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The size and mass distribution of firebrands collected from ignited building components exposed to wind

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Abstract

Wildfires that spread into communities, commonly referred to as Wildland-Urban Interface fires (WUI), are a significant international problem. Post-fire damage studies have suggested for some time that firebrands are a significant cause of structure ignition in WUI fires, yet little research has been conducted to investigate firebrand production from burning vegetation and structures. To this end, firebrand production from real-scale building components under well-controlled laboratory conditions was investigated. Specifically, wall and re-entrant corner assemblies were ignited and during the combustion process, firebrands were collected to determine the size/mass distribution generated from such real-scale building components under varying wind speed. Finally, the size and mass distributions of firebrands collected in this study were compared with the data from an actual full-scale structure burn to determine if simple component tests such as these can provide insights into firebrand generation data from full-scale structures. The results are presented and discussed.

Keywords: WUI fires; Firebrands

1. Introduction

Fires in the Wildland-Urban Interface (WUI) have been a large problem not only in the USA, but all over the world. From a pragmatic point of view, the WUI fire problem can be seen as a structure ignition problem [1]. Along these lines, ignition resistant structures under WUI fire exposure was listed as one of the major recommendations in the United States Government Accounting Office (GAO) 2005 report, Technology Assessment: Protecting Structures and Improving Communications During Wildland Fires [2], and was the subject of a Homeland Security Presidential Directive [3]. Further effort is needed to understand the processes of structure ignition during WUI fires.

While firebrands have been studied for some time, most of these studies have focused on how far firebrands fly or travel [4–14]. Unfortunately, very few studies have been performed regarding firebrand generation [15–17] and the subsequent ignition of materials or fuels by firebrands [18–21]. In order to develop scientifically based mitigation strategies, it is necessary to understand

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the firebrand generation from structures and the vulnerabilities of structures to firebrand showers.

Recently Manzello et al. [22–25] developed an experimental apparatus, known as the NIST Firebrand Generator (NIST Dragon), to investigate ignition vulnerabilities of structures to firebrand showers. The NIST Firebrand Generator is able to generate a controlled and repeatable size and mass distribution of glowing firebrands. The experimental results generated from the marriage of the NIST Dragon to the Building Research Institute's (BRI) Fire Research Wind Tunnel Facility (FRWTF) have uncovered the vulnerabilities that structures possess to firebrand showers for the first time [25]. These detailed experimental findings are being considered by standards-making bodies such as ASTM, as a basis for performance-based building standards with the intent of making structures more resistant to firebrand attack.

The firebrand sizes generated by the NIST Dragon have been tied to those measured from full-scale tree burns and a real WUI fire – the 2007 Angora Fire near Lake Tahoe, California [16,26,27]. The Angora Fire firebrand data are believed to be the first such information quantified from a real WUI fire. Little data exist with regard to fire size distributions from actual structures or WUI fires [28–30]. It is believed that the structures themselves may be a large source of firebrands, in addition to the vegetation. Yet, due to such limited studies, it cannot be determined if firebrand production from structures is similar to that of vegetation, or if firebrand production from structures is a significant source of firebrands in WUI fires. Detailed studies are needed to address this question.

To this end, firebrand production data was collected from ignited building components (wall and re-entrant corner assemblies) exposed to well-controlled wind fields generated at BRI's FRWTF. During the combustion process, firebrands were collected using an array of water pans positioned downstream of the assemblies. These building component experiments conducted at the FRWTF were compared to firebrand generation data from an actual full-scale structure burn conducted (by the authors) in Dixon, CA [17]. For the first time, it is possible to compare firebrand generation data from individual building components under well controlled laboratory conditions to those of a more realistic full-scale structure burn in the field.

2. Experimental discription

Experiments were performed in BRI's FRWTF by varying the experimental conditions as shown in Table 1. A wall assembly and re-entrant corner assembly, shown in Fig. 1, were used for experiments since they are typical residential building components found in the USA. Wall assemblies were used in these experiments since it was thought that they are a significant component of firebrand production when actual structures are ignited in WUI fires. The schematic of experimental layout is shown in Fig. 2. The wall assembly for Experiment No. 1 was 1.22 m wide by 2.44 m high and the re-entrant corner assemblies for Experiment No. 2 and No. 3 were 1.22 m wide for each side by 2.44 m high. For both assemblies, wood studs were spaced 40 cm on center and oriented strand board (OSB) was used as the exterior sheathing material. The assemblies were installed inside the test section of the FRWTF at BRI show in Fig. 2. The facility was equipped with a 4.0 m diameter fan to produce a wind field up to a 10 m/s ($\pm$10%). The wind velocity distribution was verified using a hot wire anemometer array. To track the evolution of the size and mass distribution of firebrands, a series of water pans was placed downstream of the assemblies.

