Visualization of flow field in narrow space on flame spread along a thin paper disk with fingering combustion

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1 Introduction

An example of a flame spreading accident in a narrow space is a fire caused by ignition of a curing sheet used for repair work. If there is a narrow space on the sheet, floor, or wall, a high-temperature heat source, such as chips generated during welding and melting, can fall and a fire may occur. Therefore, it is considered necessary to clarify the mechanism of flame spread in a narrow space to take fire-prevention measures.

Olson et. al. [1] reported finger-like smoldering patterns over a thin cellulose-based fuel with external airflow in microgravity. Zik et al. [2] and Uchida et al. [3] reported fingering propagation along a thin solid in a narrow space with external airflow under normal gravity. They confirmed the influence of the Lewis number. Daitoku et al. [4] reported the relationship between the type of flame spread and the flame spread rate along a paper disk in narrow gaps.

Takahashi et al. [5] reported the phenomenon of flame spreading like fingers, as shown in Fig. 1 when thin flammable solids combust in a narrow space under natural convection. This phenomenon is called fingering. In addition, smoke generated immediately after the heating initiated was visualized by sheet-like laser light installed orthogonal to the fuel, and the flow field in the vertical cross section was observed. As shown in Fig. 2, convection occurred in the upper gap, indicating that the flow moved toward the ignition source on the fuel surface.

In previous studies [6], we analyzed the velocity field of the vertical section of a flame spreading in a narrow space by dispersing a trace amount of tracer particles on the surface of the fuel and visualizing the movement with laser light. We observed the front of the flame tip of the fingering. The horizontal and vertical velocities increased towards the tip of the flame and the particles rolled up vertically near the tip of the flame. From the horizontal direction it was impossible to visualize the flow field between the fingers splitting the flame and the flame.

In this study, the fingering was observed from above, and smoke generated by combustion was visualized using laser light. By analyzing this smoke, we attempt to elucidate the flow field in the fingering.

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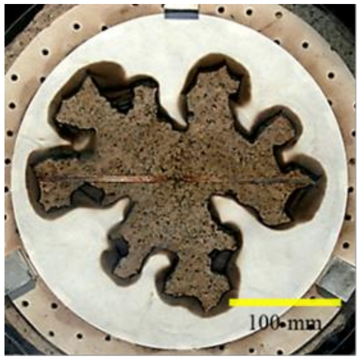


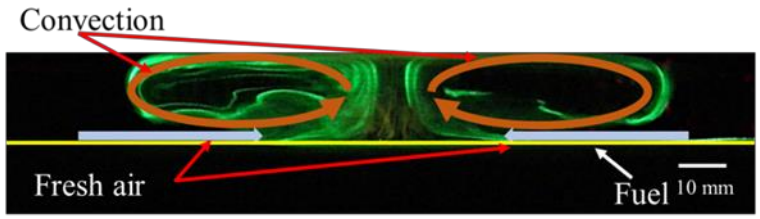
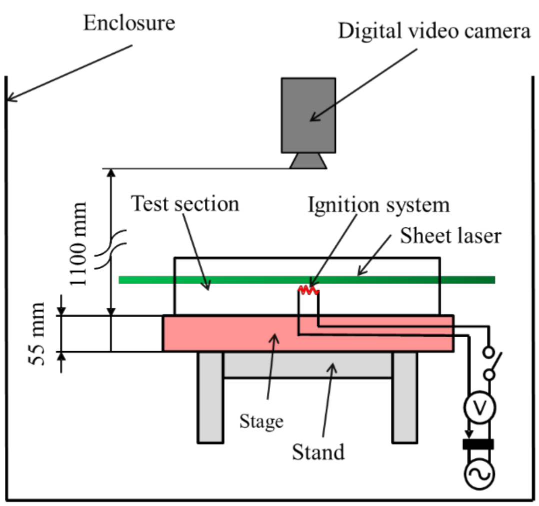


Fig. 1. Finger-like flame spread [1]

Fig. 2. Behavior of smoke in the upper gap [1]

2 Experimental Apparatus and Method

Fig. 3 shows a schematic of the experimental apparatus, which consists of a test section, stage, ignition system, digital video camera, and enclosure. The upper part of the enclosure is in the open state, and the side surface has a window for incidence of laser light. The stage is made of granite stone 400 mm in diameter and 55 mm thick. A coil-like chromel thin wire was installed in the center of the base for ignition. The coil is approximately 3.5 mm in diameter, and was installed in the center of the stage. Electrical heating was applied until the flame traveled 15 mm from the center. The time at which energization of the chromel thin wire initiated is defined as t = 0 s. To visualize the smoke in the upper gap, a sheet-like laser with a wavelength of 532 nm was used and it was incident horizontally on the fuel surface. The camera shot the test section at a shooting speed of 60 fps vertically from the top.



