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Investigating Firebrand Deposition Processes in Large Outdoor Fires

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Abstract: Devastating large outdoor fires have been responsible for destruction of vast amounts of infrastructure and loss of human life. Wildland fires that spread into urban areas, known as wildland-urban interface (WUI) fires, are capable of enormous destruction. WUI fires are distinct from wildland fires; WUI fires include the combustion of both vegetative and human-made fuels and occur where large population centers exist whereas wildland fires include the combustion of vegetative fuels and occur in uninhabited areas. The rise of densely populated urban areas has also seen the development of large urban fires. The most recent of these occurred in the winter of 2016 in Niigata, Japan. Similarly, the USA has also experienced several major urban fires. In some cases, earthquakes have served to initiate these fires, but it is not a necessary condition for these urban fires to develop. In addition, the rise of informal settlement communities in Southeast Asia and Africa continues to result in large outdoor fires capable of great destruction. Firebrands, or smoldering and/or flaming particles, are in fact the main culprit to destroy structures in large outdoor fires. Recent comprehensive review of firebrand combustion reported that deposition processes remain largely unexplored. As part of this work, a series of intricate experiments were undertaken to investigate firebrand deposition processes. A firebrand generator was utilized, and various flow obstructions were placed down stream of these firebrand generators to better understand these complex deposition processes. Results of these investigations for multiple wind speeds, firebrand size and mass distributions, and obstacle placement are presented and discussed.

Keywords: large outdoor fires; firebrands; wind; deposition

1. INTRODUCTION

Wildfires that spread into communities, referred to as Wildland-Urban Interface (WUI) fires, are a dilemma throughout the world [**1**]. Japan has experienced large urban fires. Some after strong earthquakes, such as 1997 Hanshin-Awaji Earthquake. Yet, it is not a necessary condition for these urban fires to develop.

A major factor in both WUI and urban fire spread, is firebrand production [**2**]. When structures burn in these fires, pieces of burning material, known as firebrands, are generated, become lofted, and are carried by the wind. This results in showers of wind-driven firebrands. These spot fires overwhelm firefighting resources [**1-2**].

In Japan, several city fire spread models were developed for damage estimation. These models were based on the past city fire damages and use empirical formula under limited situations

[**3**]. There is a lack of scientific and reliable data needed to advance such models further; especially for firebrand accumulation.

As structures are exposed to wind, stagnation planes are produced around structures. The authors demonstrated that firebrands may accumulate in these stagnation planes [**4**]. In a subsequent study performed by the authors [**5**], a series of full-scale experiments revealed that wind speed influences not only the spatial location and extent of the accumulated firebrands in the stagnation plane in front of the obstacle, but also the nature of the smoldering combustion intensity of the accumulated firebrands. This paper describes an in-depth study of this phenomenon at reduced-scale to determine if useful insights may be obtained from simpler experiments. The firebrand distributions were varied to simulate *both* burning structures and vegetation, as prior studies were focused on vegetative firebrands [**4-5**]. The paper closes with a brief comparison to full-scale experiments described in Suzuki and Manzello [**5**].

2. EXPERIMENTAL DESCRIPTION

A reduced-scale continuous firebrand generator was used to generate firebrand showers (**Figure 1**). The following experimental description follows those presented elsewhere [**6**].

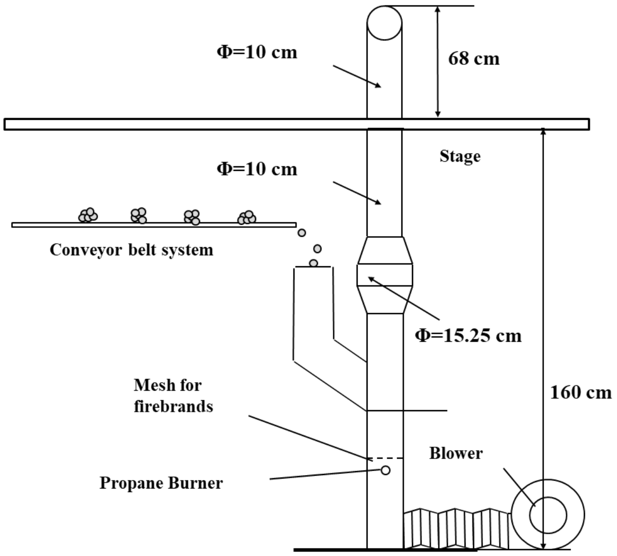

Figure 1 The reduced-scale firebrand generator is shown installed in NRIFD’s wind facility. Wood pieces are continuously feed into the device to generate firebrand showers.

