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短時間微小重力環境を利用した アルミニウム粉塵爆発の火炎伝播挙動解明

Flame propagation in aluminum dust explosions using short duration microgravity environments

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1. Introduction

NASA's plan for sustained lunar exploration and development to human missions of the Moon and Mars was announced, and safety is one of the first priorities for a sustainable human presence. Risk assessments of dust explosions in space and planetary environments are necessary for the prevention and mitigation. The flame propagation mechanism of dust explosion remains arguably an important question to be addressed because the explosion parameters included in risk assessments of dust explosion depend on the flame propagation behaviors [1, 2]. However, the difficulties of fundamental experiments in the constraints of gravitational fields and complicated phenomena make the problem difficult to elucidate the mechanisms, and therefore the previous researches conducted microgravity experiments to overcome these problems [3-5]. Additional studies on the effect of dispersibility on flame propagation to understand more completely the mechanisms of dust explosion are required because the flame propagation behavior is strongly affected by the dispersibility of combustible powders. In the present study, microgravity experiments were conducted to observe both dust clouds and flame propagation considering the dispersibility of combustible particles. The objective of this work is to elucidate the dependence of dust concentration on flame propagation in a microgravity environment.

2. Experiments

2.1 Experimental set up

Aluminum powder that is widely used in the various industrial fields and known for its violent reaction was investigated. The microgravity experiments of aluminum dust explosion were conducted at 50 m drop tower COSMOTORRE (HASTIC, Hokkaido Aerospace Science and Technology Incubation Center). The simultaneous observation system was developed and loaded on the drop capsule. The motion behaviors of particle and flame in 1.176 L combustion vessel are captured by the high-speed visualization system as shown in **Fig. 1**. In the microgravity experiment, the dispersion of aluminum powder, with a mean particle diameter of 20 μm, supplied by Kojundo Chemical Lab. Co., Ltd. was triggered by the start of the capsule dropping and lasted for 0.6 seconds. The combustion experiments were carried out with the ignition time delay of 2 seconds after start of capsule dropping. Aluminum dust clouds formed by discharging the 15 kPa air pressure were ignited by electric discharge of 15 kV and propagating a flame through the clouds were recorded by FASTCAM AX 100 high-speed cameras at 3000 frames per second. A schematic of the experimental setup is described already in the previous work [6].

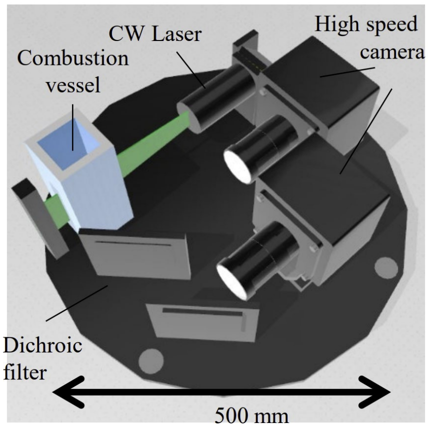

Fig. 1 A high-speed visualization system [6]

2.2 Results and discussion

To understand the influence of dispersibility on the flame propagation, aluminum particle speed and mean particle distance were estimated from the high-speed images. The experimental results demonstrated that the mean particle speed and its distance fluctuated intensely during the dispersion. After the end of the dispersion, mean particle speed decreased gradually, and mean particle distance became constant. The estimated value of mean particle distance corresponding to dust concentration existed in the flammable range. This result indicates that the risk of dust explosion lasts once a combustible dust cloud is formed in a microgravity environment.

As shown in **Fig. 2**, to obtain further knowledge of flame-particle interaction during the dust explosion, the motion behaviors of aluminum particles and the flame in the front of propagating flame were visualized. A dark zone in which most particles disappear on the frontier of the visible flame front was observed. In addition, the particles ahead of this zone were pressed due to the flame expansion. The results of the analysis on the distribution of mean particle speed and distance in the flame front demonstrate that mean particle speed reached a maximum value at a distance of 3 mm from the visible flame front, then it diminished with farther distance. Mean particle distance decreased sharply within the distance of 5 mm and it became nearly constant. The observed zone with 3-5 mm distance from the visible flame front is associated with the combustion zone. The findings that thicker zone compared to homogenous gaseous mixtures exists are directly in line with the previous study that the preheat zone of a few millimeters thickness places in front of flame during dust explosion [7]. The flame speed increased with a decrease in the mean particle distance of the flame front. This finding at least indicates that the flame speed depends on the dust concentration. It is worth investigating these interesting facts that the flame speed is strongly affected by the dust concentration obtained by the results of microgravity experiments.

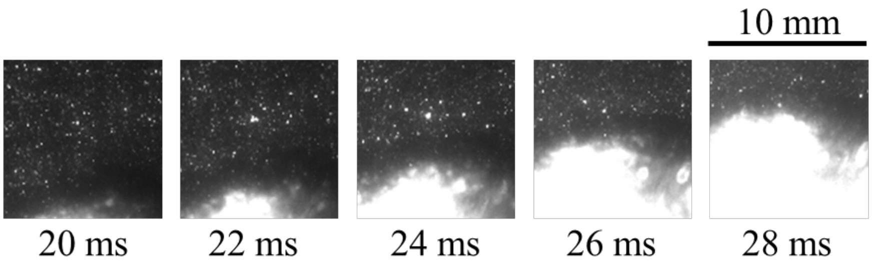

Fig. 2 Aluminum particle near the visible flame edge after the ignition timing

4. Conclusion

The microgravity experiments using 2.5-seconds drop tower were conducted to evaluate the effect of particle concentration on flame propagation behavior. The motion behavior of particle and flame in microgravity were observed using the developed visualization system. Mean particle speed which fluctuated during the dispersion decreased gradually and then the flame propagated uniformly through aluminum dust clouds. Particles near the visualized flame edge that behaved like to be pressed by flame were expected to locate in preheat zone. Flame speed increased with decrease mean particle distance corresponding to dust concentration. Further studies on the interaction of particle and flame at the quasi-steady flow state by using long-duration microgravity tests are being prepared because the reduced particle velocity also affects the flame propagation.

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