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Review of Low Char Fire Retardant Treatment Options for Wood

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Abstract

Treatment options are needed to enhance the fire performance of thin structural members without generating additional char. This review explores potential opportunities for low-char fire retardant treatments and fire protective coatings for wood products, and briefly discusses the technical and code-based barriers to their adoption.

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1 Objective

- To review low-char fire retardant treatment options for wood products.

2 Introduction

Buildings need to be constructed such as to limit the probability that, as a result of their design or construction, a person in or adjacent to the buildings is exposed to an unacceptable risk or injury due to fire and that a building is exposed to an unacceptable risk of damage also due to fire. These objectives, among others, are set forth in the National Building of Code of Canada related to occupant safety and property protection.

For wood-framed construction, the most common means of protecting wood elements from fire is covering them with fire-rated gypsum boards. However, there are applications for wood where using gypsum boards may not be appropriate, such as wood windows, and designers are increasingly interested in expressing the visual impact of wood inside buildings. Surface flaming characteristics of wood elements may then require improved fire performance, especially in buildings required to be of non-combustible construction.

The fire performance of wood can be enhanced by fire-resistant coatings or pressure-treatment with fire retardant chemicals (Van Zeeland and Hicks 2013). There are four major mechanisms through which fire retardants work. Thermal shielding occurs when intumescent coatings expand and when an extra char layer builds up in fire-retardant treated wood. Gas phase dilution occurs when pyrolysis gases are diluted by the release of non-combustible gases, such as water and carbon dioxide. Endothermic (energy absorbing) degradation occurs in minerals such as aluminum hydroxide and magnesium hydroxide that undergo endothermic reactions when exposed to fire. Gas phase radical quenching occurs in halogenated fire retardants that slow radical chain reactions involved in combustion.

When untreated wood burns, the formation of char provides an insulating layer, and slows the rate of combustion of underlying wood. For thick structural members this may be advantageous, as the load carrying capacity of the member will remain higher for a longer period, allowing occupants time to safely leave the building, and achieving longer structural integrity. Therefore many fire retardant chemicals aim to reduce surface combustion properties such as time to ignition. Typically, an effective charred layer of wood is assumed to be about 25 mm thick. Wood therefore needs to char for a certain period of time for its charred layer to become “thermally efficient”. For thin structural members, such as traditional dimensional lumber of 38 mm thickness, their thickness does not allow enough time to generate the required thermal protection and their mechanical strength is then rapidly reduced. Fire retardant treatments that provide additional thermal protection are needed to protect such products. Recent reviews of fire retardants by White and Dietenberger (2010), Weil (2011), Alemdar (2011) and Winandy (2013) provide a good picture of the current state of the industry. Throughout the literature there is little differentiation between fire retardants that enhance char, and those that do not. This may be because the downside of char for thin materials has not been widely acknowledged, or it may simply be because the vast majority of fire retardant systems increase wood charring once their thermal protection is consumed. This review examines the literature more closely for fire retardant treatment options that might reduce char.

3 Pressure Treatments

Pressure-impregnated fire retardants are dominated by ammonium, borate, and phosphate systems. Well known actives include ammonium sulfate, ammonium phosphates and polyphosphates, borax, boric acid, and organophosphates, such as urea-phosphoric acid, guanidine phosphate, and guanylurea phosphate (Winandy 2013). All of these systems increase the formation of char, and decrease the amount of volatile combustive vapours emitted.

One of the downsides of conventional fire retardants is their leachability, which limits them to interior use. For this reason, among others, the National Building Code of Canada requires that fire-retardant-treated wood be subjected to the ASTM D2898 accelerated weathering test before evaluating their fire performance properties. Water-insoluble organic compositions based on resins polymerized after impregnation or grafted onto cellulose have been developed for exterior use (White and Dietenberger 2010). Additional research has aimed to reduce leachability by the development of wood-inorganic composites through sol-gel processes (Saka *et al*. 1992) and by impregnation with low solubility nano-particles (Laks and Heiden 2003).

Many wood-inorganic composites have demonstrated enhanced fire performance (i.e. reduced surface burning characteristics). Saka *et al*. (1992) reported the development of wood inorganic composites prepared by a sol-gel process. Alkoxysilanes were impregnated into hinoki sapwood and dried to silica gel formed selectively in the cells due to reaction with bound water. These treated samples retained their porous nature, while increasing the hygroscopicity and anti-swell efficiency, and decreasing flammability, when measured by the oxygen index method. Subsequent work reported improved fire performance with various silica-based sol-gel treatments (Saka & Ueno 1997; Miyafuji & Saka 2001; Canosa *et al*. 2013). Wood-inorganic composites based on sol-gel derived TiO_2 have similarly been reported to improve the fire performance of wood (Miyafuji & Saka 1997; Mahr *et al*. 2012a, 2012b, Wang *et al*. 2012). SiO_2- and TiO_2-wood composites have demonstrated reduced flammability, as indicated by higher limiting oxygen index values, and higher residue mass/initial mass ratios, indicating that less wood was consumed by fire (Mahr *et al*. 2012a). However, further study demonstrated that the improved fire performance of TiO_2 wood-inorganic composites fell far short of the performance obtained by a commercial fire retardant treatment (Mahr *et al*. 2012b). Cationic silica gel impregnated into cell lumens resulted in slightly improved fire performance in a Bunsen burner test, though this was at least in part due to increased char formation (Pries & Mai 2013). While wood-inorganic composites can improve fire performance, the degree of improvement may be insufficient. This is likely why hybrid wood-inorganic composite/fire retardant systems have been investigated (Miyafuji & Saka 1996; Saka & Tanno 1996; Miyafuji *et al*. 1998). Moreover, the degree to which wood-inorganic composites affect char formation is unclear.

