Characterization of FIREBRANDS

Generated from Selected Vegetative Fuels

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Leyland Cypress tested in idle wind speed.
PHOTO COURTESY OF IBHS

WILDLAND-URBAN INTERFACE (WUI) AND WILDLAND FIRES cause damages to infrastructure and the environment, resulting in loss of life, property, and increasing cost of mitigation. Firebrands are known as one of the leading fire-spread mechanisms in wildland and WUI fires. The three stages of the firebrand phenomenon are generation, transport, and ignition of recipient fuel.

The generation and distribution of firebrands is a complex phenomenon that depends on fire characteristics, fuel characteristics, and environmental conditions. Studies on firebrand production have been performed since the 1950s; however, these studies were hindered by the means with which the firebrands are characterized.

The firebrand generation process is the basis for understanding the firebrand phenomenon. Firebrand characterization is a critical step in firebrand generation studies. These studies to date have been limited to report mean values of physical properties of firebrands using a small number of samples without utilizing a rigorous statistical process. To better understand the spotting phenomenon, a mathematical framework is required to describe firebrand physical properties alongside their interaction with environmental variables.

Most of the studies reported the experimental procedures and raw data but provided limited or no data analysis. As part of a Joint Fire Science Program (JFSP) project on firebrand production[2], this study presents an effort toward building a statistics-based framework and developing mathematical models to characterize the physical properties of firebrands from selected vegetative fuels.

Experimental Design

Full-scale firebrand production experiments were designed and carried out in a large wind tunnel facility. Details of the experiments can be found in the project final report [2].

There were two main criteria for choosing vegetative fuels in this study [2]:

1. Vegetative fuels should represent typical wildfire fuels in various regions of the United States prone to generate firebrands.
2. Vegetative fuels should be accessible to the research team for collection and testing purposes.

A diverse range of wildfire fuels from four states in the United States was selected, collected, and delivered to the Insurance Institute for Business & Home Safety (IBHS) Research Center in Richburg, South Carolina. Wet and dry moisture content of vegetative specimens were monitored and recorded per arrival and before tests. Species and collection sites are summarized in Table 1.

A water-filled pan layout was designed to collect the firebrands in two chamber test stations. The pan layout and burning sample are shown in Figure 1.

A staggered, water-filled pan layout was designed for this experiment to collect lofted firebrands, assuming a symmetrical distribution of flying firebrands. For each test station, 46 aluminum pans (0.65 meters long by 0.45 meters wide) were used downwind of vegetation in the test chamber. A screen mesh was submerged into the water in each pan to capture landed firebrands. The mesh screen facilitated the collection of firebrands.

Experiments were conducted at three average wind-speed levels: idle non-fluctuating (5.36-m/s), medium fluctuating (11.17-m/s), and high fluctuating (17.88-m/s).

Three replicates for each species were used at each wind speed. Where the idle wind velocity was constant, the 3-second gust peaks for the fluctuating wind speeds were 14.3-m/s, and 23-m/s for the fluctuating medium- and high-wind velocity record, respectively. Collected firebrands were transferred from the water-filled pans by removing the screens to an oven maintained at 103°C (217°F) for a minimum of 24 hours. Photographs in Figure 2 show the snapshots of several experiments.

Firebrand Characterization and Data Analysis

To better understand the spotting phenomenon, the characterization of firebrands from various fuels, both structural and vegetative, is necessary. Characterization is typically based on the physical properties of firebrands. A thorough understanding of firebrand phenomena is required to accurately characterize the parameters of generated firebrands including mass, area, shape, flying distance, and others.

A digital balance (SARTORIUS H51) with resolution of 0.0001-g was used to measure firebrands mass values. To measure the projected area, firebrands were scattered over a white sheet, photos were captured, and digitalized information was subsequently

Vegetation Level	Vegetation Type [Scientific Name]	Collection State [Site]
Grass	Little Bluestem Grass [*Schizachyrium scoparium*]	Texas
Shrubs	Chamise* [*Adenostoma fasciculatum*]	Southern California [North Mountain Experimental Area near Riverside]
	Saw Palmetto [*Serenoa repens*]	South Carolina [Victoria Bluff Heritage Preserve/ Wildlife Management in Bluffton]
Trees	Loblolly Pine [*Pinus taeda*]	South Carolina [IBHS Property]
	Leyland Cypress [*Cupressus × leylandii*]	[Tree Farm in Chester County and IBHS Property]

