Firebrand Production From Burning Vegetation[1]

Samuel L. Manzello*, Alexander Maranghides, William E. Mell,
Thomas G. Cleary, and Jiann C. Yang
*Building and Fire Research Laboratory, National Institute of Standards and Technology,
100 Bureau Drive, Gaithersburg, MD 20899 USA*
*Corresponding author: +1-301-975-6891 (office), email: samuelm@nist.gov

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Abstract: A series of real scale fire experiments were performed to determine the size and mass distribution of firebrands generated from Douglas-Fir (*pseudotsuga menziesii*) trees. The results of the real scale fire experiments were used to determine firebrand sizes to perform reduced scale ignition studies of fuel beds in contact with burning firebrands. The firebrand ignition apparatus allowed for the ignition and deposition of both single and multiple firebrands onto the target fuel bed. The moisture content of the fuel beds used was varied and the fuels considered were pine needle beds, shredded paper beds, and shredded hardwood mulch. Firebrands were constructed by machining wood (Douglass-Fir) into small cylinders of uniform geometry and the size of the cylinders was varied. The firebrand ignition apparatus was installed into the Fire Emulator / Detector Evaluator (FE/DE) to investigate the influence of an air flow on the ignition propensity of fuel beds. Results of this study are presented and compared to relevant studies in the literature.

Keywords: WUI Fires, Firebrands, Fuel Beds, Ignition

1. Introduction

Wildland-urban interface (WUI) fires have plagued the United States for centuries. Recent WUI fires include the 2003 Southern California Fires. Firebrands are produced as vegetation and structures burn in WUI fires. These firebrands are entrained in the atmosphere and may be carried by winds over long distances. Hot firebrands ultimately come to rest and may ignite fuel beds far removed from the fire, resulting in fire spread. Understanding how these hot firebrands can ignite surrounding fuel beds is an important consideration in mitigating fire spread in communities (Pagni, 1993).

Unfortunately, ignition due to spotting is one of the most difficult aspects to understand in WUI fires (Babrauskas, 2003). Furthermore, the size distribution of firebrands produced from burning vegetation and structures is relatively unknown. A major advance in WUI fire research would be the development of a model to predict: the generation of firebrands from burning vegetation and structures, their subsequent transport through the atmosphere, and the ultimate ignitability of materials due to their impact (Babrauskas, 2003). Of these, the transport of firebrands has been studied most extensively (Himoto and Tanaka, 2005; Woycheese, 2001, 2000; Tse and Fernandez-Pello, 1998; Albini, 1983, 1979; Muraszew and Feldele, 1976; Lee and Hellman, 1970; Tarifa *et al.*,

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1967, 1965). Some ignition theories have been published (Jones, 1995), but the lack of a detailed theory on the ability of firebrands to ignite remote objects limits the utility of detailed computational fluid dynamic models (CFD) that could be used to predict fire spread by firebrands (Babrauskas, 2003). Detailed experimental ignition studies of fuel beds typically found in the WUI due to firebrand impact are required to validate such models. Furthermore, as an input to firebrand transport models, experimental information with regard to firebrand size distributions generated from burning vegetation and/or structures is needed.

A very limited number of experimental studies have been performed to investigate the size distribution of firebrands produced from burning vegetation and structures. Waterman (1969) burned full scale segments of different roof assemblies and the firebrands produced were trapped by a screened chamber and fell into a quenching pool. The firebrands collected were generally disk shaped. Waterman (1969) did not perform any experiments concerning firebrand generation from vegetation. The ignition of fuels due to firebrand impact has been investigated in more detail (by no means exhaustive) as compared to firebrand generation and some laboratory studies are available in the open literature (Babrauskas, 2003). Investigations relevant to the present study are reviewed elsewhere (Manzello *et al*., 2006).

Consequently, the goal of this study is to investigate firebrand ignition of fuel beds found in the WUI. To this end, a series of real scale fire experiments were performed to determine the size and mass distribution of firebrands generated from Douglas-Fir (*Pseudotsuga menziesii*) trees. The results of the real scale fire experiments were used to determine firebrand sizes to perform reduced scale ignition studies of fuel beds in contact with burning firebrands. The experimental results presented here were compared to relevant studies available in the literature.

