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Full-Scale Experimental Investigation to Quantify Building Component Ignition Vulnerability from Mulch Beds Attacked by Firebrand Showers

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Abstract

Structure ignition by wind-driven firebrand showers is an important fire spread mechanism in large outdoor fires. Experiments were conducted with three common mulch types (shredded hardwood mulch, Japanese Cypress wood chips, and pine bark nuggets) placed adjacent to realistic-scale reentrant corners. In the first series of experiments, mulch beds were placed adjacent to a re-entrant corner constructed with wood studs and lined with oriented strand board (OSB) as the sheathing. The premise behind conducting experiments with no siding treatments applied was predicated on the notion that bare OSB mulch contact would be a worst-case scenario, and therefore, a wall assembly in the most vulnerable state to mulch ignition. In the second series of experiments, vinyl siding was applied to the re-entrant corner assemblies (wood studs/OSB/moisture barrier/vinyl siding), and the influence of vertical separation distance (102 mm or 203 mm) on wall ignition from adjacent mulch beds was determined. The vertical separation distance was maintained by applying gypsum board to the base of the re-entrant corner. The siding itself did not influence the ignition process for the mulch beds, as the mulch beds were the first to ignite from the firebrand showers. In all experiments, it was observed that firebrands produced smoldering ignition in the mulch beds, this transitioned to flaming ignition, and the re-entrant corner assembly was exposed to the flaming mulch beds. With no siding treatments applied, the flaming mulch beds ignited the re-entrant corner, and ignition was observed to propagate to the back side of re-entrant corner assembly under all wind speeds (6 m/s to 8 m/s). With respect to the re-entrant corners fitted with vinyl siding, the mulch type, vertical separation distance, and wind speed were important parameters as to whether flaming ignition was observed to propagate to the back-side of a reentrant corner assembly. Mulches clearly pose an ignition hazard to structures in large outdoor fires.

INTRODUCTION

Wildfires that spread into communities, referred to as Wildland-Urban Interface (WUI) fires, have destroyed communities throughout the world. Some recent examples in the USA include the Bastrop Complex Fire in Texas in 2011, the Waldo Canyon Fire in Colorado in 2012, and fires in Arizona, Colorado, and California, in 2013. In Europe, the 2007 fires in Greece destroyed several hundred structures, and resulted in the deaths of more than 70 people. In Australia, the 2009 fires in Victoria caused the death of 173 people and destroyed more than one thousand structures [1]. WUI fires have also ravaged Chile recently [2].

Japan does not have a large problem of fires spreading from the wildlands to communities, such as the WUI fire problem in the USA and other countries [3]. Rather, Japan experiences many earthquakes. After large earthquakes, many fires may simultaneously occur that can easily overwhelm fire-fighting resources. Since most Japanese cities are densely populated, severe fire spread can occur within these urban areas [3].

When vegetation and structures burn in outdoor fires, pieces of burning material, known as firebrands (embers), are generated, become lofted, and are carried by the wind. This results in showers of wind-driven firebrands. Structure ignition by firebrand showers is an important fire spread mechanism in both WUI and urban fires [3–7]. The development of more ignition resistant structures in large outdoor fires, not only WUI fires, but urban fires in Japan, will greatly benefit fire services as it is envisioned that firefighting resources may be better used to battle such fires. To enable the design of ignition resistant structures requires detailed, full-scale experiments that systematically evaluate individual building component vulnerabilities to ignition by firebrand showers.

Buildings may be surrounded by vegetation that, when ignited, can produce intense, localized firebrand showers. Ignited vegetation can also provide direct flame contact onto building elements [8]. The creation of so-called ‘defensible space’ around structures is a common mitigation strategy. Such an approach has limitations since the requirement for the creation of defensible space is either not popular due to resistance to modify the natural environment and landscaping around structures, or not practical due to limited lot size. Landscape mulches located adjacent to buildings are an obvious concern.

