Fire Protection Research at the Forest Products Laboratory

Laura E. Hasburgh
Grant T. Kirker
Katie M. Ohno
Rachel A. Arango
Kara M. Yedinak
Samuel L. Zelinka
USDA Forest Products Laboratory
Madison, Wisconsin

ABSTRACT

Sustainable timber use is vital to the health of American forests, and building materials represent a significant market for wood materials. However, due to the combustible nature of wood, wood building products are at risk of both becoming target fuel and contributing to the fuel load/fire spread. To reduce the risks, fire protection measures, such as fire-retardant treatments, can be employed. Here, a summary of current research related to the fire protection of wood building products is provided from exterior uses in the wildland-urban interface to interior applications for tall wood structures.

Keywords: Fire Retardant Treatments, Mass Timber, Wildland-urban Interface, Weathering

INTRODUCTION

When wood and other lignocellulosic materials are exposed to an external heating source, they will undergo pyrolysis, which is the thermal decomposition of a material. Pyrolysis of wood has been characterized based on the decomposition kinetics of the three main polymeric components: hemicellulose, cellulose, and lignin [1]. Irreversible changes in the wood begin to occur around 200°C. Above 200°C, the chemical structure of the polymeric components decomposes into light pyrolysis products, such as carbon monoxide, carbon dioxide, and water vapor, which volatize from the exposed surface. As the temperature increases, flammable volatiles that are generated react with oxygen and produce an exothermic reaction. The exothermic reaction contributes to a chain reaction where more flammable volatiles are generated, resulting in more heat. At the same time, these volatiles are undergoing oxidation, char is forming on the material surface as an evolving interface. The char acts as both a site for further exothermic reactions and as an insulating layer that slows down both the diffusion of heat into the wood and the mass transport of volatiles being released [2].

Use of wood-based building materials can be limited in use because of their combustibility. Fire retardants treatments (FRT) were developed in the 1800s and designed to interrupt the pyrolysis process and, in turn, provide enhanced passive protection for wood building materials [3]. Past studies have identified five mechanisms by which these fire retardants work [2, 4]. These mechanisms include:

- Promotion of char formation: increasing the char yield results in an increase in the insulating properties of the char layer.
- Ceramification: this process results in a wood-inorganic composite that is less flammable.
- Dilution of the flammable gases: the release of inert gases, such as nitrogen, prevents the formation of a flammable mixture.
- Inhibition of chemical reactions: incomplete combustion results in less heat available to sustain burning.
- Alteration of thermal properties: several properties can be altered such as adding compounds that act as a chemical heat sink, lowering the temperature of the wood near the flame.

Evaluations of FRTs have been a part of the U.S. Department of Agriculture-Forest Service, Forest Products Laboratory's (FPL) research activities since their development in 1910. White [3] summarized the seminal research activities that occurred at FPL from 1910 through 2005. This research involved developing new test methods to evaluate FRTs including, but not limited to, measuring the time to ignition [5], determining mass loss during combustion [6], quantifying flame spread [7-9], and determining effects on strength [10]. In addition to developing test methods, previous research evaluated over 130 inorganic chemical treatments [11], plywood roof sheathing [12-14], and composite materials with FRT [15, 16].

Here, summaries of recent and on-going fire-retardant research at FPL representing three distinct end-use applications are provided. The three end-use applications include: 1) materials intended for interior use in a structure, 2) materials intended for exterior use on a structure or infrastructure, and 3) wildland fuels.

CURRENT FRT RESEARCH AT FPL

Interior FRT Application

There has been a recent uptick in taller and larger wood buildings utilizing and exposing mass timber. In turn, there is an increased need to identify treatment options for mass timber and particularly cross laminated timber (CLT) to increase both durability and fire safety. However, compared to other mass timber products, such as glue-laminated beams, it is difficult to treat CLT panels because the assembled panels are often too big to fit into standard pressure-treatment cylinders.

