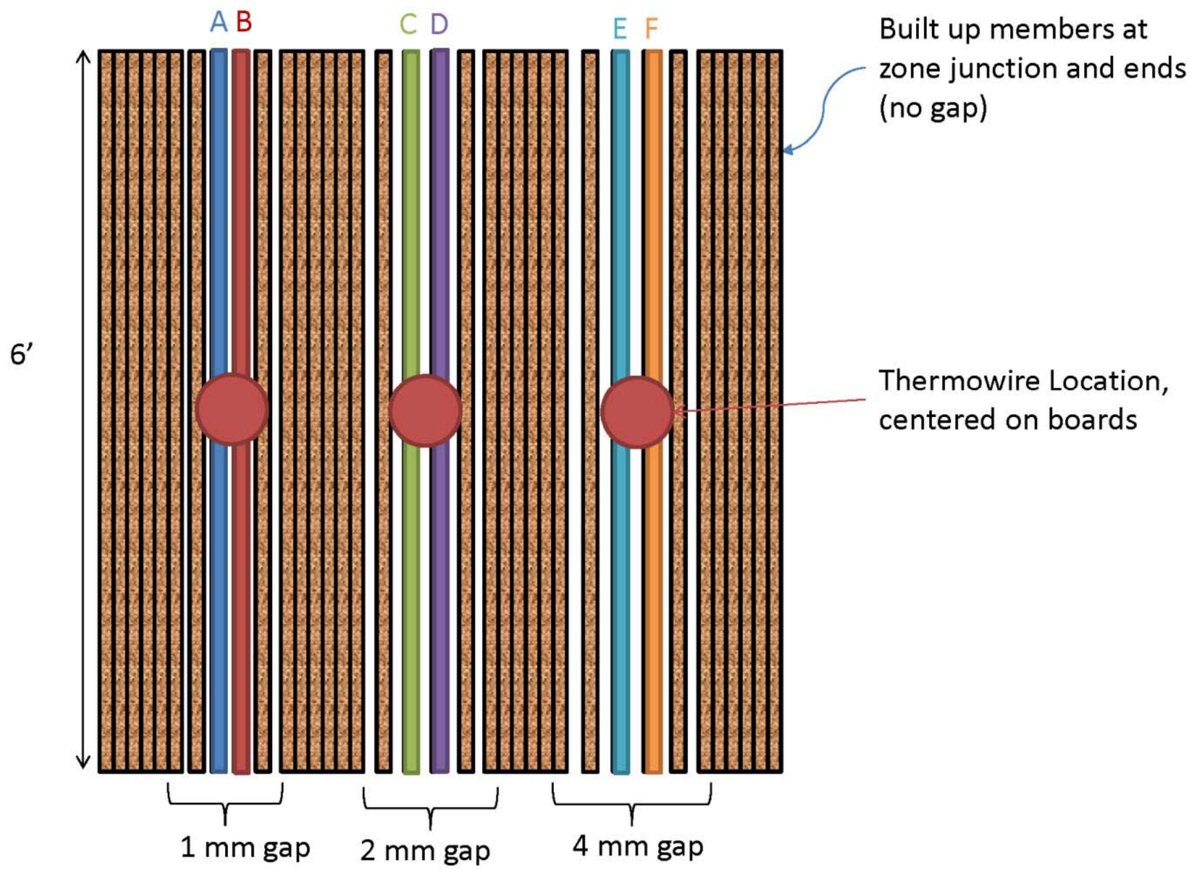


**Figure 4:** Floor/Ceiling Assembly Layout

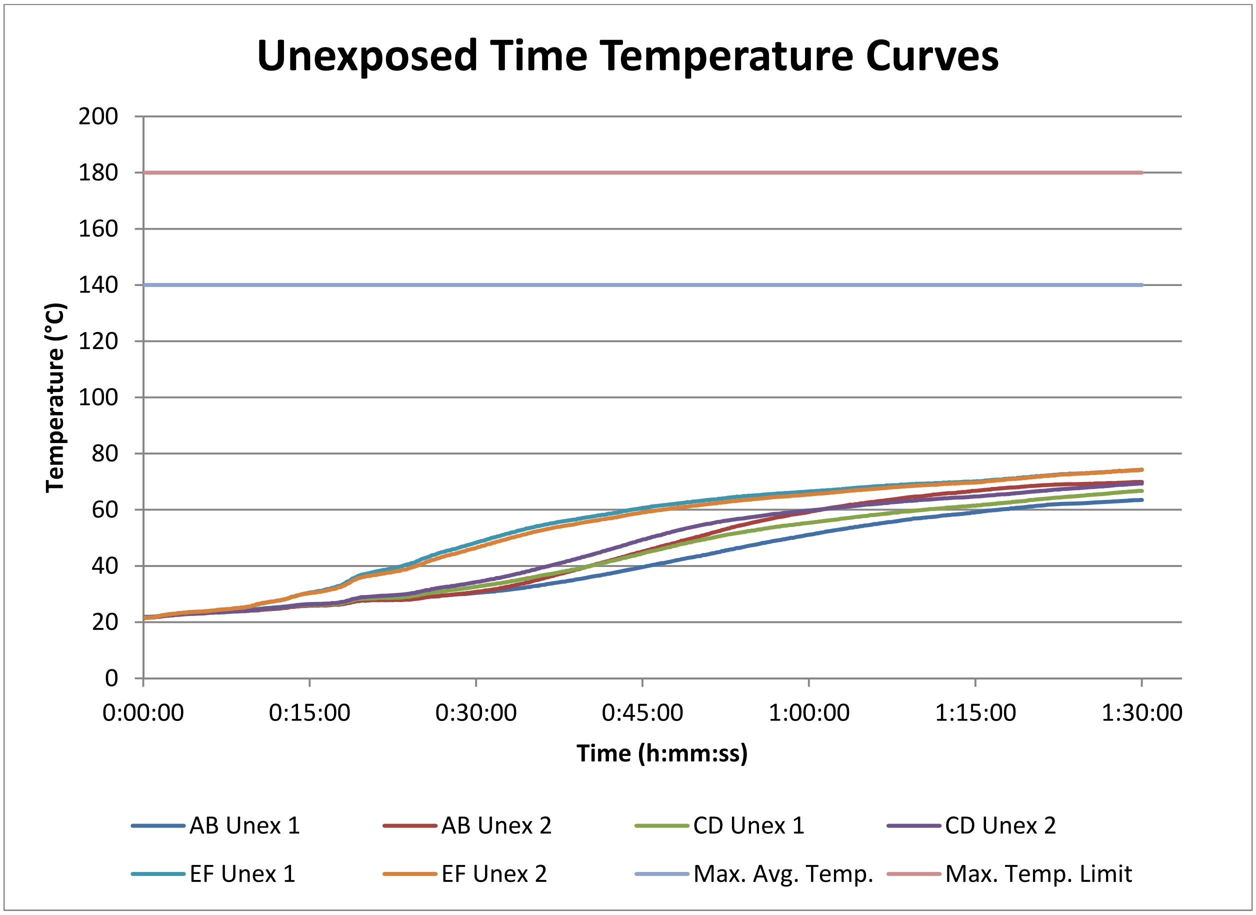


**Figure 5:** Unexposed Time Temperature Curves

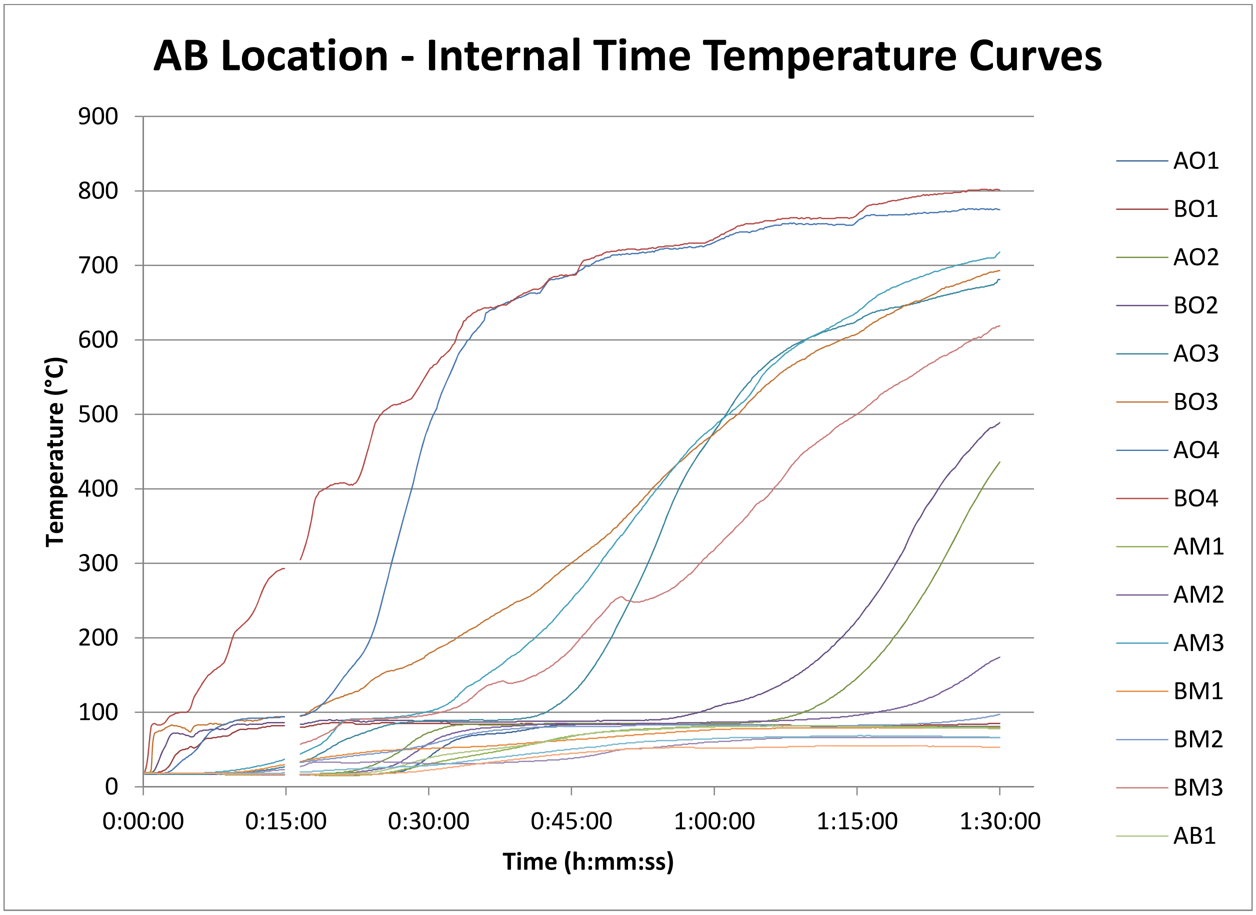


**Figure 6:** Internal Time Temperature Curves

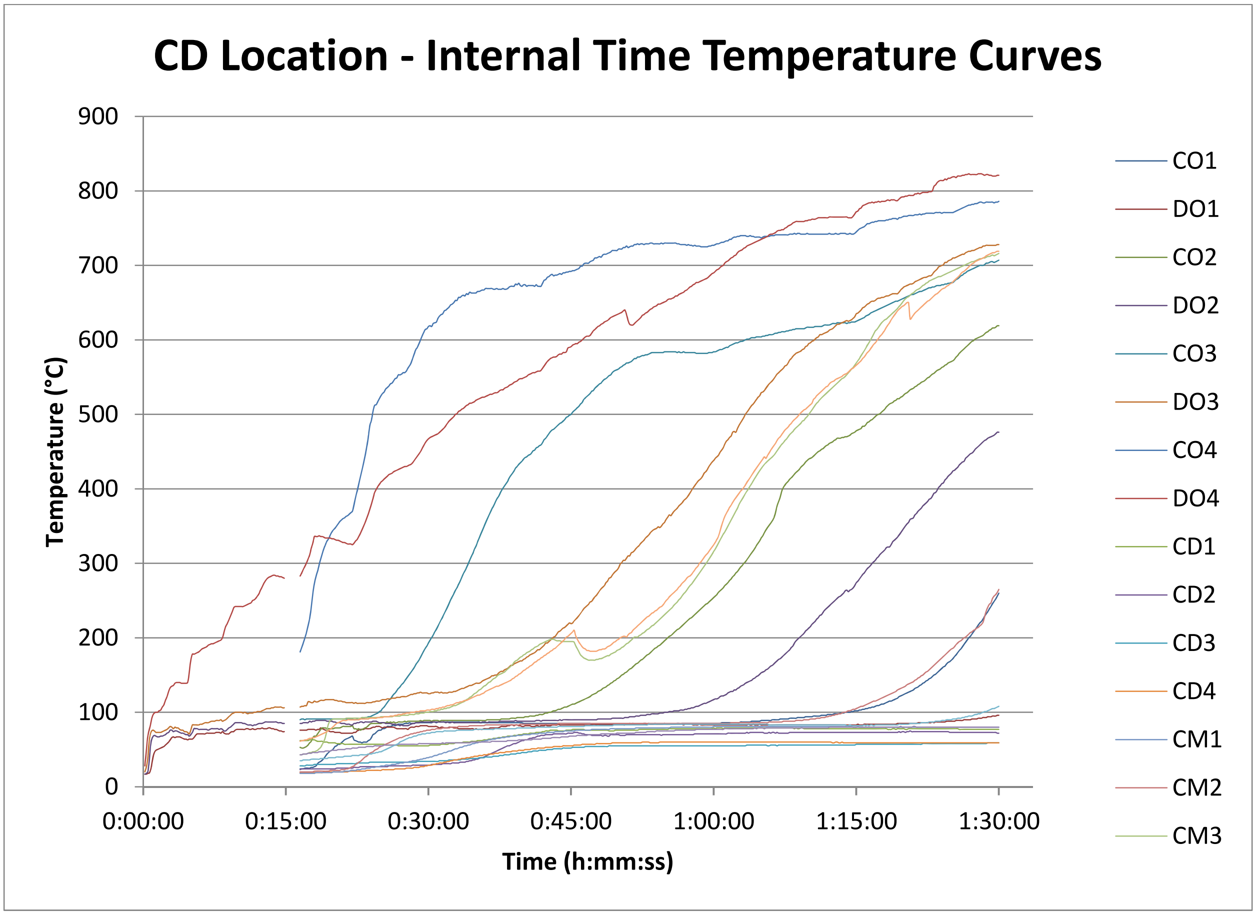


**Figure 7:** Internal Time Temperature Curves

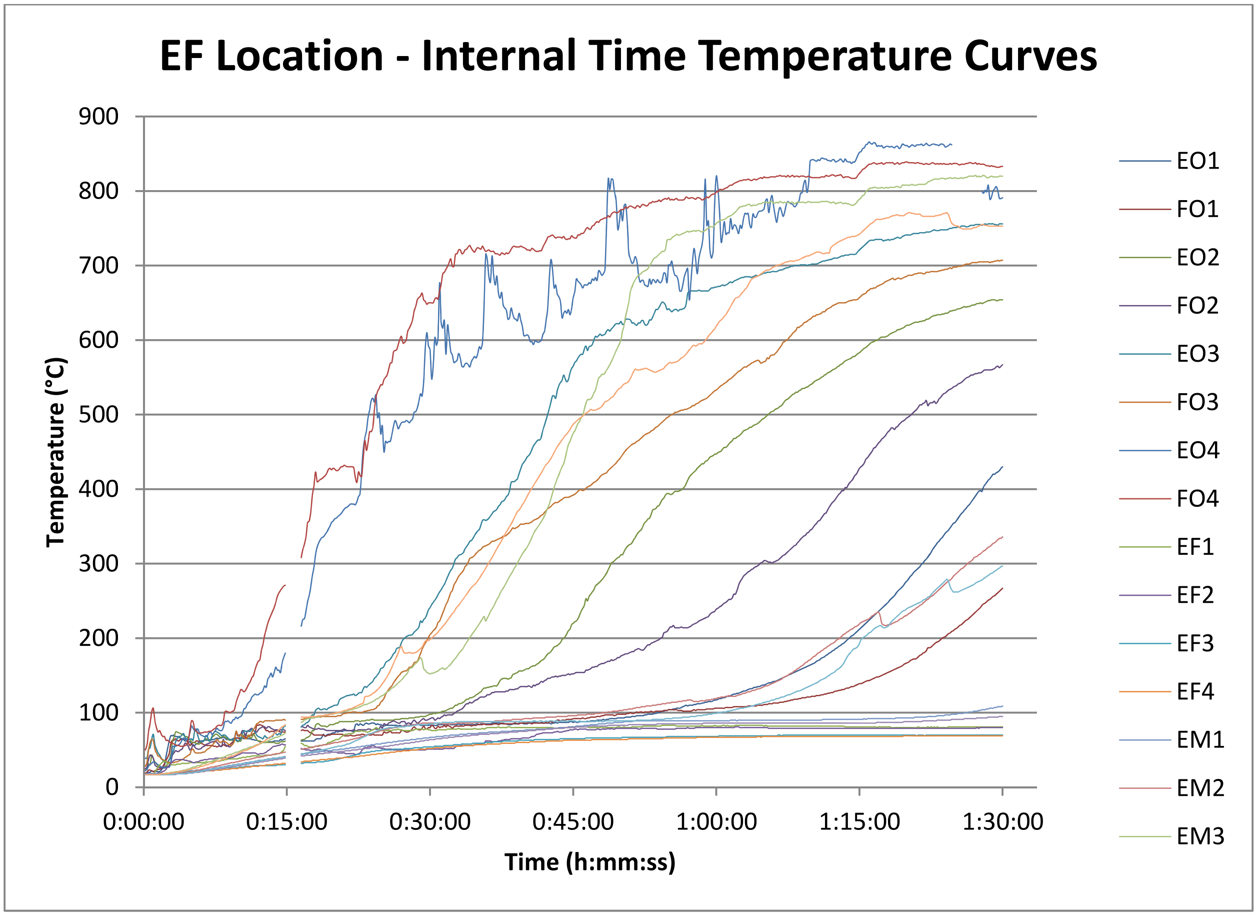


**Figure 8:** Internal Time Temperature Curves

# APPENDIX B

**Figure 9:** The unexposed side of the assembly prior to the gypsum being installed.

**Figure 10:** The exposed side of the assembly prior to the fire test.


**Figure 11:** The unexposed side of the assembly during the fire test.

**Figure 12:** The exposed side of the assembly after the fire test.

# APPENDIX II

QAI Test Report – Test 2 – 2x8 NLT with Copper Penetration

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3980 North Fraser Way
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**CLIENT:** **FPInnovations**
580 Booth St.
Ottawa, ON
K1A 0E4

| Test Report No: T895-8B Rev. 1 | Revision Date: March 7, 2019 |
|---|---|

**SAMPLE ID:** Nail Laminated Timber (NLT) floor/ceiling assembly with a 2 mm gap between timbers, including a copper pipe penetration.

**SAMPLING DETAIL:** The FPInnovations NLT floor/ceiling assembly was constructed including through-penetration, by the client. The test assembly was not independently selected for testing.

