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Intermediate Scale Encapsulation Tests

Author(s): Joseph Su, Patrice Leroux, Pier-Simon Lafrance, Rob Berzins, Karl Gratton, Eric Gibbs, Andrew Frade

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Executive Summary

Encapsulation materials and assemblies of encapsulation materials are commonly used to protect mass timber structural elements in tall and large timber buildings against fire. The time for an encapsulation material or assembly of encapsulation materials to delay the ignition and combustion of the encapsulated mass timber element when exposed to fire, is critical data needed for fire safety design of these mass timber buildings.

A series of intermediate-scale furnace tests with five different arrangements of gypsum board to encapsulate a timber substrate were conducted to fill data gaps in their encapsulation times. The test method was based in principle on CAN/ULC-S146. However, intermediate-scale furnace and test assemblies were used in this series of tests, a deviation from CAN/ULC-S146 that requires the use of full-scale furnace and test assemblies similar to that required by standard CAN/ULC-S101.

A commercial product of three-ply 76-mm thick cross laminated timber (CLT) was used as the timber substrate. Multiple layers of 12.7 mm or 15.9 mm thick Type X gypsum board were installed on one side of the CLT substrate. Wood furring was used in one test and installed on the CLT substrate before installing the gypsum board layers. The test assemblies were exposed to standard and non-standard fire curves, respectively, in the furnace.

The temperature rises at the interface between the gypsum board and the CLT substrate were used to determine the encapsulation times. The time at which the average temperature at the interface exceeded 250 °C above its initial average temperature or the temperature at any individual points of the interface exceeded 270 °C above its initial temperature was determined as the encapsulation time, whichever occurred first.

Four tests were conducted using a standard time-temperature curve in the furnace. The encapsulation time was 80 min with three layers of 12.7 mm thick Type X gypsum board (Test 1); the addition of wood furring increased the encapsulation time slightly by 5 min (Test 2). The encapsulation time was 61 min for two layers and 100 min for three layers of 15.9 mm thick Type X gypsum board, respectively (Test 3 and Test 4).

One test (Test 5) was conducted using a non-standard time-temperature curve derived from a full-scale furnished bedroom fire test, which provided a more severe fire exposure to the test assembly for the initial 40 min but a less severe exposure after 40 min than the standard time-temperature curve. As the result, the encapsulation time in Test 5 was reduced to 52 min for three layers of 12.7 mm thick Type X gypsum board, compared to 80 min in Test 1 with the standard fire exposure, which was a 35% reduction in the encapsulation time under this non-standard fire condition.

The test results provide additional data on encapsulation times of gypsum board materials for use in the fire safety design of mass timber buildings.

Intermediate Scale Encapsulation Tests

Joseph Su, Patrice Leroux, Pier-Simon Lafrance, Rob Berzins, Karl Gratton, Eric Gibbs, Andrew Frade

Fire Safety, National Research Council of Canada

1 INTRODUCTION

Mass timber is increasingly used as structural materials for tall and large wood buildings. To limit the potential contribution of mass timber to fire severity in the event of a fire, encapsulation materials and assemblies of materials are used to protect structural mass timber elements. Comparative performance of different encapsulation materials and assemblies of materials is indicated by their encapsulation times during which the ignition and combustion of a protected timber substrate are delayed by limiting the temperature rise on the surface of the timber substrate under specified fire exposure conditions. There are knowledge gaps in the encapsulation times of certain encapsulation materials and assemblies of materials.

As a part of Project A1-015805 to advance scientific knowledge of fire safety for mass timber construction, the National Research Council Canada conducted a series of intermediate-scale furnace tests with various arrangements of gypsum board to encapsulate a mass timber substrate to obtain data on their encapsulation times. This report describes the tests and documents the results.

2 TEST METHOD AND SETUP

The test method for this series of tests was based in principle on CAN/ULC-S146 [1], which is a method to evaluate encapsulation materials and assemblies of materials for the protection of structural timber elements. An intermediate-scale furnace and test assemblies were used to evaluate encapsulation materials, instead of full-scale furnace tests.

2.1 Intermediate-scale Furnace and Time-Temperature Curves

The intermediate-scale fire tests were conducted using a 1.33 m by 1.94 m horizontal furnace. Four dual-element Chromel-Alumel K-type thermocouple probes were used to measure the temperature inside the furnace chamber. These furnace thermocouples were located approximately 150 mm below the underside of the test assembly. The average temperature measured using these four thermocouples was used to control the furnace. A full description of the intermediate-scale furnace facility is provided by Sultan et al. [2]. **Figure 1** shows photographs of the intermediate-scale furnace.

Four tests were conducted with the temperature in the furnace following the standard time-temperature curve in CAN/ULC-S101 [3]. One additional test was conducted using a non-standard time-temperature curve derived from the average upper layer temperature measured in a full-scale furnished design fire room test [4].

(a) furnace chamber (b) furnace with test assembly

Figure 1. Photograph of intermediate-scale furnace.

Figure 2 shows the standard time-temperature curve and the non-standard time-temperature curve used. The non-standard time-temperature curve gives a higher temperature than the standard time-temperature curve in the first 40 min. As such, the intermediate-scale furnace test using the non-standard time-temperature curve imposed to the test assembly a more severe fire exposure in the initial 40 min but a less severe fire exposure after 40 min than using the standard time-temperature curve.

