

RESEARCH ON IGNITION AND FLAME SPREAD OF SOLID MATERIALS IN JAPAN

Kenichi Ito and Osamu Fujita
Hokkaido University
Sapporo, Japan

Introduction

Fire safety is one of the main concerns for crewed missions such as the space station. Materials used in spacecraft may burn even if metallic. There are severe restrictions on the materials used in spacecraft from the view of fire safety. However, such restrictions or safety standards are usually determined based on experimental results under normal gravity, despite large differences between the phenomena under normal and microgravity. To evaluate the appropriateness of materials for use in space, large amount of microgravity fire-safety combustion data is urgently needed.

Solid material combustion under microgravity, such as ignition and flame spread, is a relatively new research field in Japan. As the other reports in this workshop describe, most of microgravity combustion research in Japan is droplet combustion as well as some research on gas phase combustion.

Since JAMIC, the Japan Microgravity Center, (which offers 10 seconds microgravity time) opened in 1992, microgravity combustion research is robust, and many drop tests relating to solid combustion (paper combustion, cotton string combustion, metal combustion with Aluminum or Magnesium) have been performed (ref.1). These tests proved that the 10 seconds of microgravity time at JAMIC is useful for solid combustion research.

Some experiments were performed before JAMIC opened. For example, latticed paper was burned under microgravity by using a 50 m drop tower to simulate porous material combustion under microgravity (ref.2). A 50 m tower provides only 2 seconds microgravity time however, and it was not long enough to investigate the solid combustion phenomena.

Current Research Activities

Some theoretical and numerical approaches on ignition and flame spread of paper sheet have been performed by the Nagoya University group (ref.3). They have described the events occurring during paper preheating, ignition, and flame spread at various oxygen concentrations.

A research program titled 'Combustion properties of solid materials' and supported by JSUP under an agreement for the international collaboration between NEDO and NASA under the research project 'Advanced Combustion Science Utilizing Microgravity Combustion Research', has been started in 1994. Prof. Ito of Hokkaido University and Prof. Hirano of the University of Tokyo participate in the program on the Japanese side. From NASA, Ms. Sandra L. Olson, LeRC, and Dr. Takashi Kashiwagi, NIST, participate. According to the agreement, microgravity experiments of paper combustion were performed using the JAMIC facilities in March, 1995. A summary of this experiment will be reported in this workshop by the US side. This program will continue for 3 years.

The Hokkaido University group is investigating flame propagation phenomena with two types of solid materials. The first is flame spread on wire insulation which is heated up to 125 °C by an inner wire electric current. The flame spread rate is measured under various oxygen concentrations and pressures. The second is flame propagation of a porous material using polystyrene foam. Polystyrene foam beads of ϕ 2-3 mm are two-dimensionally arranged to simulate a porous material in ignition and flame spread. This research has been performed by using the 10 second drop shaft and a 1.2 second (10 m) drop tower.

This report describes the experimental results from these two kinds of solid material combustion tests.

Wire Insulation Combustion

A nichrome heated coil was used as the ignitor. The sample wire was placed at the center of the ignition coil. A schematic diagram of the experimental apparatus is shown in Fig 1. The motion of the flame was recorded by a Hi8 video camera. The shape of the molten insulator and products from the insulator were visualized by Schlieren images and also recorded by 8mm video camera. Wire tension was provided by a tension spring to avoid slackening during the combustion. The dimensions of the samples are listed in Table 1.

A part of the experimental results are shown in Fig 2. In microgravity, the flame becomes spherical 1 or 2 seconds after the capsule release. The flame moves at constant speed during the drop. The pressure dependency of the flame spread is shown in Fig.3 with the results under normal gravity. In addition, results without current were shown in the figure. Under microgravity, in the heated condition, the flame spread rate decreases with increasing pressure. However, the effect of the pressure is not so large. A pressure change of 4 times (1.6/0.4) results in a 30% decrease in the flame spread rate. Without current, we can estimate almost the same results. Compared with normal gravity, the flame spread rate is remarkably slow. Roughly, the spread rate at 1 g is 2.5 times that under microgravity.

