Experimental Investigations of the Performance of Water Mist System for the Protection of Mass Timber Buildings Focused on Post-fire Damage

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Abstract
For mass timber buildings with exposed timber elements, fire suppression systems need to be designed considering not only the fire suppression effectiveness but also the ability to minimize fire and water damages on the exposed timber elements. To compare the effectiveness on minimizing post-fire damages on the timber structures, a series of fire suppression tests were conducted using high pressure water mist systems (HPWM), low pressure water mist system (LPWM) and conventional sprinkler systems.

Keywords: water mist system, sprinkler, post-fire water damage, mass timber buildings

Introduction
In recent years, North American building regulations and codes have begun allowing the construction of mid/high rise wood frame buildings owing to the advancements in new technologies and mass timber products, such as Cross Laminated Timber (CLT). The International Building Code (IBC) has recently accepted the proposed changes for IBC 2021, which allow a maximum of 9 storeys of exposed mass timber construction for residential and business occupancies with sprinkler protection. The proposed changes also allow exposed mass timber for all occupancies with varying height limitations as long as sprinkler protection is provided.

Sprinklers are the most commonly used fire protection system in buildings due to the proven effectiveness in limiting the severity of fire and fire spread beyond the fire origin. In application to mass timber structures, however, there are some concerns that sprinkler systems could create post-fire water damage and mold problems. As a potential alternative solution to sprinkler systems, water mist systems could be
considered for the protection of timber buildings because they use much less water compared to sprinkler systems.

There are many questions unanswered regarding potential benefits of water mist systems in protection of mass timber buildings and their performance in comparison to conventional sprinkler systems. A review of current building regulations and standard requirements for the use of water mist systems for the protection of mass timber buildings found that none of the standards considers the use of water mist systems in mass timber buildings [1].

The National Research Council Canada experimentally investigated the performance of water mist suppression systems in fire scenarios involving mass timber structures, with a focus on residential occupancies. A series of fire suppression tests were conducted using high pressure water mist systems (HPWM) and low pressure water mist system (LPWM) in comparison to conventional sprinkler systems to substantiate potential benefits of water mist systems in minimizing fire and water damages on the exposed mass timber structures.

**Test set-up**

As shown in Figure 1, the test room (approximately 8.53 m (L) × 4.27 m (W) × 2.4 m (H)) was constructed with light-weight wood frames and sheathed with non-combustible materials on the walls and ceiling. The floor of the room was non-combustible materials (concrete). At the corner where the fuel package was located, the walls and ceiling was built with CLT panels (made from Canadian spruce/pine/fir) with dimensions approximately 2.4 m (L) × 2.4 m (W). Ventilation was provided by 2 doors of 2.2 m height each.

A wood crib and simulated furniture were used as fuel for the fire for repeatability, similarly in the standard test protocols from UL 2167 [2]. The crib had a cross sectional area of 0.3 × 0.3 m² and 0.15 m thickness and placed at 0.15 m from the ground. Two polyether foam sheets were used to simulate the furniture. The dimensions of the sheet were 0.865 m width, 0.075 m thick and 0.775 m height. An actual upholstered chair fire is reported to release the peak heat release rate of 1.2-1.4 MW in 3-4 minutes. When placed at a room corner, the peak heat release rate is reported approximately 1.8 MW [3].

The foam sheets and the wood crib were placed on top of non-combustible panel on the floor and ignited using a heptane burner.

In this testing program, two high-pressure water mist (HPWM) nozzles, one lower pressure water mist (LPWM) nozzle and one residential sprinkler nozzle were tested. Table 1 shows the specifications of the selected four pendent type nozzles tested. The nozzles were tested mainly with automatic operation, but Type A, B and C nozzles were also tested with delayed activations.
Table 1. Fire suppression systems tested

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>System</th>
<th>K factor ([\text{lpm/bar}^{1/2}])</th>
<th>Max. Spacing [m]</th>
<th>Temperature Rating [°C]</th>
<th>Operating pressure [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HPWM</td>
<td>2.4</td>
<td>4.27</td>
<td>79</td>
<td>50 or 70</td>
</tr>
<tr>
<td>B</td>
<td>HPWM</td>
<td>4.1</td>
<td>5</td>
<td>79</td>
<td>80</td>
</tr>
<tr>
<td>C</td>
<td>LPWM</td>
<td>16.5</td>
<td>4.5</td>
<td>79</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>Sprinkler</td>
<td>43.2</td>
<td>4.3</td>
<td>79</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Fig. 1. Test room.

Temperatures in the test room were measured throughout the test, and a thermocouple was installed on the exposed CLT ceiling panel at the fire corner to measure the surface temperature and to assess the capability to protect the exposed CLT elements of each system.
After each fire test, fire damages on the CLT surfaces were photographed and the damaged CLT panels were replaced with new ones for the next test. In each test, moisture contents of the CLT walls and ceiling were measured before and after the test.

**Spray characteristics**

The most distinct characteristic of the HPWM and LPWM (i.e. operated at the relatively high pressures of 52-80 bar and 8.6 bar, respectively) was fine water droplets generated from the nozzles. Due to the fine water droplets, both HPWM an LPWM system demonstrated effective smoke cooling in the room.

