FIRE RETARDANTS FOR WOOD APPLICATIONS

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Summary

The National Building Code of Canada sets forth design provisions with respect to combustible wood elements and their use in buildings. In order to meet certain requirements fire retardant coatings or pressure-impregnation methods can be employed to improve the flammability of wood elements. An overview of current relevant code requirements and their associated standard test methods is presented.

1. Introduction

Wood building products, such as lumber or mass timber, are inherently effective at resisting fire. This is due to the propensity of wood to char at a slow predictable rate when exposed to high temperatures. As a char layer develops, it insulates interior wood and protects it from direct exposure to the fire.

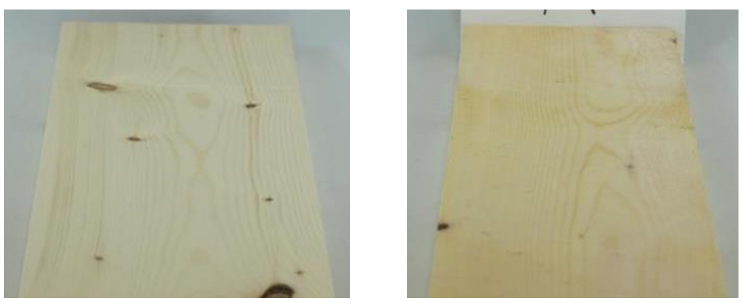
Fire retardants aim to improve the fire performance of a material. They can target specific aspects of performance such as reducing flame spread ratings (FSR), reducing the heat released early in a fire, or improving ignition resistance. Fire retardants can work in different ways such as by reducing the effective heat of combustion or reducing the flammable volatiles that are released from a substrate (White & Dietenberger, 2010). It is important to note that fire retardants do not typically improve the fire-resistance of an assembly (i.e. load-bearing capacity).

The use of wood products in building applications is regulated by the 2010 National Building Code of Canada (NBCC) (NRCC, 2010). In some instances, such as for interior finishes, fire retardant coatings can be applied to meet code requirements; alternatively, there are certain specific situations where fire retardant treated (FRT) wood can be used where combustible wood elements might otherwise not be permitted.

Division B of the 2015 edition of the NBCC will provide prescriptive solutions to allow 5- and 6-storey buildings of “combustible construction”. This represents a greater market opportunity for the use of wood products and potentially an expanded market for the use of fire retardant products for wood applications. There is also growing interest, both in Canada and internationally, to construct taller wood buildings. Under the current building code, these taller buildings would be required to follow an ‘Alternative Solution’ which could very well benefit from improved fire performance of wood products through the use of fire retardants. Some potential applications for fire retardants include any exposed wood elements which need to meet FSR requirements, or for use during construction to mitigate potential fire risks.

2. Fire Retardant Wood Products

There are two main categories for fire retardants based on their application methods: surface-applied or pressure-impregnated. Surface coatings can be applied by brush, spray, roller, or dipping. These coatings are proprietary in nature and therefore can be different in many ways; their fire performance, application and treatment requirements, or long-term durability can vary drastically. Some coatings require a topcoat to protect the surface while others do not. Commonly the coating is pigmented and can sometimes be tinted with paint colour additives. There are some transparent coatings that preserve the natural wood aesthetic, which are ideal for exposed wood applications; an example of coated lumber is given in Figure 1. Currently, there are no specific testing or manufacturing standards for these products, making an user reliant on proprietary test data.



a) SPF No 2. b) Clear intumescent coating

Figure 1 – Example of clear coating (Dagenais, 2015)

Fire retardant coatings for wood applications are most commonly intumescent, that is they expand to form a low density char layer when exposed to high temperatures. A review of low-char fire retardants for thin structural members was conducted but no commercial or near commercial products were identified (Stirling & Dagenais, 2014). An example of an intumescent coating which has been exposed to heat is shown in Figure 2. The expanded layer protects the substrate by insulating it for a given time; different products expand to different volumes and have different properties. Well-performing coatings will increase the time to ignition, decrease the heat released early in a fire, and decrease the FSR of a material; once a heat source is removed the material should stop charring.

