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FIRE PERFORMANCE OF MASS TIMBER

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A significant amount of fire researches have been conducted on mass timber over the last 10 years in Canada. This has supported the successful design and construction of numerous low-, mid- and even high-rise wood buildings. This has also fostered the introduction of new provisions into the National Building Code of Canada which has made wood and mass timber construction more accessible.

However, the fire performance of these systems remains to be a concern for many potential occupants or owners of these buildings, not to mention building officials and fire departments. Research at FPInnovations continues to support designers and builders in the use of mass timber assemblies by ensuring fire safe designs.

Mass Timber Construction

Mass timber construction is a relatively new type of construction soon to be implemented in the National Building Code of Canada (NBCC). It is a cost-competitive wood-based solution that complements existing wood-frame and heavy timber systems and is a suitable candidate for some applications which currently use concrete, masonry and/or steel.

Mass timber construction is a type of construction where the level of fire safety is calculated/engineered based on the large cross-sections of elements. Mass timber construction is not to be confused with "heavy timber construction", per the NBCC definition. Its fire performance exceeds the performance attributed to "heavy timber construction"; its performance is more similar to that of most non-combustible construction.

While timber of large dimensions is still suitable in many cases, "modern" mass timber now consists of engineered wood products such as glue-laminated timber (GLT), cross-laminated timber (CLT), mechanically laminated timber (MLT) and structural composite lumber (SCL) and has broader applicability.

Cross-Laminated Timber

Mass timber provides excellent fire resistance, often comparable to typical massive assemblies of non-combustible construction. This is due to the nature of thick timber wood members to char slowly at a predictable rate, allowing massive wood systems to maintain significant structural capacity for extended duration when exposed to fire.

A significant number of full-scale fire resistance tests has been completed in Canada since the last decade to evaluate the CLT fire resistance and to validate a calculation method for code conformity. A floor fire resistance furnace is shown in Figure 1.

CLT assemblies were tested in accordance with CAN/ULC-S101, which reproduces the standard fire severity of the ASTM E119 standard. Different load ratios were applied depending on the number of plies and the assembly type (wall or floor).

Figure 1. Removal of a GLT floor after a FPInnovations fire resistance test conducted at National Research Council Canada

CLT panels were constructed following ANSI/APA PRG 320 layups and came from different manufacturers across Canada. The panels were manufactured with a structural polyurethane adhesive conforming to ANSI/APA PRG 320, prior to its 2018 edition. The assemblies were instrumented with thermocouples, embedded throughout the assemblies, to evaluate charring rates. Some of the CLT panels were fully exposed to fire (unprotected) while others were protected by Type X gypsum board(s).

The results were used to develop a fire resistance calculation method, as detailed in the latest editions of the Canadian and US CLT Handbooks and now implemented in Annex B of CSA O86 (Canada) and Chapter 16 of the National Design Specification for Wood Construction (US). Figure 2 shows the calculated fire resistance times using the Canadian method compared to test data.

Since 2017, researches conducted by FPInnovations on heat delamination of adhesives led to the improved performance requirements implemented in ANSI/APA PRG 320 (updated in 2018). Fire test results are now being used to validate that CLT heat delamination is no longer an issue and that a constant one-dimensional charring rate of 0.65 mm/minute could be used for design, regardless of the position of the first bond line. FPInnovations initiated a change proposal to CSA O86 in January 2020 to revise the applicable charring rate for CLT elements.

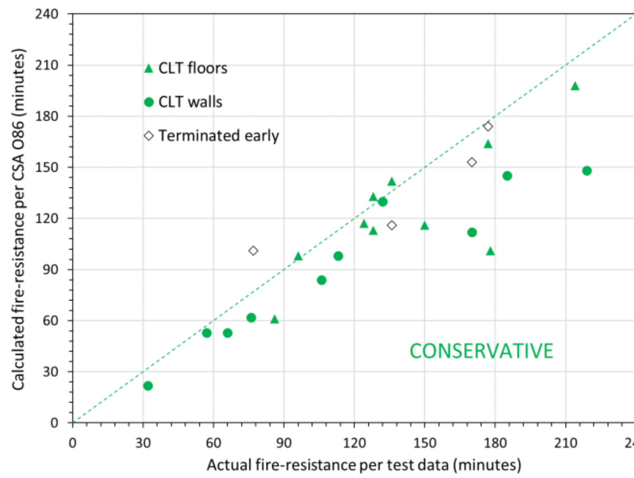

Figure 2. Calculated CLT fire resistance vs. test data

Other Mass Timber Products

Since 2018, FPInnovations has conducted a series of eight full-scale fire-resistance tests on other laminated mass timber assemblies. This has included researches on nail-laminated timber (NLT), dowel-laminated timber (DLT), glued-laminated timber decks (GLT) and cross-laminated veneer lumber (X-LVL).