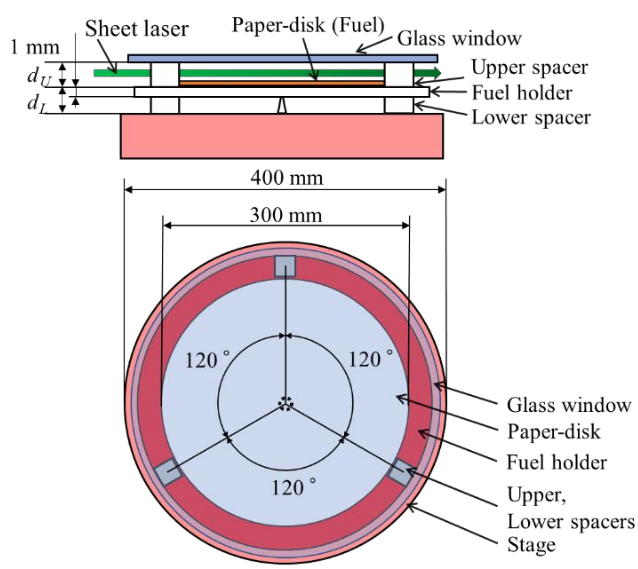


Fig. 3. Schematic of experimental apparatus

Fig. 4. Diagram of test section

Fig. 4 shows detailed top and side views of the test section. The fuel was a disk-shaped homogeneous filter paper (ADVANTEC, No.1), 300 mm in diameter with a thickness of 0.20 mm. This fuel was fixed to a mica holder with outer and inner diameters of 360 and 280 mm, responsibility, and a thickness of 1.0 mm, using double-stick tape. This holder was installed using a spacer between the stage and the glass window. The interval between the stage and the fuel is defined as d_L mm, and the interval between the glass window and the fuel as d_U mm. The glass window has a diameter of 390 mm and a thickness of 5.0 mm. The incident position of the laser is assumed to be h mm from the surface of the fuel.

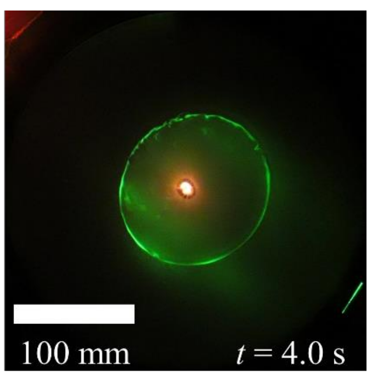
The experiment was conducted under the conditions under which the fingering occurs, d_L = 9.5 mm and d_U = 19.0 mm. The laser was incident at a position of h = 3 mm (near the fuel surface) and 16 mm (near the glass window).

3 Reaults and Discussion

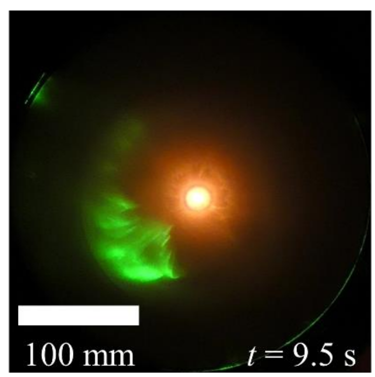
3.1 Visualization of the smoke in upper gap

We attempted to create an image showing only smoke from image of flame spread. In this study, the smoke was illuminated by a green laser with a wavelength of 532 nm. The image of flame spread was split into RGB. Since the flame also contained green brightness, it is also displayed in the image from which green was extracted. Therefore, by subtracting red extracted image from green extracted image, it is possible to create flame-removed image.

Smoke was observed immediately after electric heating. Fig. 5 (i) shows an example of smoke near the glass window, and Fig. 5 (ii) shows an example of smoke visualized near the fuel surface. The incident positions of the laser light were h = 16 mm and 3 mm.Near the glass window in Fig. 5 (i), smoke was generated around the ignition system and spread almost uniformly. Therefore, it can be seen that uniform heating was achieved. Smoke near the fuel surface in Fig. 5 (ii) flowing toward the ignition system. It is understood that this smoke flowed non-uniformly from the time of electrical heating.



(i) Near the glass window (h = 16 mm)



(ii) Near the fuel surface (h = 3 mm)

Fig. 5. Flow of smoke during electrical heating

Fig. 6 and Fig. 7 show the smoke observed near the fuel surface (h = 3 mm) during and after the fingering. The smoke was visualized when partial extinguishing occurred. This smoke was observed only near the extinguishing position, and no flow field exhausted to the outside of the experimental apparatus along the fuel surface was observed. It is considered that buoyancy caused the smoke generated by the extinguishment to move from near the fuel surface to the upper part in the upper gap and be discharged. Fig. 8 shows the elapsed time and inflow state of the smoke in Fig. 7. From Fig. 7, it is observed that smoke flowed from the outside of the experimental equipment towards the flame along the fuel surface. In this study, fuel was the only source of smoke. Therefore, it is considered that the smoke released from the inside of the gap flowed in again toward the flame together with the oxidizing agent from outside the experimental apparatus.