**DATE OF RECEIPT:** Samples were received at QAI on September 19, 2018 in good condition.

**TESTING PERIOD:** September 24, 2018.

**AUTHORIZATION:** QAI Test Proposal Number 18MB05222R1, signed and dated on May 25, 2018, by Sylvain Gagnon.

**TEST PROCEDURE**: Tested to the requirements of the following test standard:

- CAN/ULC S115-11, *Standard Methods of Fire Tests of Firestop Systems.* (CAN/ULC S115).

**TEST RESULTS:** The tested FPInnovations NLT floor / ceiling assembly with through penetration copper pipe detailed on page 3 of this report, met the requirements for a 2 hour F-rating when tested in accordance with CAN/ULC S115.

**Prepared By**

**Signed for and on behalf of**
**QAI Laboratories, Ltd.**

**Scott Leduc, EIT**
Project Manager

**Matt Lansdowne**
Director of Engineering

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## Introduction:

This report documents the fire testing conducted by QAI Laboratories Ltd. for FPInnovations of a NLT floor / ceiling assembly with a copper pipe through-penetration. The assembly was evaluated in accordance with CAN/ULC S115 on September 24, 2018.

## Test Description:

**Table 1:** Test Assembly Description

| COMPONENT | DESCRIPTION | |
|---|---|---|
| **Floor/Ceiling Assembly** | Overall Size: | 1.83 m (72 in.) length x 1.42 m (56 in.) width x 171 mm (6.75 in.) thickness. |
| | Type: | Nail Laminated Timber (NLT) floor/ceiling assembly. |
| **Framing** | Type: | No. 2 SPF wood studs nail laminated. |