Varying degrees of plywood or gypsum board protection were provided. Assemblies were instrumented with thermocouples embedded within the assemblies to evaluate charring rates. For most assemblies, charring rates stayed below the accepted design charring rate for mass timber products of 0.65 mm/minute.

For mechanically fastened NLT and DLT assemblies, air-seal protection is needed on the unexposed side of assemblies to limit the potential for integrity failures. It was found that gaps between lumber boards, namely in NLT, led to premature integrity failures (i.e., flame-through) if adequate protection was not provided. For assemblies which used adhesives, X-LVL and GLT, integrity failure was not an issue.

Figure 3. End of a DLT wall fire resistance test

Flame Spread

Standard surface flammability tests conforming to CAN/ULC-S102 have been completed on several mass timber products, including CLT, SCL (PSL, LVL and LSL), GLT timber decking and NLT. Flame spread rating (FSR) and smoke-developed classification (SDC) for these products are summarized in Table 1. The use of materials that exhibit FSRs lower than typical combustible interior finish materials would result in a reduced "risk" of ignition, fire growth and a potentially longer time to flashover conditions, depending on the configuration of the room of fire origin.

Table 1. Surface flame spread test results

Mass Timber Product	Flame Spread Rating	Smoke-Developed Classification
Cross-laminated timber E1 layup (min. 105 mm) V2 layup (min. 99 mm)	35 40	40 30
Structural composite lumber PSL (min. 89 mm on flat) LVL (min. 140 mm on edge) LSL (min. 89 mm on flat)	35 35 75	25 30 85
Glue-laminated timber SPF decking (min. 64 mm)	40	55
Nail-laminated timber SPF flat surfaced (min. 64 mm)	50	55

The use of a fire-retardant intumescent coating was also evaluated on CLT which further reduced its FSR to 25 or less. This confirms that, when permitted by building codes, surface treatments can be a viable option for designers wishing to leave the wood or wood-based products fully exposed for aesthetic purposes.

Fire Stopping

Integrity and continuity must be maintained for fire separations required to provide fire resistance to prevent passage of hot gases or increased temperature on the unexposed side. Vulnerable locations, where gaps or holes are introduced into mass timber systems, are susceptible to fire spread. A key design consideration is to limit heat transfer from the pipe penetration to the wood so that charring adjacent to the penetration is similar to that away from the penetration. Tests have also shown that fire stops approved for concrete construction are suitable for CLT elements, so long as adequate detailing is provided.

Fire stop testing has been completed on CLT and NLT assemblies; fire door testing has also been conducted on CLT walls. Many of the fire stop systems, which included both metallic and plastic through penetrations, were able to achieve 1-½-hour F-ratings, in accordance with CAN/ULC-S115, which would be required for 2-hour fire resistance rated assemblies, such as for use in tall wood buildings.

Connections

As stipulated in CSA O86, connections that are critical to support the gravity loads acting on the structure shall be designed to have at least the same fire resistance rating as the elements they support. Connections in which the steel is located within the effective cross-section of the wood element shall be considered properly protected, and therefore, not affected by thermo-degradation of the steel components.

Many fire tests on connections have been conducted. However, they mostly used traditional fasteners such as bolts, dowels using steel plates and for relatively short fire exposure (+/- 30 minutes), which has limited applicability for buildings required to provide fire resistance of 45 minutes or more. Some recent fire tests suggest that a connection residual resistance and yield mode could be estimated using the reduced timber cross-section, coupled with subtraction of an additional layer that would ensure the wood fibres remained under 100 °C. Additional research is warranted to further validate this finding and applicability to a broad range of fasteners and details.

FPInnovations is continuing to collaborate with universities and other international research organizations to increase knowledge on the fire performance of mass timber connections, including self-tapping screws and modern connection details. The ultimate objective is to gather sufficient information to develop a calculation method in the near future.