Prior to the recent work of the authors, Beyler *et al.* [9] is the only work to *systematically* investigate mulch bed ignition on realistic scales. The mulch beds were contained in 0.6 m square containers. In their work, shredded hard mulch was held at 13.3 % moisture content (MC), and the mulch depth was fixed at 76 mm. Different wood cribs, so-called Class A, B, C, 0.5 C, and 0.25 C, were used to simulate firebrands. They observed it was possible to only produce flaming ignition (FI) in shredded hardwood mulch at 13.3 % MC when using a Class A flaming firebrand. In their work, FI was defined as whether spread of visible flame front propagation after firebrand (crib) deposition was observed. Class A firebrand is a very large wood crib (30.48 cm × 30.48 cm × 5.715 cm). None of the smaller sized firebrands used could produce FI. No wind speed was applied in these experiments and wind is known to be important in large outdoor fire spread [3].

Recently, the authors have demonstrated that continuous application of small wind-driven firebrands resulted in flaming ignition of realistic-scale mulch beds (only shredded hardwood mulch was used) under various moisture contents [8]. It was observed that continuous application of small wind-driven firebrands, with sizes similar to those observed in actual WUI fires in California and Texas, resulted in FI of mulch beds held at MC up to 83 % under wind speeds of 8 m/s. The accumulation of firebrands was a key factor to produce ignition. In that study, the walls of the re-entrant corner were lined with gypsum board since these experiments were focused on *mulch ignition*, not the ignition of the wall assembly itself. It is important for the reader to grasp that it was not believed that small wind-driven firebrand showers would even be able to ignite realistic-scale mulch beds.

The literature lacks detailed, systematic experiments that demonstrate if certain mulch types ignite building elements. To this end, this paper outlines a series of experiments conducted with various mulch types placed adjacent to realistic-scale re-entrant corners. Mulch beds are a useful *surrogate* for various fuels that may be located near structures during the outbreak of large outdoor fires, such as WUI fires and urban fires. In the case of the USA, mulch beds are most often *the fuel* located adjacent to structures. In the first series of experiments, mulch beds (1.2 m by 1.2 m, 51 mm in depth) were placed adjacent to a re-entrant corner constructed with wood studs and lined with oriented strand board (OSB) as the sheathing. The premise behind conducting experiments with no siding treatments applied was predicated on the notion that bare OSB mulch contact would be a worst-case scenario, and therefore, a wall assembly in the most vulnerable state to mulch ignition.

In the second series of experiments, siding treatments were applied to the re-entrant corner assemblies (wood studs/OSB/moisture barrier/siding), and the influence of vertical separation distance on wall ignition from adjacent mulch beds was determined. For both experimental series, three different common mulch types were used: shredded hardwood, Japanese cypress woodchips, and pine bark nuggets. A limited number of these experimental findings have been presented in a recent conference proceedings [10], but this paper provides detailed results of these experiments for the archival literature.

EXPERIMENTAL DESCRIPTION

The full-scale Continuous Feed Firebrand Generator was developed in order to produce continuous wind-driven firebrand showers. The detailed description of this device is available elsewhere [8, 11] and the description here follows prior treatments on this device closely [8, 11]. This version of the device is modified from the NIST Dragon [12] and consisted of two parts: the main body and continuous feeding mechanism. The feeding system consisted of a pneumatic cylinder coupled to a cylindrical container where wood pieces were stored (see Figure 1). The pneumatic cylinder was contained inside a metal sleeve. Inside the metal sleeve, the sliding rod of the pneumatic cylinder was connected to a plate that allowed the volume of wood contained within the sleeve to be varied. This volume was set precisely to allow a specific mass of wood pieces to fall into this volume. When the air pressure was applied, the sliding rod of the pneumatic cylinder moved forward, forcing the wood pieces within the volume of the metal sleeve to the first gate, where they are then dropped into the second gate that leads to the Dragon where they are ignited (see Figure 1).