The reduced-scale continuous-feed firebrand generator consisted of two parts; the main body and continuous feeding component. The capability of a smaller-sized firebrand generator to develop continuous firebrand showers has been described [**6**]. Japanese Cypress wood chips and Douglas-fir wood pieces were used to produce firebrands. The Japanese Cypress wood chips had dimensions of 28 mm ±7.5 mm (L) by 18 mm ± 6.3 mm (W) by 3 mm ± 0.8 mm (H) (average ± standard deviation), respectively, before combustion. These were provided from a supplier and filtered to remove really small wood chips by using a 1 cm mesh. Douglas-fir wood pieces were machined to dimensions of 7.9 mm (H) by 7.9 mm (W) by 12.7 mm (L).

The obstacle was placed downstream of the firebrand generator and the wind speed was varied at 4 m/s, 6 m/s, 8 m/s and 9 m/s. Specifically, the obstacle used in this study had the dimensions of 660 cm (H) by 1275 cm (W) and was located at a distance of 3 m from the device to visualize the transport process.

3. RESULTS AND DISCUSSION

Figure 2 displays images of experiments with a 660 cm (H) x 1275 cm (W) obstacle with different wind speeds (4 m/s and 8 m/s) and feeding materials (Japanese Cypress chips and Douglas-fir wood pieces). Images shows that firebrands made from Japanese Cypress wood chips and from Douglas-fir wood pieces accumulated differently in front of the same obstacle.

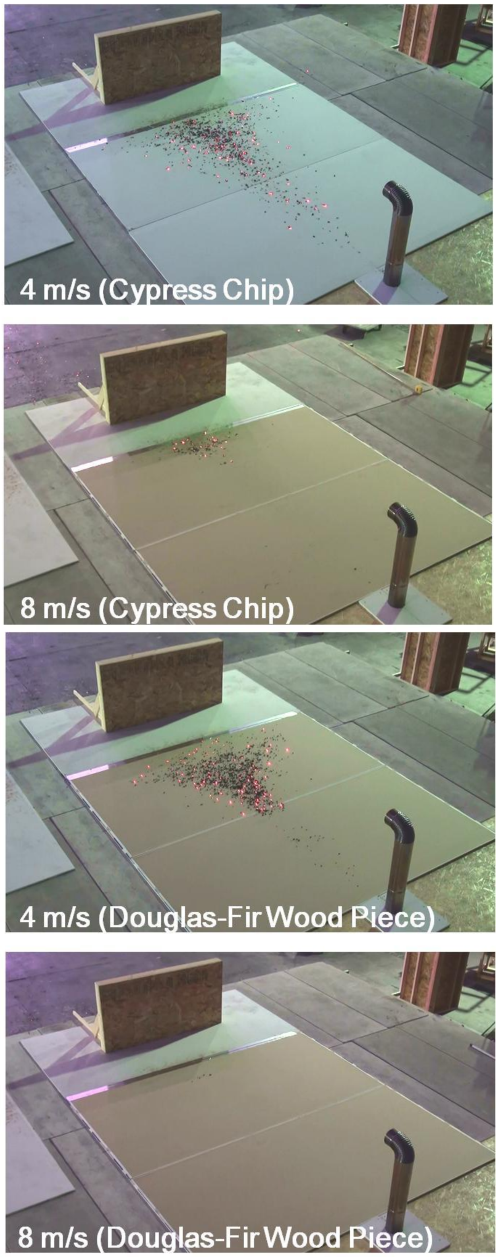

Figure 2 Images of experiments with a 660 cm (H) by 1275 cm (W) obstacle under different wind speeds -4 m/s and 8 m/s, with different feeding materials –Japanese Cypress wood chips and Douglas-fir wood pieces. 10 min of firebrand exposure has elapsed in these images.