Porous Material Combustion

Porous materials are considered as a model of many flammable real solids, such as waste paper, accumulated room dust, cloth, and buffer materials. In this experiment, an array and two-dimensional arrangements of beads of polystyrene foam (PSF) were used as a model of porous materials. PSF contains air in the order of 60 or 80 times of the solid volume. PSF beads shrink

immediately by radiation from flames, and the rate of shrinkage is faster than the burning time of the bead. Consequently, we can estimate the heat flux radiated from the surrounding flames by the shrinkage rate or mass-loss of the beads. This particular characteristics of polystyrene foam makes it possible to use the beads of polystyrene foam simultaneously as combustible material and heat flux detector.

In a part of the microgravity experiments, we used the new 10 m drop tower, shown in Fig.3, at Hokkaido National Industrial Research Institute (HNIRI). A linear motor braking system is employed and the pay load is 100 kg.

Single arrays of beads and two kinds of two-dimensional arrangements were examined. The diameter of beads, the distance between beads, and oxygen concentration were varied. A model of the combustion process is shown in Fig.4. Both auto-ignition and gas phase propagation were observed. The effects of the oxygen concentration with a single array is shown in Fig.5. Figure 6 is a record of the flame position from the ignition point. The distance between beads was increased from 2.5mm to 5.5 mm. Above 5.5 mm, there is no flame spread.

The results with the two-dimensional arrangement are shown in Figs 7 and 8. Ignition was at the center. It is evident that shrinkage occurs at first and then ignition follows. In the case of a square lattice, the flame spread towards 45 degrees is slower than that at right angles. For the hexagonal arrangement, there are still differences in the flame spread in different directions.

Conclusions and Future Plans

The studies conducted to date in Japan have provided new information on the behavior of solid flame spread under microgravity. In 1995, a series of microgravity experiments on flame spread of materials will be conducted by NASDA using the MGLAB drop shaft which was completed in February, 1995. The University of Tokyo and IHI Research Institute will participate in the experiment. The Hokkaido University group is planning to use parabolic flights of the MU-300 airplane. Flame spread rate of un-heated materials will be measured. Up to now, there is no research project on solid ignition in Japan. But, we consider the necessity of high energy ignition studies under microgravity for future crewed space activities essential.

References

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2. Ito, K., Fujita, O., and Ito, H.: Observation of fire spreading over porous materials under microgravity, 29th Symposium (Japanese Section) on Combustion, 1991, pp. 16-18.
3. Nakamura, U., Kushida, G., Yamashita, H. and Takeno, T.: Numerical analysis on paper combustion mechanism under microgravity environment, 32nd Symposium (Japanese Section) on Combustion, 1994, pp. 221-223.

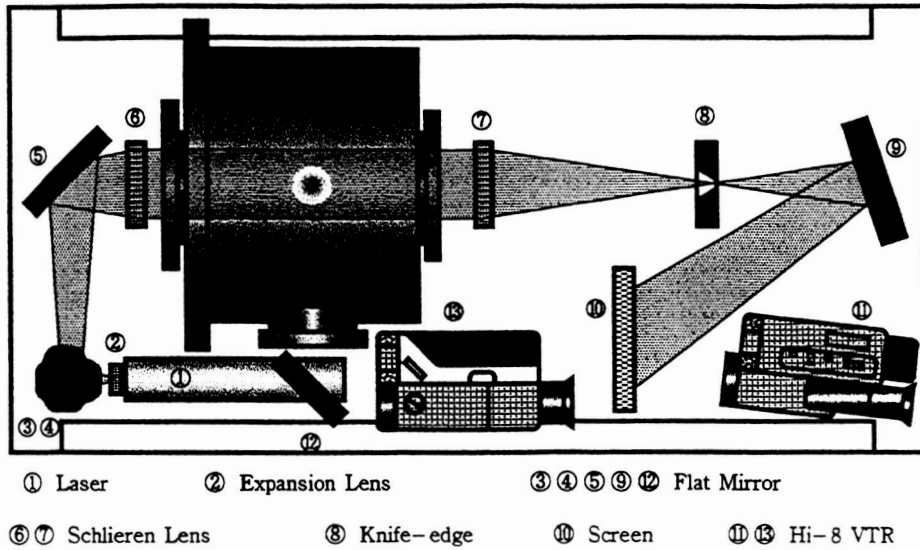
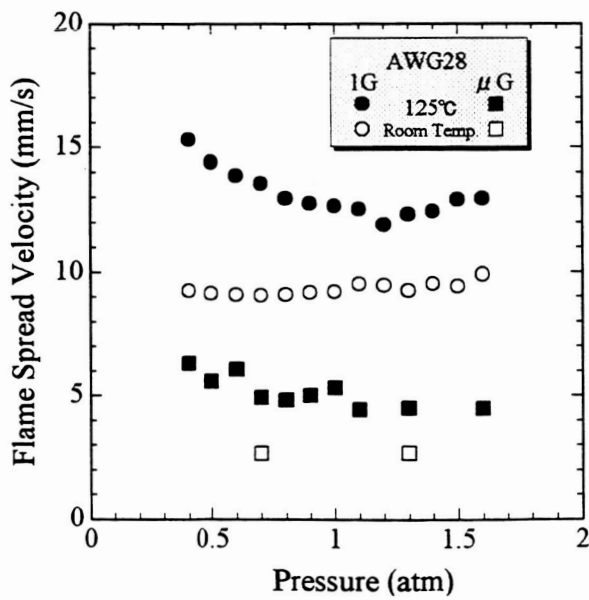