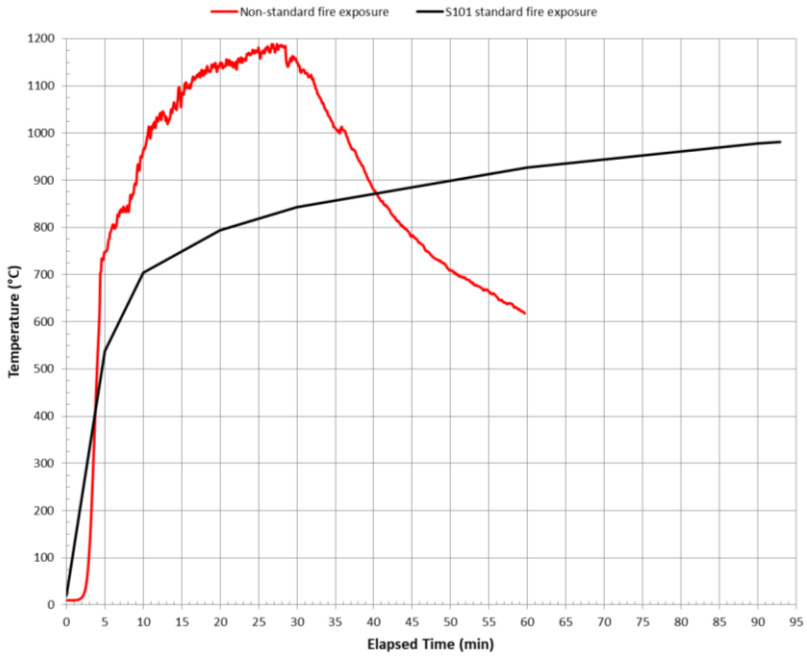


Figure 2. Standard and non-standard time-temperature curves.

2.2 Test Materials and Assemblies

2.2.1 Mass timber substrate

A commercial product of three-ply cross laminated timber (CLT) was used as a timber substrate for the test series. The CLT consisted of 22 mm outside ply, 32 mm middle ply, and 22 mm outside ply to form the 76 mm thick panel. Each test used a new CLT panel of 1970 mm long and 1334 mm wide and 86-88 kg weight as the substrate. The strength was in the long direction (1970 mm), i.e. the outside ply was laid in the long direction. **Figure 3** shows the CLT substrate.

Figure 3. Photograph of CLT substrate.

2.2.2 Encapsulation materials

Multiple layers of 12.7 mm or 15.9 mm thick Type X gypsum board were used to encapsulate the underside side of the CLT substrate and tested under standard and non-standard fire curves, respectively, as shown in **Table 1**. For Tests 1, 2, 4 and 5, three layers of gypsum board were used with a joint incorporated on the base and face layers, respectively, and no joint on the middle layer; the joints on the face and base layers were staggered. For Test 3, two layers of gypsum board were used with a joint incorporated on the face layer and no joint on the base layer. In addition, 17.0 mm x 60.0 mm wood furring was installed on the CLT substrate with 406 mm spacing on centre for Test 2 before installing the gypsum board layers.

To allow gypsum board to fall off freely during the test, the gypsum board was installed to cover the CLT substrate in the area within the furnace chamber such that the gypsum board was not supported on the walls of the furnace (with a side clearance of 25 mm from the furnace walls). Since the inner dimension of the furnace is 1700 mm x 1120 mm, this gypsum covered CLT area within the furnace chamber was 1650 mm x 1070 mm. The surface of the CLT substrate around furnace outer edges (supported on the furnace walls) was protected using separate gypsum board sections. **Figure 4** illustrates the gypsum board layout on the CLT substrate.

Table 2 shows details of drywall screws used to fasten the gypsum board. The screws were spaced at 406 mm on centre. Near the gypsum board joints and edges, screws were placed at 38 mm from the edges of the gypsum board sections. Care was taken not to over drive the screw head into the gypsum board. On the face layer, the joints between gypsum board sections were covered with tape and joint compound, and the screw heads were also covered with joint compound. **Figure 5** shows the drywall screw pattern. **Figure 6**(a) illustrates the wood furring locations between the CLT substrate and the base layer of gypsum board for Test 2.

Table 1. Gypsum board used for CLT encapsulation.