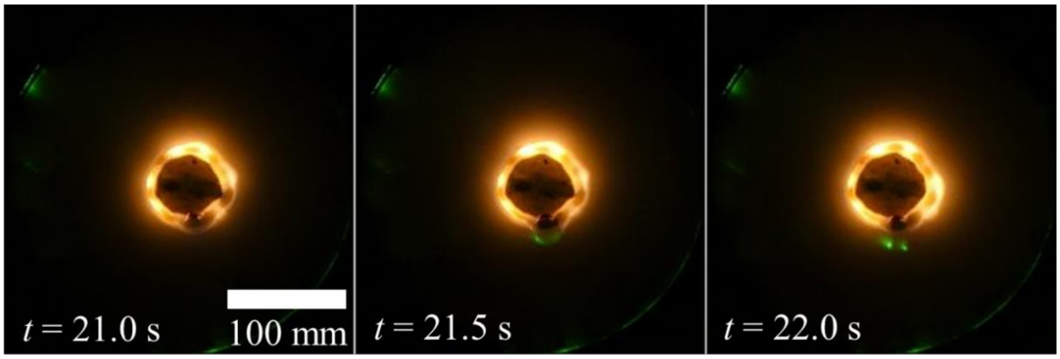


Fig. 6 Smoke generated after extinguishing (h = 3 mm)

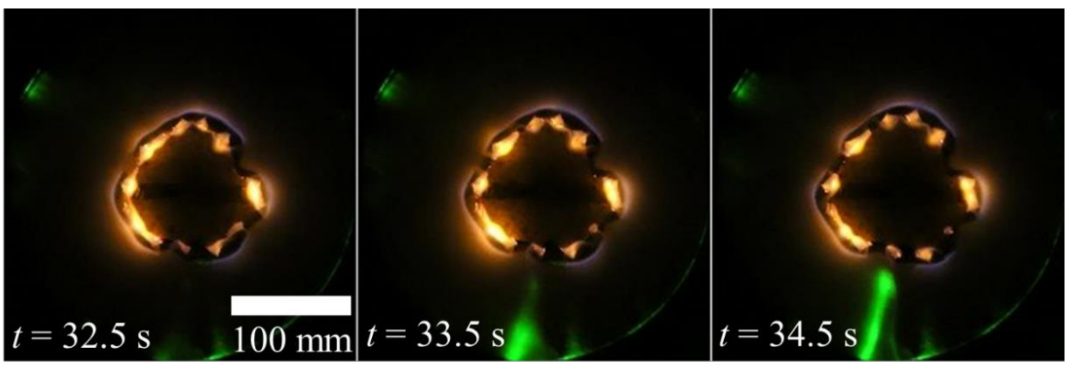


Fig. 7 Smoke flowing into a flame (h = 3 mm)

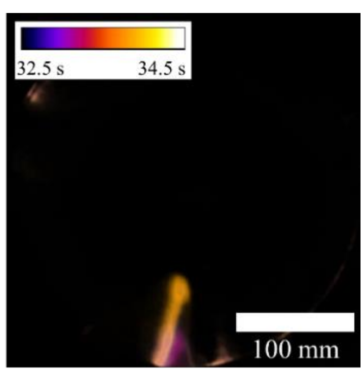


Fig. 8 Elapsed time and inflow of smoke (h = 3 mm)

Fig. 9 shows the smoke observed near the glass window after the fingering. Fig.10 shows elapsed time and exhaust of smoke in Fig. 9. This smoke was exhausted to the outside of the experimental apparatus. It is thought that the smoke generated by extinguishing, such as shown in Fig. 6, rose to near the glass window from the fuel surface and was discharged.

