Determining Ignition Regime Maps of Building Materials Exposed to Continuous Wind-Driven Firebrand Showers

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1. ABSTRACT

Firebrands are a major cause of structural ignition in urban fires in Japan and WUI fires in the USA, yet little research has been conducted to investigate the ignition of building materials to wind driven firebrand showers. To this end, the present investigation was undertaken to construct a new and improved Dragon's LAIR facility. This entailed removing the NIST Baby Dragon from the wind tunnel facility and inserting the new and improved NIST continuous feed Baby Dragon. The unique features of the continuous feed Baby Dragon, over the current NIST Baby Dragon, is the capability to produce a constant firebrand shower in order to expose building materials to continual firebrand bombardment. It is now possible to precisely control the number flux, mass flux, and state of combustion of firebrands generated using this facility. The efficacy of this bench scale experimental facility to determine ignition regime maps of building materials exposed to wind driven firebrand showers is presented.

2. INTRODUCTION

Wildland-Urban Interface (WUI) fires have caused significant damage to communities throughout the world. Many studies suggest that the firebrands are a major cause of structural ignition of WUI fires in USA and Australia [*e.g.* 1]. Firebrands are produced as vegetation and structures burn in these fires. Most of the prior firebrand studies have been focused on how far firebrands fly, known as spotting distance, (see Koo *et al.* [2] for recent review) and are of limited use to mitigate ignition of structures from wind driven firebrand showers.

Manzello *et al.* [3-4] developed an experimental apparatus, known as the NIST Firebrand Generator (NIST Dragon), to investigate ignition vulnerabilities of structures to firebrand showers. The experimental results generated from the coupling of the NIST Dragon to the Building Research Institute's (BRI) Fire Research Wind Tunnel Facility (FRWTF) have quantified vulnerabilities that structures possess to firebrand showers for the first time.

Full-scale experiments are required to observe the vulnerabilities of structures to firebrand showers, but bench-scale test methods afford the capability to evaluate firebrand resistant building elements and may serve as the basis for new standard testing methodologies. To this end, Manzello *et al.* [4] developed the NIST Dragon's LAIR (Lofting and Ignition Research) facility to simulate wind driven firebrand showers at reduced-scale. This facility consists of a reduced-scale Firebrand Generator (known as the NIST Baby Dragon) coupled to a bench-scale wind tunnel. While the NIST Dragon's LAIR facility and the full-scale NIST Dragon coupled to BRI's FRWTF have been used to expose building elements to firebrand showers, the duration of exposure using the existing apparatus is limited. To develop test methods needed to evaluate different building materials resistance to firebrand showers requires the capability to generate firebrand showers of varying duration.

Accordingly, the NIST reduced-scale continuous feed Firebrand Generator (the NIST continuous feed Baby Dragon) was developed. The unique features of the NIST continuous feed Baby Dragon, over the present NIST Dragon, are the ability to produce a constant firebrand shower in order to expose building materials to continual firebrand bombardment. In a very recent study, Suzuki and Manzello [5] characterized the performance of this device. Another key issue is that the firebrand size and mass produced using the NIST continuous feed Baby Dragon has been tied to those measured from full-scale tree burns and actual WUI fires. This is incredibly critical since empirical characterization of firebrand exposure is extremely limited especially with respect to firebrand size distributions during actual WUI fire conditions. Consistently small sizes of windblown firebrands, similar to those generated using this device, were observed by data collection adjacent to a home that survived severe interface fire exposure. This is in stark contrast with the size of firebrands referenced in existing test standards and wildfire protection building construction recommendations [6].

The main reason to develop the new Dragon's LAIR is to allow detailed study of firebrand ignition of building materials under continual firebrand bombardment. It is desired that the facility may be used to evaluate and compare firebrand resistant technologies. A detailed description of this new and improved Dragon's LAIR facility is available in an upcoming publication [7].

3. EXPERIMENTAL DESCRIPTION

The description of the NIST reduced scale continuous feed Baby Dragon has been described in detail elsewhere [5]. However, the device required considerable redesign to be able to be interfaced with the wind tunnel (see Figure 1). A conveyer was used to feed wood pieces continuously into the device. The conveyer belt was set at 1.0 cm/s, and groups of wood pieces were put on the conveyer belt at 12.5 cm intervals. In each experiment, the group size placed on the conveyer belt was varied to allow for different firebrand exposures to the target (described below). For all tests, Douglas-fir wood pieces machined with dimensions of 7.9 mm (H) by 7.9 mm (W) by 12.7 mm (L) were used to produce firebrands. These same size wood pieces were used in past studies and have been shown to be commensurate with sizes measured from full-scale burning trees as well as distributions obtained from actual WUI fires [6].

An important operational parameter that was varied was the blower speed. When the blower was set to provide an average velocity below 4.4 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. Above 4.4 m/s, smoke production was mitigated but then the firebrands produced were in a state of flaming combustion as opposed to glowing combustion. It is possible for firebrands to remain in a flaming state under an air flow and, it is reasonable to assume that some firebrands may still be in a state of flaming combustion upon impact yet the purpose of this device is to simulate firebrand showers observed in long range spotting and therefore glowing firebrands were desired.

The Dragon's LAIR consisted of a reduced scale continuous feed Firebrand Generator (Baby Dragon) coupled to a reduced scale wind tunnel (see Figure 1). The test section of the wind tunnel was 50 cm x 50 cm x 200 cm. The flow was provided by an axial fan 91 cm in diameter.

