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Generating wind-driven firebrand showers characteristic of burning structures

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Abstract

Firebrands are a significant source leading to structures ignited and lost in large outdoor fires, such as Wildland–Urban Interface (WUI) fires, a large international problem, and urban fires, common in Japan. Sadly, hardly any information is available with regard to firebrand production from burning structures or actual large outdoor fires in general. To this end, an experimental database is being generated from firebrand generation from structure combustion. This paper will focus on how these detailed database results are being used to generate firebrand showers using a redesigned firebrand generator experimental apparatus installed in a full-scale wind tunnel, with the intent to experimentally simulate firebrand showers produced from structure combustion in large outdoor fires.

Keywords: Wildland–Urban Interface (WUI) Fire; Urban fires; Firebrand generation

1. Introduction

Wildland–Urban Interface (WUI) fires, or fires that start in the wildlands and move into communities, have become an increasing international dilemma. The WUI fire problem, sadly, has impacted countries all over the world in the past five years [1]. The world watched as an entire Canadian city in 2016 was subjected to the wrath of a gargantuan WUI fire. The recent Canadian WUI fire also showed how such events can negatively impact natural resources, such as blocking oil production.

In Japan, after earthquakes, many fires may develop that can stretch and eventually overwhelm available suppression resources. Once suppression efforts are exhausted, intense fire spread has been documented within such urban areas in Japan. Firebrands, also referred to as embers, are a key structure ignition mechanism in WUI fires and urban fires [2]. Perhaps even more surprising is that only a handful of literature studies are available with regard to firebrand production from burning structures or actual large outdoor fires in general.

Due to such past little research into WUI fires, the ability to unravel the complex interaction of exactly how structures may be vulnerable to firebrands has only just begun. Due to the page

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Table 1
Salient results of current experimental database on firebrand production from structure combustion.

	Peak fire intensity	Materials	Wind speed	Measurement methods	Salient findings
Two-story house [6]	Not quantified	Wood and brick	6 m/s	Water pans	All firebrands less than 1 g
					Most the firebrands less than 10 cm^2
Simplified structure [7]	1.76 MW/m^2	OSB and wood 2×4 studs	6 m/s	Water pans	More than 90% of firebrands were less than 1 g
					More than 90% of the firebrands less than 10 cm^2
Real-scale building components [8]	Not quantified	OSB and wood 2×4 studs	6 m/s	Water pans	More than 90% of firebrands were less than 1 g
			8 m/s		More than 90% of the firebrands less than 10 cm^2

limitations of papers published as a part of the international combustion symposium, a complete discussion of this firebrand generator capability is impossible presently [3]. An obvious commonality of our prior studies was that the firebrand size produced using the firebrand generator was tailored to those measured from burning vegetation, and a recent WUI fire [4–5]. While these prior studies have been recognized as a major first step to begin to unravel the complete problem of WUI fire spread, it is more than apparent that considerably more information is needed for firebrand size/mass distributions from various types of vegetation, structures, and actual WUI and urban fires [3]. In particular, in the case of WUI fires, once the fire spreads from the wildlands to the communities, structure combustion, and therefore firebrand production from structures, becomes important, just as in the case of urban fire spread in Japan.

To this end, the authors have embarked on making a comprehensive database of firebrand production from burning structures/structure components [6–9], a major challenge itself. This paper describes efforts to generate firebrand showers using a redesigned continuous-feed firebrand generator with size and mass similar to distributions in this structure firebrand database. To accomplish these goals required the design and construction of an entirely new feeding system, a major challenge as the experimental device was fitted to a full-scale wind tunnel facility.

2. Development of database of structure firebrand production from actual structure combustion to simple building component combustion

The reader is referred to historical studies in the literature [10–12], yet the firebrand collection methodologies differ widely, making a direct comparison difficult at best. For example, prior firebrand collection strategies have ranged from plastic sheets to wet pans and dry pans. It is critical for the reader to grasp that these are not sophisticated diagnostic methods. Therefore, the authors have embarked on developing a database on firebrand production from structures using similar, quantifiable experimental collection techniques. Specifically, experiments have been conducted from a range of complexities and scales to determine if far simpler experiments may be used to provide greater depth of understanding into firebrand generation from the combustion of structures. As wind is important in large outdoor fire spread, the database also compares firebrand production under similar wind speeds. A brief overview of these prior studies is delineated below (see Table 1).