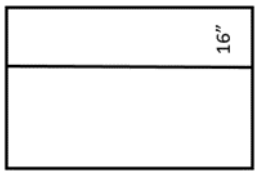
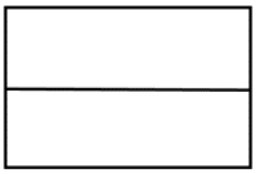
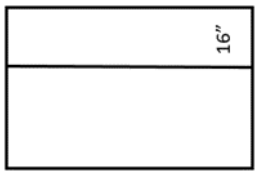
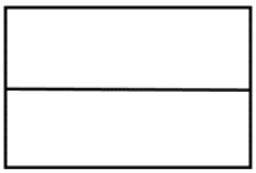
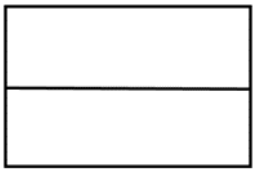
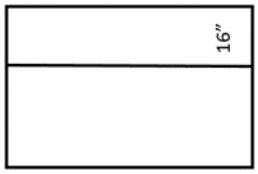
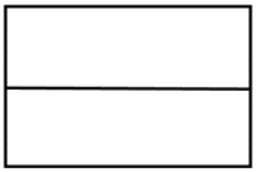
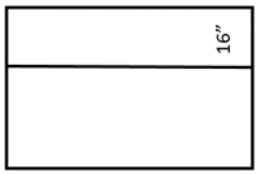
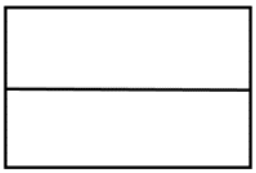
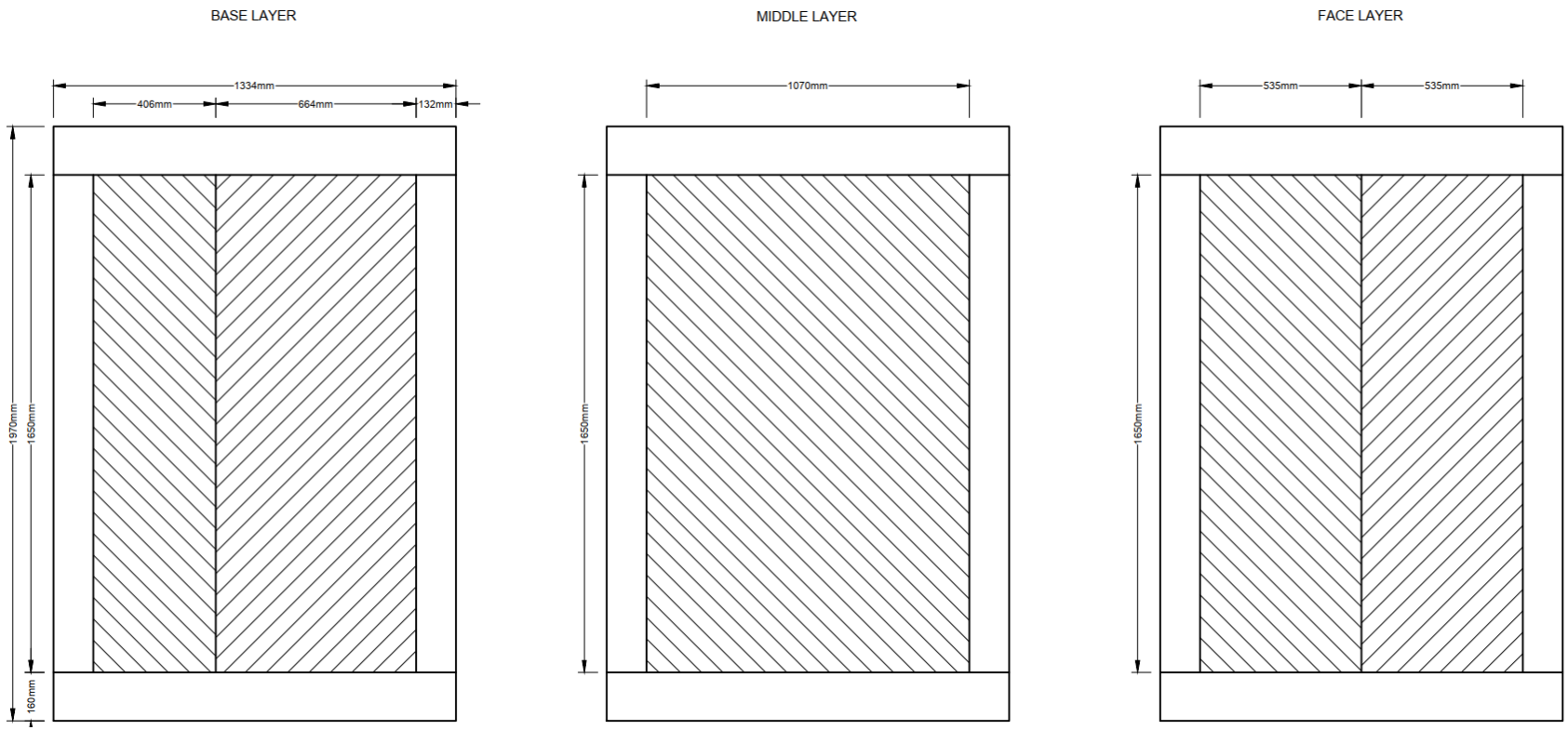
Type X gypsum board # of layer x thickness	**Base layer**	**Mid layer**	**Face layer**	**Fire exposure**
Test 1: 3 x 12.7 mm thick				S101
Test 2: 3 x 12.7 mm thick on wood furring				S101
Test 3: 2 x 15.9 mm thick		none		S101
Test 4: 3 x 15.9 mm thick				S101
Test 5: 3 x 12.7 mm thick				Design Fire

Table 2. Drywall screws used for gypsum board installation.

Gypsum board and screw	Screws on 12.7 mm thick Type X gypsum board			Screws on 15.9 mm thick Type X gypsum board	
	Test 1	**Test 2**	**Test 5**	**Test 3**	**Test 4**
Base layer	41 mm	41 mm	41 mm	41 mm	41 mm
Middle layer	51 mm	51 mm	51 mm	none	57 mm
Face layer	63 mm	76 mm	63 mm	51 mm	76 mm