Figure 2 – Example of an intumescent coating

It is important to note that the expanded char layer only protects the wood so long as it stays in place. Some tests conducted by FPInnovations have observed the intumescent layer peeling off and delaminating after extended fire exposure, thus allowing the substrate to ignite, as shown in Figure 3 (Dagenais, 2015).

Figure 3 – Evidence of intumescent coating delamination (Dagenais, 2015)

If a wood product is intended for an exterior application it will be much more challenging to maintain the coating protection than interior applications due to weathering, leaching, and UV exposure. Exterior coatings typically require maintenance and reapplication throughout the lifetime of a building.

Surface coatings are intended for applications where a lower FSR is desirable; pressure impregnated fire retardants are more suited for interior applications where the elements will not be visible as this process changes the appearance of the wood, such as for use in roofs.

To be specifically labelled as FRT wood the NBCC requires that the product undergoes high pressure impregnation in accordance with CSA O80, "*Wood Preservation*" (CSA, 2008) and meets a FSR not more than 25 when tested per CAN/ULC S102 "*Standard Method of Test for Surface Burning Characteristics of Building Materials and Assemblies*" (ULC, 2010a). Except for the FSR requirement, this is the same procedure that is used for wood preservation and can use the same borate type chemicals. As with other fire retardants this procedure will reduce the amount of heat released early in a fire, and reduce the FSR and smoke production. When exposed to high temperatures the product will release non-flammable gases and water vapour, which will limit flaming from occurring. When FRT wood is to be used for exterior applications it requires special non-leaching treatment as well as regular maintenance.

3. Combustibility

The 2010 NBCC places several restrictions on the use of wood materials specifically in relation to their fire performance. The most significant code impediment to the use of wood is related to the concept of "combustibility". Materials are defined to be either "combustible" or "noncombustible" depending on their performance when tested in accordance with CAN/ULC-S114,*"Standard Method of test for determination of non-combustibility in Building Materials"* test (ULC, 2005), or alternatively CAN/ULC-S135, "*Standard Test Method for the Determination of Combustibility Parameters of Building Materials Using an Oxygen Consumption Calorimeter*" (ULC, 2004). The intent of this categorizing of materials is to "*limit the probability that materials will contribute to the growth and spread of fire* (CCBFC, 2012)." The NBCC outlines when combustible or noncombustible elements can be used in construction depending on the height and area of a building, occupancy, and whether the building is sprinklered. There are, however, some exceptions including for nonloadbearing wood partition walls and some interior finishes. Wood protected with a fire retardant coating, or FRT wood are both still classified as a combustible material.

The CAN/ULC-S114 is a relatively severe pass/fail test where even gypsum board is deemed to be a combustible material due its paper face. In this test a small 38 mm x 38 mm x 50 mm sample is exposed to heat 750^{o}C for 15 minutes.

A material fails the test, and is deemed "combustible" if, during the test duration:

- The mean of the maximum temperature rise for 3 samples exceeds 36^{o}C
- There is flaming of any of the three specimens after the first 30 s of the test
- Maximum mass loss of any of the three specimens exceeds 20%

The cone calorimeter, shown in Figure 5, can also be used to assess a material's contribution to fire growth following CAN/ULC-S135. This apparatus exposes a 10 cm x 10 cm x 0.5 cm material sample to an uniform 50 kW/m^2 radiant heat flux. The products of combustion are captured and analysed to determine, among other parameters, heat release rate, time to ignition, effective heat of combustion, smoke obscurity and production, and toxic gas concentrations (ex: CO_2, CO, O_2).