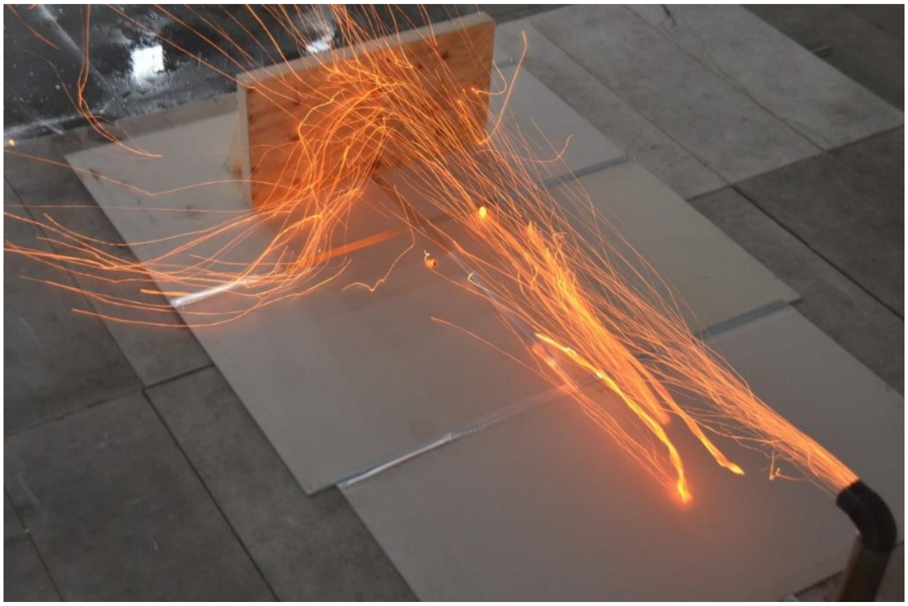

Figure 3 As an example of the physics involved, showers of laboratory generated firebrands combusting in a wind field of 8 m/s are directed at a simplified flow obstruction of 660 cm (H) by 1275 cm (W) obstacle. Here, Japanese Cypress wood chips are used as the source of firebrands.

Under a 4 m/s wind, it was observed that firebrands were unable to accumulate into one compact zone, rather scattered. As a wind speed increases, firebrands accumulated more in one zone. It was observed that firebrands made from Japanese Cypress wood chips managed to accumulate in front of the obstacle up to 10 m/s while those made from Douglas-fir wood pieces did not accumulate under 8 m/s and 10 m/s wind.

The accumulated area was measured using image processing software. Based on repeat measurements of different areas, the standard uncertainty in determining the projected area was ±10%. It is also important to mention that the obstacle was exposed to firebrand showers for the same duration. **Figure 3** displays an instantaneous image, displaying the complex physics involved.

Figure 4 displays the measured area of the accumulated firebrands as a function of wind speed. As the wind speed was increased, the area of accumulated firebrands was reduced significantly. It is obvious in **Figure 4** that firebrands from Douglas-fir wood pieces accumulated to smaller areas than those from Japanese Cypress wood chips.

Comparison was made in order to investigate the difference of accumulation behaviors of firebrands. **Figure 5** displays the mass and size distributions of firebrands made from Japanese Cypress wood chips and Douglas-fir wood pieces under the same wind speed (6 m/s). Similar to the authors prior full-scale studies, firebrands made from Japanese Cypress wood chips have approximately double the projected areas at a certain mass, compared to firebrands generated from Douglas-fir wood pieces. It suggests that the difference of firebrand characteristics has effect on the accumulation behavior of firebrands in front of wall assemblies.

