OS4-7

FLARE/FLARE2 軌道上実験による可燃性評価法の開発

Development of Flammability Evaluation Method via FLARE/FLARE2 Orbital Experiments

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1. Introduction

Fire safety is one of the most important issues in manned space missions. In the past, NASA STD-6001 [1)] was used for fire safety. The standard has a long history and is considered as a conservative test method. However, the test is conducted under normal gravity condition and therefore there is concern that the result can guarantee fire safety under reduced/micro gravity conditions. In FLARE, the ISS orbital experiment project, conducted by JAXA, we have been developing a novel method for estimating the flammability of solid material in microgravity environment. In the present article, we first introduce the developed evaluation method which can give an index to the material considered in microgravity environments, then mention the future works that is planned in the successive ISS orbital experiment project, FLARE2.

2. Flammability index under microgravity condition

2.1 Flammability tests on ground

For flat plastic materials, there are many flammability test methods suggested. Figure 1 shows the schematics of typical flammability tests, NASA STD 6001 test1 and ISO 4589-2, the Oxygen Index (OI) test [2)]. NASA standard test is upward flame spread test whereas the OI test is downward flame spread test. In general, it is regarded that the upward flame spread is more severe scenario than downward flame spread, therefore, the NASA standard is considered as a conservative

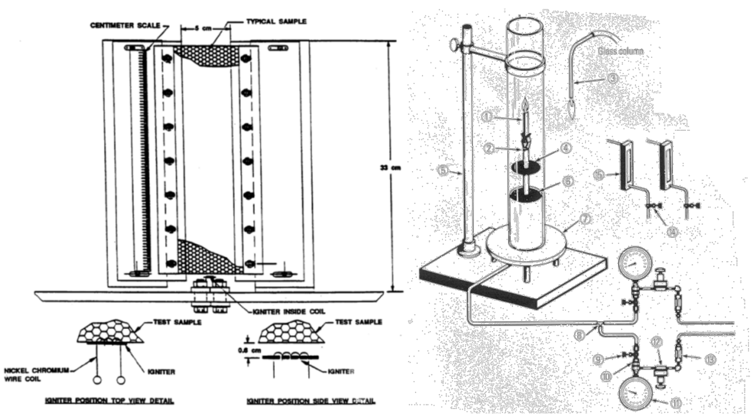


Fig. 1　Schematics of flammability test method; a) NASA STD-6001B and b) Oxygen Index test (ISO 4589-2)

test method. In manned space missions, the NASA standard has been used for long period. However, the NASA standard is a pass/fail test, therefore, it is not desirable for screening materials. On the other hand, the OI test is an index test that gives the OI as the flammability index of the material considered, which is very useful for the screening. Additionally, the downward flame spread has high repeatability and reproductivity whereas in contract to the upward flame spread. The OI test has been used among plastics manufacturing industries for checking the properties of their products. In the FLARE project, we focused on the OI test from the point of view that it gives an index to the material. If we can give some fire safety index to the material in microgravity environments, it would be helpful information. The OI test is conducted in normal gravity where buoyant flow exists, then our question is how the limiting oxygen concentration (LOC) in reduced gravity differs from the OI obtained by ground-based OI test.

2.2 Prediction of LOC in reduced gravity

The limiting curve of a flat material in opposed flow is a result of coupling the quenching flammability branch and blow-off flammability branch, and typical flammability limiting curve represents a U-shaped curve shown in Fig. 2 [3,4]. Therefore, if the OI test is conducted in normal gravity, the buoyant flow, which is 30-40cm/s, is imposed to the material. In such a situation, the obtained OI is the LOC at point A in Fig. 2. On the other hand, under microgravity condition, the LOC is a function of opposed flow velocity because of the absent of buoyancy. If we can specify the minimum limiting oxygen concentration (MLOC) of the materials, it would be helpful information for fire safety in orbital gravity level. Hence, in FLARE, we developed a simplified model for flame spread over a thin flat plastics material [5,6] and produced an application software (see Fig. 3) that calculate the limiting curve of the material from its composition, pyrolysis temperature, ambient conditions, and the OI/HOI test results. The HOI test is a novel ISO standard (ISO 4589-4) proposed by the FLARE project to obtain the LOC in high gas velocity (HOI) used in the developed evaluation method [7]. The

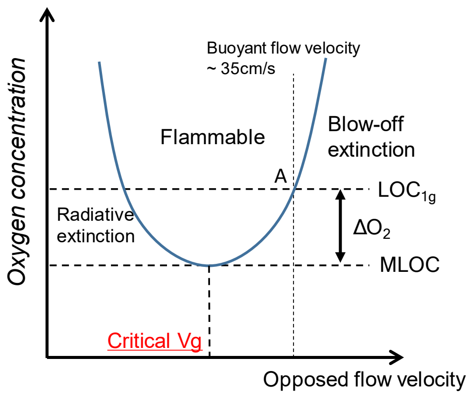


Fig. 2 Flammability map of a thin flat sample.