The gate system was required to contain the fire from spreading from the Dragon to the feed system and each gate was driven by pneumatic cylinders as well. For all tests, Douglas-fir wood pieces machined to dimensions of 7.9 mm (H) by 7.9 mm (W) by 12.7 mm (L) were used to produce firebrands. The same-size wood pieces were used to feed the bench-scale continuous Firebrand Generator in past studies and have been shown to be commensurate with sizes measured from full-scale burning trees, as well size distributions obtained from actual WUI fires [13].

If the blower was set to provide an average velocity below 3.0 m/s measured at the exit of the Dragon when no wood pieces were loaded, insufficient air was supplied for combustion and this resulted in a great deal of smoke being generated in addition to firebrands. At blower velocities above 3.0 m/s, smoke production was mitigated, but many firebrands produced were in a state of flaming combustion as opposed to glowing combustion. The purpose of this device is to simulate firebrand showers observed in long-range spotting and therefore glowing firebrands were desired [8, 11].

As in prior experiments using the NIST Dragon, the experimental device was installed inside the test section of the Building Research Institute's Fire Research Wind Tunnel Facility (FRWTF). The facility was equipped with a 4.0 m diameter fan to produce the wind field. The cross section of the FRWTF is 5.0 m wide by 4.0 m high. Maximum wind speeds of 10 m/s ($\pm 10\%$) are possible using this facility. The wind velocity distribution was verified using a hot wire anemometer array.

Mulch beds were installed in front of a re-entrant corner assembly to *attempt* to simulate mulch application in front of *actual structures*. The distance of the re-entrant corner assembly from the Continuous Feed Firebrand Generator, as well as its orientation in the wind tunnel, was based on prior work [14]. Specifically, a parametric study was conducted to determine the influence of various configurations to be able to have the greatest number flux/mass flux of firebrands arrive at the front of a re-entrant corner assembly in order to simulate worst-case conditions [14]. As a result of that work [14], the re-entrant corner was placed at a distance of 3.25 m downstream of the full-scale Continuous Feed Firebrand Generator.

The dimensions of the re-entrant corner assembly were 1.2 m wide by 2.44 m high on each side. The re-entrant corner was constructed from wood studs (2 by 4; cross-section with dimension of 38 mm by 89 mm) and in the first series of experiments, only oriented strand board (OSB) was applied as the sheathing material.

In the second series of experiments, OSB was once again used, and a moisture barrier (Tyvek¹; a commercial product of Dupont) was applied on top of the OSB. The re-entrant corner was finished with vinyl as the siding treatment. These are common wall construction guidelines in the USA. A vertical separation distance of either 102 mm inches or 203 mm (from the top of the mulch layer to the base of the siding treatment) was maintained by applying 12.5 mm thick gypsum board to the base of the re-entrant corner. The premise of

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¹Certain commercial products are identified to fully describe the experiments. This in no way implies endorsement or recommendation from NIST.

the vertical separation distance was to determine if it was possible to mitigate ignition of wall assemblies if the mulch was located sufficiently far from the siding itself.

Each of the mulch beds was installed inside the re-entrant corner assembly at the base (ground level). In all experiments, the mulch beds were 1.2 m by 1.2 m. Shredded hardwood mulch (0.25 g/cm^3), Japanese cypress woodchips (0.14 g/cm^3), and pine bark nuggets (0.17 g/cm^3) were used, and the thickness was fixed at 51 mm; a commonly recommended mulch thickness [9]. Each of the mulch types were oven dried order to simulate the worst-case scenario in real large outdoor fires. The base of the container used to house the mulch beds was lined with gypsum board. This was done to mitigate any ignition of the mulch bed container.