In a recent study [17], we evaluated dip and spray applications of disodium octaborate tetrahydrate (DOT) on small-scale CLT specimens. Borate treatment was chosen because it is highly soluble in water which can lead to a higher penetration and retention in wood. The small-scale, 3-ply CLT specimens were manufactured with Douglas-fir (*Pseudotsuga menziesii*) and either a polyurethane adhesive or an emulsion polymer isocyanate adhesive. Two different treatment processes were evaluated. The first was a dip method where the specimens were submerged in a 7 wt.% aqueous DOT with final retention rates of 2.7 and 4.5 kg/m^3. The second method consisted of spraying the specimen surface once with a 20 wt.% aqueous DOT solution.

This study evaluated the DOT treatments in several ways including the development and validation of a retention model, the effect of treatment on adhesion and shear strength, and the effect on durability as determined by decay and termite resistance tests. Full methodology and results can be found in Bagheri et al. [17]. To evaluate the effect of the DOT treatments on fire performance, the specimens were exposed to a constant heat flux of 50 kW/m^2 using a cone calorimeter in accordance with ASTM E1354, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter* [18]. Untreated CLT specimens were also evaluated for comparison to treated CLT specimens. A total of six specimens were tested for each treatment type, and the results were averaged. Since both DOT treatments were largely confined to the surface, the results focused on the initial peak heat release rate (pHRR) (Figure 1), and the time to reach the initial pHRR (Figure 2). All treatment methods resulted in a lower initial pHRR compared to the pHRR from the untreated specimens, but a higher retention rate would be required to reduce flammability. The initial pHRR ranged from 111 to 187 kW/m^2 for all specimens. Both dip treatments were effective at reducing the initial pHRR by at least 20 kW/m^2 when compared to the untreated and spray treated specimens.

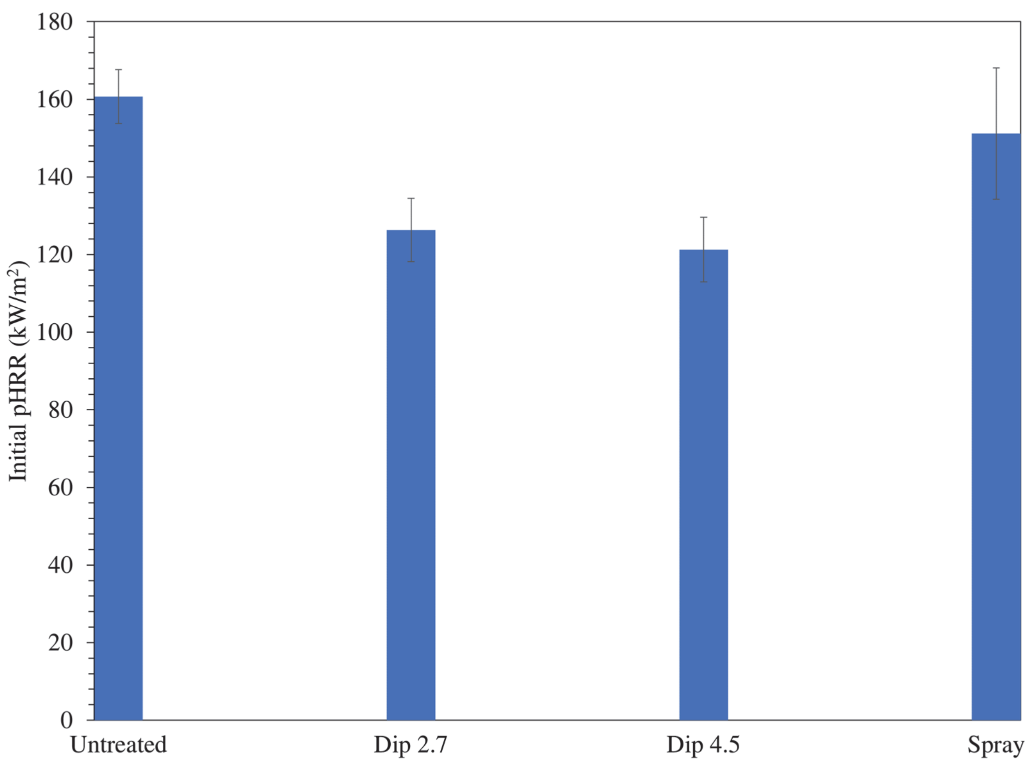

Figure 1. Average initial pHRR for each treatment type (n=6). Error bars represent standard deviation.

