Observations of Wire Ignition Phenomena at Excess Electric Current Application in Reduced Gravity

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1 Introduction

A most likely cause of fires in space is the combustion of the electric wire harness of spacecraft [1], which generally start by a short circuit or overloading of an electric wire. Therefore it is important to know the ignition characteristics of overloaded wires in microgravity to improve fire safety in space, and in future space exploration missions, activities on the surface of the Moon and Mars must be considered. Therefore fire safety issues under reduced gravity conditions should also be investigated in research on fire safety in space [2]. In previous research [3], the authors reported dramatic extensions of ignition limits with the supplied electric current in microgravity. A comparison of the ignition processes in microgravity and normal gravity were also reported. At present there is no published data the effect of gravity intensity changes, reduced gravity effects, on wire ignition. The present work performed ignition experiments of overloaded wire under reduced gravity conditions attained by aircraft parabolic flights.

In this study, overloaded wires exposed to reduced gravity conditions were observed and a determination of the occurrence of ignition was made. An ignition map showing ignition conditions based on electric current and gravity conditions was developed. The behavior of pyrolyzed gas motion was also observed with a high speed camera and optical methods in reduced gravity to discuss the relationship between pyrolyzed gas motion and wire ignition.

2 Experimental system and conditions

An outline of the experimental setup is shown in Fig.1. The setup has a 16.4-litter chamber (380 Wx 250 Hx 173 D in mm) with a sample wire inside, a constant current supply system (EX-375L, Takasago), high-speed camera (Motionpro X4, Redlake), and a digital video (DV) camera (DCR-TRV900, Sony) to record the outbreak of ignition. In some experiments, continuous images with backlight were taken to observe the generation of pyrolyzed gases by the high-speed camera. To take images with backlight, a matrix of LED lights was placed behind the wire sample. A programmable controller (FN2N-16MR, MELSEC) was used to effect a simultaneous start of the current supply, video time–code initiation, and the recording by the gravity sensor. The tested sample wire which is specially provided for the experiments here has a nickel-chrome core coated with polyethylene. The outer diameter of the sample wire is 0.8 mm and the inner core diameter is 0.5 mm, the sample length is 70 mm. The sample is set in the sample holder, which provides moderate tension to cancel the axial thermal expansion of the core wire during the period of combustion. Experiments were performed in air at about 293 K and at a pressure of 0.1 MPa. The oxygen concentration, supplied current, and the gravitational force was changed as shown in Table 1. The actual gravitational forces used in this paper are calculated by averaging the gravity acceleration data. The fluctuation of gravity intensities are within ± 0.3 of these values except for microgravity experiment ($G=0.003\pm0.01$ of the value).

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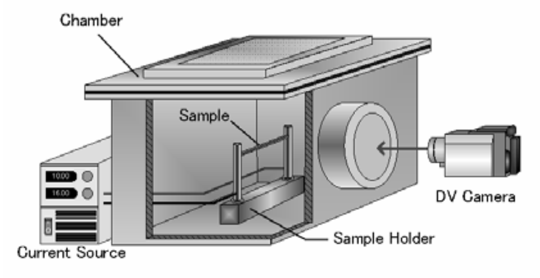


Fig.1 Experimental setup

Table 1 Experimental Condition Matrix

Gravitational intensity G (=g/g_0)	Current value I (A)	Oxygen concentration O_2□X%
0.003, 0.1, 0.2, 0.3 0.4, 0.5, 0.6, 0.7, 0.8, 1.0	8.0, 11.0, 13.0, 14.0, 15.0	21
	6.0, 6.5, 7.0, 9.0, 13.0	40

g_0 : gravity acceleration on the ground

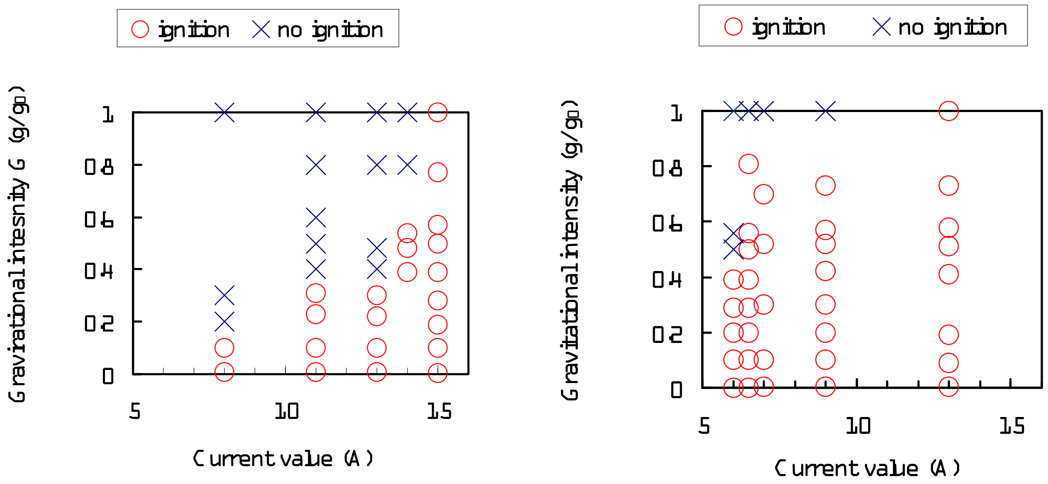
Reduced gravity experiments were provided by the Diamond Air Service (Aichi Prefecture, Japan) reduced gravity aircraft MU-300. Parabolic flight trajectories attain a reduced gravity environment for 15-20 s. During the tests, three orthogonal gravity accelerations were recorded at a sampling rate of 100 Hz. The DV camera provides color images at 30 frames per second and the high-speed camera provides monochrome images at 1000 frames per second.