A very important aspect of this study was to determine the best ignition method in order to provide repeatable conditions to collect firebrands during the combustion of the assemblies. It is important to realize that is very difficult to simulate the conditions of an actual WUI fire in a controlled laboratory setting. The influence of wind speed on the influence of the firebrand size and mass distribution generated from a given assembly configuration is an important parameter to study. For this study, each assembly was ignited using a natural gas T-shaped burner with a heat release rate of 26 kW positioned adjacent to the assemblies for 10 min under conditions of no wind. The T-shaped burner was placed on the outside of the assemblies since the purpose of this study was to simulate ignition from an outside fire. If the burner was applied under wind (e.g., 6 m/s), flaming combustion of the assembly was difficult to achieve due to convective heat loss from the applied wind flow. In addition, another advantage of ignition under no wind, with the burner applied for the same duration for each assembly, was that it provided more uniform initial conditions for the experiments. Specifically,

Table 1
Experimental Conditions.

	Experimental assemblies	Wind speed (m/s)	Time to finish (min)
No. 1	Wall assembly	6	30
No. 2	Re-entrant corner assembly	6	30
No. 3	Re-entrant corner assembly	8	6

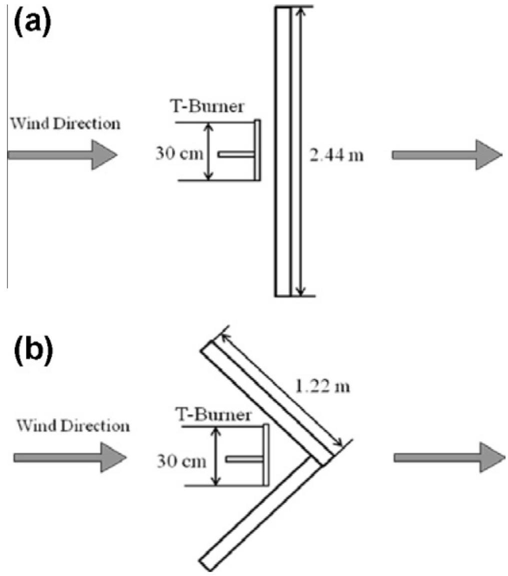

Fig. 1. Schematic of experimental assemblies (a) Wall assembly (Experiment No. 1). (b) Re-entrant corner assembly (Experiment No. 2 and No. 3).

the area exposed to direct flame contact was similar for a given assembly. If igniting under wind, in addition to large convective heat loss, the contact area of the burner onto the OSB surface of the assembly was non-steady due to the difficulty of sustaining the flame from the T-shaped burner under such conditions.

With the application of the T-shaped burner to the assembly under no wind, flaming combustion was observed on the exterior of the OSB. Once the burner was switched off (after 10 min) and the wind tunnel was switched on, flaming combustion was observed to diminish and intense self-sustaining smouldering combustion appeared. With continued application of the applied wind field, the self-sustaining smouldering combustion eventually transitioned to flaming combustion. Firebrands were collected until the assemblies were consumed to such a degree that they could no longer support themselves. Figure 3 displays an image after sufficient combustion occurred to penetrate the OSB sheathing. The assemblies were also tethered to the wind tunnel using fine wires to prevent them from collapsing due to the applied wind field. Firebrands were collected by using a series of water pans placed behind the assemblies shown in Fig. 2. Water was necessary to quench the combustion process of the generated firebrands. After deposition into the water pans, firebrands were filtered from the water using a series of fine mesh filters. Firebrands were dried in an oven at 104 °C for 24 h. The mass and size of each firebrand was measured by a precision balance (0.001 g resolution) and using digital image analysis, respectively.