The times for the initial pHRR range were similar for the control specimens, dip-treated specimens at the 2.7 kg/m^3 retention rate, and the spray-treated specimens. The time to reach the initial pHRR was delayed slightly for the dip-treated specimens with a 4.5 kg/m^3 DOT retention rate (Figure 2).

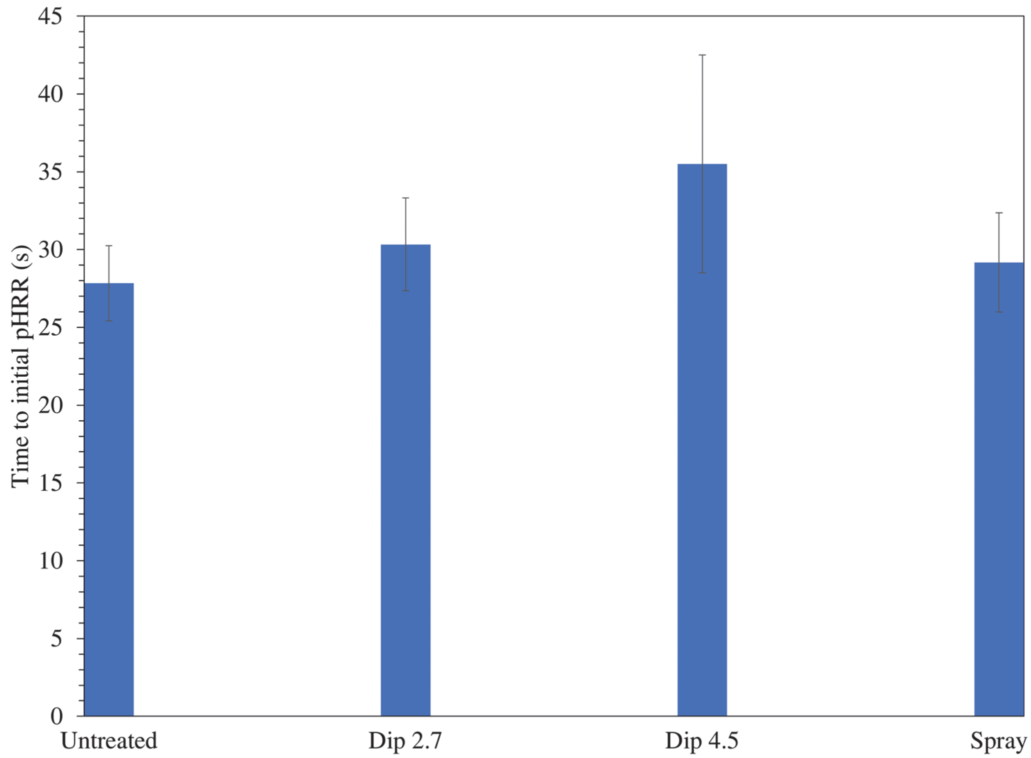

Figure 2. Average time to initial pHRR for each treatment type (n=6). Error bars represent standard deviation.

Ultimately, while other studies confirmed the reduction in heat release from wood treated with various borate compounds, the dip- and spray-treatments used here did not result in a significant reduction in the heat released from the CLTs as expected. This is likely because fire retardant treatments require five- to ten-times higher chemical loading levels when compared to preservative treatments as noted by Levan and Tran [19]. While the overall results of the DOT treatments showed significantly higher resistance against decay and terminates, to increase the fire performance other application methods to obtain higher retention rates must be evaluated.