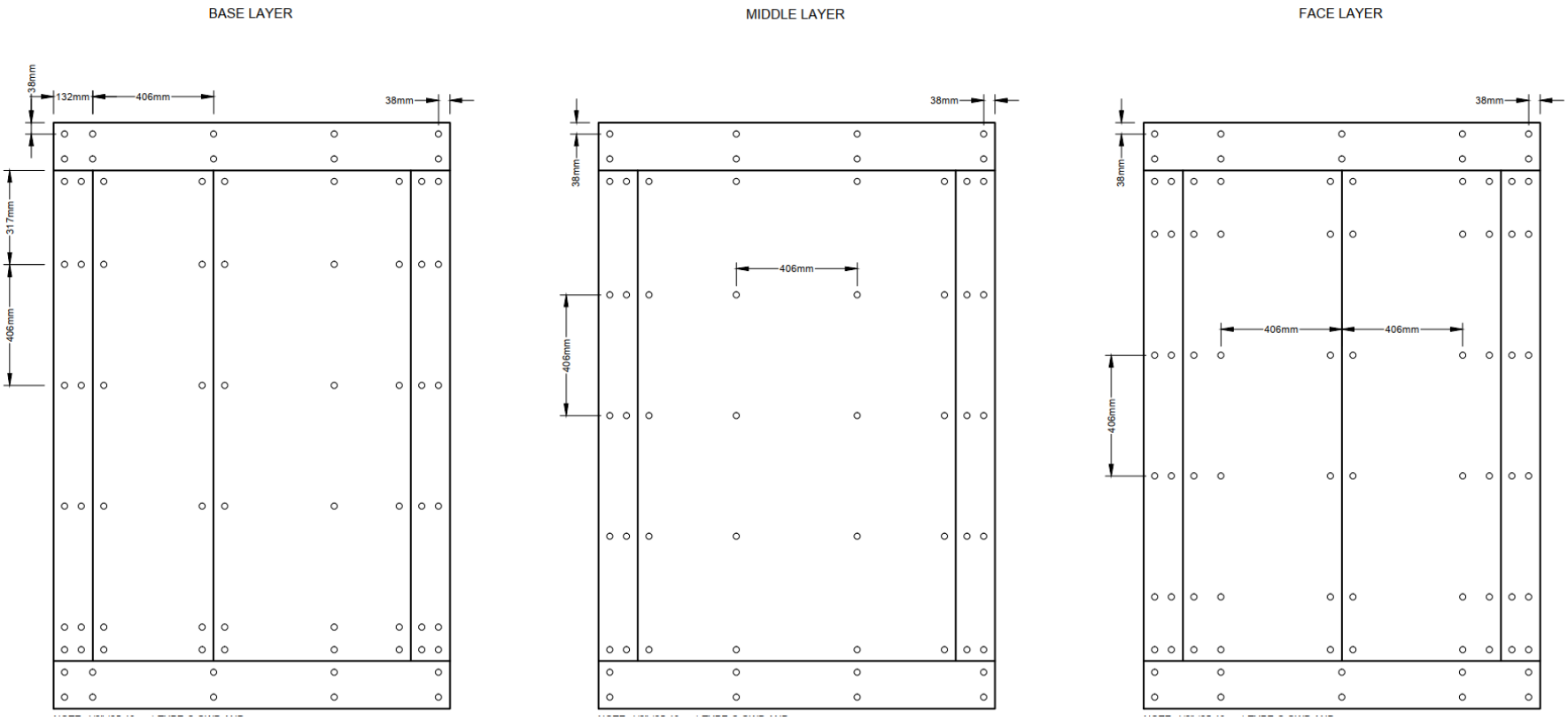


Gypsum board area within the combustion chamber (with a side clearance of 25 mm from the furnace walls)

Separate gypsum board area supported on the furnace walls around the outer edges

Note: there was no middle layer for Test 3 with 2 x 15.9 mm gypsum board encapsulated specimen, but the base layer had no joint in Test 3.

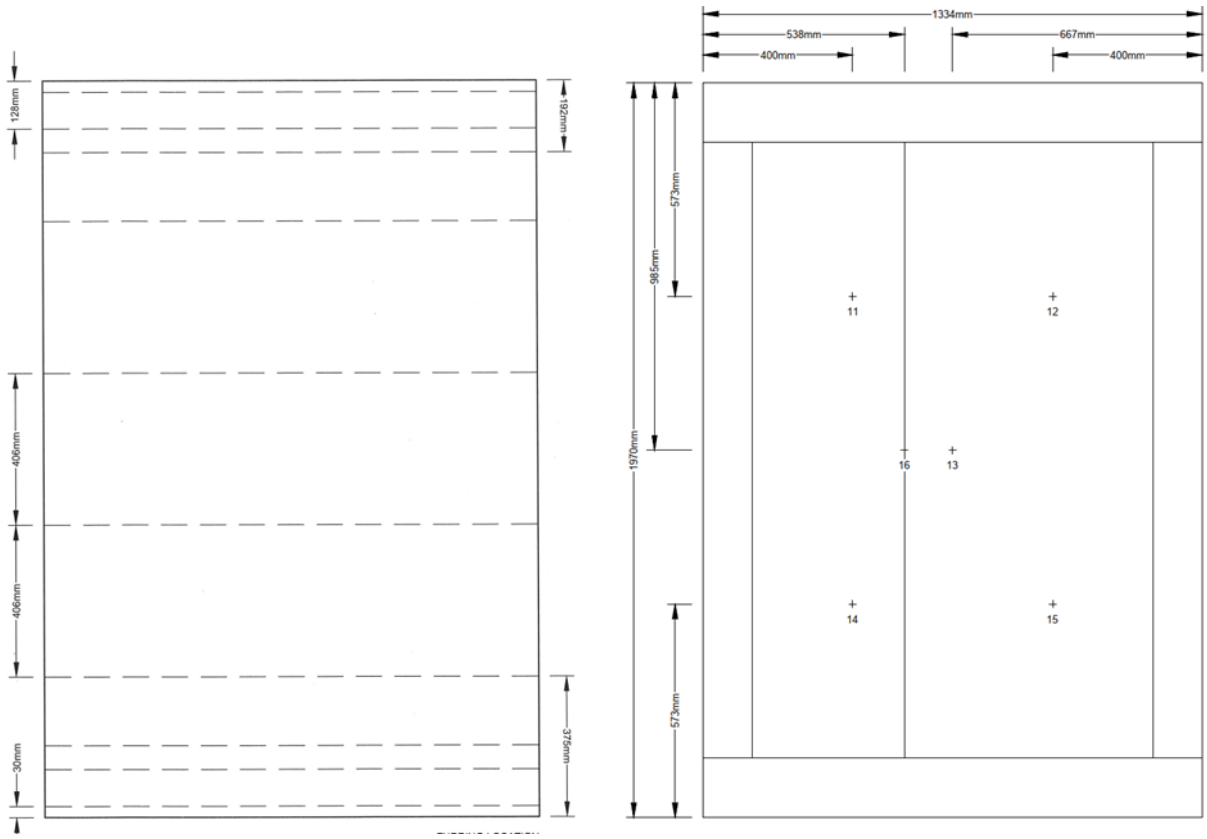
Figure 4. Gypsum board layout on CLT substrate.



Note 1. The screw pattern for Test 2 with furring was shifted in the long direction to coincide with the furring locations (see **Figure 6**(a)).

Note 2. There was no middle layer for Test 3 with 2 x 15.9 mm gypsum board encapsulated specimen, but the base layer had no joint in Test 3.

Figure 5. Drywall screw pattern.



(a) furring layout (only in Test 2)

(Note: each dashed line represents the centerline of a furring strip.)

(b) thermocouples (+) between CLT substrate and gypsum board base layer

(Note: In Test 3, TC #16 was not used as the 1650 mm x 1070 mm area in the center was a whole sheet of gypsum board base layer without the joint.)

Figure 6. Details of furring and thermocouple locations.