3 Results and Discussion

An ignition map is drawn in the plane of the gravity intensity G (=g/g_0 where g_0 is the gravity on the ground) and the supplied electric current as shown in Fig.2. In the figure, "○" shows that ignition took place, and "×" shows that there was no ignition. The figure shows that the wire ignitions caused by overload are susceptible to changes in the gravitational force. As can be seen, a criterion of ignition depending on gravity intensity can be developed from the data. With 21% O_2, there is a clear effect of gravity on wire ignition and the value of the ignition threshold based on the magnitude of the gravity increases with increases in the current value. At 40% O_2, ignition occurs more easily than that in 21% of O_2 but there is still a threshold gravity for ignition at the lower electric current conditions, which also increases with increases in the current value.

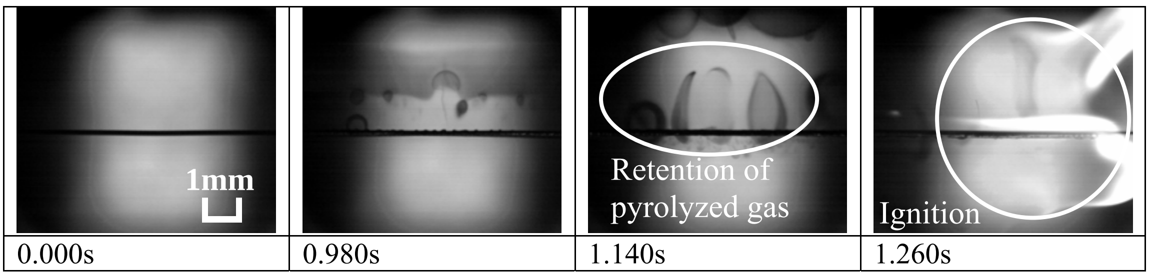
A matter of special note here is the extension of the ignition limit, defined as the minimum electric current to cause ignition, when compared with zero-gravity experiments ($G=g/g_0 <10^4$) attained by a 100m droptube [3]. In the zero-gravity experiments [3], the ignition limits were 8 A at 21% of O_2 and 6.5 A at 40% of O_2. The ignition limit in Fig.2 is 6 A at 40% of O_2 under a G of 0.003, 0.10, 0.20, 0.29, and 0.39. A possible reason for the difference is the long ignition delay at the ignition limit as will be shown in a later section. The droptube used in the previous work provides only 4.5 s of microgravity. Therefore ignition limit at 40% of O_2 may have been reported as 6.5 A because the ignition delay time at 6 A can exceed 4.5 s as will be shown later (see Fig.4). In the present test, the reduced gravity duration was 15-20 s allowing observation of significant extensions of the ignition limit. Overall, the results imply that longer duration microgravity is necessary to establish a more realistic ignition map.

Figure 3 shows two video sequences around the wire with ignition (Fig.3 (a), G=0.10, O_2=21%, I=13 A) and without ignition (Fig.3 (b), G=0.41, O_2=21%, I=13 A). These images were taken with backlight to visualize the distribution of the pyrolyzed gas by the high-speed camera. The times shown below each image are elapsed time from the start of the current supply. There are clear differences between the two video sequences, remaining pyrolyzed gas is observed in the sequence of (a) in G of 0.10 until ignition (t=1.260 s), while no pyrolyzed gas is observed at the same time (t=1.260 s) in sequence (b). In sequence (b) at 1.260 s pyrolyzed gas has moved outside the view area, implying