Exterior FRT Application

There is an increasing trend of homes and buildings being destroyed in urban areas from wildfires as well as in the wildland-urban interface (WUI). Leavell et al. [20] noted that 25% of homes lost in the Tubbs Fire (Sonoma County, California) were in an urban setting and not in a WUI. Active and passive mitigation strategies can be used to protect buildings. Active measures require activity by a person (e.g., the resident or a fire fighter) or a device shortly before or immediately as a fire threatens a structure. Passive measures require no additional activity when a wildfire threatens a building and include developing and maintaining an effective home defense zone and use of ignition resistant design features and materials. One potential passive option for existing structures is the use of fire-retardant coatings. Fire-retardant coatings are thermally-resistant chemical compounds that can be applied to the surface of a material to increase the time to ignition and reduce fire spread. Most fire-retardant coatings are intumescent and swell to a char-like layer when exposed to heat. Currently, there is little information to support consideration of fire-retardant coatings as a longer-term passive measure on common combustible materials such as wood and wood-based materials [21]. This is due to the limited information regarding fire performance of these coatings post-weathering. Weathering, and particularly from the UV exposure, can have several negative impacts on coatings, including fading and surface erosion, which will result in decreased fire-retardant capabilities.

In an on-going study, the fire performance of two types of water-based intumescent coatings are being examined post-weathering. The coatings were applied to red cedar (*Juniperus virginiana*) shingles, which were either painted or sprayed on according to manufacturer's specifications. In addition to the specimens with properly applied coatings, specimens with an improper application of the coatings were also made by applying only one layer of coating instead of two. Weathering of specimens was conducted in accelerated laboratory tests and under natural weathering conditions. The naturally weathered specimens were installed on a house in Mill Valley, California and removed after a year. Laboratory accelerated weathering was conducted in a QUV accelerated weathering chamber (Q-Lab) located in Madison, Wisconsin following the specifications of Method B found in ASTM D2898, *Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing* [22]. Coated and uncoated shingles, both weathered and unweathered, will be tested at three heat fluxes (25, 50, and 75 kW/m^2) using the cone calorimeter [18]. Figure 3 shows preliminary heat release rate (HRR) results (averaged over triplicates) from naturally weathered specimens that were coated per the manufacturer's instructions (AT) and naturally weathered, uncoated cedar shingles exposed to a constant heat flux of 50 kW/m^2. These curves show that the coating results in higher initial pHRR when compared to the uncoated cedar shingles, but immediately after the initial peak, the intumescent char layer rapidly forms, causing the peak to be less broad and the drop in HRR more significant. The specimens with the coatings also delayed the contribution of the backside of the specimens resulting in a delay in the second peak.

