JASMAC
Conference of the Japan Society of Microgravity Application

OR4-5

微小重力環境における アルミニウム粉体の火炎伝播挙動に及ぼす粒径の影響

Effect of particle size on aluminum flame propagation in a microgravity environment

佐伯琳々[1], 上野寧子[1], 足立紘輝[1], 桑名一徳[2], 金佑勁[1]
Rinrin SAEKI[1], Yasuko UENO[1], Koki ADACHI[1], Kazunori KUWANA[2] and Wookyung KIM[1]
[1] 広島大学，Hiroshima University,
[2] 東京理科大学，Tokyo University of Science,

1. Introduction

Various dust explosion accidents have occurred in recent years with the industrial developments. The number of scenes in which fine powders are handled is increasing, and reports of accidents involving metal powders are also increasing. The field of industry is expanding into the space planetary environments. It is planned to use lunar regolith and 3D printers for manned space exploration and base camps in the future, and there is concern about the use of fine powders and handling dusts in microgravity. In particular, the presence of air in the living spaces such as inside of spacecraft is expected to be highly hazardous because it is a confined, closed space. If a dust explosion accident occurs in such an environment, it would cause a rapid pressure rise. A risk assessments of dust explosion is essential for the prevention and mitigation of dust explosions in human space exploration and habitation. Some characteristic values, such as Minimum Explosive Concentration (MEC) and Minimum Ignition Energy (MIE), are used for a dust explosion risk assessment, but all these values are the result of flame propagation behavior. The scientific question is a knowledge of interparticle flame propagation mechanism. However, experimental difficulties have been pointed out in basic studies of flame propagation behavior in dust clouds. For example, it is difficult to remain particle suspended in the air because of gravity settling. Therefore, combustion experiments are usually conducted by using an air flow as an external force in a gravity field. This causes the combustion behavior to be affected by flow fields, which complicates the combustion phenomena. Particularly for metal powders, it is difficult to investigate the dependence of flame propagation behavior on particle size because the terminal velocity varies greatly depending on the particle size.

The knowledge of single-particle aluminum combustion has been studied for use as a rocket propellant. It has been experimentally shown that the particle size (d) dependence of single-particle combustion time (t_c) differs between the nanoscale and the micron-scale, with $t_c \propto d^{0.3}$ for the nanoscale and $t_c \propto d^{1.8}$ for the micron-scale aluminum particle [1-3]. If flame propagation in dust explosions is regarded as continuous particle ignition, the particle size is expected to play an important role in the flame propagation mechanism.

In this study, dust explosion experiments were conducted in microgravity environments using a drop tower COSMOTORRE to investigate the effect of particle size on flame propagation behavior of aluminum powder. In order to evaluate the particle dispersibility, unburned powder and flame propagation were simultaneously observed by a visualization system.

2. Microgravity experiments

2.5 seconds-microgravity experiments were conducted in 50 m-drop tower COSMOTORRE (Hokkaido Aerospace Science and Technology Incubation Center, HASTIC). A drop capsule had a double structure, and the experimental apparatus was mounted in the inner capsule (φ500 mm×1050 mm.) [4]. The observation tube had a rectangular shape (30 mm×30 mm×255 mm, inner) and aluminum powders were dispersed from the bottom end of the observation tube. Compressed air from an air tank was used to disperse the powders, and the timing was controlled by a solenoid valve. The dispersed powder in the explosion tube was ignited by electric discharge. The electrodes were tungsten rods located 50 mm away from the bottom end of the observation tube. The electrode spacing was 2 mm and the discharge was 15 kV from a high-voltage transfer. A program controller was used for the time sequence. The powder dispersion started at the start of the capsule dropping and continued for 1 second. Ignition was performed 1 second after the solenoid valve was closed, and combustion experiments were conducted in a reduced flow as much as possible within the microgravity duration time.

Aluminum powders were supplied by Toyo Aluminium K.K.. **Figure. 1** shows particle size distributions and SEM images of aluminum powders. Particle shape of 20 μm and 32 μm aluminum powders were nearly spherical, but 46 μm aluminum powder had irregular shape.

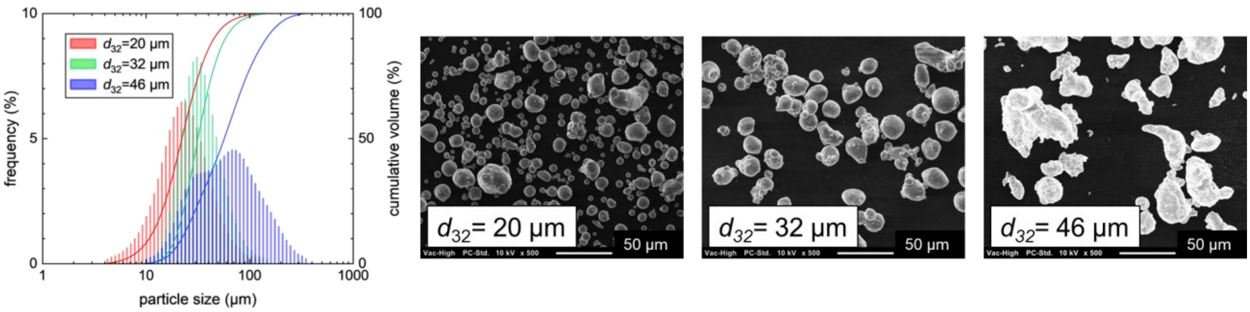

Figure 1. The particle distributions and SEM images of aluminum powders (Toyo Aluminium K.K.).