| | Size: | 38 mm x 184 mm (Nominal 2 in. x 8 in.) |
| | Gap Spacing: | The gaps between timbers was 2 mm. |
| | Fasteners: | 102 mm (4 in.) smooth shank nails placed in two rows top and bottom spaced 178 mm (7 in.) OC. |
| **Subfloor** | Type: | Plywood. |
| | Thickness: | 13 mm (1/2 in.) |
| | Fasteners: | No. 8 Wood screws. |
| **Firestop Assembly** | Opening Size: | 152 mm (6 in.). |
| | Penetrant: | Nominal 100 mm (4 in.) copper pipe. |
| | Fill Material: | Rockwool Roxul ComfortBatt insulation. |
| | Caulking: | Hilti FS-One Max Intumescent Firestop Sealant was applied to a depth of 13 mm (1/2 in.) on the top of the assembly. |
| | Install: | The pipe was positioned in the center of the annular space. The mineral wool was packed tightly between the pipe and the floor/ceiling assembly stopping 13 mm (1/2 in.) from the top surface of the floor. The 13 mm (1/2 in.) void was filled with the firestop sealant. |

## Test Apparatus:

The furnace used in the tests is a pilot-scale fire burning apparatus with interior dimensions of 70 in. in height, 75 in. in width, and 52 in. in depth.

Temperatures within the furnace were monitored using four thermocouples. The temperatures are controlled by adjusting fuel to the furnace burners to conform to the time/temperature curve specified by the test standards. Temperature measurements are recorded by a Keithley 2750 data acquisition unit (ID# DMM1) which passes the readings to a computer for graphical display and storage.

33 thermocouples were placed at various locations inside and between the studs as well as below and above the subfloor and on the unexposed face of the test floor/ceiling and firestop assembly. See Appendix A figure 3 and 4 for detailed locations.

One pressure tap is installed along the longitudinal center line of the test assembly. The pressure tap is attached and monitored by Setra model 264 pressure transducers (ID# Pressure T3). The furnace pressure is controlled by adjusting a damper in the furnace exhaust stack.

**Figure 1:** Pilot-Scale Furnace

## Test Conditions:

The FPInnovations floor/ceiling and firestop assembly outlined on page 3 was supported by the walls of the furnace. A ceramic fiber gasket was used to maintain an air tight seal between the furnace and the floor/ceiling assembly.

The pressure of the furnace was monitored throughout the test. The pressure was continuously monitored using calibrated pressure transducers. After the first 5 minutes of the test the pressure was maintained at 0.01 in. water column 12 in. below the slab.

Prior to the fire endurance test the test assembly was placed on top of the furnace, the front panel was moved into place and the burners were ignited. The fire endurance test was initiated immediately after igniting the burners. The temperature inside the furnace was controlled to follow the standard time/temperature curve within the limits described in the test standard.