Figure 1 displays images of these experiments, from actual house combustion to simple wall combustion. Firstly, firebrands were collected using water pans from a two-story house ignited under a wind speed of 5.8 m/s [6]. Subsequently, firebrand production from a simplified structure under well-defined laboratory conditions was determined using similar wind speeds and similar firebrand collection methodologies as the two-story house experiment [7]. Finally, firebrand production from real-scale building components was studied under laboratory conditions [8]. It was reported that key similarities of the mass/size distributions of firebrands were observed from components as compared to the full-scale structure experiments under similar wind speeds. These results were very exciting since component experiments are much simpler to undertake, leading to useful insights in firebrand production processes.

Most recently, component experiments have been conducted with the addition of commonly found wood siding treatments [9]. The addition of actual siding types is an important consideration in the development of this database. A summary of the current stage of the database is provided in Table 1. In particular, Table 1 provides detailed data regarding the collected firebrand size and mass distributions for all these complex experimental investigations mentioned above.

Fig. 1. Experiments conducted, in order of complexity, to quantify firebrand production from structures.

3. Experimental description

With further understanding of firebrand production from structures combined with the knowledge that simple combustion of walls provides insight into the firebrand production process, experiments were undertaken to simulate firebrand showers generated from burning structures. Figure 2 is a schematic of the redesigned experimental apparatus. The description differs from prior work since the feeding system was redesigned to be able to cope with large wood fuels [4–5]. The use of larger wood chips affords the ability to experimentally produce firebrand exposure conditions over different regimes, and as described below, results in firebrand showers more closely aligned to those from burning structures.

The experimental apparatus consisted of the main body and the continuous feeding component, and again, in the present investigation, the main body was essentially the same as prior investigations (Dragon component). The feeding system was completely redesigned as compared to prior studies of continuous firebrand generation. *It cannot be overstated* that the development of an entirely new feeding system was a significant and challenging task, as these are full-scale experiments, and the authors have developed the world's first firebrand generation experimental apparatus. There exists no other prior research, other than prior studies of current authors, to guide the development of the new feeding system constructed for the present study.

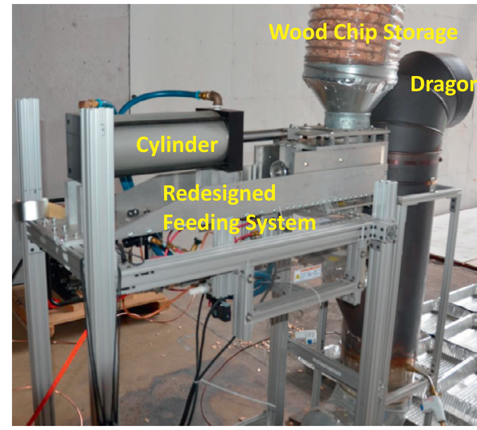

Fig. 2. Schematic of continuous-feed firebrand generator. The redesigned feed system is shown.

In this experimental apparatus, airflow required for firebrand combustion/lofting was provided by a variable frequency drive blower that was coupled to the main body [4–5]. The airflow speed was initially varied to determine optimal operating conditions for glowing firebrand generation. In this work, the airflow used for firebrand generation had an average velocity of 2.0 m/s. These velocities were measured at the exit of the Dragon component using an anemometer. Due to the larger projected area of the wood chips used here, as described below, these blower speeds were lower than prior studies.

The feeding system made use of a large air driven cylinder. A custom constructed receptacle was used to store the wood chips (see Fig. 2). Directly beneath the wood storage area, a custom metal plate was fitted that allowed changes in the volume of wood to fall from the storage receptacle to the first gate. By adjusting this volume, the amount of wood chips that enter the main body (Dragon) for eventual combustion may be varied. When the air pressure was energized, the rod of the air cylinder slid forward and separated the wood pieces from the storage receptacle to the first gate, where they were then deposited towards the second gate that leads to the Dragon where they are ignited using a propane fueled burner that is kept on continuously during the experiments (see Fig. 2). Great attention was taken to select the air cylinder used here. Presently it had a maximum load of 12.0 kN, much greater force than our prior feeding appara-

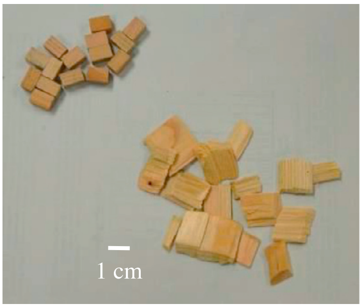

Fig. 3. Fuel sources used to produce firebrands. Douglas-fir pieces (top left) are compared to Japanese Cypress wood chips (bottom right). The newly designed feeding system (Fig. 2) was required for Japanese Cypress wood chips.

tus; see [4–5]. Initially, smaller sized air cylinders were observed to be unable to push through the wood chips, resulting in jamming. The gate system was required to mitigate any potential fire from spreading to the Dragon from the feed system. Both gate one and gate two were driven by separate air (much smaller) air cylinders as well.

