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Effects of surface tension and wood surface roughness on impact splash of a pure and multi-component water drop

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ABSTRACT

Concerning the deeper understanding of the mechanisms on fire suppression with multi-component water mist/spray, the dynamical process of a water drop with or without additives impacting upon wood surfaces is preliminarily studied. The initial diameters of the pure water drop and the water drop with NaCl additive are about 2.4 ± 0.1 mm, and the diameter of the water drop with AFFF (Aqueous Film-Forming Foam) additive is about 1.8 ± 0.1 mm. The drop impact velocities are varied from 1.13 m/s to 2.80 m/s. A Photorn FASTCAM high-speed video camera coupled with a Nikon 200 mm micro-lens is used to record the dynamical process of the drop impacting. The results show that the critical impact Weber number of the water drop with additives is obviously larger than that without additives, and the critical impact Weber number increases with decrease of the wood surface roughness. In addition, the current empirical models both on predicting the critical Weber number and the maximum spread factor just partially agree with the experimental results. The current results are limited to the interaction of a single water drop impacting upon a horizontal wood surface.

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1. Introduction

Liquid drop impact upon a surface is interesting in a variety of practical applications, such as thermal spray coating by depositing (or propelling) molten droplets onto a substrate, fire suppression by water mist/spray, spray cooling of hot surfaces by impinging liquid droplets, ink-jet printing, spray painting, etc. [1–7]. The fluid dynamical phenomena of liquid drop impact on solid surfaces include spreading, receding, rebounding and splashing [8,9]. The collision of drops impinging onto solid metallic surface, solid and liquid coexist surface, structured rough substrates with grooves, have been widely studied [10–15]. However, most of the above studies mainly focused on drop impact upon metallic surfaces, there is few study focused on drop impact upon wood surfaces, although it may be the key mechanism of an A-type (solid combustible material) fire suppression with water-based agents. Chen et al. [16] and Lan et al. [17] studied the water drop impact on wood surfaces, but they did not consider the effects of additives on water drop impaction.

Water mist has been regarded as a better substitute of conventional means known as halon agents for fire suppression, and the fuel surface/flame cooling being considered as one of the dominant mechanisms [18–20]. There are two phenomena

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Nomenclature

T	temperature (K)
R_a	average surface roughness (μm)
R_0	initial surface roughness (μm)
D	drop diameter (mm)
We	Weber number
Re	Reynolds number
V	drop velocity (m/s)
h	height (m)
g	gravity acceleration (m/s^2)
a	coefficient
b	coefficient
u	drop velocity at x direction (m/s)
v	drop velocity at y direction (m/s)
t^*	dimensionless time after drop impact

Symbols

σ	surface tension (mN/m)
μ	dynamic viscosity (mm/s)
ρ	density (Kg/m^3)
ξ	dimensionless spread factor
ζ	vortices

Subscripts

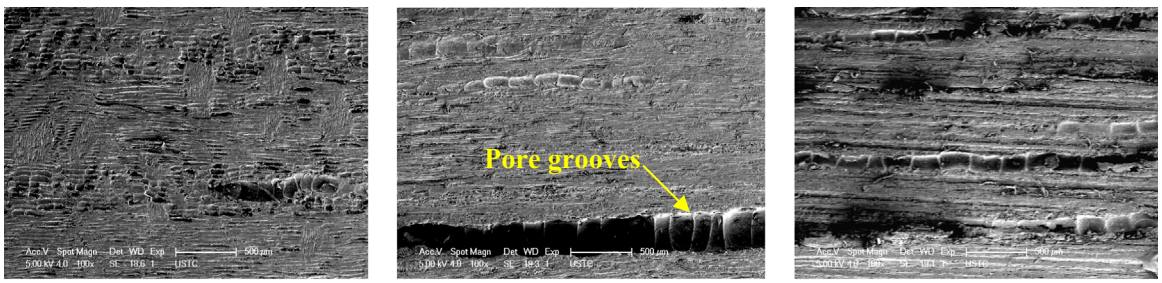
d	drop
g	gas
c	critical
max	maximum
w	wall
0	initial

that limit the efficiency of drop deposition from sprays: splashing and bouncing [21]. If the splashing and bouncing phenomena can be avoided or limited, the efficiency of fire suppression with water-based technologies may be well improved. Many studies had been done to improve the efficiency of the technologies by mixing additives into water [22–24]. Some of the results indicate that the efficiency of fire suppression with water mist or multi-component foam agents can be improved by adding additives with an optimized concentration, especially for wood crib fires. However, the reasons of such improvement and the interaction dynamics of a multi-component water drop impact upon wood surface are still not clear enough. Therefore, the impact process of a pure and multi-component water drop impinging upon different wood surfaces is conducted in this study.

2. Experimental apparatus and test conditions

The experimental apparatus mainly consists of a drop generator system, a 1000 W iodine tungsten filament lamp, and a high speed video camera etc. Water drop was generated at the tip of an injection syringe and detached off the needle under its own weight, and the schematic diagram had been described in detail elsewhere [25]. The drop impacting process was recorded by a Photorn FASTCAM high-speed video camera at 2000 fps with 1024 × 1024 pixels. The average surface roughness (R_a) of the wood surface was measured by a TR240 system with accuracy of 0.001 mm. The liquid viscosity and surface tension were measured by a Brookfield HBDV-II viscometer and a SL201 Surface Tension meter, respectively. A Sirion200 field emission scanning electron microscope (SEM) was used to observe the microstructure of the wood surfaces.

Three kinds of wood, such as paulownia, Fraxinus mandshurica and jatoba are considered, since they are the common combustible materials and widely used for making timber flooring, office furniture, etc. Before the experimental test, the wood blocks were dried to wipe off the water and resin previously. Fig. 1 gives the images of paulownia, Fraxinus mandshurica and jatoba surfaces scanned by SEM. It shows that paulownia block has exquisite surface, Fraxinus mandshurica block has big pore grooves, while jatoba has slimsy pore grooves. The measured basic density and the average surface roughness are listed in Table 1.



Paulownia surface Fraxinus mandshurica surface Jatoba surface

Fig. 1. Microscopic structure images of the three kinds of wood surface.

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