2.2.3 Thermocouples installed in the test assemblies

Six thermocouples were installed at the interface between the CLT substrate and the gypsum board base layer. For Test 2 assembly with the wood furring, the thermocouples were attached on the CLT substrate with a 17-mm air gap to the gypsum board base layer. The interface thermocouples were located at the quarter and centre points of the test assembly as well as a gypsum board joint, as shown in **Figure 6**(b). In addition, a thermocouple with a cotton pad was installed at the centre of the unexposed side of each test assembly (see **Figure 1**(b)). These thermocouples were type K, glass-sheathed, 20-gauge of 0.8 mm diameter wires, bare-bead thermocouples. The temperatures measured by the interface thermocouples in the tests were used to determine the encapsulation times.

2.2.4 Moisture content of timber elements

Test materials and assemblies were conditioned in an ambient atmosphere at 50 ± 5 % relative humidity and 23 ± 3 °C. The conditions in the lab space were generally in these ranges. The moisture content of each CLT substrate measured using a handheld moisture meter were in the range of 7-10%.

2.3 Test Procedure

The following procedure was used for the fire tests. No structural load was applied other than the self-weight of the test assemblies.

(1) Data acquisition system started and data recorded at intervals of 5 s;
(2) Furnace started to follow the CAN/ULC-S101 time-temperature curve (Tests 1-4) or the design fire time-temperature curve (Test 5);
(3) Test terminated after all temperatures at the CLT substrate interface exceeded 300 °C;
(4) Test assembly examined after the fire test (photographs, charring depth, etc.).

3 RESULTS AND DISCUSSIONS

The encapsulation performance of the gypsum board materials on the CLT substrate were evaluated in the intermediate-scale furnace tests, including four tests using the standard time-temperature curve and one test using the non-standard time-temperature curve. **Figure 7** to **Figure 11** show temperature and pressure profiles in the furnace and temperature profiles at the interface between the gypsum board and the CLT substrate.

The temperature profiles at the interface between the gypsum board and the CLT substrate followed the typical three-stage heat transfer pattern – an initial temperature rise, a period with gypsum board dehydrating, then a more rapid rise of the temperature. The time at which the average temperature measured by the interface thermocouples exceeded 250 °C above its initial average temperature or the temperature measured by any individual interface thermocouple exceeded 270 °C above its initial temperature was determined as the encapsulation time, whichever occurred first. **Table 3** shows the encapsulation times of the gypsum board materials on the CLT substrate in the intermediate-scale furnace tests.

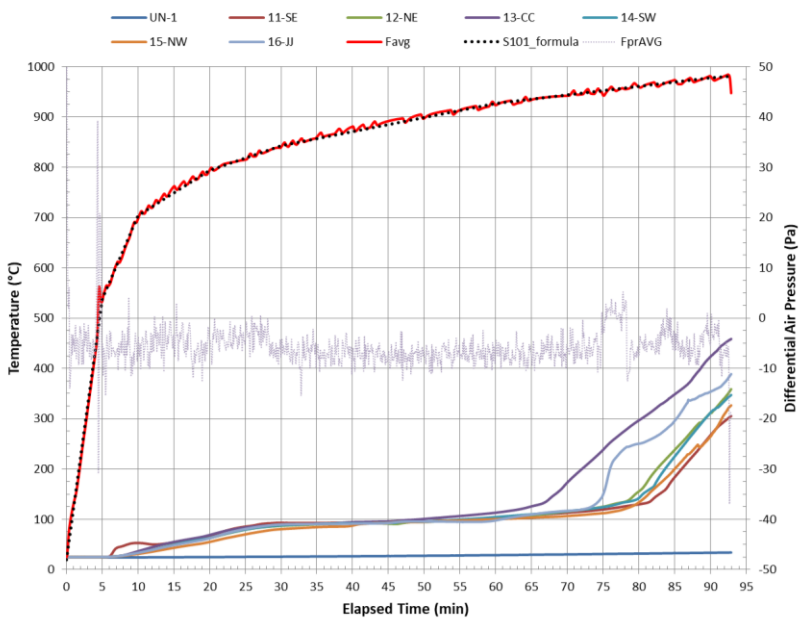
Tests 1-4 were conducted with the standard time-temperature curve as the fire exposure. The encapsulation time was 80 min with three layers of 12.7 mm thick Type X gypsum board in Test 1; the addition of wood furring increased the encapsulation time slightly by 5 min in Test 2. The encapsulation time was 61 min for two layers and 100 min for three layers of 15.9 mm thick Type X gypsum board, respectively, in Test 3 and Test 4.

In Test 5, the non-standard time-temperature curve resulted in a more severe exposure to the test assembly for the initial 40 min, with the furnace temperature being much higher than the standard time-temperature curve (see **Figure 2**) and reaching 1200 °C. However, the fire exposure was less severe after 40 min than the standard exposure as this non-standard fire exposure included a fire decay as in a compartment fire. As shown in **Table 3**, the encapsulation time in Test 5 was reduced to 52 min for three layers of 12.7 mm thick Type X gypsum board, compared to 80 min in Test 1 with the standard fire exposure (35% reduction in this non-standard fire condition). In the previous mid-rise project, a 40% reduction in the encapsulation time was observed under the non-standard fire exposure for two layers of 12.7 mm thick Type X gypsum board [5, 6].

Table 3. Time when interface temperature rise exceeded average and single-point criteria.