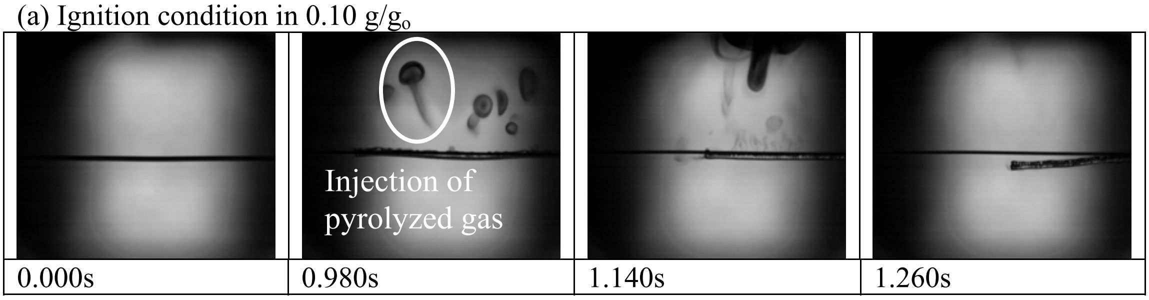


(a) Ignition map at 21% of O_2 (b) Ignition map at 40% of O_2

Fig.2 Ignition map of the overloaded wires



(a) Ignition condition in 0.10 g/g$_o$

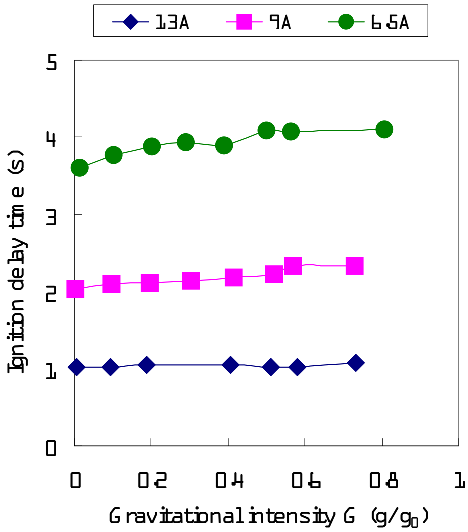


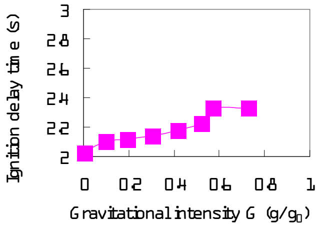
(b) Non- ignition condition in 0.41 g/g$_o$

Fig.3 Video sequences of the wire with backlight (21%O_2-N_2 balance, 13 A and 0.1 MPa)

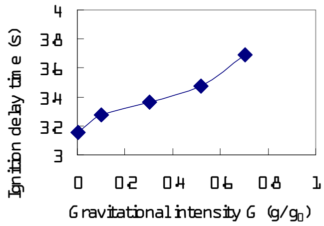
a shorter residence time of the pyrolyzed gas than the ignition delay in the gas phase. This difference could be a cause of the influence of gravity intensity on the differences in the ignition delay time.

Ignition delay times at the 40% O_2 condition are shown in Fig.4. The delay time is determined from the video sequences as a function of gravitational intensity. As seen in Fig.4 (a) the ignition delay is mainly determined by the electric current, as the time to heat up the sample wire to the degradation temperature by Joule heat occupies the main part of the total delay. This delay is not strongly affected by the gravitational intensity. However, detailed observations of the effect of gravity in Fig.4 (b), (c), and (d), and the closeup of (a), show a clear dependence of the ignition delay on gravitational intensity. The increase in the delay with G may include both (1) a physical effect by increased heat loss from the sample surface until the temperature reaches the degradation temperature and (2) a stretch effect in the gas phase by the effect of flow field changes such as numerically discussed in Ref. [4]. The latter delay can strongly affect the ignition criteria at gravitational intensities when the residence time of the pyrolyzed gas at the gravity condition is limited as seen in Fig.3.

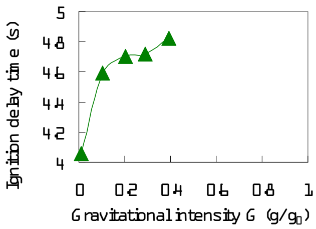




(b) Enlargement of the 9 A graph



(c) Enlargement of the 7 A graph



(d) Enlargement of the 6 A graph

(a) Panoptic comparison at 40% O_2-N_2 balance experiments

Fig.4 Ignition delay times vs. Gravitational intensity G (=g/g_0)

4 Conclusions

The ignition phenomenon of overloaded wires in reduced gravity was investigated to obtain basic data for fire safety in space. The results obtained in the investigation may be summarized as follows:

(1) An ignition map, considering gravitational intensity and supplied electric current is newly presented based on the reduced gravity parabolic flight experiments. This map shows existence of ignition criteria related to gravitational intensity above which ignition does not occur. The critical gravitational intensity increased with increases in electric current values and oxygen concentrations.

(2) Ignition delays as a function of gravitational intensity were established for a range of electric current values. The ignition delay is affected by both of electric current and gravitational intensity. The major part of total ignition delay time was determined by Joule heat generation directly determined by the current, however there is a clear dependence of the delay on gravitational intensity. The importance of the delay changes with gravitational intensity as critical in determinations of limits on the gravitational intensities leading to ignition.

Acknowledgement

This research was supported by the “Ground-Based Research Program for Space Utilization” promoted by Japan Space Forum (2006-2009).

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