Figure 5 – FPInnovations' cone calorimeter

4. Flame Spread Rating

The NBCC specifies allowable FSRs of interior finishes with the intent of limiting "*spread of fire across the exposed surfaces of the finishes* (CCBFC, 2012)." FSR is determined in accordance with CAN/ULC-S102 for most products. Flooring components are to be evaluated per CAN/ULC-S102.2, "*Method of Test for Surface Burning Characteristics of Flooring, Floor Coverings, and Miscellaneous Materials and Assemblies*" (ULC, 2010b). The use of combustible finished flooring materials are not limited in buildings permitted to be of combustible or noncombustible construction. The FSR for generic wood products is given in Table D-3.1.1.A of Appendix D of the NBCC; a generic value of 150 is assigned for lumber. Table 3.1.13.2 of the NBCC provides FSR requirements for walls and ceilings in buildings.

In many cases, including in noncombustible construction, interior walls are finished with gypsum board, having a FSR of 25, i.e. the wood elements are protected. In order for wood elements to be exposed they need to meet the FSR requirements for interior finishes; if the FSR of the wood material is too high then fire retardant coatings may be used to reduce the necessary FSR. There are certain instances in the NBCC which permit the use of FRT wood where combustible elements are not otherwise allowed.

The FSR test procedure for most interior finishes uses the Steiner Tunnel, shown in Figure 6, where a material is placed along the top of the tunnel and exposed to fire via a burner at one end. How quickly the flame spreads down the tunnel determines the dimensionless FSR of the material as compared to a red oak calibrant which receives a FSR of 100. The test requires a minimum of three replicates. Cement board has a FSR of 0.

Figure 6 – CAN/ULC-S102 25-ft Steiner tunnel

The Shlytcher modified flame spread test, following ASTM D3806, "*Standard Test Method of Small-Scale Evaluation of Fire-Retardant Paints*" (ASTM, 2011) can be used to evaluate the fire performance of fire retardant paints. The results of this smaller 2-foot tunnel are indicative of the full-scale Steiner Tunnel, but an official FSR cannot be determined from this test, it is intended more for experimental and research purposes. Various properties are measured including the weight of the panel consumed, the time of after flaming and afterglow, char dimensions, and the degree of intumescence.

FPInnovations has recently conducted some exploratory testing using a modified 2-foot tunnel, shown in Figure 7, which demonstrated that an intumescent coating limited the distance of flame spread advance compared to uncoated specimens of the same lumber species group (Dagenais, 2015).

Figure 7 – FPInnovations' modified 2-foot tunnel

5. Fire-Resistance

As mentioned previously, fire retardants do not necessarily improve the fire-resistance of an assembly. It is important to make the distinction between flame spread of specific materials, ex: plywood, cement board, etc., versus the fire-resistance of building assemblies, ex: wall, floor, beams, columns, etc. Fire-resistance ratings are specified for assemblies in order to create fire-rated compartments within a building to limit fire spread beyond the room of fire origin. Fire-resistance relates to a complete assembly's ability to prevent the passage of fire and hot gases, the transmission of heat and to maintain its structural capacity (if applicable) when subjected to CAN/ULC-S101, "*Fire Endurance Tests of Building Construction and Materials*" (ULC, 2007); a typical assembly includes all components such as wood studs, screws, and gypsum board.

The fire-resistance of an assembly, given as a time, is determined by exposing an assembly to the standard time-temperature curve, given in Figure 8. The fire-resistance is determined when an assembly:

- Is no longer able to carry the applied load (structural failure);
- Allows passage of flame or hot gases enough to ignite a cotton pad (integrity failure); or
- Exhibits temperature increase on the unexposed surface an average of 140°C or a single point of 180°C above ambient conditions (insulation failure).