3. Results and discussion

After it was safe to enter the wind tunnel, the pans were collected and firebrands were separated from the water using filters. The firebrand image was converted to an 8 bit grayscale image. Image analysis software was used to determine the projected area of a firebrand by converting the pixel area using an appropriate scale factor. Naturally, firebrands are three dimensional objects. For all analyses in this study, the projected area reported was the maximum value for a firebrand placed on a flat surface. The average mass and size of firebrands in this study with standard deviation are as follows: Experiment No. 1, 0.16 ± 0.34 g and 2.27 ± 2.88 cm^2, No. 2, 0.30 ± 0.45 g and 3.13 ± 3.17 cm^2, No. 3, 0.57 ± 0.73 g and 4.52 ± 4.09 cm^2.

Firebrands collected from structure components (wall/re-entrant corner assemblies) are plotted in Fig. 4. In each experiment, two or three big firebrands with more than 100 cm^2 projected area, which were charred wood studs or charred pieces of OSB, were also obtained. The focus here was on smaller sizes since more than 95% of firebrands collected were less than 1.0 cm^2 size [26]. The total number of firebrands collected in Experiment No. 1, No. 2, and No. 3 were 500, 1000, and 1900 pieces, respectively. Figure 4 shows that the size and mass distribution of firebrands from Experiment No. 2 and No. 3 were quite similar, while the one from Experiment No. 1 had more variety of projected area at a certain mass such as 0.5 g, especially within a 10 cm^2 projected area. All the firebrands collected in this study with some exception, have less than 5 g mass and 30 cm^2 projected areas. In more detail, the percentage of firebrands with less than 1 cm^2 projected areas from Experiment No. 1, No. 2 and No. 3 were 41%, 17% and 5.2%, and that those with less than 10 cm^2 projected areas were 97%, 97% and 90%, respectively. It was found that a wall assembly produced more firebrands with small projected areas than did a re-entrant corner assembly. This also demonstrated that larger firebrands were produced as the wind speed increased. Figure 4 also shows that 65%, 37% and 15% of firebrands from Experiments No. 1, No. 2 and No. 3 were less than 0.1 g, and that 98%, 94% and 84% of them were less than 1 g, respectively. Even though some of firebrand collected from the assemblies have larger projected areas and mass, these results shows that more than 90% of firebrand collected in this study had less than 1 cm^2 projected area and mass less than 1 g.

Little information is available in the literature regarding firebrand generation data from vegetation and structures [30,31]. It is useful to compare the results presented here to prior work by the authors as well as the few legacy studies in the literature. Manzello et al. [16,27] measured the mass