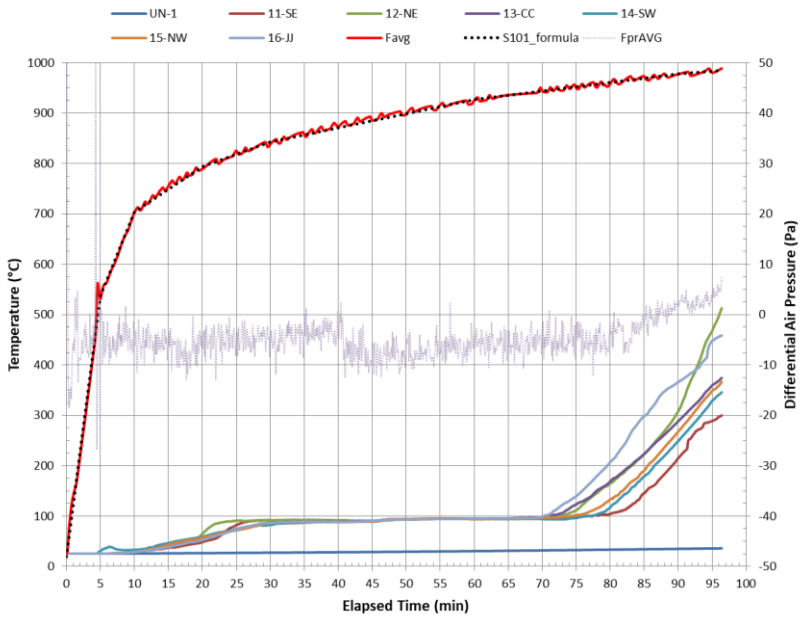
Test	Gypsum board layers	Encapsulation time (min)*	Time (min)						
			single point ΔT > 270 ºC						ΔT > 250 ºC
			TC11	TC12	TC13	TC14	TC15	TC16	Average
1	3 x 12.7 mm	80	92.0	88.9	79.8	89.0	91.4	85.0	86.7
2	3 x 12.7 mm on furring	85	95.8	89.5	90.6	93.1	91.8	84.8	89.6
3	2 x 15.9 mm	61	66.5	65.3	61.3	66.4	65.9	na	64.1
4	3 x 15.9 mm	100	105.6	malf	102.0	104	99.7	103.6	102.0
5**	3 x 12.7 mm	52	57.1	51.6	54.5	57.1	52.6	58.8	53.6

Notes:
* the shortest time for any single-point or average temperature rise, rounded to the nearest minute
** non-standard fire exposure
malf: thermocouple malfunction
na: not available



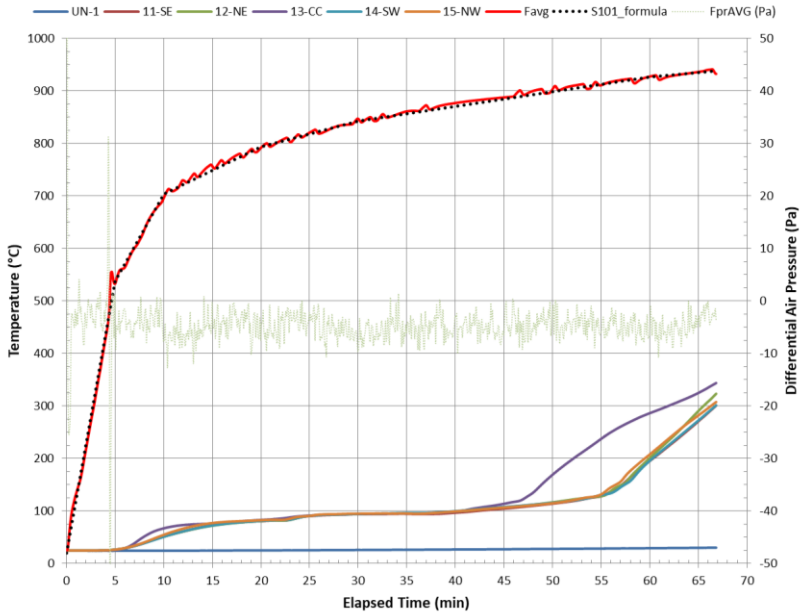
UN-1 – temperature on the unexposed side
11-SE, 12-NE, 13-CC, 14-SW, 15-NW, 16-JJ – interface temperatures
Favg – furnace average temperature
FprAVG – furnace pressure

Figure 7. Furnace temperature and pressure and temperatures at CLT interface in Test 1.



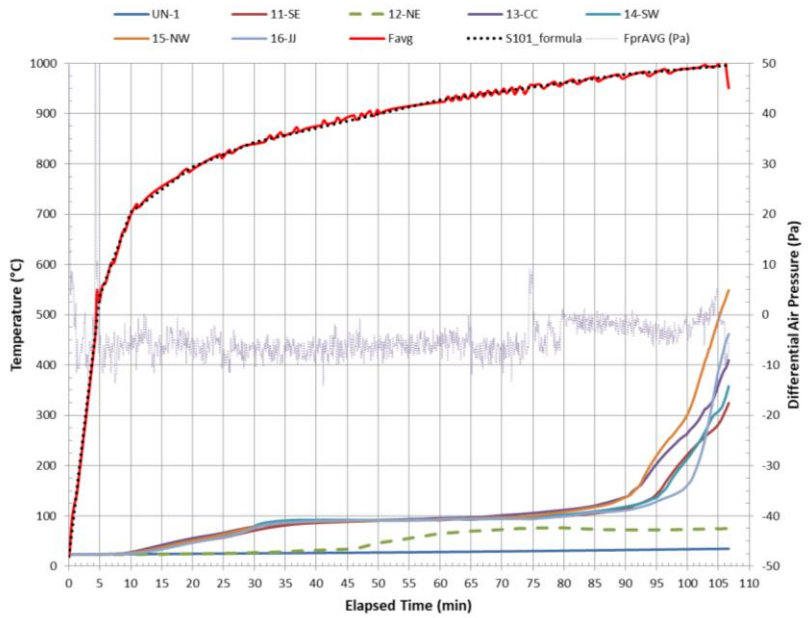
UN-1 – temperature on the unexposed side
11-SE, 12-NE, 13-CC, 14-SW, 15-NW, 16-JJ – interface temperatures
Favg – furnace average temperature
FprAVG – furnace pressure

Figure 8. Furnace temperature and pressure and temperatures at CLT interface in Test 2.