2. Experimental Description

Real Scale Douglas-Fir Experiments

Douglas-Fir was selected as the tree species for these experiments since it is abundant in the Western United States of America and it is here that WUI fires are most prevalent (Pagni, 1993; Albini, 1983). The height of the Douglas-Fir trees used for the firebrand collection experiments was varied from 2.4 m to 5.2 m. The maximum girth dimension was 1.5 m wide and 3.0 m wide, for the 2.4 m and 5.2 m tree heights, respectively. The trees were size selected from a local nursery, cut, and delivered to the Large Fire Laboratory (LFL) at NIST. Subsequently, the trees were mounted on custom stands and the trees were allowed to dry. During the experiments, no wind was imposed on the trees.

The moisture content of the tree samples was measured using a Computrac[2] moisture meter. Needle samples as well as small branch samples (three heights, four radial locations at each height) were collected for the moisture measurements. The measurements were taken on a bi-weekly basis. The moisture content, determined on a dry basis, is given as:

$$Moisture\ Content = \frac{M_{wet} - M_{dry}}{M_{dry}} * 100 \qquad (1)$$

[2] Certain commercial equipment are identified to accurately describe the methods used; this in no way implies endorsement from NIST

where M_{wet} and M_{dry} are the mass of the tree samples before and after oven drying, respectively. At ignition, the tree moisture content was varied from 10 % to 50 %. The total combined uncertainty in these measurements is estimated to be ± 10 %. More than 30 days of drying time was required to reach moisture content levels at or below 30 %. The justification for this moisture range is given below.

A total of nine Douglas-Fir trees were burned to collect firebrands; six 2.4 m trees and three 5.2 m trees. The trees were ignited using a custom burner assembly specifically designed for these experiments. The burner surrounded the tree at its base and was fueled with natural gas. The total ignition time was 15 s. Both digital still photography and standard color video (standard 30 frames per second) were used to record the ignition and burning process of the Douglas-Fir trees.

Figure 1 displays a schematic of the firebrand collection pan assembly. An important issue during the experimental campaign was that the hood assembly (9 m by 12 m) in the LFL needed to be switched off to collect the firebrands. If the hood system was operated, the firebrands generated would be drawn into the hood; thus no firebrand collection was possible. This presented considerable safety challenges. A series of scoping experiments were performed using small trees (on the order of 1.8 m) in order to bootstrap up to the larger tree sizes. Based on these scoping experiments, the 5.2 m trees were the largest size tree we could safely burn in the LFL. When testing the 5.2 m trees, the entire 9 m by 12 m hood was filled with flames during the testing.

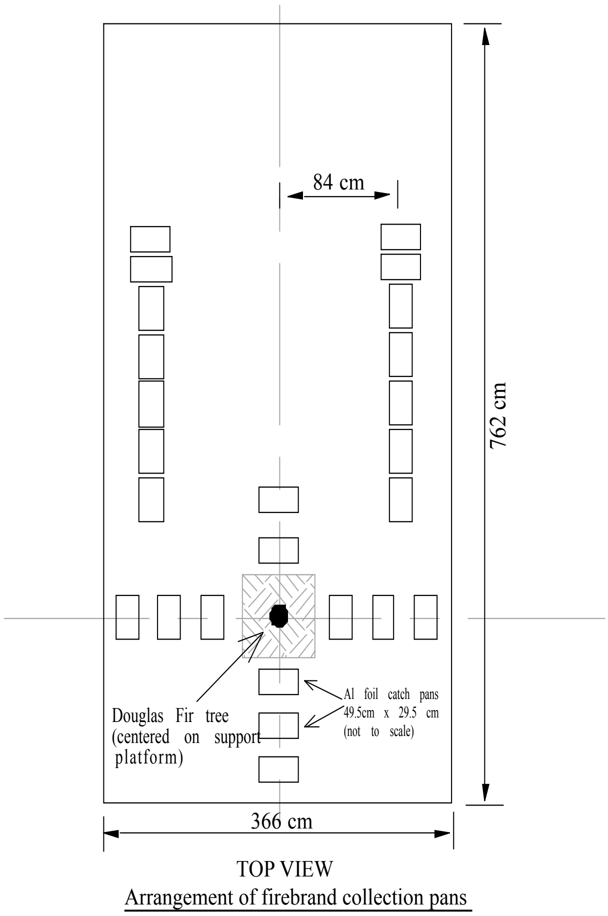

Fig. 1 Schematic of firebrand collection pan assembly.