## Test Results:

### Observations

The following observations were taken over the duration of the fire test:

**Table 2:** Test Observations

| Test Time (min) | Unexposed | Exposed |
|---|---|---|
| 1:15 | | Ignition. |
| 9:30 | Light smoking of the firestop next to the copper pipe. | |
| 23:00 | Charring and smoking of the firestop around the perimeter of the copper pipe. | |
| 58:30 | | Pieces of char are falling from the assembly. |
| 90:00 | No changes. | |
| 120:00 | Test discontinued. | |

### Flaming and Penetration

No flaming occurred on the unexposed face of the test assemblies, and no through penetrations or openings were observed during the fire test. The fire stop assembly met the requirements for a 2-hour F-Rating.

### Unexposed Temperature Rise

The maximum temperature rise of 181°C above initial for a T-rating on the firestop system was reached at 17 minutes. The fire stop assembly did not meet the requirements for a T-rating.

## Conclusions:

QAI performed testing in accordance with CAN/ULC S115 on an NLT floor/ceiling assembly with a copper pipe penetration as described in table 1.

The firestop assembly evaluated by QAI and outlined in this report met the requirements of CAN/ULC S115 for a 2-hour F-rating.

# APPENDIX A

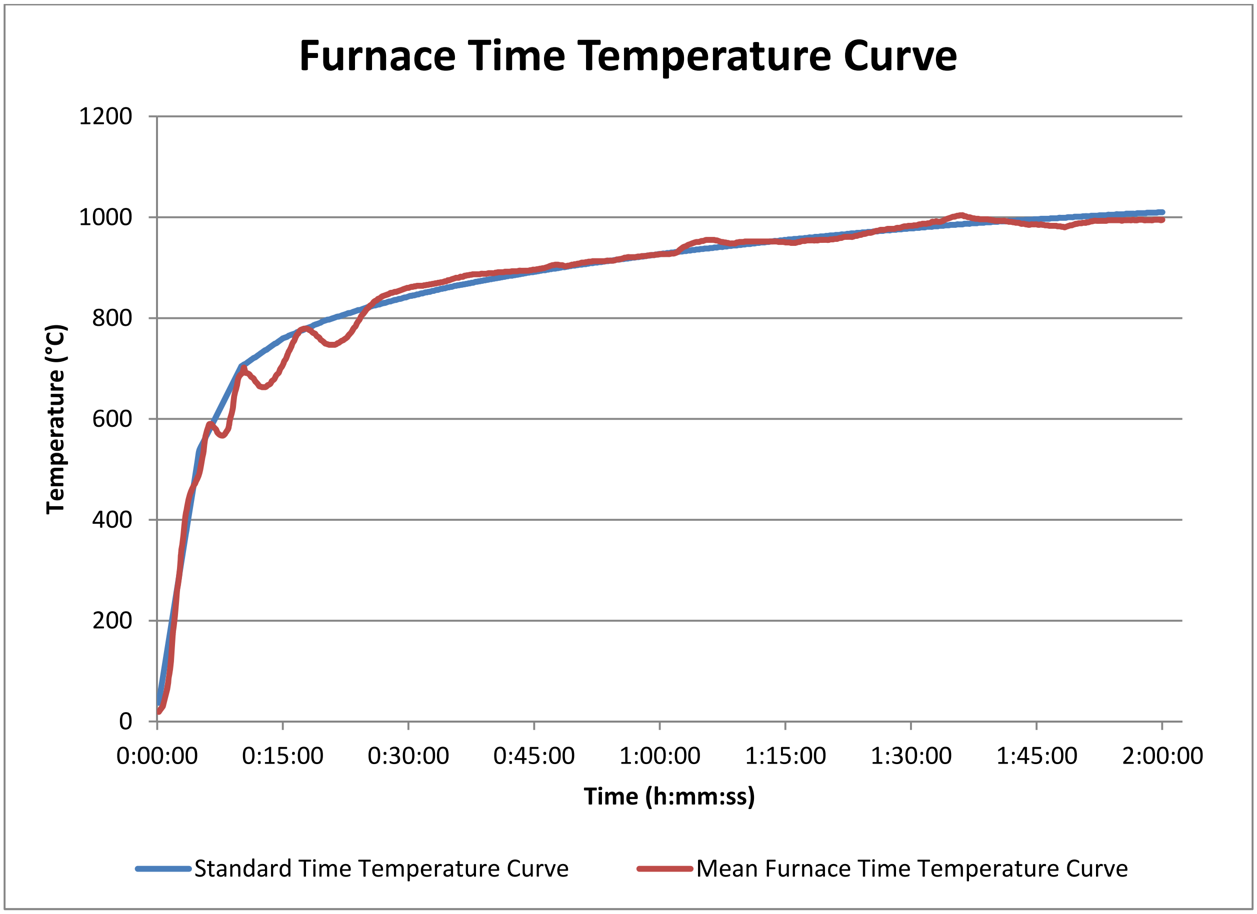


**Figure 2:** Time Temperature Curve

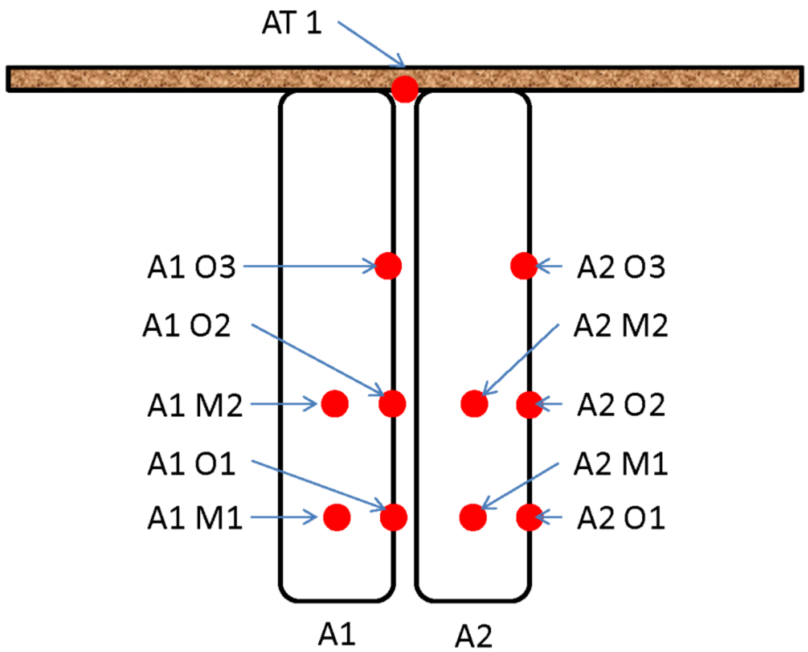


**Figure 3:** Location A Interior Thermocouple Locations

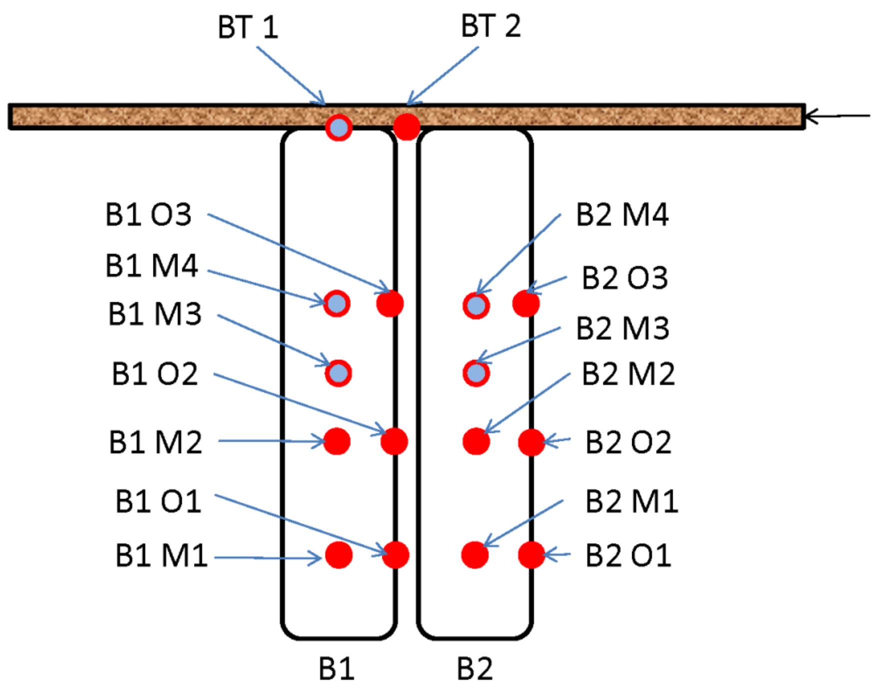


**Figure 4:** Location B Interior Thermocouple Locations

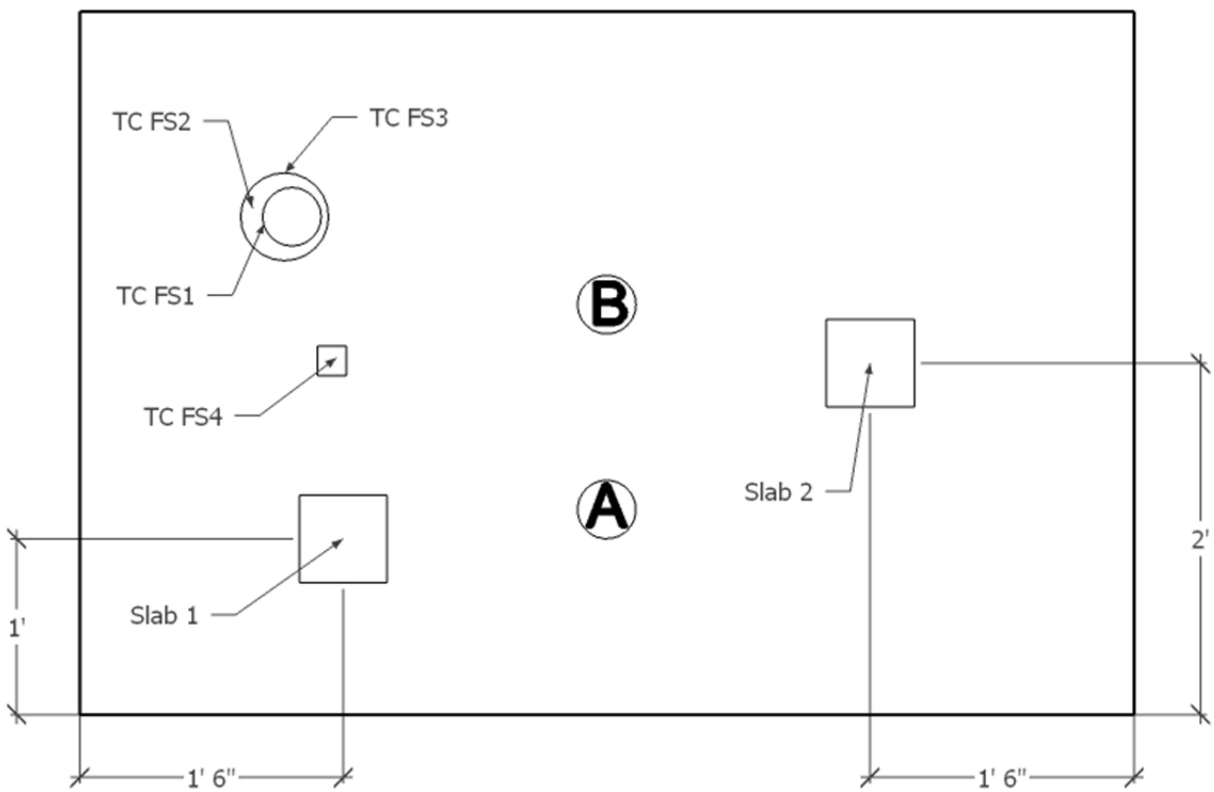


**Figure 5:** Unexposed Thermocouple Layout

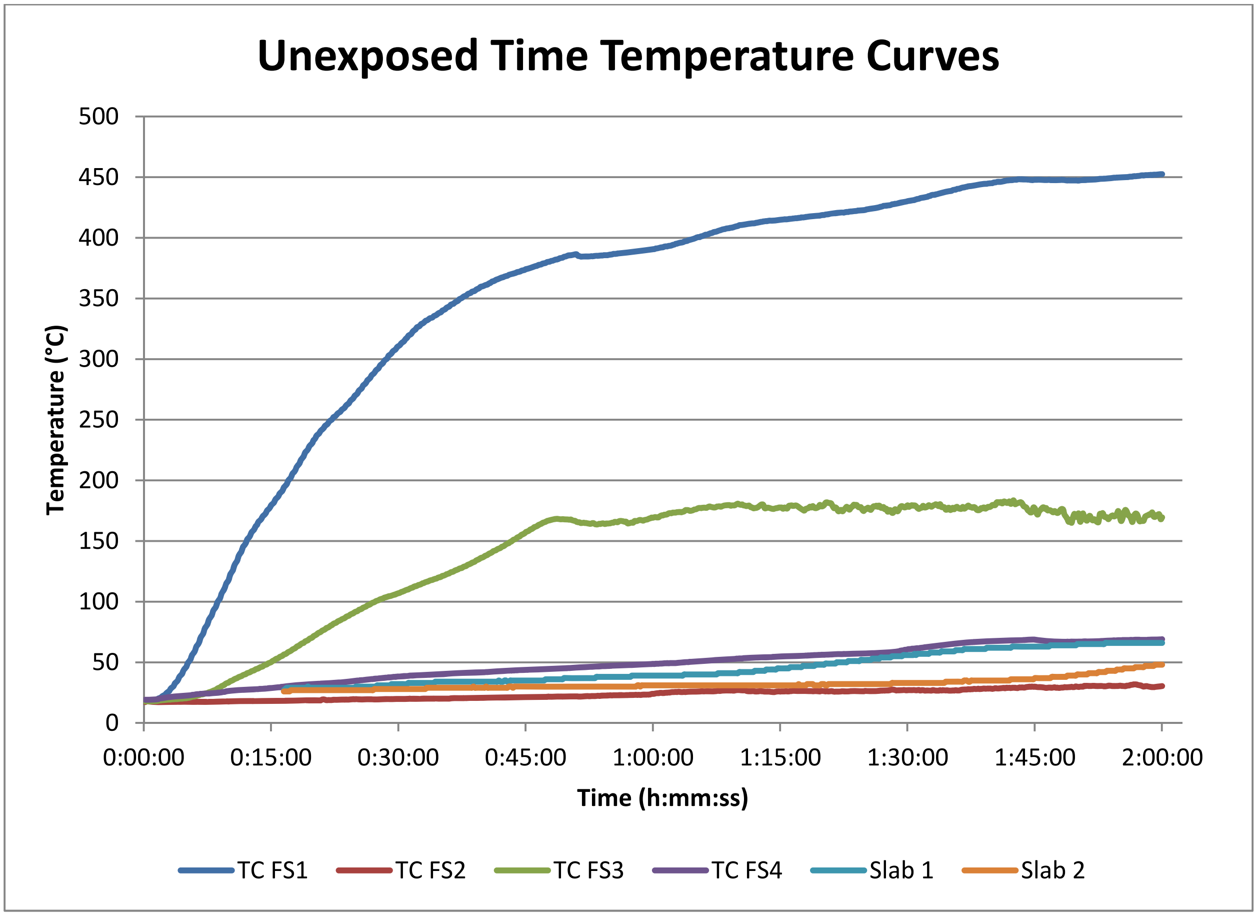


**Figure 6:** Unexposed Time Temperature Curves

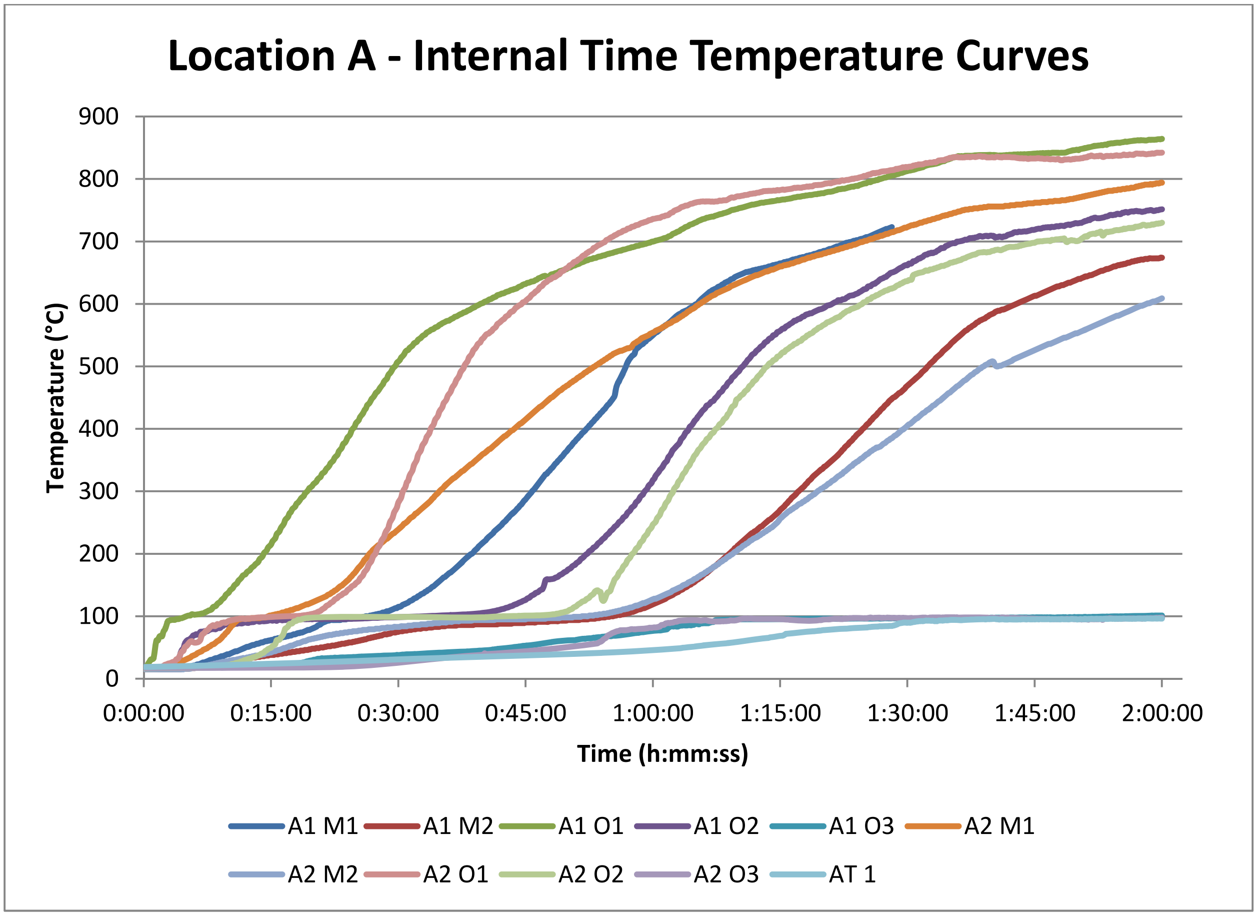


**Figure 7:** Internal Time Temperature Curves

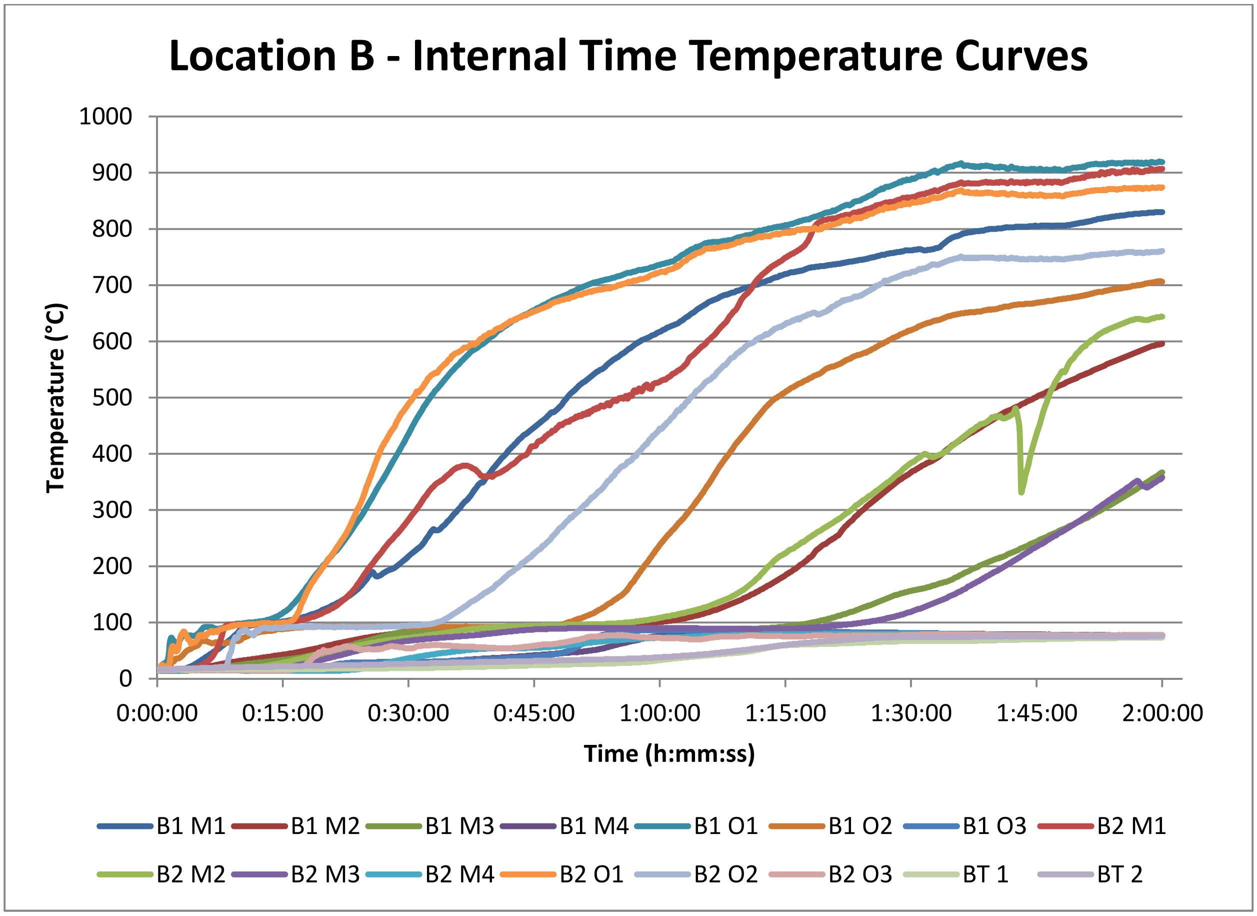


**Figure 8:** Internal Time Temperature Curves

## APPENDIX B

**Figure 9:** The unexposed side of the assembly prior to the gypsum being installed.

**Figure 10:** The exposed side of the assembly prior to the fire test.

**Figure 11:** The unexposed side of the assembly at the end of the fire test.

Table 3: Revision History

| Date | Page | Details | Issuer |
|---|---|---|---|
| October 11, 2018 | All | Original Test Report | Scott Leduc |
| March 7, 2019 | 3 | Corrected timber size. | Scott Leduc |
| March 7, 2019 | 6 | Corrected F-rating. | Scott Leduc |

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