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www.publish.csiro.au/journals/ijwf *International Journal of Wildland Fire*, 2006, **15**, 427–431

Ignition of mulch and grasses by firebrands in wildland–urban interface fires*

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Abstract. Firebrands or embers are produced as trees and structures burn in wildland–urban interface (WUI) fires. It is believed that firebrand showers created in WUI fires may ignite vegetation and mulch located near homes and structures. This, in turn, may lead to ignition of homes and structures due to burning vegetation and mulch. Understanding the ignition events that are due to firebrands is important to mitigate fire spread in communities. To assess the ignition propensity of such materials, simulated firebrands of uniform geometry, but in two different sizes, were allowed to impinge on fuel beds of shredded hardwood mulch, pine straw mulch, and cut grass. The moisture content of these materials was varied. Firebrands were suspended and ignited within the test cell of the Fire Emulator/Detector Evaluator (FE/DE) apparatus. The FE/DE was used to investigate the influence of an air flow on the ignition propensity of a fuel bed. Ignition regime maps were generated for each material tested as a function of impacting firebrand size, number of deposited firebrands, air flow, and material moisture content.

Additional keywords: fuel beds.

Introduction

Firebrands are produced as trees and structures burn in wildland–urban interface (WUI) fires. These firebrands are entrained in the atmosphere and may be carried by winds over long distances. Hot firebrands may ignite fuels far removed from the fire, resulting in fire spread. This process is commonly referred to as spotting. It is believed that firebrand showers created in WUI fires may ignite vegetation and mulch located near homes and structures (Cohen 1991). This, in turn, may lead to ignition of homes and structures due to burning vegetation and mulch. Understanding the ignition events that are due to firebrands is important to mitigate fire spread in communities (Pagni 1993).

Unfortunately, ignition due to spotting is one of the most difficult aspects to understand in these fires (Babrauskas 2003). As a result, the ignition of fuels due to firebrand impact has been investigated, but a limited number of laboratory studies are available in the open literature (Babrauskas 2003).

The goal of the current study is to understand how lofted firebrands created by WUI fires ignite the impacted fuel bed. This paper describes an apparatus that has been constructed to investigate the ignition propensity of the materials due to the impingement of firebrands. This apparatus has been used to determine the ignition propensity of structural materials due to firebrand impact (Manzello *et al.* 2004, 2005*a*, 2005*b*, 2006). The apparatus was designed to be implemented into the Fire Emulator/Detector Evaluator (FE/DE). The FE/DE was used here as a wind tunnel to investigate the influence of air flow on the ignitability of fuel beds.

Shredded hardwood mulch and pine straw mulch were used as the test fuel bed for these experiments, as these mulch types are commonly used in the USA. The impact of burning firebrands on the mulch beds was designed to simulate the showering of firebrands into landscaped areas around homes. In addition to mulch, the ignitability of cut grass due to firebrands was also investigated. Cut grass was used as a surrogate for typical vegetation located around homes and other structures. The moisture content of all fuel beds used was varied. The total number of firebrands deposited upon the fuel beds was varied to assess the influence of multiple firebrand contact on ignition propensity. Ignition regime maps were generated for the material tested as a function of impacting firebrand size, number of deposited firebrands, air flow, and material moisture content.

Materials and methods

Figure 1 is a schematic of the experimental apparatus used for the firebrand impact studies. The firebrand ignition apparatus

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10.1071/WF06031 1049-8001/06/030427

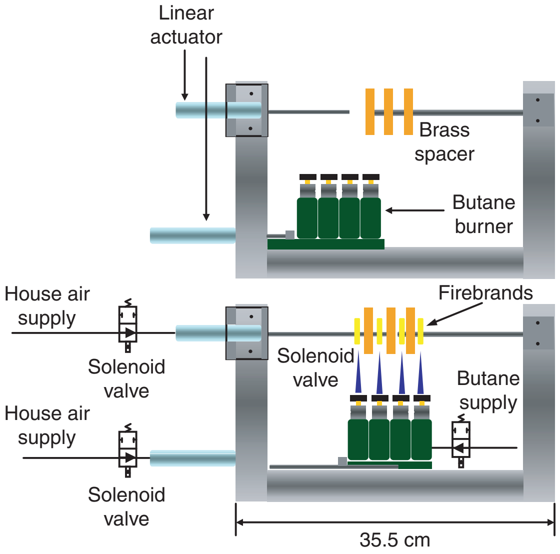

Fig. 1. Schematic of the firebrand ignition and release apparatus. The schematic demonstrates the loading process for four firebrands.