A total of 26 rectangular pans (water filled) were used to collect firebrands. Each pan was 49.5 cm long by 29.5 cm wide. The arrangement of the pans was not random; rather it was based on scoping experiments to determine the locations where the firebrands would land. After the experiments were completed, the pans were collected and the firebrands were filtered from the water using a series of fine mesh filters. The firebrands were subsequently dried in an oven held at 104 °C for eight hours. The firebrand sizes were then measured using precision calipers (1/100 mm resolution). Following size determination, the firebrands were then weighed using a precision balance (0.001 g resolution). For each tree burned, more than 70 firebrands were dried and measured. In all, more than 400 collected firebrands were sized and weighed.

Two different load cells were used in order to resolve the disparate initial mass loading for the two tree heights considered. The voltage from the load cells was recorded using custom data processing software as the trees burned.

Reduced Scale Firebrand Ignition Experiments

The firebrand ignition apparatus consists of four butane burners and a firebrand mounting probe. The butane flowrate is controlled by a metering valve coupled to a solenoid valve. The firebrand, or in the case of multiple firebrand impact, firebrands, are held into position and the air pressure is activated, which moves the actuator and clamps the firebrand(s) into position. The retraction of the burner upon ignition and the free-burn time of the firebrands are computer controlled which ensures repeatability. Each butane burner was designed to be switched on or off, depending upon the number of firebrands needed for the particular experiment. Further details of the apparatus, including the FE/DE, are described in detail elsewhere (Manzello *et al*., 2006).

Firebrands were constructed by machining wood into sections of uniform geometry. For the present study, firebrands were simulated as cylinders of two different sizes. The first size produced was 10 mm in diameter with a length of 76 mm. The second size used was 5 mm in diameter with a length of 51 mm. These sizes were determined from the measured firebrand size distributions generated from the real scale Douglas-Fir experiments (as discussed below). Naturally, Douglas-Fir was selected as the wood type for the reduced scale firebrand ignition experiments. Prior to machining the cylinders, the Douglas-Fir planks were stored in a conditioning room at 21 °C, 50 % relative humidity. After the disks were machined, they were stored in the conditioning room prior to the experiments.

Three different materials were used as test fuel beds for the ignition studies: (1) pine needles, (2) shredded paper, and (3) shredded hardwood mulch. The impact of burning firebrands on pine needle beds was designed to simulate the showering of firebrands into gutters. Shredded paper beds were used to simulate firebrand impact upon materials within attic spaces. Shredded hardwood mulch beds were used to simulate the collection of firebrands on mulch located outside homes and structures. Such materials are believed to be prone to ignition in WUI fires (Cohen, 1991).

The pine needles, shredded paper, and shredded hardwood mulch were contained in aluminum foil pans of 23 cm long by 23 cm wide by 5.1 cm deep. The initial mass was fixed for the fuel beds to ensure repeatability. The moisture content of these materials was varied from 0 % to 11 %. The moisture content was determined by oven drying the samples. It was found that three hours of oven drying at 104 °C was sufficient to remove all the moisture in the pine needle beds, shredded paper beds, and shredded hardwood mulch. The firebrand ignition process and release onto the target fuel beds was captured using a CCD camera coupled to a zoom lens.