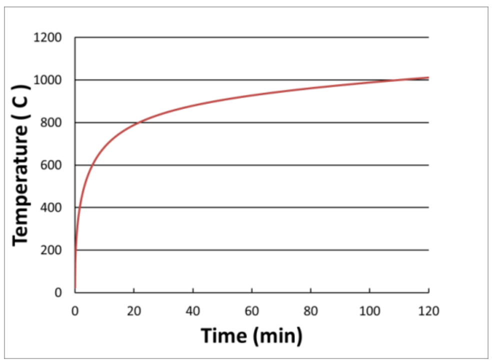


Figure 8 – CAN/ULC-S101 Standard time-temperature curve

6. Exterior Flame Spread

Provisions in the NBCC dictate the use of combustible elements in the construction of exterior walls to limit fire spread on the exterior of a building and to limit fire exposure from and to adjacent buildings. According to Division B of the 2010 NBCC, buildings up to four stories permitted to be of combustible construction have no limits on the use of combustible cladding, except if adjacent properties are in close proximity (i.e. spatial separation). In the 2015 NBCC, mid-rise (5- and 6-storey) combustible construction and buildings of larger areas will be permitted; however, these buildings will be permitted to have no more than 10% of the cladding be combustible, depending on limiting distances. If an exterior wall assembly having combustible elements passes the CAN/ULC-S134, "*Fire Test of Exterior Wall Assemblies*" (ULC, 2013) then it will be permitted to be used under the new 2015 NBCC building allowances. Should FRT wood be included in an assembly to be tested under CAN/ULC-S134, then the wood must first be subjected to ASTM D2898, "*Standard Practice for Accelerated Weathering of Fire-Retardant-*

Treated Wood for Fire Testing" (ASTM, 2010). The exterior wall test setup is shown in Figure 9.

Figure 9 – CAN/ULC-S134 Exterior wall test (FPI/NRC/CWC Mid-rise consortium)

7. Non-Standard Fire Tests

On occasion non-standard fire test procedures are used. There are several reasons why this might be done, such as there is not an established standard procedure to demonstrate a certain performance aspect, or there is a desire to demonstrate the overall performance of a structure which goes beyond individual material or assembly performance. In some cases standard test methods are now being looked upon as outdated or not realistic. One example is the CAN/ULC-S101 standard time-temperature curve which is not necessarily representative of a real fire, but rather a means for comparing various components under similar test conditions. Typically a fire has an initial growth stage, reaches flashover (where all combustible contents in a room are burning), becomes a full-developed fire, and eventually the fire will decay, which is not accounted for in a standard fire-resistance test. This discrepancy is giving rise to more use of "design fires" which can better replicate a real room fire scenario.

FPInnovations has been involved in several projects which have used large scale non-standard fires to evaluate the overall performance of building systems. During the Research Consortium for Wood and Wood-Hybrid Mid-Rise Buildings, involving National Research Council Canada (NRC), the Canadian Wood Council (CWC), and FPInnovations, four full-scale apartment units were constructed and burned to compare the performance of the structure when either elements of combustible or noncombustible construction were used (Su & Lougheed, 2015). One of the general conclusions of these tests was that the combustibility of structural elements is not indicative of the fire dynamics within a compartment and overall fire performance of a structure.

In 2014, FPInnovations conducted a full-scale demonstration fire at NRC to support the construction of a tall wood building; this was funded by the Quebec Ministère des Forêts, de la Faune et des Parcs (Osborne and Dagenais, 2015). The three-storey exit shaft with adjacent furnished apartment unit is shown during the test in Figure 11. The interior of the shaft was unprotected cross-laminated timber, but the actual building design requires Type X gypsum board protection to meet FSR requirements. Fire retardant coatings could be considered for use in shafts such as this to meet FSR requirements and could allow for the wood to remain exposed.

Figure 11 – Full-scale demonstration fire of exit shaft

8. Conclusions

The upcoming 2015 NBCC building code provisions, which will allow 5- and 6-storey buildings of combustible construction, represent an increased market opportunity for wood products. This may also increase the demand for fire retardant wood products, specifically for interior finishes, or exposed structural elements.

Currently fire retardant coatings and FRT wood can be used to meet certain fire performance requirements in the building code, mainly relating to FSR. Other fire requirements such as combustibility and fire-resistance are not significantly influenced by the presence of fire retardants.

Surface applied coatings are all proprietary and their performance greatly varies. The development of manufacturing and performance standards would be helpful to make these products more easily accepted for building applications.

9. Literature

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