Insurance

Fire and subsequent water damage are the main concerns for insurance companies contemplating mass timber construction. Based on statistics, most residential fires are small, and only localized fire damage might be expected. Most fires are controlled by a single sprinkler head. Whenever water is applied to control a fire, any residual water should be addressed quickly since water infiltration into wood increases with the duration of wetting. After a fire, a condition assessment of all affected timber elements should be carried out. In most fires, which are small, localized charring will likely not have a significant effect on structural elements, but any charred surfaces should be removed, and the structural condition of the residual element assessed. Any surfaces, such as gypsum board, that have been affected by the fire or water should also be removed to ensure water is not concealed behind them. If water is present, wood elements need to be dried before interior finishes can be reapplied.

For larger fires, where structural elements might be impacted, the condition of the structural elements should be assessed to determine whether elements can be repaired or require replacement. Various non-destruction evaluation methods to assess the condition of wood after fire exposure are available.

Conclusion

With the resurgence of sustainable construction materials such as wood, new products and systems have been developed and introduced in North American markets. When demonstrating code compliance for a prescriptive or performance-based design using mass timber, fire safety remains a major hurdle for expanding wood use in buildings.

FPInnovations' fire research group has led the development and supported implementation of mass timber construction by completing a large number of standard or custom fire tests over the past decade (Figure 4). The results have been used for many mass timber buildings, which would have otherwise been required to be constructed using noncombustible construction.

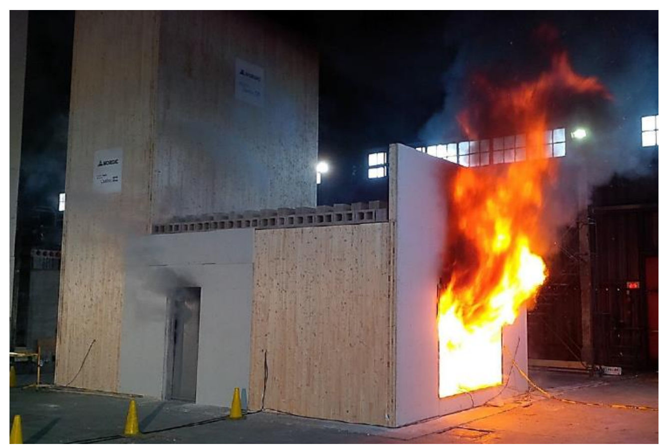

Figure 4. Demonstration fire in support to Origine building (financially supported by the Ministère de la forêt, de la faune et des parcs du Québec – MFFP)

Additional information with respect to fire performance of wood products and building systems can be found in the latest editions of FPInnovations' CLT Handbook and Technical Guide for the Design and Construction of Tall Wood Buildings in Canada, as well as in numerous technical reports from FPInnovations.

References

Harmsworth A. & C. Dagenais (2014). *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada (SP-55E): Chapter 5 - Fire Safety and Protection*. FPInnovations.

Dagenais C., Ranger L. & N. Benichou (2019). *Canadian CLT Handbook 2019 Edition (Special Publication SP-532E): Chapter 8: Fire Performance of Cross-Laminated Timber Assemblies*. FPInnovations.

Dagenais C., Ranger L. & N. Benichou (2019). *Solutions for Upper Mid-Rise and High-Rise Mass Timber Construction: Fire Performance of Cross-Laminated Timber with Adhesives Conforming to 2018 Edition of ANSI/APA PRG-320 (Project 301013085)*. FPInnovations.

Ranger L., Dagenais C. & N. Benichou (2019). *Solutions for Upper Mid-Rise and High-Rise Mass Timber Construction: Fire Resistance of Mass Timber Laminated Elements (Project 301013085)*. FPInnovations.

Ranger L., Dagenais C. & N. Benichou (2019). *Evaluating Fire Performance of Nail-Laminated Timber (Project 301013024)*. FPInnovations.

Ranger L. & C. Dagenais (2019). *Evaluating Fire Performance of Nail-Laminated Timber: Surface Flammability (Project 301013024)*. FPInnovations.

Ranger L. & C. Dagenais (2019). *Evaluating Fire Performance of Nail-Laminated Timber: Influence of Gaps (Project 301013024)*. FPInnovations.

Ranger, L. (2019). *Solutions for Upper Mid-Rise and High-Rise Mass Timber Construction: Rehabilitation of Mass Timber Following Fire and Sprinkler Activation (Project 301013070)*. FPInnovations.

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