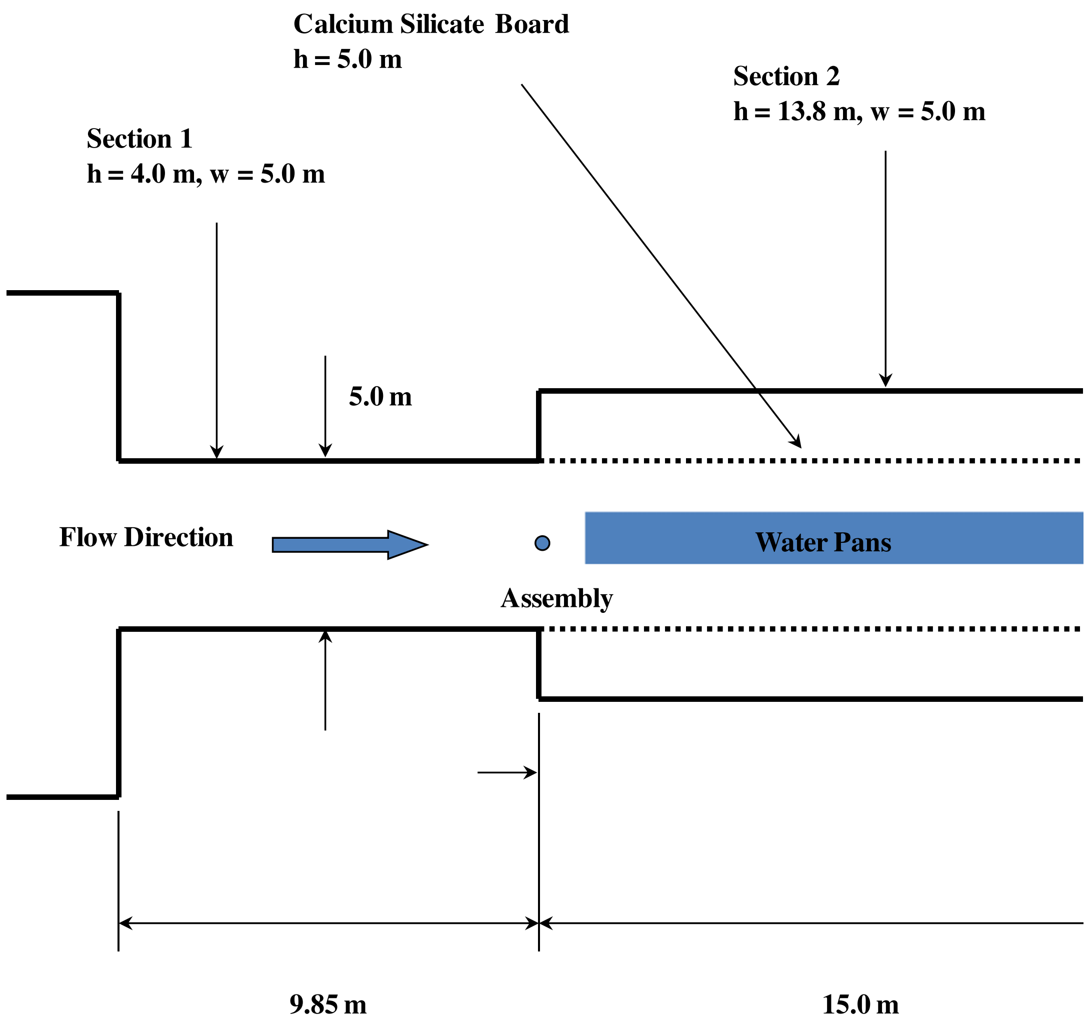

Fig. 2. Schematic of layout for experiments.

and size distribution from burning trees. In that work, an array of pans filled with water was used to collect the firebrands that were generated from the burning trees. In the experiments of Suzuki and Manzello [17], the structure used for the experiments was a two story house located in Dixon, CA. Debris piles were used to ignite the structure and it took approximately two hours after ignition for complete burn down. A large amount of water was poured onto the structure several times to control the fire since the house was located in a populated section of downtown Dixon. Firebrands were collected by using a series of water pans placed near (4 m) from the structure and on the road about 18 m downwind to the structure.

Vodvarka [29] measured data on fire spread rate radiant heat flux, firebrand fallout, buoyancy pressures, and gas composition from eight separate buildings. Firebrands were collected by laying out sheets of polyurethane plastic downwind from three out of eight experiments. Two of the buildings were all wood construction, one was cement-block construction, and one had wood floors and asphalt shingles over wood singles applied to wood sheathing. In total, 2357 firebrands were collected. More than 90% of firebrands have less than 0.90 cm^2 projected area and 85% of them have less than 0.23 cm^2 projected area. Only 14 out of 2357 firebrands had a projected area greater than 14.44 cm^2. Mass data was not reported in this study.

The firebrand data in this study were plotted and compared with firebrand data from burning vegetation [27] and the full-scale structure burn by Suzuki and Manzello [17], and are shown in

Fig. 3. Picture of flaming re-entrant corner assembly at 6 m/s wind speed (Experiment No. 2).

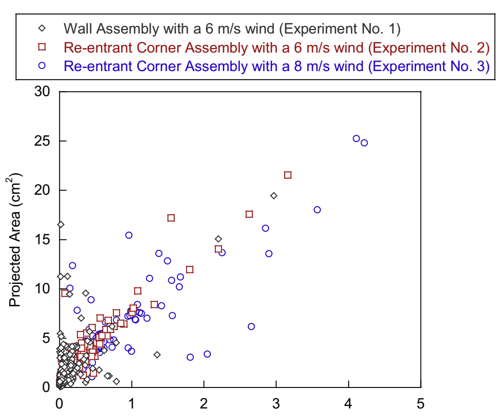

Fig. 4. Size and mass distribution of firebrands collected in this Study.