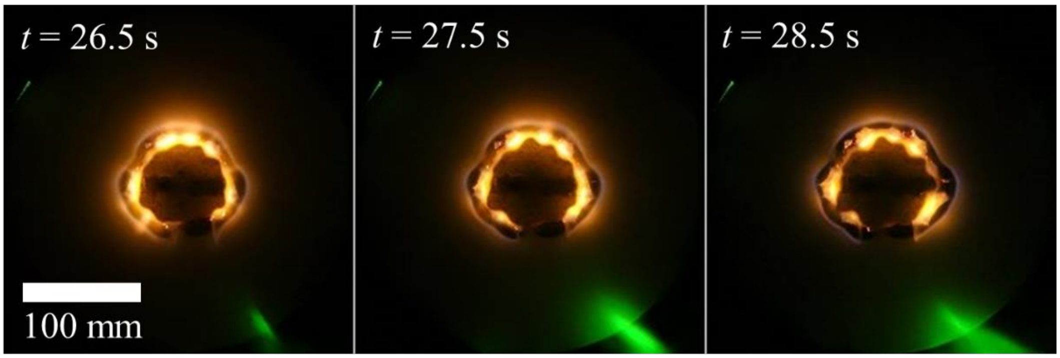


Fig. 9. Exhaust of smoke (h = 16 mm)

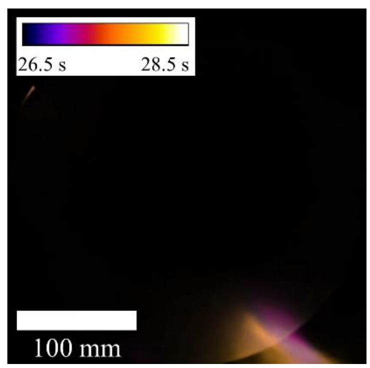
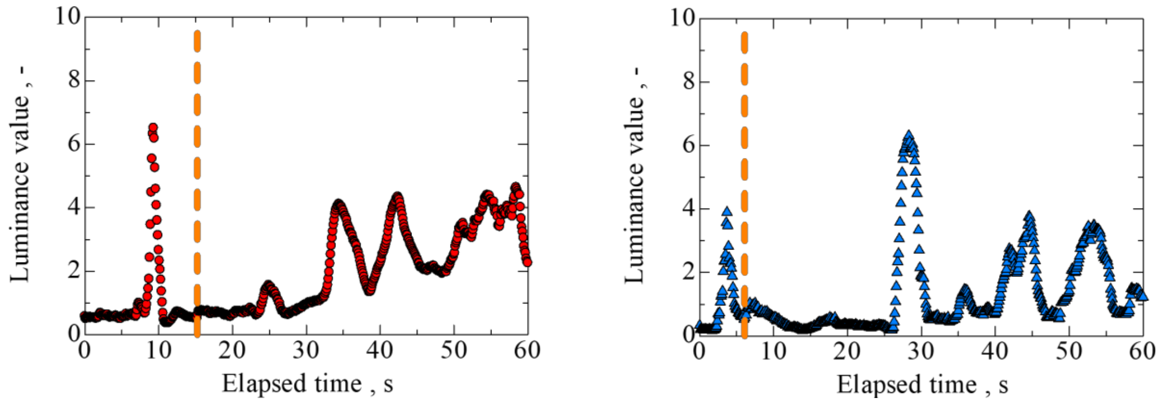


Fig. 10 Elapsed time and exhaust of smoke (h = 16 mm)

3.2 Relationship between incident position of laser light and luminance value of smoke

We attempted to clarify the timing of the smoke occurrence. Fig. 11 shows the time variation of the average luminance obtained from the image showing only smoke.The abscissa of the graph represents the elapsed time from the start of electrical heating, and the ordinate represents the average luminance. The average luminance was plotted at 0.1-s intervals. The electrical heating end time is indicated by a dotted line, and was somewhat around depending on the contact condition between the chromel wire and the fuel.

Smoke was visualized during electrical heating. At this time, it is thought that smoke spreading near the glass window and smoke heading toward the ignition source near the fuel surface was visualized. Then, the luminance remained relatively constant. This result is thought to have been obtained because the flame spread evenly and a significant amount of smoke did not occur. The luminance near the fuel surface rises after approximately 22 s from the start of electrical heating. At this time, it is thought that this result was obtained because the flame spread form changed to fingering, causing flameless combustion, and smoke started generating near the fuel surface and flowed from outside the experimental equipment. Near the glass window, a change in value was observed after 26 s. It is thought that the rising smoke generated near the fuel surface was observed. Thereafter, the luminance changed continuously. This is because the smoke was generated and began to flow in from the outside, and the laser light illuminated the fuel deformed by combustion.



(i) Near the fuel surface (h = 3 mm) (ii) Near the glass window (h = 16 mm)

Fig. 11. Elapsed time and luminance value

4. Conclusion

This study visualized the smoke generated when the fingering phenomenon occurs. The following conclusions are drawn from this visualization.

(1) A non-uniform flow field existed near the fuel surface from the time of electrical heating initiation.

(2) Smoke was generated near the fuel surface after the flame was extinguished, this smoke was exhausted through the upper part of the upper gap.

(3) There was a flow field that passed through near the fuel surface and drew the oxidant into the flame.

References

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