For all wind tunnel speeds, Japanese Cypress wood chips provided the source fuel to produce firebrands (see Fig. 3). These were simply purchased from a local vendor that provided high quality chips at a reasonable cost. Once received at the laboratory, an intricate filtering procedure, using a 10 mm wire mesh to remove traces of very fine wood pieces that settled as the wood chips were bagged and shipped, was undertaken The chips were also oven dried prior to the experiments, as the chips were harvested from trees and were not dried prior to shipping. These size wood pieces were selected to produce firebrands with larger projected area at a specific mass than that used in our prior studies using continuous firebrand generation [4–5]. The overall dimensions of the fuel used for firebrand generation before combustion were 28±8 mm (length), 18±6 mm (width), and 3±1.0 mm (thickness) (average ± standard deviation), respectively. To generate the wind, all experiments were conducted at the BRI's FRWTF. The cross section of the FRWTF is 5 m wide by 4 m high, up to 10 m/s wind speed.

4. Results and discussion

Various wood chip feeding rates were considered to be able to generate firebrand showers similar to burning structures. To properly quantify the operation of the device required the determination of the firebrand number flux. Specifically, the number of firebrands generated/m^{2}s, at the exit of the device. High quality firebrand generation was observed at a feeding rate of 680 g/min. The number of firebrands was counted from video records and it was observed that the firebrand number flux reached a steady value of 530/m^{2}s.

Mass flux data (mass of firebrands generated/m^{2}s) were calculated from the product of the number flux and the average mass of each firebrand generated at a specific wood chip feed rate. To properly quantify the firebrand mass, another series of experiments was conducted using water pans placed downstream of the experimental apparatus. The pans were collected once the experiment was completed and the firebrands were filtered from the water using filters. Firebrands were dried in an oven and the temporal variation of mass was recorded to determine how much a time was required to be able to completely dry the firebrands. For completeness, Fig. 4 displays the firebrands collected in the water pan array after a representative experiment (wind speed was 6 m/s).

Figure 5 displays the projected area of the firebrands produced at three different wind speeds (6 m/s, 8 m/s, and 9 m/s). The projected areas of the generated firebrands were determined using image analysis methods. Images of coins, and other simple geometries, were used properly to evaluate the image analysis method to calculate the projected area [6]. Based on repeat measurements of various geometries, the standard uncertainty in determining the projected area was ±10%. A scale was used to measure the mass of all the firebrands and the standard uncertainty in the firebrand mass was approximately ±1%. The average mass of each firebrand was obtained and observed to be 0.03 g. Based on all the above analyses, the mass flux of generated firebrands was calculated to be 16 g/m^{2}s.

Figure 6 shows the comparison of firebrands from the firebrand generator in this work and studies related to the experimental database of firebrand production from structure components and simplified structure [6–9] under a 6 m/s wind. Firebrands generated in this study were observed to be similar to those measured from burning structure components and a simplified structure. For reference, the average projected area of firebrands generated in this study tailored to burning structure components was 1.75 cm^2 (average based on data under 6 m/s, 8 m/s, and 9 m/s speeds). It is important to note that very few firebrands had projected areas larger than 5 cm^2 for masses up to 0.2 g, yet the graph was scaled so all areas may be shown.

For the comparison in Fig. 7, the use of Douglas-fir wood pieces in prior studies was predicated on data from actual WUI fires and tree combustion firebrand generation data. Specifically, another separate investigation examined the size distribution of firebrand exposure during an actual California WUI fire [13]. In that study, the burn areas of objects exposed to firebrand attack was computed using digital image analysis.

Other researchers have followed this methodology to collect firebrand size distributions from the recent WUI fires in Texas, as well, and reported

Fig. 4. Firebrands collected in water pan array. The wind speeds in this experiments was 6 m/s. Similar pan arrays were used to collected firebrands for the various wind tunnel speeds.

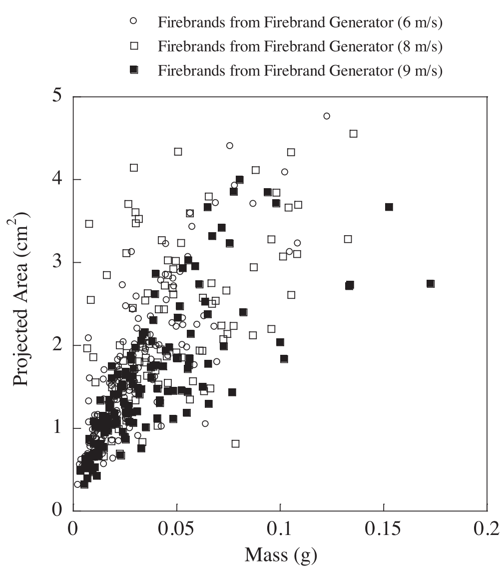

Fig. 5. Size and mass distribution of firebrands produced under various wind speeds (6 m/s, 8 m/s, and 9 m/s). The standard uncertainty in determining the projected area was ±10%. The standard uncertainty in the firebrand mass was approximately ±1%.