TABLE 1. Specifications of Vegetative Fuels

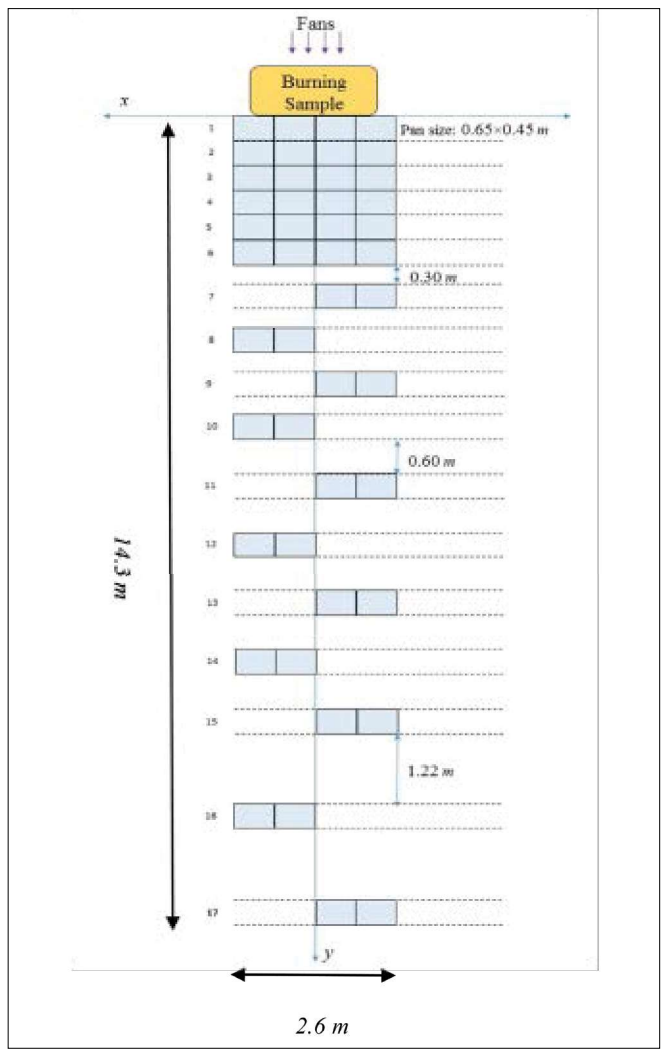

FIGURE 1. Burning Sample and Pan Layout in the IBHS Testing Chamber (*Not to scale*)