consists of four butane burners and a firebrand mounting probe. A metering valve coupled to a solenoid valve controls the butane flow rate. The firebrands are held in position by activating the air pressure, which moves the actuator and clamps the firebrands into position.

The experimental apparatus was designed to simultaneously release and deposit up to four firebrands. All firebrands were ignited with the grain oriented vertically. Further details of the apparatus are available elsewhere (Manzello *et al.* 2004, 2005*a*, 2005*b*, 2006).

The firebrand ignition apparatus was installed in the duct of the FE/DE. The FE/DE, described in further detail elsewhere (Grosshandler 1997; Cleary *et al.* 2000), was used in the current study as an air flow source for the experiments. The FE/DE allowed for air flow rates of up to 3 m/s and these velocities were verified through laser doppler velocimetry (LDV) measurements.

Firebrands were simulated by machining wood into sections of uniform geometry. Both the size and shape are important factors as it is these properties that determine the lofting characteristics and burn time of the firebrands. Firebrands were simulated as disks of two different sizes. The first size produced was 25 mm in diameter with a thickness of 8 mm. The second size used was 50 mm in diameter and 6 mm thick. Disks are believed to be a representative shape that can easily be generated by WUI fires (Woycheese 2000, 2001). In addition, disks of this size range are capable of being lofted over long distances (Woycheese 2000, 2001).

Ponderosa Pine (*Pinus ponderosa*) was selected as the wood type for these experiments as it is abundant in western USA and it is here that WUI fires are most prevalent. Prior to machining the disks the ponderosa pine planks were stored in a conditioning room at 21°C with 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) shredded hardwood mulch; (2) pine straw mulch; and (3) cut grass (Fig. 2). All materials were contained in aluminum foil pans that were 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 varied from 0 to 11%. Moisture content of 11% was achieved for each fuel bed by storing them in a conditioning room, where the temperature and relative humidity could be adjusted. 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 shredded hardwood mulch beds, pine straw mulch beds, and cut grass beds. High-resolution digital still photography (2084 × 1024 pixel resolution) was used to capture the ignition of the target fuel bed due to firebrand impact. In addition, the ignition sequences were recorded using a color CCD camera fitted with a zoom lens.

In the firebrand transport process the firebrands are formed, ignited, and land upon fuel beds. Firebrands must land onto fuel beds and still be burning to be dangerous to the surrounding environment. As a result, the burning history of the simulated firebrands was determined as a function of disk size and air flow. The ignition time for 25 mm and 50 mm firebrands was 30 s and 45 s, respectively. After ignition, the firebrands were allowed to free burn, and then released onto a load cell, and the burning history was determined.

Results and discussion

The firebrands were released onto the target fuel beds in both a flaming state and a glowing state. It has been suggested that firebrands fall at or near their terminal settling velocity. When firebrands contact ignitable fuel beds they are most likely in a state of glowing combustion, not open flaming (Tarifa *et al.* 1967; Waterman and Takata 1969). It is possible for firebrands to remain in a flaming state under an air flow and therefore it is reasonable to assume that some firebrands may still be flaming upon impact (Babrauskas 2003). Thus, the ignition propensity of the fuel beds was assessed based upon both glowing and flaming firebrand impact.

Experiments were performed for single firebrand impact (both flaming and glowing) to investigate whether it was possible to ignite fuel beds under such conditions. Figure 3 displays a characteristic image of a glowing firebrand, which was released onto the fuel beds. The results obtained for single glowing firebrand impact into shredded hardwood mulch beds, pine straw mulch beds, and cut grass beds are displayed in Table 1. Each result was based on identical, five-repeat experiments. The mass of a single glowing firebrand at the time of release into the fuel bed was 0.5 g and 1.5 g for 25 mm and 50 mm firebrands, respectively. In Table 1, the acronyms NI, SI, FI, and NT denote no ignition, smoldering ignition,

Fig. 2. Images of (*a*) shredded hardwood mulch, (*b*) pine straw mulch, and (*c*) cut grass used for the ignition experiments.