large numbers of very small firebrands were produced [14]. As a result, the average projected area of firebrands generated was 0.8 cm^2 in prior studies of continuous firebrand generation tailored to burning trees and data from an actual WUI fire. Again, in prior studies Douglas-Fir wood pieces (see Fig. 3) were used to generate firebrands and feed-

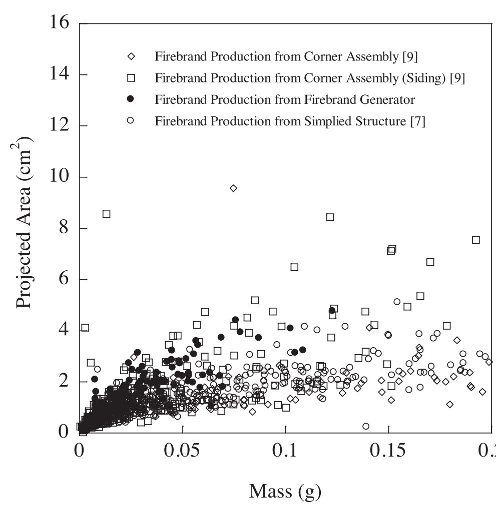

Fig. 6. Comparison of firebrands produced using firebrand generator to those measured from burning structure components and simplified structure. All comparisons are for firebrand data collected under 6 m/s wind speed. The mass range shown was selected to be able to clearly see the distribution.

ing system was different that the one used presently (see Fig. 7) [4–5].

5. Summary

This paper described efforts to generate firebrand showers with size and mass similar to distributions from a structure firebrand data set us-

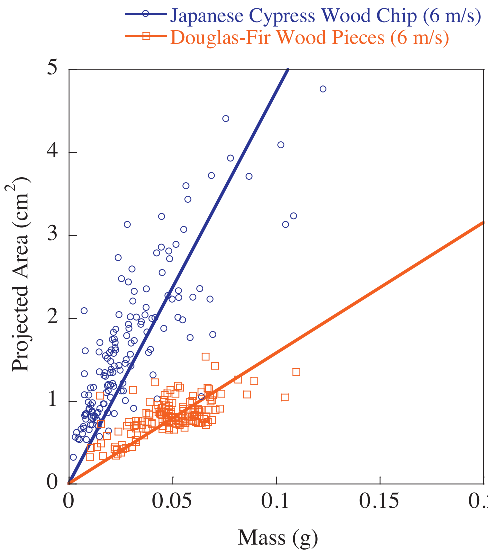

Fig. 7. Comparison of firebrands produced using two different types of feeding materials. Douglas-fir wood pieces were used to simulate firebrand sizes from actual WUI fires/ and tree combustion, and Japanese Cypress wood chips were used to simulate firebrands from burning structures (see Fig. 3 for a photo of the wood chips/pieces). Two different feeding systems were used to generate firebrand showers.

ing a redesigned continuous-feed firebrand generator installed in a full-scale wind tunnel facility. It is now possible to generate wind-driven firebrand showers with similar mass flux to prior studies of continuous firebrand generation (16 g/m^{2}s vs. 17 g/m^{2}s [4–5]), but with firebrands of about twice the average projected area. Experiments have recently been conducted to evaluate the performance of full-scale roofing components exposed to the types of structure firebrands described in this paper; the results of those experiments may be found elsewhere [15].

It cannot be emphasized enough that *more research* is needed for firebrand distributions from not only structures, but also actual large outdoor fires. New and improved diagnostic methods to quantify firebrand exposure from real fire scenes are also sorely needed. The unique experimental methodologies described as a part of this work are attempting to bring *quantification t*o the complex problem of firebrand generation and ignition of structures in large outdoor fires.

Recent WUI fire post-fire disaster investigations have revealed that structure firebrand production is of paramount importance in WUI fire spread, rendering the new experimental methodologies presented here of critical need to understand WUI fires [16]. At the same time, the authors hope that this work will be useful in the development of modeling firebrand production from structures in large outdoor fires. As several research groups have devoted entire publications to modeling the unique experimental datasets from our prior studies [17], the new structure firebrand production results presented here will add needed further understanding to this complex, unresolved area in fire research.

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