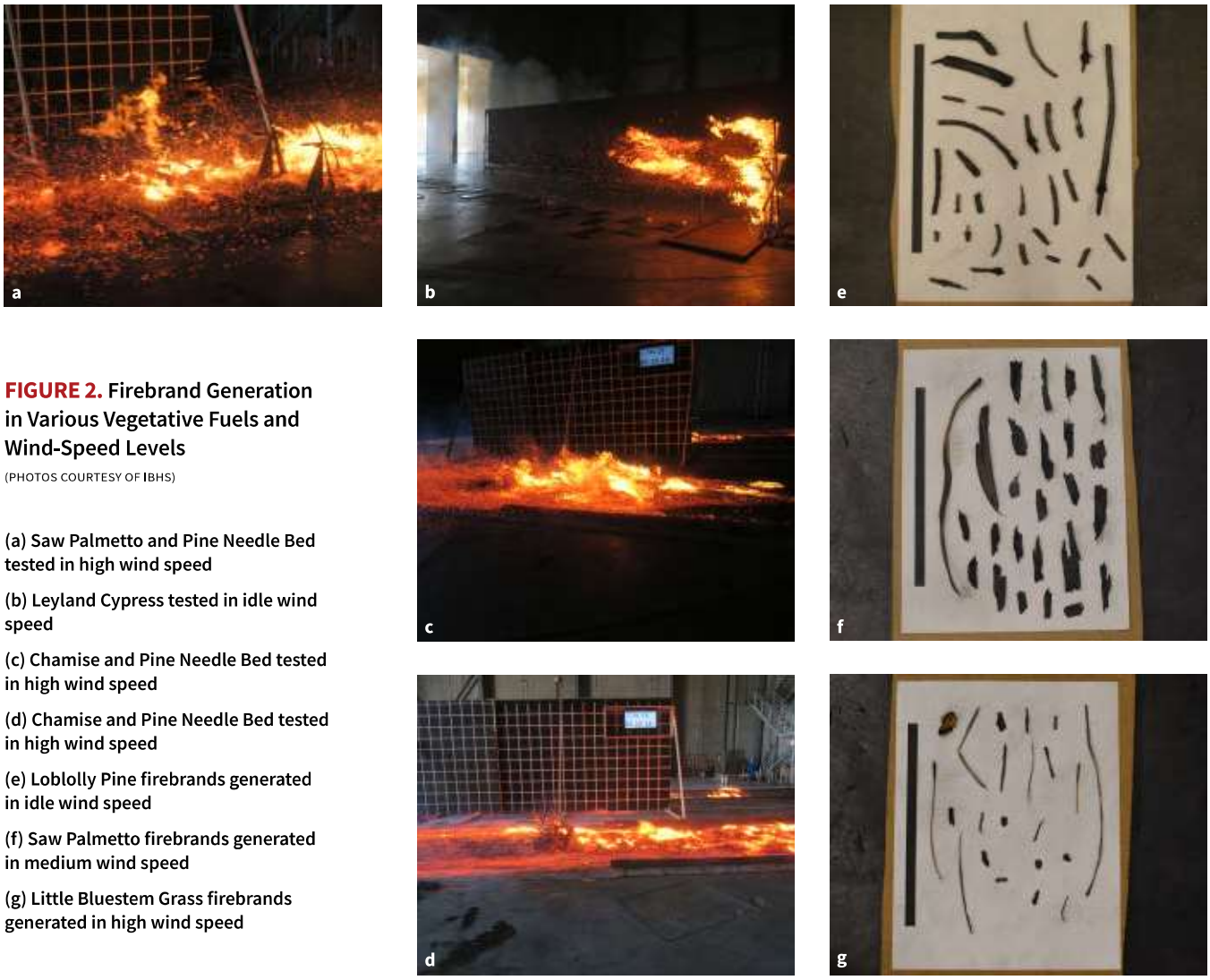

FIGURE 2. Firebrand Generation in Various Vegetative Fuels and Wind-Speed Levels

(PHOTOS COURTESY OF IBHS)

(a) Saw Palmetto and Pine Needle Bed tested in high wind speed

(b) Leyland Cypress tested in idle wind speed

(c) Chamise and Pine Needle Bed tested in high wind speed

(d) Chamise and Pine Needle Bed tested in high wind speed

(e) Loblolly Pine firebrands generated in idle wind speed

(f) Saw Palmetto firebrands generated in medium wind speed

(g) Little Bluestem Grass firebrands generated in high wind speed

analyzed in MATLAB utilizing an automated image analysis algorithm. The projected area was measured by performing the following steps: intensity increase, noise removal, thresholding, edge detection, and labeling.[1]

The Pythagorean Theorem was used to calculate the flying distance of firebrands. The diagonal distance between the burning sample and center of pans was calculated as the flying range. Previous firebrand generation studies reported a sample size between 50 and 1,500. A common problem of previous studies was the lack of adequate experimental data to use as input for characterization and/or modeling purposes.

To properly address the characterization, a regression model was developed based on the following parameters:

1. Physical properties of firebrands: mass and projected area
2. Fuel characteristics: vegetative species
3. Environmental conditions: wind speed

Although a single firebrand may not have adequate thermal inertia to initiate a spot fire, spotting can occur in wildland and WUI fires as a result of transferring a proper amount of energy from a pile of firebrands to a recipient fuel.

Having a clear understanding of the variability in firebrands results in stronger characterization and the ability to build a more robust predictive model based on fuel characteristics and environmental conditions. Descriptive analysis parameters such as mean, standard deviation, mode, range, skewness, and correlation among variables were calculated and reported to understand the variability in the dataset better.

Different probability density functions were plotted using the whole population to find the best fit. Various statistical tests such as normality, goodness-of-fit, and transformations such as logarithmic and power were utilized, and results showed that the lognormal distribution is the best probability density function (PDF)