A typical experiment was conducted using the following procedure. The mulch bed was installed inside the re-entrant corner that was to be evaluated for ignition vulnerability. The wind tunnel speed was set to the desired level (*e.g.* 6 m/s or 8 m/s). Not only were these particular wind speeds selected based on prior work, discussed above [8, 14] but test methods for roofing assemblies and decking assemblies are also within this range (again see the discussion in [8,14]). Wood pieces were first loaded into the cylinder storage container and the air compressor needed to provide compressed air for the pneumatic cylinder and gate system was switched on (air compressor pressure was set to 0.7 MPa). The blower was set at 3.0 m/s and two propane burners were ignited and inserted into the side of the device. The propane burners were operated continuously during the experiment. The pneumatic piston was then activated and the sliding rod was positioned to allow wood pieces to enter the volume in the metal sleeve. The sliding rod was moved to push the wood pieces (200 g) to the first gate. The gate was opened, closed, and the second gate was then opened, and the wood fell into the Dragon. The feeding was varied to determine the optimal conditions for continuous firebrand showers. It was observed that 200 g, fed into the Dragon every 15 s provided an adequate firebrand generation rate to ignite building materials [8, 14].

The number flux (number of firebrands generated/ m^2s), at the exit of the device, was measured at a feeding rate of 200 g every 15 s (800 g/min). To determine the number flux, the number of firebrands was counted at every frame of the video recording, and summed every second [8, 14]. Based on the analysis, the number flux, at the exit of the device, reached a steady value of $340/\text{m}^2\text{s}$ ($\pm 20 \%$) 300 s after feeding began. The first firebrands began to be generated ~ 100 s after feeding was commenced.

Mass flux data (mass of firebrands generated/ m^2s) were calculated by multiplying the number flux and the average mass of each firebrand at a feed rate of 200 g every 15 s. To measure the firebrand mass, another set of experiments was conducted using a series of water pans placed downstream of the NIST full-scale Continuous Feed Firebrand Generator. Water pans were required in order to quench combustion of the firebrands. If the water pans were not used, the firebrands would continue to burn and by the time collection was completed; only ash remained. After the experiment was finished, the pans were collected and the firebrands were filtered from the water, using a series of fine-mesh filters. Firebrands were dried in an oven, at 104°C , for 16 h. As in previous work, the mass versus drying time was monitored to determine the duration need to completely dry the firebrands [8].

Figure 2 displays the projected area of the generated firebrands at 6 m/s and 8 m/s. In the figure, an example of the repeatability of the firebrand distribution is shown under 6 m/s, with a comparison to data collected at 8 m/s using the same experimental protocols in this study for firebrand generation [11]. Image analysis software was used to determine the projected area of a firebrand by converting the pixel area using an appropriate scale factor. It was assumed that deposited firebrands would rest flat on the ground and the projected areas with the maximum dimension and the second maximum dimension of three dimensions were measured (for cylindrical and flat shaped firebrands respectively). Images of well-defined shapes (e.g. various circular objects) were used to determine the ability of the image analysis method to calculate the projected area [15]. Based on repeat measurements of different areas, the standard uncertainty in determining the projected area was $\pm 10\%$. The mass of each firebrand was measured by a precision balance with 0.001 g resolution. As in prior studies, repeat measurements of known calibration masses were measured by the balance which was used for the firebrand mass analysis. The standard uncertainty in the firebrand mass was approximately $\pm 1\%$. The mean mass and standard deviation of each firebrand were obtained and observed to be $0.05 \text{ g} \pm 0.02 \text{ g}$. Therefore, the mass flux of generated firebrands was calculated to be $17 \text{ g/m}^2\text{s}$.

Similar to prior work by the authors [8], the total number/mass flux of firebrands generated from the full-scale Continuous Feed Firebrand Generator (Dragon) was determined, and did not vary with wind speed. However, all of the generated firebrands that depart the mouth of the Dragon did not land within the mulch bed. The total number of firebrands arriving on the surface of the mulch bed was determined (by counting firebrands from the video records) as a function of the applied wind speed. Based on this analysis, approximately 42 % at 6 m/s, and 36 % at 8 m/s, of the firebrands generated from the Dragon were able to land on the surface of the mulch bed. These differences are believed to be due to the enhanced flow recirculation observed as the wind speed was increased, which made it more difficult for firebrands to arrive on the mulch bed surface with attendant increases in wind speed. The number fluxes of the firebrands that arrived at mulch surface were $7.4/\text{m}^2\text{s}$ and $6.2/\text{m}^2\text{s}$ under 6 m/s and 8 m/s wind respectively, and corresponded to $0.4 \text{ g/m}^2\text{s}$ and $0.3 \text{ g/m}^2\text{s}$ for the mass flux deposited on the mulch bed surface. These values are the same as reported in [8], was not a surprising, as the same size re-entrant corners were used in prior work [8], the wind speeds were the same, and same Dragon was used.