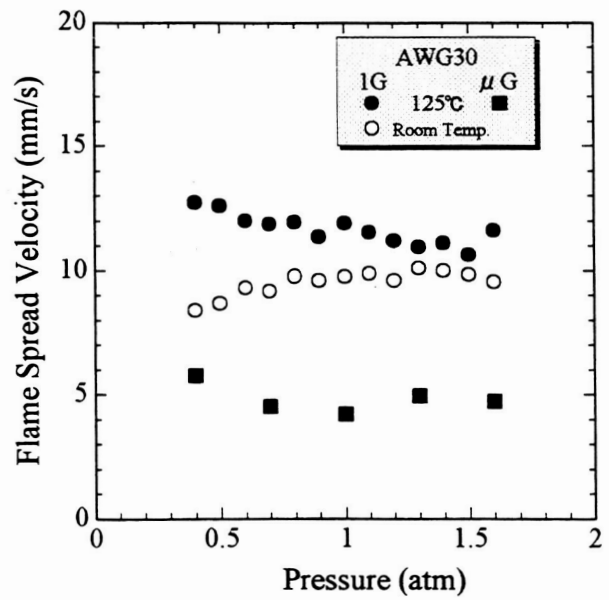
Fig. 1 Experimental Set-up for Wire Insulation Combustion

Table 1 Wire dimensions

| sample | wire diameter d_s | sample diameter d | insulator thickness Δ |
|--------|---------------------|---------------------|------------------------------|
| AWG-24 | 0.45(mm) | 1.20(mm) | 0.875(mm) |
| AWG-28 | 0.30 | 0.60 | 0.15 |
| AWG-30 | 0.25 | 0.55 | 0.15 |



(a) AGW28



(b) AGW30

Fig. 2 Effects of pressure on flame spread rate (a) AGW28, and (b) AGW30 (O_2 30 %)