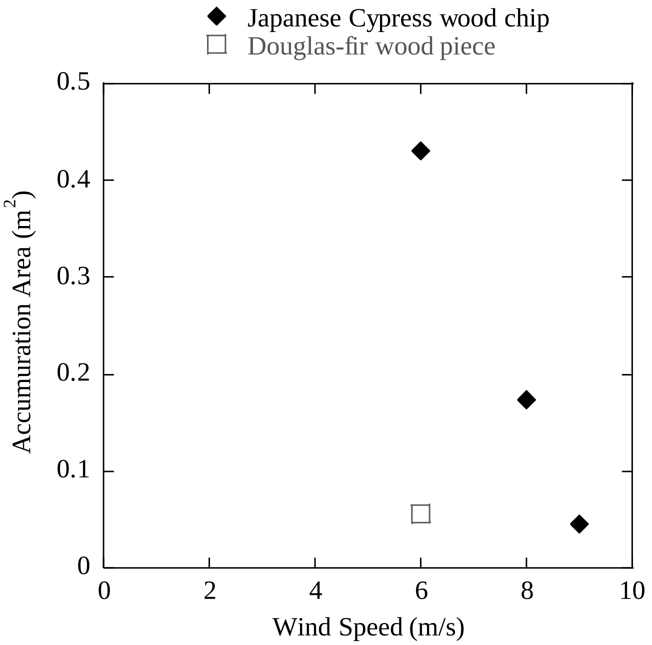

Figure 4 Measured accumulated area for various wind speeds.

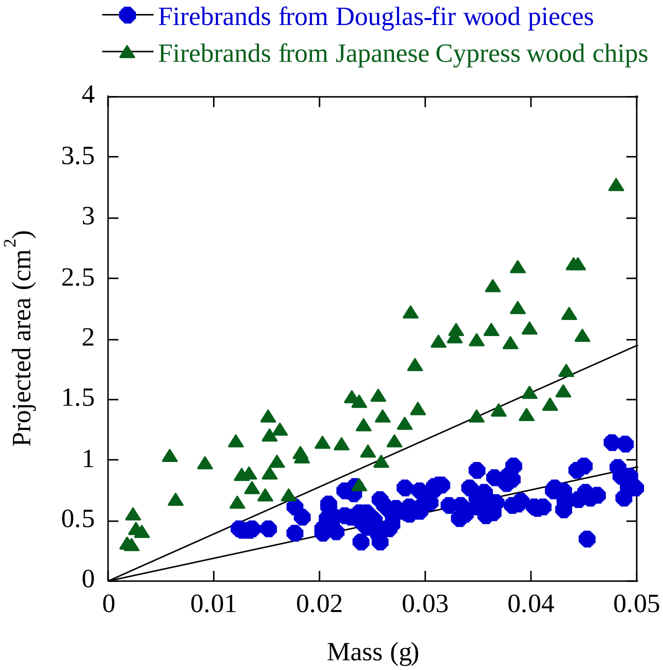

Figure 5 Mass and size distributions of firebrands made from Douglas-fir wood pieces and Japanese Cypress wood chips. Standard uncertainty in projected area (±10%) and mass (±1%).

4. COMPARISON OF ACCUMULATED INGITION PATTERNS

When firebrands accumulate into compact zones, it is known that they may provide sufficient heat feedback to ignite materials [**5**]. In full-scale experiments of Suzuki and Manzello

[**5**], when firebrands were observed to accumulate into compact zones in front of obstacles, the paper of the gypsum board was observed to ignite due to accumulated firebrands (see **Figure 6**).

Figure 6 Accumulated firebrands swept off after the completion of the experiments. Ignition points of the gypsum board paper are observed. Douglas-fir wood pieces were used to simulate vegetative firebrands, wind speed of 6 m/s, and the obstacle was 1.32 m (H) by 2.44 (W) [**5**].