The firebrand size and mass produced using the NIST Dragon can be tailored to those measured from full-scale tree burns, and actual WUI fires [13]. Specifically, firebrand distributions from a real WUI fire (2007 Angora Fire) were quantified for the first time [13]. The most salient result reported was the documentation of the consistently small size of firebrands ($< 0.5 \text{ cm}^2$) and the close correlation of these results with the sizes of experimentally generated firebrands from the NIST Dragon. The Texas Forest Service has used this methodology to collect firebrand size distributions from the recent Texas Bastrop Complex fires in 2011, reporting similar findings to the 2007 Angora fire [16].

RESULTS AND DISCUSSION

Re-entrant Corners Constructed from Wood Studs/Oriented Strand Board (OSB)

No Siding Treatments Applied—Figure 3 (a) – (c) shows each of the three mulch types used and their placement adjacent to the re-entrant corners with only OSB applied. In all cases, smoldering ignition (SI), due to continuous firebrand attack, was observed first within the mulch bed, and then SI was observed to transition to flaming ignition (FI) of the mulch bed.

The flaming mulch beds were observed to produce ignition of the OSB sheathing (nominally 10 % moisture content on dry basis), with flame penetration observed on the back side of the re-entrant corner assemblies (see Figure 4). In Figure 4, Japanese cypress woodchips were used but similar ignition behavior was observed for all mulch types. For completeness, experiments were also performed under higher wind speeds (8 m/s), and the observed ignition behavior of the re-entrant corners were more severe. A summary of the re-entrant corner ignition behaviors when only OSB was applied as the sheathing are summarized in Table 1.

Re-entrant Corners Constructed from Wood Studs/Oriented Strand Board (OSB)/Moisture Barrier

Vinyl Siding Treatments Applied—The first series of experiments described above demonstrated that all three mulch types were not only ignited by wind-driven firebrand showers, but these flaming mulch beds ignited reentrant corners fitted with OSB as the sheathing material. Consequently, the second series of experiments was focused on determining ignition vulnerabilities of re-entrant corners fitted with siding treatments. The re-entrant corners were fitted with vinyl siding and two different vertical separation distances were used: 102 mm and 203 mm.

For shredded hardwood mulch, the flame penetration on the back-side of re-entrant corner assembly was observed for a separation distance of 102 mm, under an applied wind speed of 6 m/s (see Figure 6). Conversely, for shredded hardwood mulch, the flame penetration on the back-side of re-entrant corner assembly was *not* observed for a separation distance of 203 mm, under an applied wind speed of 6 m/s (see Figure 7). As the wind speed was increased from 6 m/s to 8 m/s, flame penetration was observed on the back-side of the re-entrant corner assembly with shredded hardwood mulch with a 203 mm separation distance. Clearly, the wind speed played an important role for this type of mulch.

For the two other mulch types used, re-entrant corner ignition was observed *even* with a 203 mm vertical separation distance at 6 m/s (see Figure 8–9). Due to the intense fire and siding combustion observed, experiments for vertical separation of 102 mm were not conducted at either 6 m/s or 8 m/s for these two mulch types. Table 2 summarizes all the finding under a wind speed of 6 m/s.