Firebrands were ignited for a fixed duration and were allowed to free burn. The firebrands were then released onto a load cell and the burning history of the firebrands was obtained from the gravimetric measurements. Three conditions were measured: (1) no air flow, (2) air flow of 0.5 m/s, and (3) air flow of 1.0 m/s. No air flow conditions were used presently to investigate the influence of an air flow on firebrand burning only. Under air flow conditions, the firebrands were ignited under low flow conditions and the air flow was ramped up as soon as the ignition process was over. The ignition time for 5 mm and 10 mm firebrands was 10 s and 75 s, respectively. Under no air flow conditions, the firebrand remained in a flaming state. When an air flow was introduced, the air flow blew off the envelope flame from the leading edge of the firebrand and gradually blew the flame off the back side of the firebrand. After the flame was blown off, a glowing firebrand resulted. A similar result was observed using ponderosa pine disks (Manzello *et al.*, 2006). The ignition propensity of the pine needle beds, shredded paper beds, and shredded hardwood mulch beds was assessed based upon *both* glowing and flaming firebrand impact.

When the burning firebrands were deposited onto the fuel beds, experiments were performed only under conditions of an air flow (0.5 m/s and 1.0 m/s), since it is not expected that the flow conditions would be quiescent as firebrands impact fuel beds during WUI fires. It is important to note that the ambient temperature inside the duct of the FE / DE was monitored and fixed at 21 °C for all experiments reported here. Ambient temperature conditions are known to influence ignition outcomes for fuel beds (Hughes and Jones, 1994).

3. RESULTS AND DISCUSSION

Prior investigations using Douglas-Fir trees have focused on measuring heat release rates (HRR) as a function of moisture content (Baker, 2005; Babrauskas, 2002). These measurements were used to assess flammability of trees located close to homes and structures. It was reported that for Douglas-Fir trees with moisture content (determined on a dry basis) greater than 70 %, it was not possible to sustain burning after ignition. Within moisture content limits of 30 % to 70 %, a transition regime occurs where Douglas-Fir trees will only partially burn after an ignition source is applied. Below 30 % moisture content, Douglas-Fir trees will be fully consumed after ignition (Baker, 2005; Babrauskas, 2002).

Therefore, the firebrand collection experiments were performed in the following manner. Douglas-Fir trees of 2.4 m were ignited at a moisture content of 50 % (within transition regime); three replicate experiments were performed. Similar to previous work, it was observed that the Douglas-Fir trees would only partially burn. Furthermore, at the 50 % moisture content level, firebrands were not produced. From these results, experiments were then performed using 2.4 m trees within the vigorous burning regime. Under these conditions, the Douglas-Fir trees were observed to burn intensely; typically the entire tree was engulfed in flame within 20 seconds after ignition. A similar methodology was adopted for the 5.2 m Douglas-Fir trees. In summary, Douglas-Fir trees generated firebrands only if the moisture content was maintained below 30 %, within the vigorous burning regime (Baker, 2005; Babrauskas, 2002).

Figure 2 displays a digital photograph of the firebrands collected from the Douglas-Fir tree burns. For all experiments performed, the firebrands were cylindrical in shape. The average firebrand size measured (based on three replicate experiments; 210 firebrands measured in total for each height) from the 2.4 m Douglas-Fir trees (10 % moisture content) were 3 mm in diameter, 40 mm in length. The average firebrand size measured (based on three replicate experiments) for the 5.2 m Douglas-Fir trees (18 % moisture content) was 4 mm in diameter with a length of 53 mm. For the present experiments, moisture contents of 10 % and 18 % are similar, based on the uncertainty analysis.

Fig. 2 Digital photographs showing samples of the firebrands collected as a function of tree size and moisture content. Tree Height 5.2 m, Moisture Content 20 %.

The mass distribution obtained for the 2.4 m and 5.2 m Douglas-Fir trees is displayed in figure 3. A large percentage of the firebrands collected and weighed were less than 0.3 g in weight. The largest mass of firebrands measured for the 2.4 m Douglas-Fir trees were in the range of 2.1 g to 2.3 g. Overall, the mass distribution of firebrands produced from the two different tree sizes under similar tree moisture levels was similar. The only noticeable difference occurred in the largest mass class. Firebrands with masses up to 3.5 g to 3.7 g were observed for the larger tree height used. The surface area distribution was also calculated assuming cylindrical geometry and plotted versus the measured mass for the collected firebrands. These data are shown in figure 4. The surface area of the firebrands scaled nearly linearly with firebrand weight.