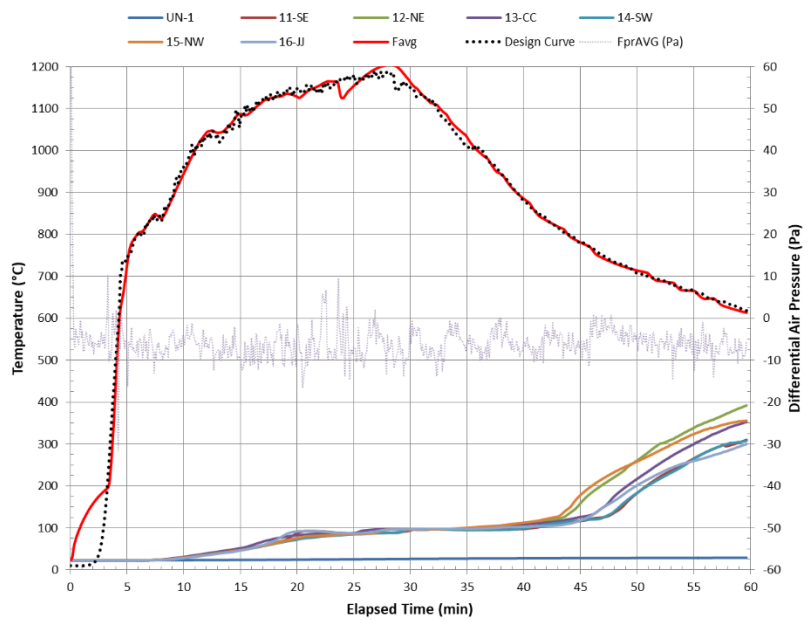
UN-1 – temperature on the unexposed side
11-SE, 12-NE, 13-CC, 14-SW, 15-NW – interface temperatures
Favg – furnace average temperature
FprAVG – furnace pressure

Figure 9. Furnace temperature and pressure and temperatures at CLT interface in Test 3.



UN-1 – temperature on the unexposed side
11-SE, 12-NE, 13-CC, 14-SW, 15-NW, 16-JJ – interface temperatures
Favg – furnace average temperature
FprAVG – furnace pressure

Figure 10. Furnace temperature and pressure and temperatures at CLT interface in Test 4.

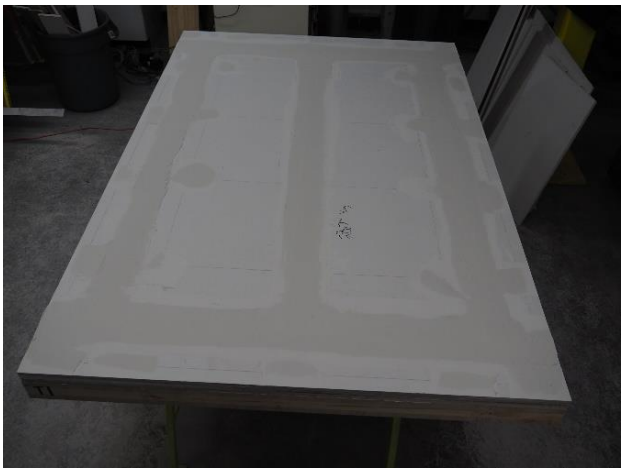


UN-1 – temperature on the unexposed side
11-SE, 12-NE, 13-CC, 14-SW, 15-NW, 16-JJ – interface temperatures
Favg – furnace average temperature
FprAVG – furnace pressure

Figure 11. Furnace temperature and pressure and temperatures at CLT interface in Test 5.

Figure 12 to **Figure 16** are photographs of the test assemblies before and after the tests. After shutting off the furnace and stopping the data acquisition in each test, the test assembly was lifted off the furnace. As shown in **Figure 12**(c) **Figure 16**(c), the face layer gypsum board had already fallen off during Tests 1, 2, 4 and 5; the middle layer gypsum board had also fallen during Tests 2 and 4. During Test 3, the face layer gypsum board remained on the test assembly because the fire exposure duration was 30% shorter (compared with the other tests using the standard fire exposure only). The remaining gypsum board on each test assembly was then removed for the examination of char. **Figure 12**(d) **Figure 16**(d) show the surface char (5 mm at the most) on the CLT substrate. One must note that it took up to 10 min from the end of the test to actually lift the test assembly off the furnace and remove the remaining gypsum board; most char was developed during this period.

(a) encapsulated side



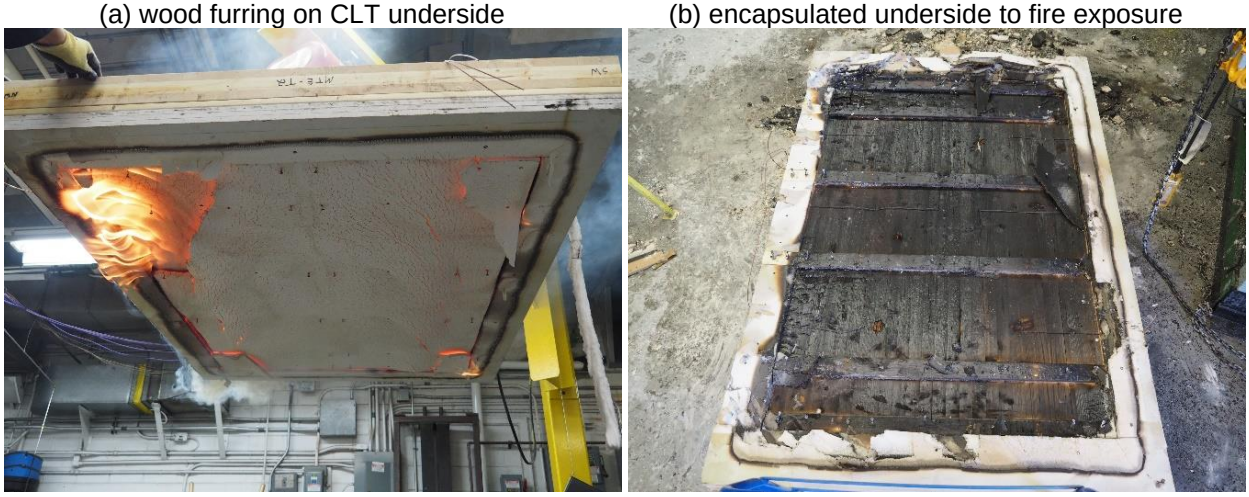
(b) encapsulated underside to fire exposure

(c) gypsum board face layer lost during test

(d) char on CLT substrate

Figure 12. Photographs from Test 1.