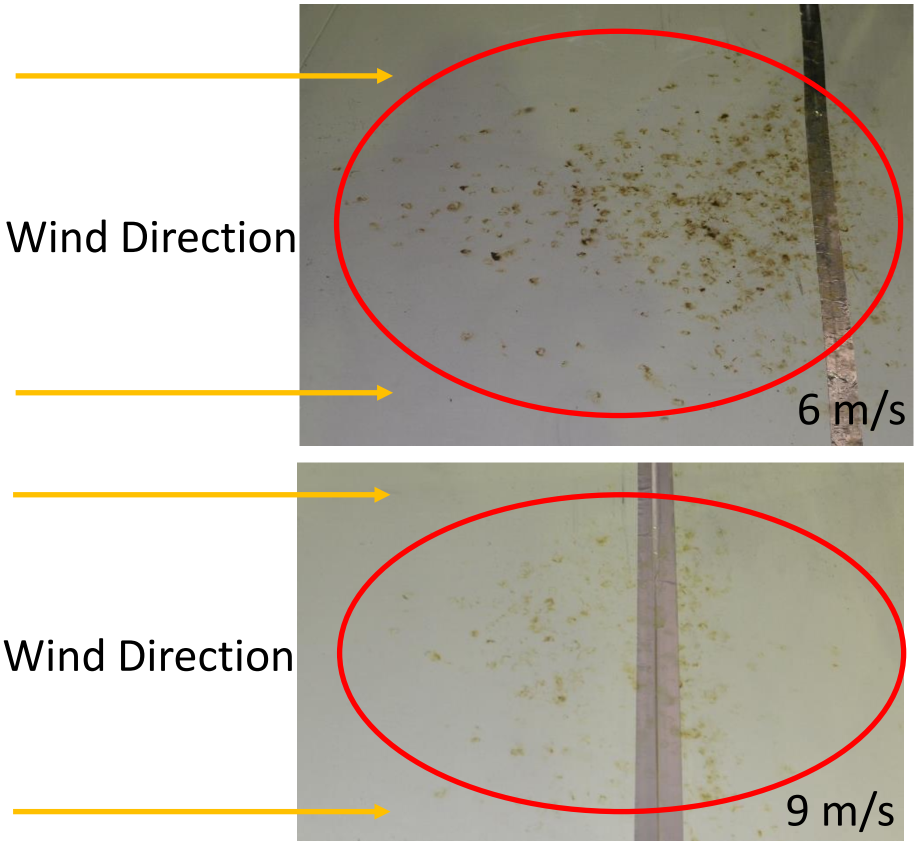

Figure 7 Accumulated firebrands swept off after the completion of the experiments. Ignition points of the gypsum board paper are observed at 6 m/s but not 9 m/s. Japanese Cypress wood chips were used to simulate structure firebrands, the wind speed was 6 m/s, and the obstacle was 660 cm (H) by 1275 cm (W).

Similar behavior was observed in these reduced-scale experiments. **Figure 7** displays images of the gypsum board surfaces after firebrands have been swept away. In the top image, the wind speed was 6 m/s and several ignition points were observed. At 9 m/s, it may be seen that, since the firebrands were unable to accumulate into compact zones, sufficient heat feed-back was not provided to ignite the gypsum board.

5. SUMMARY

A series of reduced-scale experiments were performed in order to investigate firebrand accumulation in front an obstacle using Japanese Cypress wood chips and Douglas-fir wood pieces. For a specified wind speed, it was found that the characteristics of firebrands has an effect of accumulation behavior of firebrands in front of an obstacle. Important qualitative similarities between the full-scale and reduced-scale firebrand studies is that increased wind speed resulted: (1) decreased firebrand accumulation areas (2) less ignition points on gypsum board surfaces. Detailed investigation will be needed in the future for different obstacles placed downwind from the firebrand generator, as well as further full-scale experiments generating firebrands similar to structure production for comparison. In addition, the authors plan to quantitatively measure the heat flux profiles imparted onto the surface under various experimental conditions. Methods to quantify heat flux profiles have been proposed and reviewed in the literature but it is not clear if these indeed work in more realistic experimental settings presented here [**2**].

6. REFERENCES

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