Several formulations of nano-particles have recently been investigated for fire performance. Taghiyari (2012) found that wood impregnated with a nano-silver formulation took longer to ignite due to its ability to transfer heat away from the spot closest to the flame. Despite this improved fire performance, nano-silver treated wood was less effective than the borax reference. Giudice & Pereyra (2010) reported some improved fire performance properties of wood pressure-treated with nano-silicates. These treatments exhibited improved fire performance as indicated by reduced flame spread indices in a two-foot tunnel test, and increased limiting oxygen indices. The source of this improved fire performance was believed to be due to silicate layers acting as a physical barrier to limit heat and mass transfer between the condensed and gaseous phases, and not by enhanced formation of char. Haghighi Poshtiri *et al*. (2013) investigated the fire performance of solid wood treated with nano-wollastonite (a calcium silicate mineral). At 10% retention they reported longer times to ignition and reduced char area, as the nano-wollastonite acted as a physical barrier. Taghiyari *et al*. (2013) reported similar results on nano-wollastonite treated MDF.

Clay nano-particles have been shown to improve the fire performance of wood-plastic composities (e.g. Guo *et al*. 2007), but there are few reports of their evaluation in wood composite, or solid wood products. Fufa *et al*. (2013) investigated the fire performance of wood treated with TiO_2 and clay nanoparticles. These treatments did not significantly improve performance in a cone calorimeter test, though the authors noted that higher retentions should be evaluated. Treatability will be a factor in all of these nano-particle based systems since many Canadian species are refractory, and many of these treatments rely on maximizing wood-particle interactions to provide an effective physical barrier that will limit heat and mass transfer between the condensed and gaseous phases.

Recent work by Miyafuji & Fujiwara (2013) reported enhanced fire performance of wood treated with ionic liquids. The ionic liquids were associated with dehydration of the wood during heating, which increased char.

4 Non-Pressure Treatments

Fire-retardant coatings for wood include non-intumescent coatings, which typically contain well known fire retardants such as ammonium, phosphate, or borate compounds, and intumesecent coatings which swell when heated to provide an insulating layer to protect the underlying wood (White and Dietenberger 2010). Intumescent coatings are the most common type of fire protective coatings for wood products and steel-framed assemblies. Basic intumescent coatings contain a binder, a dehydrating agent (e.g. phosphates, borates), a carbonizing agent (e.g. sucrose, starch, dipentaerythritol), and a blowing agent (e.g. melamine, dicyandiamide, guanidine, urea) (White and Dietenberger 2010; CFCM 2013). When exposed to heat, the binder is softened, phosphates or borates release organic acids, the binder is carbonized, intumescents release non-combustible gas to expand the coating, and the expanded coating is strengthened through cross-linking reactions (CFCM 2013). Since the char formed by intumescent coatings is derived primarily from the coating itself, rather than the underlying wood, these products seem suitable for reducing the surface flaming characteristics (i.e. flame spread) and potentially increase fire-resistance of wood products. However, fire-resistance tests on cross-laminated timber wall assemblies showed that the coated CLT failed earlier than the unprotected CLT (Osborne and Dagenais 2013). While the time difference was not that significant, one of the explanations for such variance is that by the time the intumescent coating no longer provides its thermal insulation, the furnace temperature (i.e. heat flux emitted to the CLT surface) is significantly greater and the uncharred wood then ignites and burns faster than usual (much faster than 0.65 mm/min), reducing the effective cross-section faster, leading to faster structural failure. Fire-resistance efficacy depends on coating composition, thickness, presence of top coats and fire exposure duration. Weil (2011) provides a comprehensive review of fire resistant coatings formulations.

The use of intumescent coatings is limited by their high price, limited resistance to weathering, limited appearance options, and code acceptance. There is currently no generally accepted pathway for coatings to be used to improve the structural fire resistance of a wood member (White and Dietenberger 2010).

5 Conclusions

From this review of currently available fire retardant coatings, no commercial, or near-commercial, low-char fire retardant treatments were identified.

Early research suggests that impregnations with nano-silicates may have potential to be developed into low-char fire retardant systems, though much more research is needed to quantify efficacy, treatability, effects on ancillary properties (e.g. strength, hygroscopicity, corrosion), and cost.

Intumescent coatings are usually developed and commercialized for reducing the surface combustion properties of wood products (i.e. flame spread). They may have the potential to improve structural fire resistance without significantly enhancing the rate of char formation on underlying wood, but have yet to be properly evaluated for such performance attributes.

6 Recommendations

Develop a strategy that will define how FPInnovations will further the development and code acceptance of low-char fire retardant treatments and fire resistant coatings.

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