It is important to note that the siding itself did not influence the ignition process for the mulch beds, as the mulch beds ignited first whether the re-entrant corner was fitted with siding or only OSB. Among three types of mulch, pine bark nuggets took longest to ignite

(required the greatest number of firebrands; average of 2066 firebrands for ignition; varied from a minimum of 1508 firebrands to a maximum of 2624 firebrands), but once ignited, pine bark nuggets were observed to burn for long duration. Pine bark nugget mulch was also the hardest to extinguish. It is important to note that the nuggets smoldered even after copious amounts of water was applied.

Figure 5 shows the time to FI among three different mulches installed in these re-entrant corner configurations at 6 m/s. Time to FI was defined as time to sustained FI minus time the first firebrand landed on the mulch beds. The scatter in the time to FI may be explained as follows. As the generator continually supplied firebrands to the mulch beds, more and more firebrands are deposited, leading to an increased likelihood that firebrands will eventually accumulate in a specific location and produce ignition. It only required a few of these small firebrands to eventually produce ignition at given location, similar to our previous study focused on only shredded hardwood mulch [8]. The scatter in the data is largest for the pine bark nuggets, since this mulch types possessed the roughest surface (least continuous due to nuggets) of the three mulches and was most sensitive to firebrand accumulation.

Towards Standard Laboratory Test Methods

A pragmatic approach to address structure ignition in large outdoor fires is hardening of structures [17]. In the case of WUI fires, it cannot be over-stated that current understanding of building component type to WUI exposure is still mainly predicated on *anecdotal* evidence [18]. The very limited WUI building codes and standards in practice lack scientific rigor and, when implemented, it is not clear if they present any benefit to structures in the path of hazardous WUI exposures [18].

Before test standards are developed, detailed full-scale experiments that systematically evaluate individual building component vulnerabilities to ignition by firebrand showers are required. It is critical to understand full-scale assembly performance when exposed to firebrand showers since weak points in a given assembly can be investigated. In turn, this will lead to determining the necessary configuration of building component mock-ups that can be used in standard laboratory test methods.

The use of full-scale experiments to guide the development of laboratory standard test methods, was used in developing a new ASTM Standard on Firebrand Resistant Vents. During the development of the ASTM standard test method for firebrand resistant vents, there was unanimous agreement by the ASTM task group to conduct a detailed comparison testing protocol to full-scale experiments by NIST to determine if the proposed standard test method could produce similar ignition results. The results of this comparison testing protocol are included in the ASTM Standard Test Method for Vents [19].

As part of an ongoing collaboration between Building Research Institute (BRI) in Japan, NIST in the USA, and the National Research Institute of Fire and Disaster (NRIFD) in Japan, efforts are underway to extend this methodology to develop needed standards for building components, such as roofing, decking, and fencing assemblies, and walls. It is desired that the full-scale experiments outlined in this paper will serve as the scientific

foundation to begin to develop standard laboratory scale test methodologies for mulch beds/wall assemblies.

As needed physical understanding is being collected from full-scale experiments such as those in this paper, work is required to develop reduced-scale test methods that are able to reproduce results of the full-scale experiments. A new experimental capability developed at NRIFD has been developed for this purpose. The description of this facility is beyond the scope of this paper but the interested reader is referred to a recent conference paper on this facility [20].

CONCLUSIONS

The salient features of the study are that it is possible for wind-driven firebrands with sizes traced to actual WUI fires to ignite a variety of mulch types and these ignited mulches may ignite realistic scale-building components. In particular, the siding itself did not influence the ignition process for the mulch beds, as the mulch beds were the first to ignite from the firebrand showers. In all experiments, it was observed that firebrands produced smoldering ignition in the mulch beds, this transitioned to flaming ignition, and the re-entrant corner assembly was exposed to the flaming mulch beds. With no siding treatments applied, the flaming mulch beds ignited the re-entrant corner, and ignition was observed to propagate to the back side of re-entrant corner assembly under all wind speeds (6 m/s to 8 m/s).