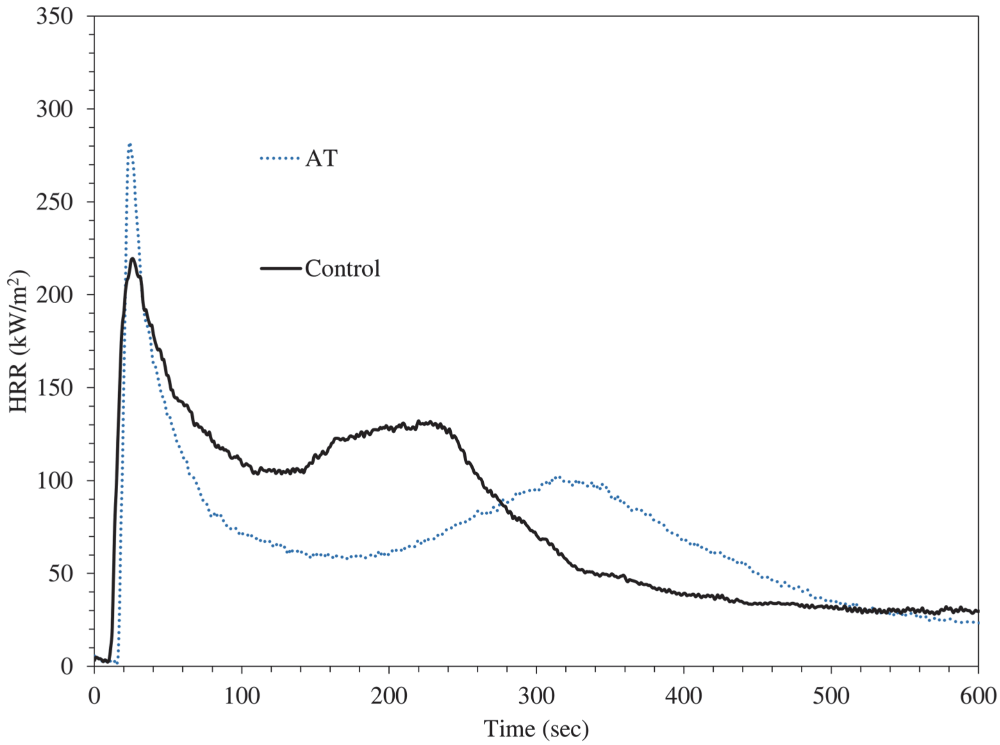

Figure 3. Average (n=3) heat release rate curves for fire retardant coated (AT) and uncoated cedar shingles (control), exposed to natural weathering conditions.

Wildland FRT Application

Currently, the Wildland Fire Chemical Systems program area uses only one combustion-retarding effectiveness qualification test in the evaluation of new wildland fire retardant chemicals, which are typically aerially applied. This test is known as STP-2.1 [23] and requires the use of the wind tunnel and combustion chamber of the Missoula Fire Science Lab. The use of only one test for each product limits FRT effectiveness evaluations to only one set of conditions. More realistically, products will be used on a variety of fuel types under wildly different weather conditions and terrains in a real-world wildland fire scenario. It is critical to develop additional effectiveness tests to help characterize product strengths and weaknesses and provide a more robust testing protocol. The main objective of on-going research in this area is to develop a new screening fire test for the effectiveness of wildland fire retardant treatment chemicals.

Since the wildland FRT treatments are applied to a variety of lignocellulosic materials, appropriate but repeatable substrates must be identified. Development of additional testing methods are needed as the current wind tunnel test is expensive, labor intensive, and access to the wind-tunnel for testing is limited. Lastly, new testing processes shall provide a metric for pass/fail acceptance limits that are consistent with the wind tunnel test results and expand the range of variables the FRT treatments are exposed to. Modified bench-scale tests, such as the cone calorimeter [18] and the mass loss calorimeter [24], are currently being considered with a variety of substrates to properly represent the range of applicable fuels. The substrate configurations are being conditioned to equilibrium in a 32°C and 20% relative humidity chamber to represent dry fuels. Once the repeatability of the substrates is determined, pass/fail parameters will be determined by comparing the bench-scale results to those from existing fire-retardant systems evaluated in the wind tunnel.

AWKNOWLEDGEMENTS

The authors would like to thank our collaborators on these current research projects summarized here: Sajad Bagheri, Mona Alinejad, Mojgan Nejad at Michigan State University, Steven Quarles and Faraz Hedayati at the Insurance Institute for Business and Home Safety, and Hunter Jones and Andrew Gutknecht at the U.S. Forest Service National Technology and Development Program.