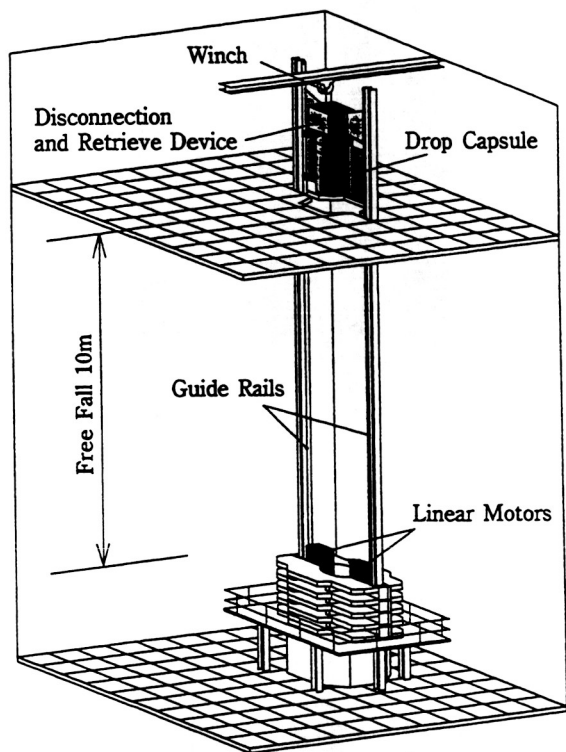


Fig. 3 10 m drop tower in HNIRI

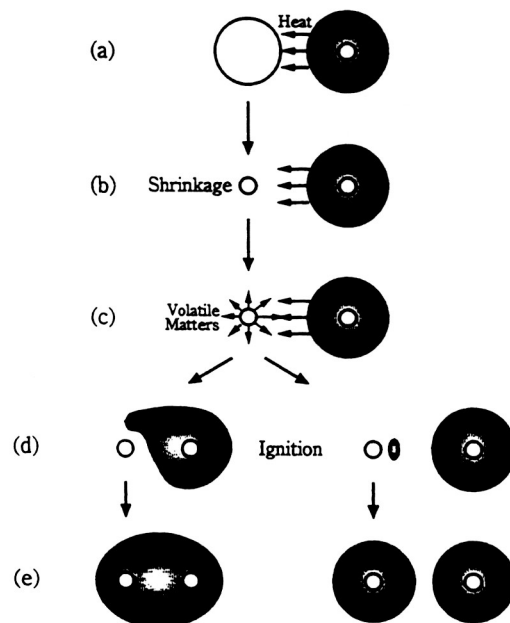


Fig. 4 Combustion process of polystyrene foam

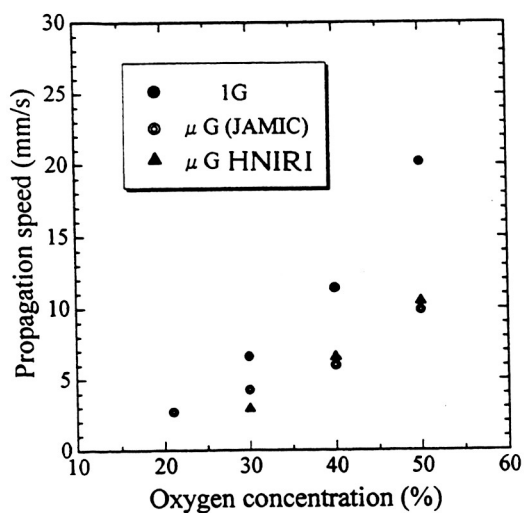


Fig. 5 Propagation speed of single array ($\phi : 2.5\text{mm}$, space: 2.5mm)

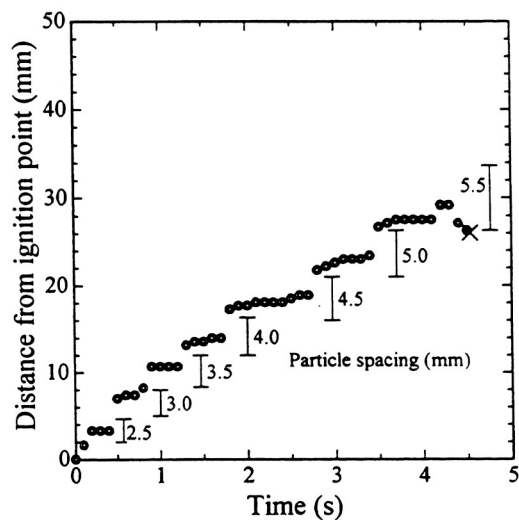
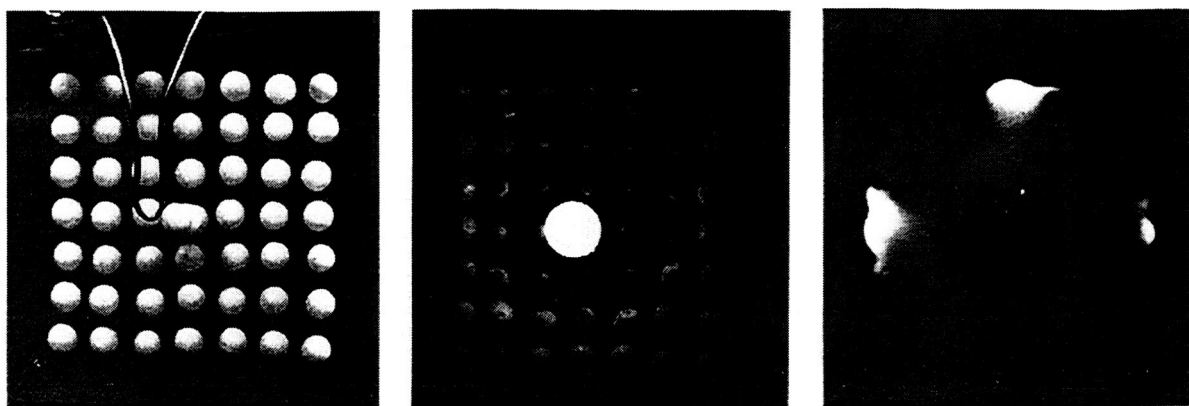