(a) wood furring on CLT underside (b) encapsulated underside to fire exposure



(c) face layer and partial mid layer of GB lost (d) char on CLT substrate

Figure 13. Photographs from Test 2.

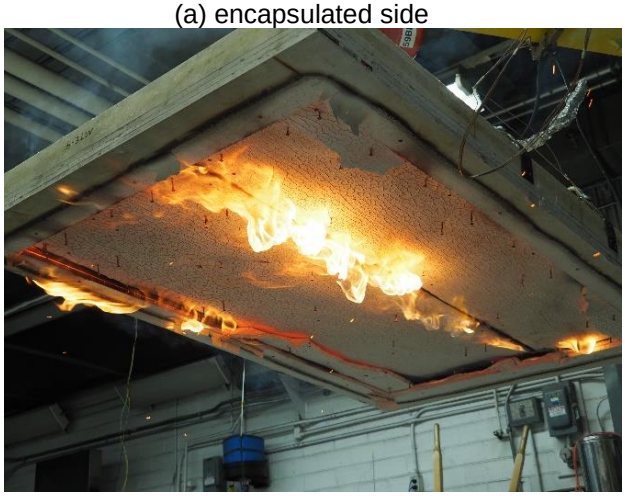
(a) encapsulated side (b) encapsulated underside to fire exposure

(c) gypsum board stayed during test (d) char on CLT substrate

Figure 14. Photographs from Test 3.

(a) encapsulated side

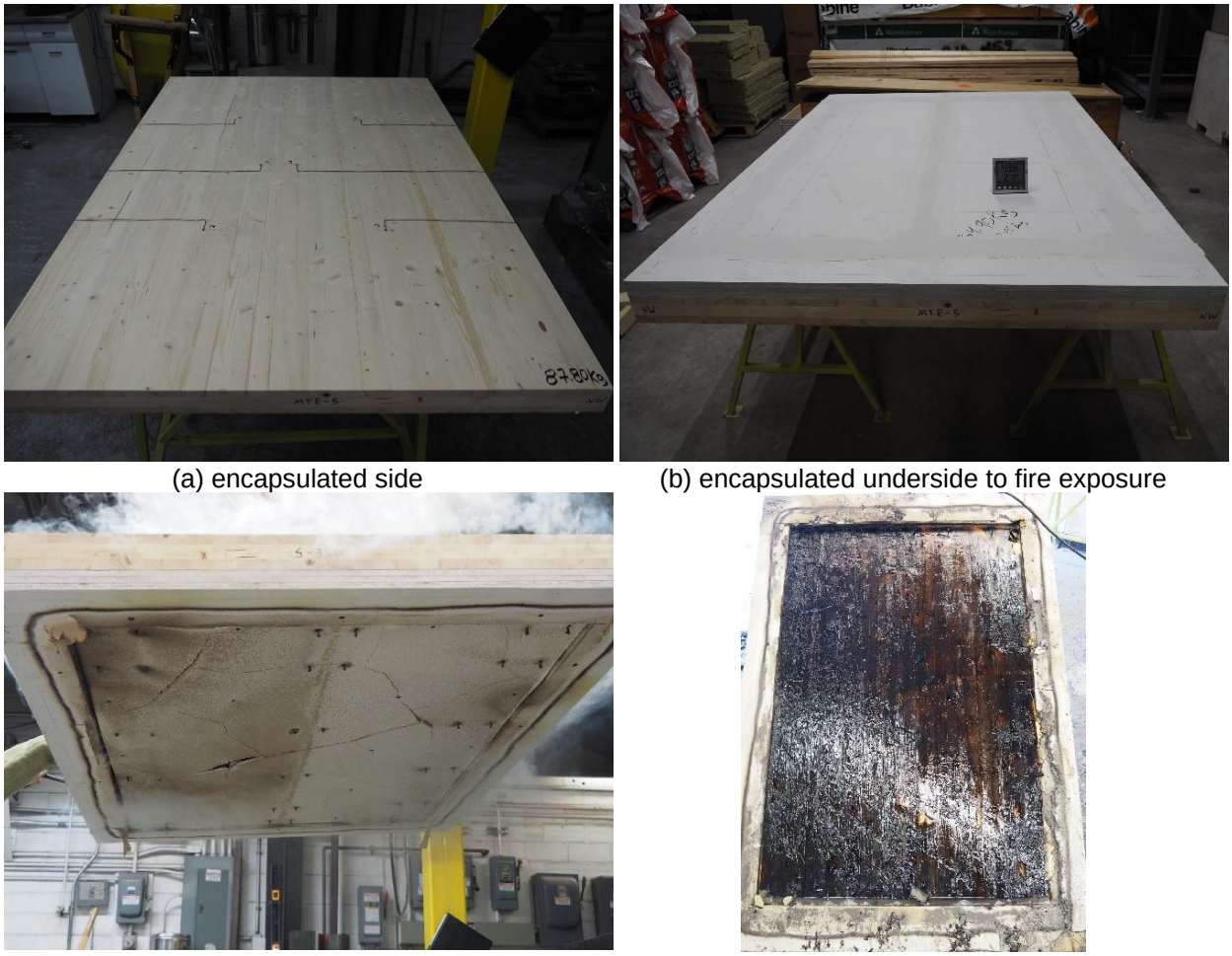
(b) encapsulated underside to fire exposure



(c) gypsum board face and mid layers lost

(d) char on CLT substrate

Figure 15. Photographs from Test 4.



(a) encapsulated side (b) encapsulated underside to fire exposure

(c) gypsum board face layer lost (d) char on CLT substrate

Figure 16. Photographs from Test 5.

4 CONCLUSIONS

A series of intermediate-scale furnace tests with five arrangements of gypsum board to encapsulate a timber substrate were conducted to fill the knowledge gaps in the encapsulation times of gypsum board materials. The results provide additional data for use in the fire safety design of tall and/or large mass timber buildings along with other available data.

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