The HPWM system with Type A nozzle sprayed fine water mist with a relatively narrow spray angle (approximately 90°), and the fine water mist, filling up the test room, suppressed the fire and limited the fire spread to the CLT walls and ceiling. On the contrary, the HPWM system with Type B nozzle, the LPWM system with Type C nozzle and sprinkler system with Type D nozzle sprayed water at wide angles, which were enough for water sprays to reach the walls surrounding the fire corner. These systems with wide spray angles resulted in limited fire damage on the CLT walls.

**Water spray rate**

Two nozzles were installed in the room as shown in Fig. 1, and the activation times of the nozzles were monitored. After the ignition, the fire developed quickly over the simulated furniture and wood crib. The activation time of Nozzle #1 was approximately 1.2-1.8 minutes with automatic activation of the nozzle, which has the same temperature rating of 79 °C. While only Nozzle #1 was activated in the HPWM and LPWM tests, Nozzle #2 was also activated after approx. 1 minute from the activation of Nozzle #1 in all sprinkler system tests.

The HPWM system had the lowest spray rate (17.3 l/min for Type A at 52 bar and 36.7 l/min for Type B at 80 bar) among the 3 systems. The spray rate per nozzle of the LPWM and sprinkler systems were comparable (48.4 l/min and 42 l/min); however the total spray rate of the sprinkler was higher (twice the aforementioned value) due to the activation of the 2 nozzles.

**Fire suppression**

Due to the distinct spray angles, spray patterns and water spray rates, each system resulted in varying degrees of protection for the test room. Fig. 2 shows flame temperature measured at the fire corner.
Fig. 2. Flame temperature measured above the wood crib at the fire corner at 0.4 m height.

HPWM Type A nozzle required the longest time (approx. 17 minutes) to control the flame temperature below 300 °C, but HPWM Type B nozzle required only 1.5 minutes to extinguish the fire. The effectiveness of the sprinkler system in suppressing fire was comparable to the HPWM systems. However, it should be noted that the sprinkler system needed the subsequent activation of Nozzle #2 (at approx. 2.7 minutes), which was mainly due to the challenges in suppressing the simulated furniture fire.

**Fire damages on CLT panels**

One thermocouple was installed on the CLT ceiling panel at the fire corner to measure the surface temperature. As shown in Fig. 3, initially for the first 1 minute, the CLT ceiling temperature increased rapidly until the activation of the fire suppression system. Notably, the ceiling surface temperature abruptly decreased for the HPWM Type B nozzle. The measured CLT ceiling temperature also decreased within 1 minute from the activation of the LPWM and sprinkler system. With the sprinkler system, the measured maximum CLT ceiling temperature was 264 °C.

To investigate the performance of the HPWM, the activation of the nozzle was delayed approximately one minute in selected tests. As shown in Fig. 3, the ceiling temperature rapidly increased reaching 800 °C, which indicates that the fire spread to the CLT ceiling and walls.

The damage made on the CLT wall and ceiling panels varied depending on the system types and nozzle specifications. With the normal operation of the suppression systems, there was no severe fire damage made on the ceiling CLT panel but for the wall panels with significant charring. Fig. 4 shows the fire damage on the CLT panels. The HPWM with Type B left only slight charring on the wall panels.
With the delayed activation of about 1 minute, the damage made on the CLT walls and ceiling was severe. When delayed activations are expected in system designs (e.g. employing dry pipe systems), the risk of fire spread to the combustible mass timber should be considered.

Fig. 3. CLT ceiling temperature (the measurement location being above the wood crib).

Fig. 4. Fire damage on the CLT panels.
Water damage

Moisture contents of the CLT walls and ceiling were measured before and after the test using a pin-type moisture meter. 14 measurements points were depicted, and the measurements are plotted in Fig. 5. The ambient temperature was 20 ± 5 °C, and the average humidity during the week of the testing was 56 ± 21 %.

Fig. 5. Moisture content measured before and after the suppression tests.
The pre-test moisture contents were similar among the tests with the values averaged over the measurement points being in the range of 12.3 – 15.1 % for all tests. When measured in 20 minutes, the post-test value was 37 % higher than the pre-test value, and the post-test value was 17.2 % when measured in 2 hours. Therefore, the recovery of moisture contents were not monitored beyond the time period of 24 hours since the changes were not apparent beyond the time. The post-test values measured in 18- 24 hours were similar to the pre-test value.

While the wet CLT wall panel surfaces quickly dried regardless of the system tested, a large water pool was formed on the floor in each test. The size of the water pool appeared proportional to the total water spray rate in each test, and the moisture contents measured indicated that water can penetrate into the joints along the bottom edge of the CLT wall panels.

**Conclusion**

The test results showed that the water spray rate of HPWM was four times lower than that of the sprinkler system while both systems effectively control the residential fire scenario involving mass timber structure. Most systems (HPWM, LPWM and sprinklers) tested in this study did not prevent the fire damage on the exposed mass timber walls, but HPWM system with a wide spray angle demonstrated rapid fire suppression and effective protection of the exposed mass timber walls. The moisture contents measured after the tests indicated that water could be absorbed effectively through the joints along the bottom edge of the mass timber walls. A further study is necessary to understand the long term effects of the water damage on the mass timber.

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**References**