Fig. 6 Records of flame position (O_2 40%, $\phi : 2.5\text{ mm}$)

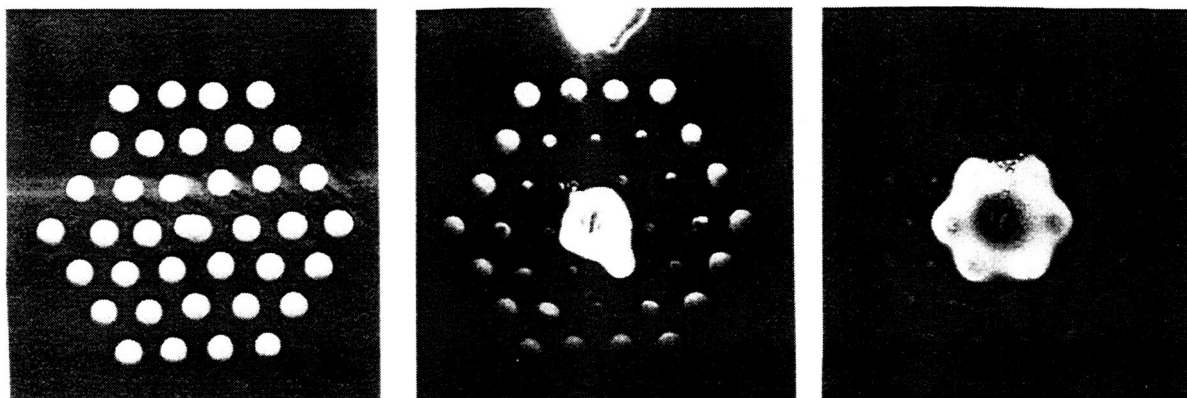


(a) before ignition

(b) 1.0 s after ignition

(c) 3.6 s

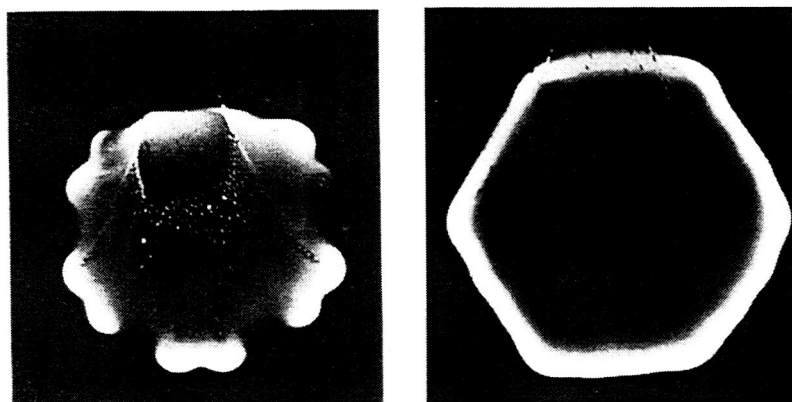
Fig. 7 Two-dimensional flame spread; Square lattice arrange
(O_2 40%, ϕ :2.5mm,space:3.5mm)



(a) before ignition

(b) 1.1 s after ignition

(c) 1.6 s



(d) 2.9 s

(e) 4.0 s

Fig. 8 Hexagonal lattice arrange (O_2 40%, ϕ :2.5mm,space:4.5mm)