REFERENCES

1. Dietenberger, MA and Hasburgh LE. (2016) Wood products: thermal degradation and fire. Reference module in materials science and materials engineering: 1-8.
2. Lowden, LA and Hull, TR. (2013) Flammability behavior of wood and a review of the methods for its reduction. Fire science reviews, 2, 1-19.
3. White, RH. (2010) Ten decades of flame retardancy testing at the U.S. Forest Products Laboratory. Review Process: Non-Refereed (Other).
4. Winandy, JE, Wiesner, F, Hassan, B, Morrell, JJ. (2022) Fire performance of timber: review for use in wildland-urban interfaces. Holzforschung.
5. Prince, RE. (1915) Tests on the inflammability of untreated wood and of wood treated with fire-retarding compounds. Proc. NFPA, 19, 108-158.
6. Truax, TR, Harrison, CA (1929) A new test for measuring the fire resistance of wood. American Society Testing and Materials. Vol. 69 Part II, pp. 973-988.
7. Bruce, HD, Miniutti, VP (1957) Small tunnel furnace test for measuring surface flammability. USDA FS Forest Products Laboratory Research Note.
8. Bruce, HD, Downs, LE (1959) Surface flammability of various wood-base building materials. Report No. 2140. Madison, WI: USDA Forest Service Forest Products Laboratory. Superceded by Research Note 186 of same title.
9. Peters, CC, Eickner, HW (1962) Surface flammability as determined by the FPL 8-foot tunnel method. Report No. 2257. Madison, WI: USDA Forest Service Forest Products Laboratory.
10. LeVan, SL, Winandy, JE. (1990) Effects of fire-retardant treatments on wood strength: a review. Wood and fiber science, 113-131.
11. Truax, TR, Harrison, CA, Baechler, RH. (1933) Experiments in fireproofing wood. Proc. American Wood-Preservers' Association. 31:231-248.
12. LeVan, SL, Ross, RJ, Winandy, JE (1990) Effects of fire-retardant chemicals on the bending properties of wood at elevated temperatures. Research Paper FPL-RP-498. Madison, WI: USDA Forest Service Forest Products Laboratory.
13. Winandy, JE, LeVan, SL, Ross, RJ. (1992) Combined effects of fire-retardant treatments and extended exposure to elevated temperature. Proc. 87th Annual Meeting of American Wood Preservers' Association. p. 121.
14. Winandy, JE. (2001) Thermal degradation of fire-retardant-treated wood: predicting residual service life. Forest Products Journal, 51(2):47-54.
15. Stark, NM, White, RH, Clemons, CM. (1997) Heat release rate of wood-plastic composites. SAMPE, 33(5):2631.
16. Stark, NM, Mueller, SA, White, RH, Osswald, TA. (2010) Effect of fire retardants on heat release rate of wood flour-polyethylene composites. Proc. 10th International Conference on Wood & Biofiber Plastic Composites and Cellulose Nano Composites Symposium. May 11–12, 2009. Madison, WI: Forest Products Society. pp 103-112.
17. Bagheri, S, Alinejad, M, Ohno, KM, Hasburgh, LE, Arango, RA, Nejad, M. (2022) Improving durability of cross laminated timber (CLT) with borate treatment. Journal of Wood Science, 68(1), 34.
18. ASTM E1354. (2022) Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. ASTM International West Conshohocken, PA.
19. LeVan, SL, Tran, HC. (1990) The role of boron in flame-retardant treatments. First International Conference on Wood Protection with Diffusible Preservatives. Nashville, Tennessee, November 28-30, 1990.

20. Leavell, DM, Fitzgerald, SA, Berger, CA, Horn, GP. (2020) Fire FAQs — Are Structures Fuel? The Wildland Urban Interface and the 'Built' Environment. Oregon State University Extension Service. EM 9291.
21. Bahrani, B, Hemmati, V, Zhou, A, Quarles, SL. (2018) Effects of natural weathering on the fire properties of intumescent fire-retardant coatings. Fire and Materials, 42(4), 413-423.
22. ASTM D2898. (2017) Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing. ASTM International West Conshohocken, PA.
23. US Forest Service. (2020) Laboratory Procedure STP-2.1, Combustion retarding effectiveness. www.fs.usda.gov/rm/fire/wfcs/tests/documents/STP-2.1%20Combustion%20Retarding%20Effectiveness,%20Burn%20Test.pdf Accessed on 20 March 2023.
24. ASTM E2102. (2021) Standard Test Method for Measurement of Mass Loss and Ignitability for Screening Purposes Using a Conical Radiant Heater. ASTM International West Conshohocken, PA.

PROCEEDINGS

One Hundred Nineteenth Annual Meeting

of the

AMERICAN WOOD PROTECTION ASSOCIATION

Loews Ventana Canyon Hotel
Tucson, Arizona
April 3-5, 2023

VOLUME 119

AMERICAN WOOD PROTECTION ASSOCIATION
P.O. BOX 361784 • BIRMINGHAM, ALABAMA 35236-1784 • USA

ISBN (Casebound/Hardcover Edition): 979-8-9868619-0-6
ISBN (Perfect Bound/Paperback Edition): 979-8-9868619-1-3
ISSN: 2833-695X

Colin McCown, *Editor*