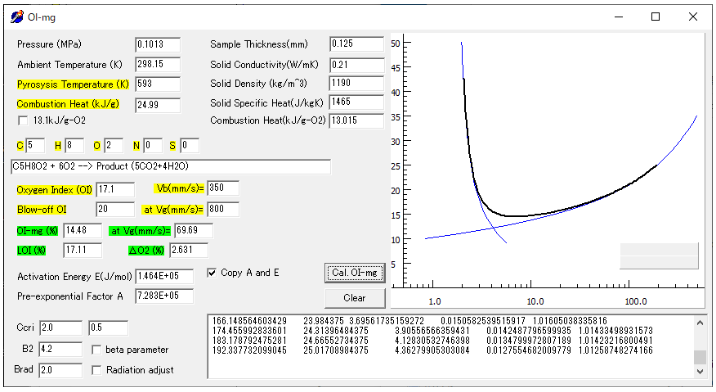


Fig. 3 Developed software for calculating the limiting curve.

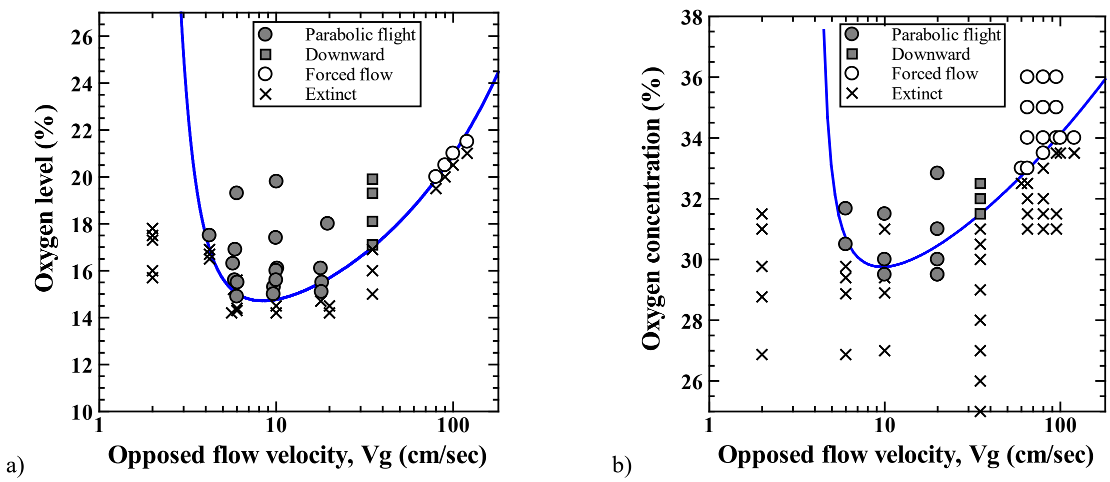


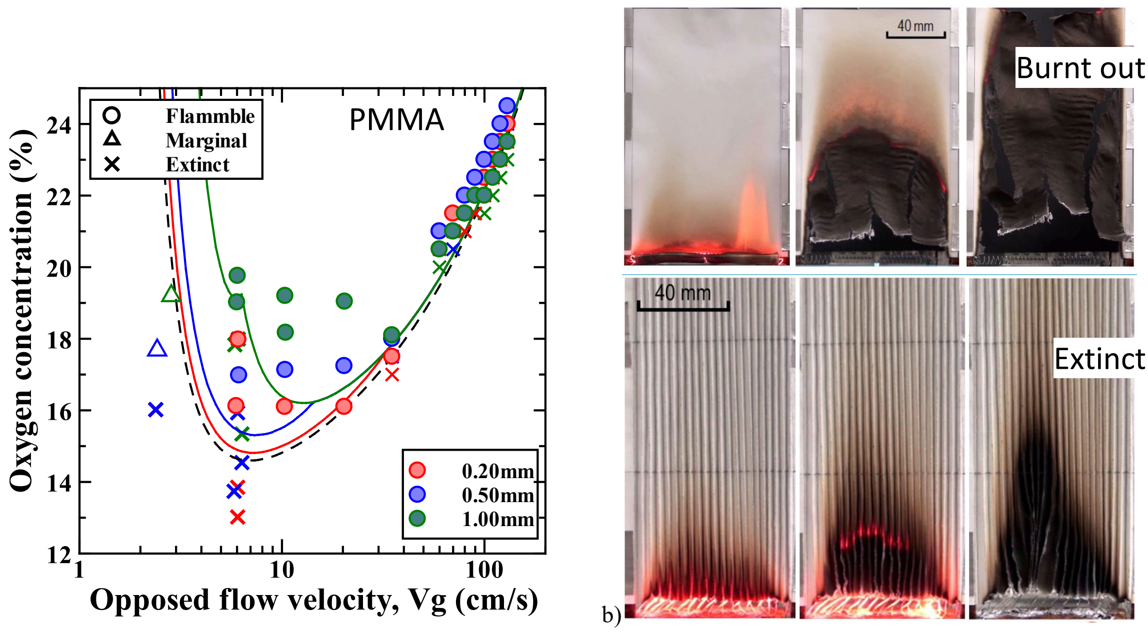
Fig. 4 Flammability map of a) PMMA (t: 0.125 mm) and b) NOMEX HT90-40 (t: 0.35 mm)