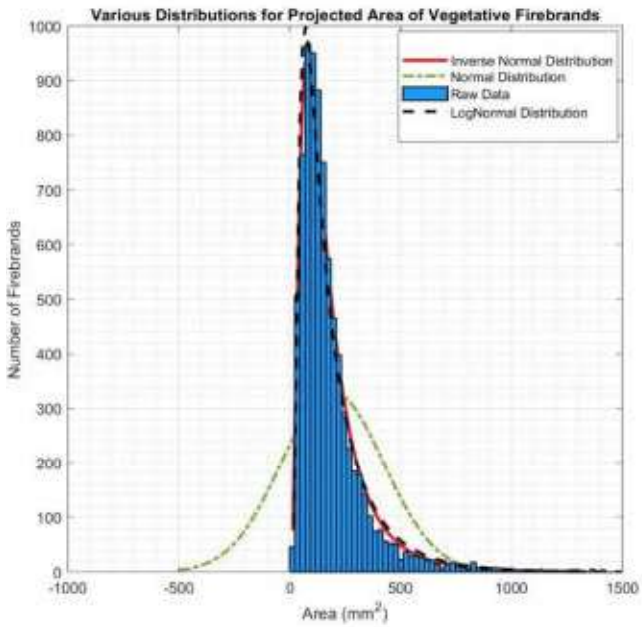

FIGURE 3. Various Probability Distributions Fitted on the Entire Projected Area Values of the Vegetative Firebrand Dataset

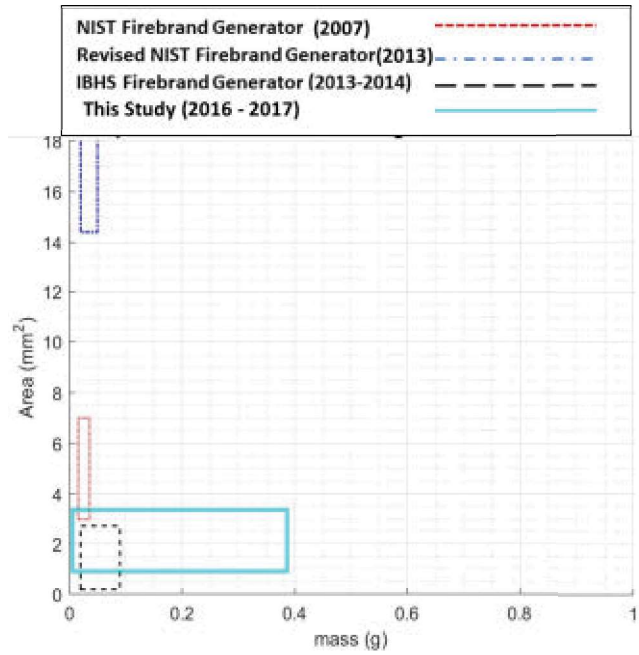

FIGURE 4. Characteristic Values of Mass and Projected Area of Firebrands from Various Experiments with 95% Confidence Interval

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to describe this dataset. Figure 4 shows various PDFs plotted on the projected area values for the dataset. Details on experimental design and characterization framework are accessible via [1] and [2].

Results

Correlation study in vegetation type and species level showed a strong relationship between mass and projected area (shape) of firebrands, regardless of fuel characteristics and environmental conditions of the experiment.

In this study, 9,814 vegetative firebrands were characterized, including 1,032 firebrands from grass specimens, 4,669 firebrands from the shrub species, and 4,113 firebrands from the tree species. To better understand the range of generated firebrands from different vegetation types in this study, the main physical properties of firebrands were summarized using a 95% confidence interval. Results showed that grass specimens could have a mass and projected area values between 0.01 to 0.33-g and 0.71 to 1.20-cm^2, respectively. For shrubs, mass and projected area values ranged between 0.01 and 0.16-g and 1.78 to 2.49-cm^2, respectively. Finally, for tree species in this study, mass and projected area values were varied between 0.08 and 0.30-g, and 1.47 to 2.35-cm^2, respectively. About 81% of the firebrands in this study had mass values smaller than 0.01 gr, and 39% had projected area values less than 1.00-cm^2.

As shown in Figure 5, a total of 41% of all firebrands were generated at the high wind-speed level, followed by 34% and 25% at medium and idle wind-speed levels, respectively. On vegetation types, increasing wind-speed levels resulted in more firebrands for shrub and tree samples. It should be noted that high wind speed was responsible for the generation of 67% of firebrands in grass samples.

Results from another statistical test on the significance of wind speed on the number of generated firebrands showed that increasing the wind speed to high, either from idle or medium, significantly changed mass and projected area of firebrands.[3] Figure 4 compares the mass and projected area of firebrands reported from various studies using a 95% confidence interval. Firebrand data for the National Institute for Standards and Technology (NIST) are obtained from [4] and [5].