Fig. 3. Glowing firebrand, $d_0 = 50$ mm.

flaming ignition, and not tested, respectively. For further clarification, a color-coding scheme was applied to the results (Table 1).

For the firebrand sizes tested and the experimental combinations considered, it was not possible to ignite shredded hardwood mulch beds, pine straw mulch beds, or cut grass beds from single glowing firebrand impact. After the firebrand impacted the mulch and grass beds, one or two pieces of mulch or grass would smolder and the smolder front would not propagate further in the bed.

Table 1 displays the results for single flaming firebrand impact onto shredded hardwood mulch beds, pine straw mulch beds, and cut grass beds. To produce flaming firebrands, the firebrands were ignited and then allowed to free burn for 30 s prior to release into the samples. The mass of a single flaming firebrand at release into the fuel bed was 1 g and 2.9 g for the 25 mm and 50 mm firebrands, respectively. It was possible to produce flaming ignition for single firebrand impact when the firebrands were released in a flaming state onto dried shredded hardwood mulch beds. It was not possible to sustain a flaming ignition when the shredded hardwood mulch beds were held at 11% moisture. The shredded hardwood mulch would ignite (by flaming) and quickly (within 5 s) self extinguish. For pine straw mulch beds, under all conditions considered, it was possible to produce flaming ignition from single firebrand impact when the firebrands were released in a flaming state.

The ignitability of cut grass beds due to single flaming firebrand impact was more complicated. For dried cut grass beds, flaming ignition was possible under all conditions tested. It was only possible to produce a flaming ignition when the cut grass beds were held at 11% moisture and a single 50 mm firebrand was deposited under an air flow of 1 m s^{-1}. When the air flow was reduced, sustained ignition was not possible. These results demonstrate that moisture content, as well as

Table 1. Firebrand ignition regime map for firebrand impact onto pine straw mulch beds, shredded hardwood mulch beds, and cut grass beds

FI, flaming ignition; NI, no ignition; NT, not tested; SI, smoldering ignition

Firebrands deposited	State of firebrand	Air flow ($\mathrm{m\,s^{-1}}$)	Firebrand size (mm)	Pine straw		Hardwood		Grass	
				Dry	11%	Dry	11%	Dry	11%
1	Glowing	0.5	25	NI	NI	NI	NI	NI	NI
1	Glowing	0.5	50	NI	NI	NI	NI	NI	NI
1	Glowing	1	25	NI	NI	NI	NI	NI	NI
1	Glowing	1	50	NI	NI	NI	NI	NI	NI
1	Flaming	0.5	25	FI	FI	FI	NI	FI	NI
1	Flaming	0.5	50	FI	FI	FI	NI	FI	NI
1	Flaming	1	25	FI	FI	FI	NI	FI	NI
1	Flaming	1	50	FI	FI	FI	NI	FI	FI
4	Glowing	0.5	25	NI	NI	NI	NI	NI	NI
4	Glowing	0.5	50	NI	NI	SI	NI	NI	NI
4	Glowing	1	25	NI	NI	NI	NI	NI	NI
4	Glowing	1	50	SI to FI	SI to FI	SI to FI	NI	SI to FI	NI
4	Flaming	0.5	25	NT	NT	NT	NI	NT	FI
4	Flaming	0.5	50	NT	NT	NT	NI	NT	FI
4	Flaming	1	25	NT	NT	NT	NI	NT	FI
4	Flaming	1	50	NT	NT	NT	NI	NT	NT

air flow, are important in order to begin an ignition event in this material.

It was apparent from the single fire brand ignition studies that it was not possible to ignite any of the fuel beds due to single glowing firebrand impact. On the other hand, for single flaming firebrands, it was possible to ignite dried shredded hardwood mulch beds, both dried and 11% moisture pine straw mulch beds, and dried cut grass beds. Shredded hardwood mulch beds, as well as cut grass beds held at 11% were more resistant to ignition. Based upon these findings, the flux of firebrands is clearly an important parameter that must be considered.