calculated limiting curves for PMMA and NOMEX HT90-40 are shown in Fig. 4. It is found that the predicted lines well agree with the parabolic flight experiments. Currently, the Solid Combustion Experimental Module (SCEM) has been launched to the ISS and we are preparing the orbital experiments. The results will be compared with the developed model to increase the accuracy.

2.3 Future works in FLARE2

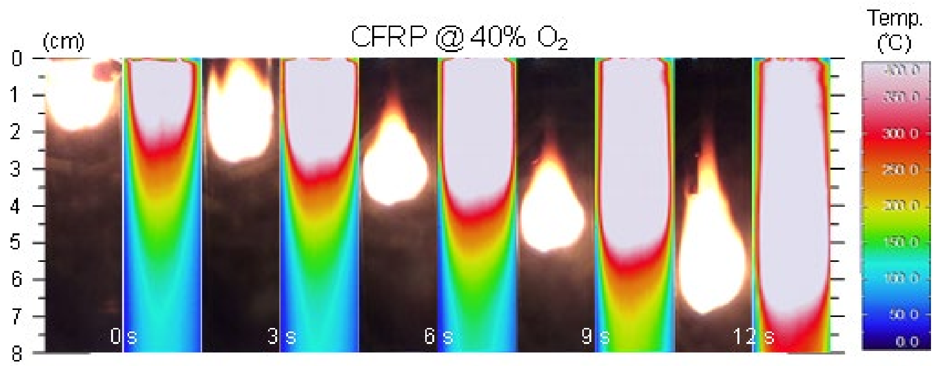
In FLARE, we developed a novel evaluation method for flammability of thin flat plastics materials used in microgravity condition. However, the fire hazard is not only for thin, flat and pure materials. In the successive FALRE2 project, we will modify the simplified model to include the effects of sample thickness, sample shape and anisotropy. Figure 5a shows the flammability map of PMMA with different thicknesses [8]. It is found that the quenching branch has affected by the sample thickness. Figure 5b shows the upward flame spread over a flat paper and bellows-shaped paper [9]. It is found that the bellows-shaped paper is more flame retardant. Figure 6 shows the flame spread over CFRP [10], and it is found that the heat transfer along the carbon fibers is significant and much affect the flame spread behavior.

Additionally, to correspond the recent Moon/Mars manned projects, we will also include the effect of pressure and gravity level. Especially on the Moon, the exploration atmosphere, reduced pressure (56.5 kPa) and increased oxygen concentration (34%), is proposed. The buoyant flow velocity can be estimated as Eq. 1, therefore, if the gravity level is varied, such as on the Moon, Mars or asteroids, corresponding buoyant flow velocity also changes; it means that the result of the OI test on the Moon varies according to the gravity level and pressure.



a) b)

Fig. 5 Effects of a) sample thickness and b) sample shape on flammability limit.



a)

Fig. 6 Downward lame spread over CFRP (t: 0.2 mm, crossing angle: 0 degree).

$$V_b \sim \left(\frac{\alpha_g g (T_{g,c} - T_\infty)}{T_\infty}\right)^{1/3} = f(g, p) \qquad (1)$$

The effect of ambient pressure will be investigated in FLARE partially in advance, and the additional orbital experiments with the same SCEM will be conducted in FLARE2. We believe that the obtained results in FLARE/FLARE2 will be helpful fire safety information not only in microgravity but also on the other planetary environments.

3. Summary

In the FLARE project, we have developed a simplified model that can predict the flammability of a thin, flat, plastics material in opposed flow. During the development, ISO 4589-4 has been published that determines the LOC in high opposed flow velocity. The calculated limiting curve well agreed with the parabolic flight experiment results, and we are now preparing the orbital experimental setup on ISS to verify the model. In FLARE2, the successive project, we will include the effects of sample configuration, anisotropy, ambient pressure and gravity level in the model. The modified model will be verified by the additional orbital experimental results.

References

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