3. Results and discussion

Figure. 2 presents the results of the flame propagation behavior of aluminum powders with different particle sizes. As can be seen in the flame front, the aluminum flame with d_{32}= 20 μm illustrates continuous flame propagation. On the other hand, flame propagation behavior became discontinuous with larger particle sizes. The discreteness parameter χ is the solution of the heat diffusion equation, which is the dimensionless time of flame propagation between particles [5, 6].

$$\chi = \frac{t_c}{t_d} = \frac{t_c \alpha}{l^2} \tag{1}$$

where t_d is the thermal diffusion time, α is the thermal diffusivity, l is the interparticle distance. If the particles are assumed to be uniformly dispersed in space, the interparticle distance is proportional to the particle size ($l \propto d$). Since the combustion time is proportional to the 1.8 power of the particle size ($t_c \propto d^{1.8}$) and the thermal diffusion time is proportional to the square of the particle size ($t_c \propto d^2$), the effect of thermal diffusion becomes stronger for larger particle size. As a result, discrete flame can be observed for d_{32}= 46 μm aluminum powder. Such discrete flame can be seen under condition close to the flammability limit, and these results will be useful for the prediction of the flammability limit, which will be investigated by conducting microgravity experiments with longer microgravity duration time and lower G level in the future.

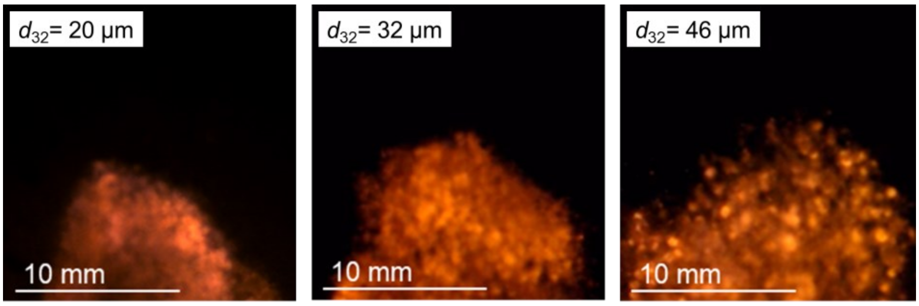

Figure 2. The images of flame propagation behavior through micron-sized aluminum powders.

4. Conclusion

In this study, microgravity experiments were carried out to investigate the effect of particle size on flame propagation through aluminum dust clouds. Flame propagation of micron-sized aluminum powder was continuous for the particle size was small and became more discontinuous as the particle size increased. This combustion phenomenon was explained by the single-particle combustion time and the thermal diffusion time between particles.

References

1) A. F. Belyaev, Y. V. Frolov and A. I. Korotkov：Combustion and ignition of particles of finely dispersed aluminum. Combust Explos Shock Waves, **4** (1968) 182, DOI: 10.1007/BF00750857.
2) M.W. Beckstead: Correlating Aluminum Burning Times. Combust Explos Shock Waves, **41** (2005) 533, DOI: 10.1007/BF00750857.
3) W. Kim, R. Saeki, Y. Ueno, T. Johzaki, T. Endo and K. Choi: Effect of particle size on the minimum ignition energy of aluminum powders. Powder Technol, **415** (2023) 118190, DOI: 10.1016/j.powtec.2022.118190.
4) W. Kim, R. Saeki, D. Ritsu, T. Endo, K. Kuwana, T. Mogi, M. Lee, M. Mikami and Y. Nakamura: Research on Risk of Dust Explosions in Microgravity for Lunar and Planetary Exploration. Int J Microgravity Sci Appl, **38** (2021) 380204, DOI: .10.15011/jasma.38.380204.
5) F. Lam, X. Mi and A.J. Higgins: Front roughening of flames in discrete media. Phys Rev E, **96** (2017) 013107, DOI: 10.1103/PhysRevE.96.013107.
6) S. Goroshin, J.H.S. Lee and Y. Shoshin: Effect of the discrete nature of heat sources on flame propagation in particulate suspensions. Symp (Int) Combust, **27** (1998) 743, DOI: 10.1016/S0082-0784(98)80468-2.