During burning, the Douglas-Fir trees were mounted on top of load cells. For the 2.4 m Douglas-Fir tree experiments performed at 10 % moisture content, the initial tree mass ranged from 10 kg to 11 kg. Upon completion of the tests, the final tree mass varied from 6 kg to 7 kg. The average firebrand mass collected in the pans, based on three replicate experiments was 18 g ± 4 g. Therefore, of the 4 kg of mass that was lost during burning, 0.45 % was measured as firebrands at the pan locations.

For the 5.2 m Douglas-Fir tree experiments performed at 18 % moisture content, the average mass lost during burning was 17 kg ± 1 kg. A mass of 50 g ± 5 g was measured as the total mass collected as firebrands in the pans. Figure 5 displays these results. This suggests that the firebrand mass collected at the pan locations scales with the total mass lost during the burning of the Douglas-Fir trees (for fixed, similar moisture content). On the other hand, when comparing the ratio of mass lost during burning to mass collected as firebrands, this ratio decreased from 0.45 % for the 2.4 m trees to 0.3% for the 5.2 m trees.

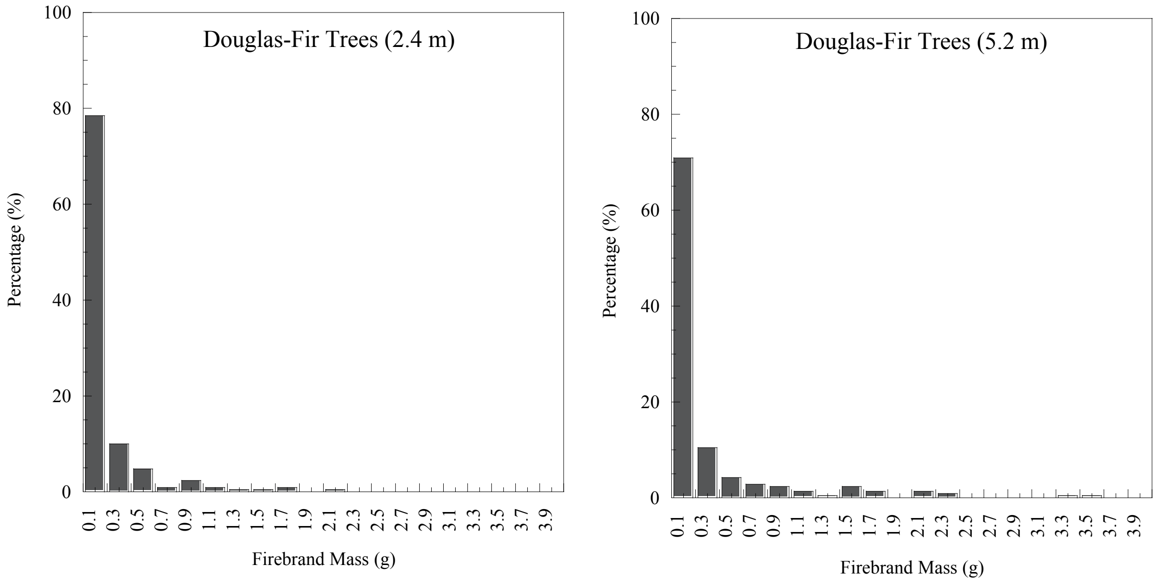

Fig. 3 Mass distribution of collected firebrands from Douglas-Fir trees.

Single Firebrand Ignition Results

Experiments were performed for single firebrand impact (both flaming and glowing) to investigate whether it was possible to ignite fuel beds under such conditions. The ignition results obtained for single glowing firebrand impact into pine needle beds are displayed in Table 1. Each result was based on identical, three repeat experiments. The mass of a single glowing firebrand at the time of release into the fuel bed was 0.2 g and 0.67 g for the 5 mm and 10 mm diameter firebrands, respectively. The acronym NI denotes no ignition, these results are colored in blue.