Fig. 5. All data, including that from vegetation, was scaled to projected area for proper comparison. The size and mass distribution of firebrands collected in this study were similar to those generated from vegetation. The firebrands in this study were observed to have a large projected area for similar mass classes. In addition, bigger firebrands with more than 50 cm^2 area were found in this study, whereas all the firebrands in [16,27] had less than 40 cm^2 area. For the data collected from the full-scale structure burn by Suzuki and Manzello [17], 139 firebrands were collected from two different places. All the firebrands collected from the burning house were less than 1 g and almost

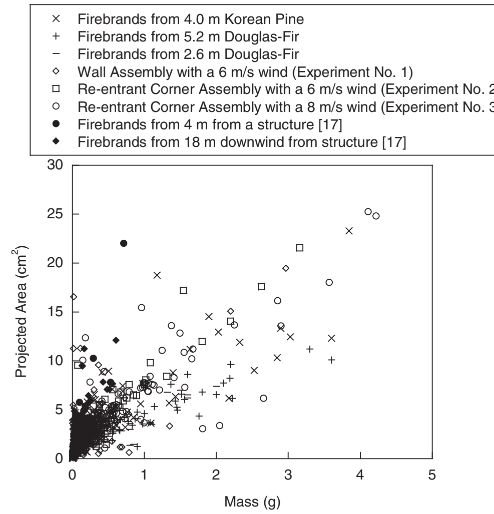

Fig. 5. Comparison of size and mass distributions of firebrands collected in this study with a previous study [17].

85% of firebrands collected 18 m from the structure and 68% of firebrands from around a structure were less than 0.1 g. In terms of the projected area, most of the firebrands, 95% of those from 18 m downwind from the structure, and 96% of those from around the structure had less than a 10 cm^2 projected area.

Figure 6 shows that the size distribution of firebrands collected in this study were shown with firebrand data from the full-scale structure burn by Suzuki and Manzello [17], and firebrand data from Vodvarka's study [29]. Only three firebrands from Experiment No. 1 had less than 0.23 cm^2 projected area and the peak of the firebrand data

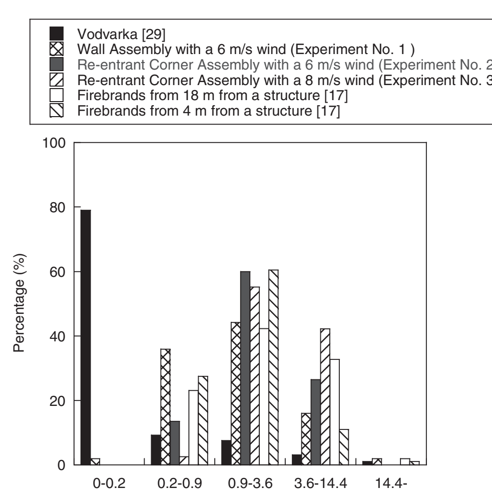

Fig. 6. Size distribution of Firebrands.

belongs to the projected area from 0.9 to 3.6 cm^2 while most of the firebrands from Vodvarka [29] were less than 0.23 cm^2.

An important question from this study is whether firebrands from individual building components are representative of firebrand generation from full-scale structure fires. As mentioned above, wall assemblies were used in these experiments since it was expected that they are a significant source of firebrand production when part of a full structure is ignited in real WUI fires. When comparing the firebrand size/mass collected from the individual building components, similar size/mass classes were found as compared to the full-scale structure experiments. The fire sizes produced from a full structure burn were larger than individual wall components and it would be expected that the buoyant plume generated from full-scale structure burns would be capable of lofting larger firebrands. Wind is another important parameter that influenced the generation of firebrands. Naturally, it is not possible to control the wind field when conducting full-scale structure burns in the field but the prevailing wind speeds of Vodvarka [29], and Suzuki and Manzello [17] were similar to the wind speeds of the individual building components data taken on in this study. In light of these findings, it is interesting to note than the most significant differences in firebrand size occurred for the smallest size range. Vodvarka's full-scale structure burn [29] produced copious quantities of small firebrands. This suggests that while the fire size was indeed bigger in his tests, firebrands may actually be consumed by the larger fire plume before being lofted to the atmosphere. To provide answers to these questions, future experiments are planned to burn structures in BRI's FRWTF under various wind speeds and compare the results to the tests presented here. This will allow for a detailed database of firebrand generation from components and structures under well controlled conditions.

4. Summary

Wall assemblies were used in these experiments since it was expected that they are a significant source of firebrand production. Individual building components provide insight into firebrand generation from full-scale structures as similar size/mass classes were found compared to the full-scale structure fire experiments.

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