Cedar crevices were constructed for ignition testing. Two pieces of cedar were aligned at an angle of 60 degrees. The dimensions of each cedar piece used were 114 mm wide by 448 mm long. The location of the cedar crevice was placed about 760 mm from the exit of the mouth of the NIST continuous feed Baby Dragon. This location was selected simply due to the fact that the firebrands were observed to land within the crevice using the wind speed selected in these experiments (6 m/s). The moisture content of the cedar pieces was varied using an oven. Cedar was selected since it is a common material used for both siding and roofing assemblies.

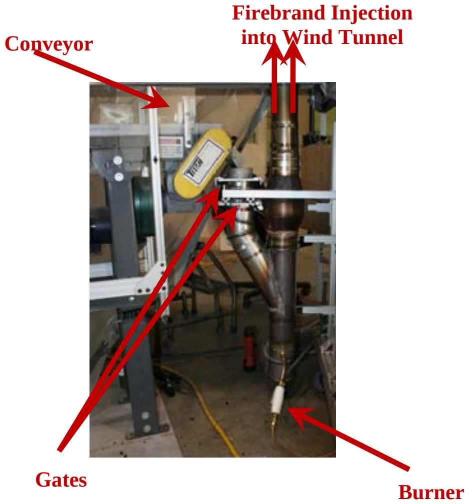

Figure 1 Schematic of NIST Continuous Feed Baby Dragon (side view) interfaced with bench scale wind tunnel.

Five different loadings of wood pieces were used for the ignition studies; the mean and the standard deviation of the mass were: 2.4 ± 0.2 g for 5 pieces (11.7 g/min), 4.8 ± 0.2 g for 10 pieces (23.1 g/min), 7.2 ± 0.2 g for 15 pieces (34.6 g/min), 14.4 ± 0.1 g for 30 pieces (69.1 g/min), and 19.1 ± 0.2 g for 40 pieces (91.7 g/min), respectively.

4. RESULTS AND DISCUSSION

The number flux, at the exit of the device, was measured as a function of the feed rate. Mass flux data were calculated by multiplying the number flux and the average mass of each firebrand at different feed rates. To measure the firebrand mass, a series of water pans were placed downstream of the NIST Reduced Scale Continuous Feed Baby Dragon after firebrand production reached steady conditions. Water pans were used to quench combustion of the firebrands.

After the experiment, 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 four hours. The mean mass and standard deviation of each firebrand was similar for all feed rates (*e.g.* 0.03 ± 0.006 g for 15 pieces, 0.04 ± 0.007 g for 30 pieces). These analyses were critical to determine the mass generation rate of firebrands for each feed rate. The generation rate (g/s) was linear and increased with an increase in wood feed rate.

Ignition regime maps were determined as a function of glowing firebrand generation rate for fixed wind tunnel speed (6 m/s) and two different cedar crevice moisture contents. Results are shown for dried cedar crevices in **Figure 2**. Ignition delay times were measured from the time the first firebrand was deposited inside the crevice to the observation of smoldering ignition (smoldering ignition, defined as intense glowing combustion within the cedar). Each data point represents the average of three experiments (average ± standard deviation). As can be seen, for a given moisture content and wind speed, the ignition delay time was observed to decrease as the firebrand generation rate was increased. For both dried and moist cedar crevices, smoldering ignition was observed for all feeding rates considered with the exception of 5 pieces.

To explain these results, it is important to consider the heat and mass transfer processes that take place at the fuel bed (cedar in this case) in contact with a glowing firebrand. The deposited firebrands heat up the surface resulting in the production of pyrolysates. As a result, flammable air/fuel mixtures are formed above the cedar crevice. Continued heat supplied from the firebrands contributes to exothermic gas-phase reaction, leading to ignition. The net heat flux, q''_{net} to the fuel bed from the impinged firebrands is given as:

$$q''_{net} = q''_{FB} - (q''_{conv} + q''_{rad} + \dot{m}'' L_v) \quad \text{(Eq. 1)}$$

where q''_{FB} is the heat flux from the firebrands, q''_{conv} is the convective heat flux, q''_{rad} is the radiative heat flux, $\dot{m}''$ is the mass loss rate per unit area, and L_v is the heat of gasification of cedar. The ignition time for thermally-thick materials is known to be proportional to the room temperature density, ρ, of the material and inversely proportional to the square of the net heat flux to the fuel bed, q''_{net} [8].

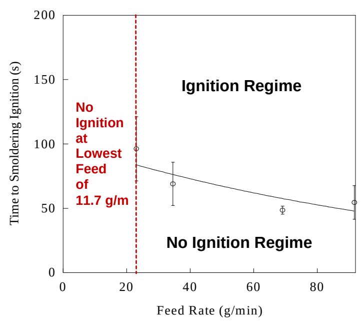

Figure 2. Ignition regime map (smoldering ignition - SI) as a function of glowing feed rate for wind tunnel speed of 6 m/s.

As the generation rate of firebrands was increased, for a given cedar moisture content and air flow, the resulting firebrand heat flux increased leading to an increase in the net heat flux to the cedar crevice. The mechanism by which the firebrand heat flux increased with firebrand generation rate was due to a greater accumulation of firebrands within the crevice itself. At a feeding rate of 5 pieces, the firebrand generation rate was insufficient to be able transfer the necessary heat flux to produce ignition. This is not to say that firebrands did not accumulate in the cedar crevice at a feed rate of 5 pieces; rather, intense glowing combustion was not sustained due to the delayed arrival times of firebrands at this low feeding rate.

5. SUMMARY

The present investigation was undertaken to construct a new and improved Dragon's LAIR facility. This work has set the stage to be able to evaluate and compare various building materials resistance to ignition from firebrand showers for the first time.

6. REFERENCES

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