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# A BRIEF REVIEW ON CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF FIREBRANDS

**Xiaomin Ni and W.K. Chow**
Research Centre for Fire Engineering, Department of Building Services Engineering
The Hong Kong Polytechnic University, Hong Kong, China

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## ABSTRACT

Firebrands produced from trees and other objects burning in wildland-urban interface (WUI) fires can be carried by winds to travel over long distances. This would lead to fast fire spreading rate and even possible for igniting houses along the wildland-urban interface areas. Chemical composition and physical characteristics are the two important factors to determine whether firebrands can ignite the surrounding fuel beds. This paper presents a review summary on the works reported on these two factors in the literature. Information would be useful to provide design guides on fire hazards due to firebrands.

## 1. INTRODUCTION

Burning embers, commonly called firebrands, are produced as trees and structures burning in wildland–urban interface (WUI) fires [1]. These hot firebrands could be entrained into the atmosphere and transported downwind to start new fires (spot fires) in receptive fuel beds, including forests and houses ahead of the main fires. This is an important fire propagation mechanism in high intensity forest fires. It is believed that firebrands may give rise to secondary fires hundreds of meters from the fire front and are the primary cause of house ignition in WUI areas [2,3]. Spotting fires dramatically alters the fire growth patterns and behavior, and makes fire suppression much more difficult. Understanding the ignition events that are due to firebrands is important to mitigate fire spread in communities [4,5].

The aerodynamic behavior and combustion properties of firebrands are closely related to their transporting trajectories, landing distance, lifted height, the terminal velocity, the flaming time, burnout time and thermal degradation, which consequently affect their potential to ignite the adjacent combustibles [6]. Other factors affecting the ultimate ignition of materials due to the firebrands attack also include weather, topography, and properties of receptive fuel beds, etc [7,8]. Among them, the chemical composition and physical characteristics are two inherent ones of firebrands themselves in determining their aerodynamic behavior and combustion properties, as well as the external factors of weather, topography, etc.

Since the capacity of firebrands to ignite receptive vegetation and consequently spot the fire depends primarily on firebrands' inherent properties, the first thing required in researching spotting fires is to study the chemical composition and physical characteristics of firebrands. Here, a review summary of the research on the chemical composition and physical characteristics of firebrands is presented. It is hoped that information provided in this review will improve the understanding of the behavior of spotting fires and aid in the development of strategies to suppress WUI fires.

## 2. RESEARH ON THE CHEMICAL COMPOSITION OF FIREBRANDS

Firebrands are actually fractured solid fuel. They burn and are able to burn other fuel. Firebrands production is a result of the pyrolysis and degradation of wood elements in the main fire [9]. Firebrands are commonly involved in bark, needles, leaves, cones, and small branches of trees. In most cases, it is presumed that loose bark comprises the majority of firebrands. The chemical composition greatly affects the combustion properties of firebrands and the following potential in initiating new fires. Knowledge of the chemical composition of firebrands can be very useful in understanding and predicting fire behavior. However, most firebrand studies, experimental and numerical, have focused on firebrand transport [3,8,10]. Little work has been done regarding the investigation of chemical composition of firebrands. Some related research focuses on studying the chemical composition of forest combustibles, especially various woods, since that wood is the raw material of firebrands.

It is known that there are two major chemical components in wood, namely lignin (18~35 w.t.%) and carbohydrate (65~75 w.t.%), which are both complex and polymeric materials [11]. The carbohydrate portion of wood comprises cellulose and the hemicelluloses. Cellulose content ranges from 40 to 50 w.t.% of the dry wood weight, and hemicelluloses range from 25 to 35 w.t.%. Minor amounts of extraneous materials, mostly in the form of organic extractives and inorganic minerals (ash) are also present in wood (usually 4~10 w.t.%). Overall, wood has an elemental composition of about 50 w.t.% carbon, 6 w.t.% hydrogen, 44 w.t.% oxygen, and trace amounts of several metal ions [12]. Unfortunately, the chemical composition of wood cannot be defined precisely for a given tree species or even a given tree, which varies with tree part, geographic location, climate, etc.

The above data are only average values defined from the analytic results accumulated from various researchers. Detailed chemical analysis is inevitable for a complete understanding of the composition. As very limited numbers of experimental studies have been performed to investigate the chemical composition of firebrands, a lot of publications on the chemical constituents of various plant species (wood, trees or vegetations) may provide information for the future research on the chemical composition of firebrands [13-15].

## 3. RESEARCH ON THE PHYSICAL CHARACTERISTICS OF FIRE-BRANDS

Firebrands lofted into the atmosphere may be carried by winds over long distances (up to several kilometers). So, knowledge of their physical characteristics is useful for improving models that deal with firebrand trajectories. The physical characteristics of firebrands involve the particle geometry, dimension, volume, weights, total surface, surface of contact with the fuel bed and total surface to volume ratio [6].

Particle geometry is an important factor in determining the transport and combustion of firebrands [16]. The common shapes of firebrands are cylindrical, disk-shaped and spherical, in which the cylindrical shape is most seen. These shapes could be observed practically in the real scale experiments with the firebrands generated from Douglas Fir trees and Korean pine trees [17-19], laboratories experiments of eight kinds of firebrands from different parts of trees of twigs, bark plates, bark, leave, cone scales, cone, acorn, and bark cube [6], as well as the wood pieces collected from the firebrand generator designed by Manzello [20]. Waterman burned full scale segments of different roof assemblies and the firebrands produced were generally disk-shaped [21]. As an elementary physical characteristic of firebrands, the geometry parameter could be used for estimating the other physical parameters of firebrands of surface contact with fuel beds, the total surface, the volume and the total surface-to-volume ratio through the geometrical formulae [16].

Size and mass are two other important physical characteristics of firebrands. It is known that generation of firebrands is a random process, relying on tree structures, mechanical status of leave and twigs, burning intensity of trees, as well as the environmental wind conditions [22]. Manzello and coworkers studied the size and mass distribution of firebrands produced from burning Korean pine tree and Douglas-fir tree [18,19]. Results showed that the average firebrand size measured for the 5.2 m Douglas fir trees was 4 mm in diameter, 53 mm in length and mass up to the range 3.5 g to 3.7 g. Data for the 4.0 m (3.6 m crown height) Korean Pine trees was 5 mm in diameter, 34 mm in length and mass up to the range of 3.7 g to 3.9 g. The surface area of the firebrands scaled with firebrand mass, but showing a dependence on tree species. As evidenced by these experimental results, the size and mass distribution of firebrands is a stochastic process. The majority of firebrands were constituted by firebrands with moderate sizes, while those with finest and maximum sizes maintain very small portions due to the nature of combustion of these bio-fuels and the mechanism of up-lofting firebrands within a fire plume [22].

## 4. CONCLUSION

Research on firebrands and spot fires has been carried out for more than 50 years [23,24]. However, these studies are not yet complete enough to form a reliable physics-based operational model that predicts spotting distances and assesses the risk of potential spot fires. As two inherent properties of firebrands, the chemical composition and physical characteristics jointly determine partly the flammability of various kinds of firebrands. Lack of the studies on the chemical composition and physical characteristics of firebrands will hamper the development of a predictive model of spotting fires. More efforts should be devoted to get the exact data of chemical composition and physical characteristics of firebrands, which are very useful for fire models to predict the behavior of spotting fires.

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