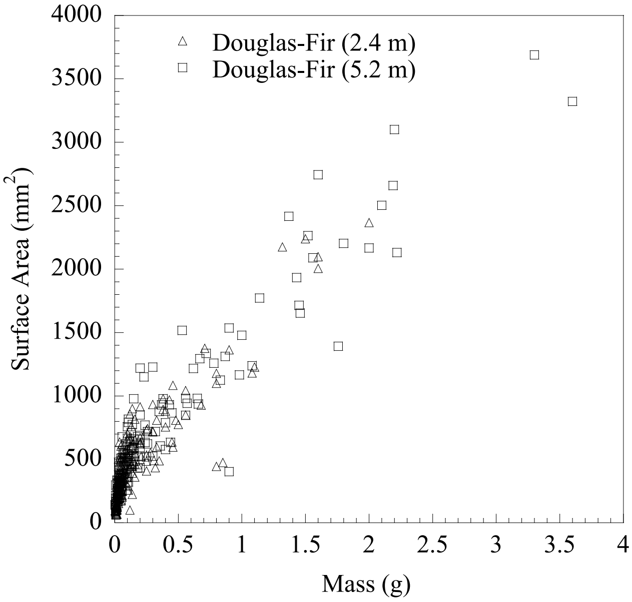

Fig. 4 Calculated surface area plotted as function of the mass of the collected firebrands.

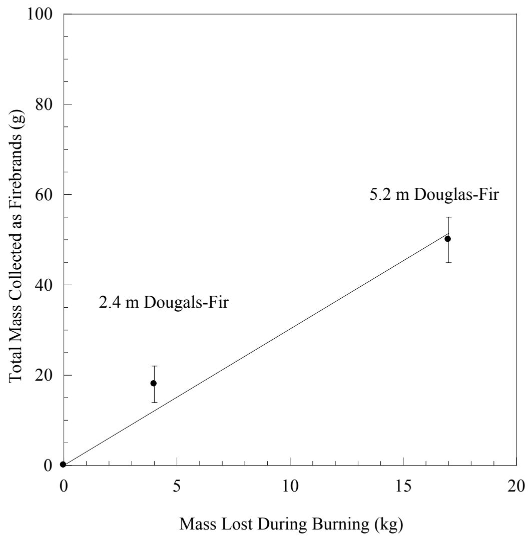

Fig. 5 Measured mass collected as firebrands (at pan locations) versus measured mass lost during burning. Data are shown for 2.4 m and 5.2 m Douglas-Fir trees held under similar moisture content (dry basis).

For the firebrand sizes tested and the experimental combination tested, it was not possible to ignite pine needle beds from single glowing firebrand impact. After the firebrand impacted the pine needle bed, one or two needles would smolder and the smolder front would not propagate further in the bed.

Number of Firebrands Deposited	State of Firebrand at Impact	Air Flow (m/s)	Firebrand Size (mm)	Pine Needles (dry)	Pine Needles (11 %)	Shredder Paper (dry)	Shredded Paper (11 %)	Hardwd. Mulch (dry)	Hardwd. Mulch (11 %)
1	Glowing	0.5	5	NI	NI	SI	SI	NI	NI
1	Glowing	0.5	10	NI	NI	SI	SI	NI	NI
1	Glowing	1	5	NI	NI	SI	SI	NI	NI
1	Glowing	1	10	NI	NI	SI	SI	NI	NI
1	Flaming	0.5	5	FI	FI	FI	FI	FI	NI
1	Flaming	0.5	10	FI	FI	FI	FI	FI	NI
1	Flaming	1	5	FI	FI	FI	FI	FI	NI
1	Flaming	1	10	FI	FI	FI	FI	FI	NI
4	Glowing	0.5	5	NI	NI	NT	NT	NI	NI
4	Glowing	0.5	10	NI	NI	NT	NT	SI	NI
4	Glowing	1	5	NI	NI	NT	NT	SI	NI
4	Glowing	1	10	SI to FI	NI	NT	NT	SI	NI
4	Flaming	0.5	5	NT	NT	NT	NT	NT	NI
4	Flaming	0.5	10	NT	NT	NT	NT	NT	NI
4	Flaming	1	5	NT	NT	NT	NT	NT	NI
4	Flaming	1	10	NT	NT	NT	NT	NT	NI

Table 1 Firebrand (cylindrical) ignition data for firebrand impact onto pine needle beds, shredded paper beds, and shredded hardwood mulch beds.