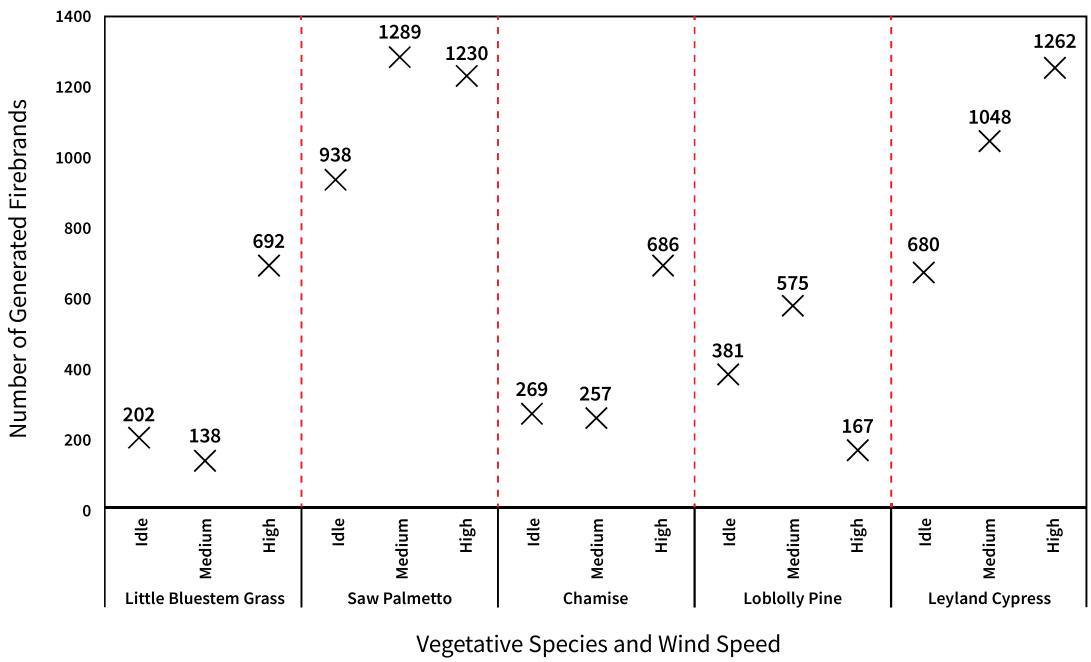

FIGURE 5. Effect of Vegetation Species and Wind Speed on Generation of Firebrands

Conclusions

Statistical comparison of values of firebrand physical properties showed that heavier (or larger) firebrands were generated in higher wind speeds. Consequently, firebrands generated in higher wind speeds are considered more lethal and could increase the chance of spotting in these species.

Methods and results in this study can help various stakeholders in wildland and WUI fire protection, such as engineering and testing standards communities, model code organizations, government agencies (such as FEMA and USDA Forest Service), the fire and emergency services (such as CAL FIRE), and property owners to better develop mitigation strategies and preparedness for wildfire spread resulting from spotting.

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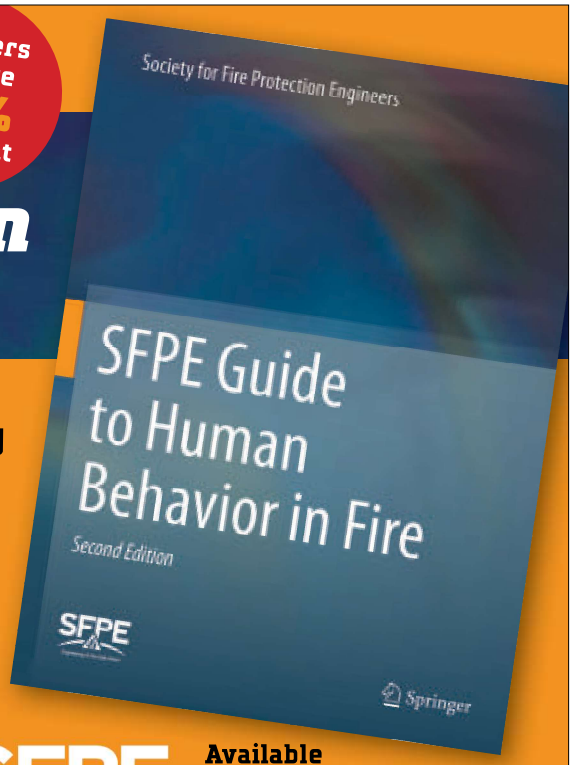

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