The experiments were repeated, but now multiple glowing firebrands were deposited upon the shredded hardwood mulch beds, pine straw mulch beds, and cut grass beds. Table 1 displays results obtained for multiple glowing firebrand impact upon shredded hardwood mulch beds. From the table, the deposition of four 25 mm glowing firebrands did not produce an ignition event under the conditions tested. For the 50 mm glowing firebrands, smoldering ignition was observed to occur when four firebrands were deposited onto dried shredded hardwood mulch beds under all air flows tested. When four 50 mm firebrands were deposited onto dried shredded hardwood mulch beds, smoldering was observed followed by a transition to flaming ignition under an air flow of 1.0 $\mathrm{m\,s^{-1}}$. Four glowing firebrands were unable to ignite shredded hardwood mulch with a moisture content of 11%. Figure 4 displays an image of transition to flaming combustion that occurred in dried shredded hardwood mulch, due to glowing firebrand impact.

Table 1 displays ignition results obtained for multiple glowing firebrand impact upon pine straw mulch beds. The deposition of four 25 mm glowing firebrands did not produce an ignition event under the conditions tested. With regard to the 50 mm glowing firebrands, smoldering ignition was observed followed by a transition to flaming ignition when four firebrands were deposited on pine straw mulch beds under an air flow of 1.0 $\mathrm{m\,s^{-1}}$, independent of moisture content. With an air flow of 0.5 $\mathrm{m\,s^{-1}}$, four 50 mm glowing firebrands were unable to produce an ignition event.

Fig. 4. Transition to flaming combustion in dried shredded hardwood mulch bed. Four ($d_0 = 50$ mm) glowing firebrands were deposited.

Ignition results observed for multiple glowing firebrand impacts upon cut grass beds are shown in Table 1. A critical flux of four 50 mm firebrands was required to ignite dried cut grass beds under the conditions tested. It was not possible to ignite cut grass beds at 11% moisture under the conditions tested.

The flux of flaming firebrands deposited upon shredded hardwood mulch held at 11% moisture, as well as cut grass beds held at 11% moisture, was varied (Table 1). A critical flux of four flaming firebrands was required to achieve ignition for multiple flaming firebrands into moist (11%

moisture) cut grass beds. Under all conditions tested here, it was not possible to ignite shredded hardwood mulch held at 11% moisture.

Conclusions

This paper has described the ignition propensity of materials due to the impingement of firebrands. Firebrands were simulated by machining wood (*Pinus ponderosa*) into small disks of uniform geometry and the size of the firebrands varied. The FE/DE was used to investigate the influence of an air flow on the ignition propensity of a fuel bed. Three different materials were used as test fuel beds for the ignition studies: (1) shredded hardwood mulch; (2) pine straw mulch; and (3) cut grass. The moisture content of these materials was varied. Ignition regime maps were generated for each material tested as a function of impacting firebrand size, number of deposited firebrands, air flow, and material moisture content.

Single glowing firebrands were unable to ignite the fuel beds considered, over the range of moisture content and applied air flow tested. Flaming single firebrands were able to ignite all fuel beds tested, with the exception of hardwood fuel beds held at 11% moisture content. Multiple glowing firebrands were unable to ignite cut grass fuel beds and shredded hardwood mulch fuel beds held at 11% moisture. Ignition was only possible for other fuel beds provided large multiple glowing firebrands were used. Multiple flaming firebrands were unable to ignite hardwood fuel beds held at 11% moisture content, but were able to ignite grass fuel beds held at 11% moisture content.

The sizes of the firebrands, degree of air flow, and moisture content of the fuel beds were important parameters to determine ignition. It is desired that these results, in conjunction with other literature studies, be used to validate firebrand ignition models.

Acknowledgements

The support of Dr Ronald Rehm, Dr William Mell, Mr Alexander Maranghides, and Dr William Grosshandler of the Building and Fire Research Laboratory at the National Institute of Standards and Technology is appreciated.

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