Table 1 displays results obtained for single glowing firebrand impact into shredded paper beds. The acronym SI denotes smoldering ignition, these results are colored in red.. Smoldering ignition was possible for single glowing firebrand impact. Presently, smoldering ignition was defined when the smoldering front propagated outwards from the deposited firebrand into the bed.

Ignition events were not observed when single glowing firebrands were deposited onto shredded hardwood mulch beds (see Table 1). Consequently, it was observed that single glowing firebrands posed an ignition danger only to shredded paper beds.

Table 1 shows ignition results for single flaming firebrand impact onto pine needle beds, shredded paper beds, and shredded hardwood mulch beds, respectively. To produce flaming firebrands, the firebrands were ignited and then allowed to free burn for 10 s prior to release into the samples. The mass of a single flaming firebrand at release into the fuel bed was 0.4 g and 1.5 g for the 5 mm and 10 mm firebrands, respectively. The acronym FI denotes flaming ignition, these results are colored in red. From these tables, under all conditions considered, it was possible to produce flaming ignition from single firebrand impact when the firebrands were released in a flaming state onto pine needle beds and shredded paper beds. These results suggest that if the firebrands are in flaming mode, only a single firebrand is required to begin an ignition event for these materials.

For shredded hardwood mulch beds, it was possible to produce flaming ignition *only* when single flaming firebrands were deposited onto *dried* mulch beds. This implies that under the conditions presented in this study, single flaming firebrands were a threat for *dried* shredded hardwood mulch.

Multiple Firebrand Ignition Results

It was apparent from the single fire brand ignition studies that it was possible to ignite shredded paper beds from single glowing firebrand impact. This result suggests that it may not require a large number of firebrands to ignite a home, provided that the firebrands are able to penetrate into attic spaces. On the other hand, for single flaming firebrands, it was possible to ignite pine needle beds and shredded paper beds, but shredded hardwood mulch beds were more resistant to ignition. Only fire brands that landed onto *dried* shredded hardwood mulch beds caused ignition. Based upon these findings, the total number of firebrands is clearly an important parameter which must be considered.

Consequently, the experiments were repeated, but now multiple firebrands were deposited upon the pine needle beds and shredded hardwood mulch beds. Since ignition was observed under conditions of single firebrand impact for shredded paper beds (both glowing and flaming,) multiple firebrand impact experiments were not performed using this material. In addition, single flaming firebrands were able to ignite pine needle beds and shredded paper, thus multiple flaming firebrand experiments were not conducted for these materials. These cases are denoted by the acronym NT, for not tested, and are colored in gray (see table 1).

Table 1 displays ignition results obtained for multiple glowing firebrand impact upon pine needle beds. The deposition of four (two and then three firebrands were deposited first, no ignition) 5 mm glowing firebrands (mass = 0.80 g) did not produce an ignition event under the conditions tested. When four 10 mm glowing firebrands (mass = 2.68 g) were deposited upon pine needle beds, smoldering was observed followed by a transition to flaming combustion under an air flow of 1.0 m/s. Under an air flow of 0.5 m/s, four 10 mm glowing firebrands did not produce an ignition.

The following conclusions were drawn from the pine needle bed experiments. Pine needle bed ignition was only observed for glowing firebrand impact under conditions of multiple firebrand deposition. The sizes of the firebrands, as well as the degree of the air flow, were important parameters in determining ignition.

Ignition results observed for multiple glowing firebrand impact upon shredded hardwood mulch are shown in Table 1. The deposition of four 5 mm glowing firebrands did not produce an ignition event under an airflow of 0.5 m/s. When the airflow was increased to 1.0 m/s, smoldering ignition was observed for dried mulch beds. With regard to the 10 mm firebrands, smoldering ignition was observed at 0.5 m/s and 1.0 m/s, under conditions of dried mulch beds. No ignitions were observed (even when four 10 mm flaming firebrands were deposited) for shredded hardwood mulch held at 11 % moisture.