With respect to the re-entrant corners fitted with vinyl siding, for shredded hardwood mulch, flame penetration on the back-side of re-entrant corner assembly was observed for a separation distance of 102 mm, under an applied wind speed of 6 m/s. Conversely, for shredded hardwood mulch, flame penetration on the back-side of re-entrant corner assembly was *not* observed for a separation distance of 203 mm, under an applied wind speed of 6 m/s. As the wind speed was increased from 6 m/s to 8 m/s, flame penetration was observed on the back-side of the re-entrant corner assembly with shredded hardwood mulch, even for a separation distance of 203 mm. For the two other mulch types used, re-entrant corner ignition was observed *even* with a 203 mm vertical separation distance at 6 m/s. Due to the intense fire observed, experiments for vertical separation of 102 mm were not conducted at either 6 m/s or 8 m/s for these two mulch types.

Mulches clearly pose an ignition hazard to structures in large outdoor fires. The experiments outlined in this paper will serve to as the scientific foundation to begin to develop standard laboratory scale test methodologies for mulch beds/wall assemblies.

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Figure 1.
Schematic of the feeding system for the full-scale Continuous Feed Firebrand Generator.
The location where the feeding system provided wood pieces into the device is shown.

Figure 2.

Projected area as a function of mass of generated firebrands under wind speeds of 6 m/s and 8 m/s. All of the mulch/re-entrant corner assemblies were exposed to firebrand size/mass distributions of these sizes. For completeness, the repeatability of the firebrand distribution is shown under 6 m/s.

Figure 3. Images of the three mulch types used in all experiments **(a)** Shredded hardwood, **(b)** Japanese cypress woodchips, and **(c)** pine bark nuggets. In these images, the re-entrant corner has only OSB as the sheathing material.

Figure 4.
Images of re-entrant corner ignition at 6 m/s. Japanese cypress woodchip mulch was ignited by firebrand showers. Flame penetration at the back-side of the wall was observed.

Figure 5.

Average time for sustained flaming ignition (FI) vs different mulch type under 6 m/s wind (for an average firebrand number flux arriving on the mulch bed of $7.36/\text{m}^2 \text{ sec}$). For all mulch types, the time to FI was observed to be within $\pm 50\%$ of the average value, based on repeat experiments.

Figure 6. Re-entrant corner fitted with vinyl siding and shredded hardwood mulch with a 102 mm vertical separation distance exposed to wind-driven firebrand showers at 6 m/s. Flame penetration on the back-side of the wall is shown.

Figure 7. Re-entrant corner fitted with vinyl siding and shredded hardwood mulch with a 203 mm vertical separation distance exposed to wind-driven firebrand showers at 6 m/s. Flame penetration on the back-side of the wall was not observed.

Figure 8.
Re-entrant corner fitted with vinyl siding and Japanese cypress woodchip mulch with a 203 mm vertical separation distance exposed to wind-driven firebrand showers at 6 m/s.

Figure 9.
Re-entrant corner fitted with vinyl siding and pine bark nugget mulch with a 203 mm vertical separation distance exposed to wind-driven firebrand showers at 6 m/s.

Table 1

Summary of re-entrant corner wall (wood studs/OSB) ignition behavior when located adjacent to various mulch types under wind speeds of 6 m/s and 8 m/s. Wall Ignition (WI) was defined a flame propagation to the back-side of the wall.

Wind Speed	Shredded Hardwood Mulch	Japanese Cypress Woodchip Mulch	Pine Bark Nugget Mulch
6 m/s	WI	WI	WI
8 m/s	WI	WI	WI

Table 2

Summary of re-entrant corner wall (wood studs/OSB/moisture barrier/vinyl siding) behavior when located adjacent to various mulch types with 102 mm and 203 mm vertical separation distance under wind speeds of 6 m/s. Wall Ignition (WI) was defined a flame propagation to the back-side of the wall. Not tested (NT); No Wall Ignition (NWI)

Separation Distance (mm)	Shredded Hardwood Mulch	Japanese Cypress Woodchip Mulch	Pine Bark Nuggets Mulch
102	WI	NT	NT
203	NWI	WI	WI