Manzello *et al.* (2006) performed firebrand ignition studies (using the identical ignition apparatus described presently) for pine needle beds and shredded paper beds (identical fuel and size of fuel beds, moisture content varied from dry to 11 %) using ponderosa pine disk shaped firebrands (25 mm diameter, 8 mm length; 50 mm diameter, 6 mm length). In that study, disks (as opposed to cylinders) were used to simulate firebrands as these shapes are known to be produced from burning structures (Woycheese, 2000; Waterman, 1969). For pine needle bed ignition from glowing firebrand deposition, Manzello *et al.* (2006) found that a minimum mass of 6.0 g of glowing firebrands (four 50 mm disks) were necessary to produce smoldering ignition. The minimum firebrand mass needed to produce smoldering ignition for shredded paper beds from glowing firebrands was 0.5 g (single 25 m disk) (Manzello *et al.*, 2006).

Consequently, the mass of glowing cylindrical firebrands necessary to produce ignition in the same fuel beds under identical moisture and airflow conditions was about half the mass required for the glowing disk shaped firebrands. It was believed that perhaps differences in contact surface area may be able to explain these differences. Since these firebrands are glowing, the contact surface area should be an important parameter to determine ignitability of a given fuel bed. From video records, for the disk shaped firebrands, only one side of the disk was observed to contact the fuel beds upon deposition (Manzello *et al.*, 2006). For the cylindrical shaped firebrands, it was observed that, due to their geometry, half of firebrand was immersed in the fuel bed at deposition.

Based on these geometrical considerations, the glowing surface area ratio was calculated for the cylindrical shaped firebrands versus the disk shaped firebrands. From these calculations, it was found that the average glowing surface area ratio of cylinders to disks necessary to produce ignition in the pine needle beds and shredded paper beds was 0.8 ± 0.1. This result demonstrates that the overall surface area of cylindrical shaped firebrands constructed of Douglas-Fir wood was similar to the overall surface area of disk shaped firebrands constructed of ponderosa pine necessary to ignite pine needle beds and shredded paper beds. The results of these experiments suggest that the contact glowing surface area of firebrands is an important parameter to determine ignition of fuel beds, not the overall mass deposited.

4. SUMMARY

A series of real scale fire experiments were performed to investigate firebrands generated from Douglas-Fir (*Pseudotsuga menziesii*) trees. Douglas-Fir trees do not produce firebrands if the moisture content is larger than 30 % and no wind is applied. The average firebrand size measured (based on three replicate experiments) from the 2.4 m

Douglas-Fir trees were 3 mm in diameter, 40 mm in length. The average firebrand size measured (based on three replicate experiments) for the 5.2 m Douglas-Fir trees was 4 mm in diameter with a length of 53 mm. Overall, the mass distribution of firebrands produced from the two different tree sizes under similar tree moisture levels was similar. The only noticeable difference occurred in the largest mass class. Firebrands with masses up to 3.5 g to 3.7 g were observed for the larger tree height used (5.2 m). The surface area distribution was also calculated assuming cylindrical geometry and plotted versus the measured mass for the collected firebrands. The surface area of the firebrands scaled nearly linearly with firebrand weight. It is important to note that the real scale Douglas-Fir tree burns were peformed under conditons for which no wind was applied. Experiments are currently in progress to determine the influence of an applied wind on firebrand generation from burning vegetation.

It was apparent from the single firebrand ignition studies that it was possible to ignite shredded paper beds from single glowing firebrand impact. This result suggests that it may not require a large flux of firebrands to ignite a home, provided that the fire brands are able to penetrate into attic spaces. On the other hand, for single flaming firebrands, it was possible to ignite pine needle beds and shredded paper beds, but shredded mulch beds were more resistant to ignition. Only 10 mm fire brands that landed onto *dried* shredded hardwood mulch beds caused ignition. The results of these experiments suggest that the contact glowing surface area of firebrands is an important parameter to determine ignition of fuel beds, not the overall mass deposited. The data generated from these experiments will be useful for fire models used to predict spotting in WUI fires.

5. ACKNOWLEDGEMENTS

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