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Ignition limits of short-term overloaded electric wires in microgravity

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Abstract

Ignition phenomena of electric wires carrying short-term excess electric currents were investigated in microgravity with experiments and calculations. Microgravity experiments were conducted in 100 m and 50 m drop towers and calculations were carried out with a one dimensional cylindrical coordinate system. The experimental results showed that the limiting oxygen concentration (LOC) under a given electric current was much lower in microgravity than that in normal gravity except for extremely large electric current overload cases. According to the calculations, the supplied electric current, the Joule energy supplied to the wire, determined the amount of pyrolysis gas from the insulation and the resulting thickness of the gaseous fuel layer around the sample in gas phase increased. The increased fuel layer thickness resulted in a longer ignition delay, which leads to lower LOC. The changes in the estimated LOC changed as a function of supplied energy and agreed well with the experimental results. Further, the minimum ignition energy causing ignition (ignition limit) is nearly constant under a constant oxygen concentration, which supports experimental findings in previous research.

Keywords: Ignition limit; Electric wire; Short-circuiting; Fire safety in space; Microgravity

1. Introduction

A most likely cause of fires in space is combustion of the wire harness of spacecraft [1,2], and such fires are generally started with short-circuiting or overloading of electric wires. Therefore, it is important to know the ignition characteristics of overloaded wires in microgravity to improve fire safety in space. To know the electric current needed for ignition of electric wires is important in the design of circuit breakers. As carbon dioxide extinguishers are used in the International Space Station [3], limiting oxygen concentration for ignition is essential to design extinguishers based on asphyxiating effects and to establish the ambient oxygen concentration in spacecraft.

Knowledge of the ignition characteristics of solid components in microgravity is a basic subject which must be studied to prevent the breaking out of fires, and a number of theoretical and experimental studies have been conducted. One example of solid ignition research in microgravity is piloted ignition of PMMA plates [4,5] and others are non-piloted ignition of thin cellulosic sheets [6–9] or PMMA sheets [10] heated by external radiant sources. However, there are few

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studies except from our research group [11,12] about spontaneous ignition of electric wires caused by Joule heat generated in the wire core.

In the previous research [11], the authors reported dramatic extensions of ignition limits in terms of supplied electric current under microgravity. In that research, excess electric current was continuously supplied until ignition occurred. In other research [12], the authors investigated the ignition characteristics with short-term excess electric currents. There, the length of the current supply was selected as the main test parameter to simulate the status of circuit breaker activation shortly after overloading happens, and delayed ignition of electric wires after short-term overloading was observed in microgravity. In the results with short-term electric current supply, the ignition delay may be longer than with a continuous current supply. The electric current is smaller in microgravity than that on the ground as in the continuous current case. The established findings [11,12] indicate the probability of ignition increases in microgravity. One matter that has not been established in the previous work is the limiting oxygen concentration, below which wire ignition does not occur even with excess electric current. A detailed knowledge of this basic parameter is essential for fire safety in space.

The present study, investigates the ignition limit; the minimum value of the electric energy supply causing ignition, and LOC; limiting oxygen concentration, below which ignition does not occur at a given electric current supply for short-term excess electric currents under microgravity, by experiments and calculations. The mechanism to determine the ignition limit and the LOC is discussed based on the numerical results.

2. Experiments

All experiments were performed in the apparatus similar to that used in previous research [12]. An outline of the experimental set-up is shown in Fig. 1. It is composed of a combustion chamber with the sample wire inside, a constant current supply system, and an image recording system. The tested sample in Fig. 2 is a nickel–chrome core wire coated with polyethylene. The outer diameter of the sample is 0.8 mm and the inner core diameter is 0.5 mm. The effective length of the sample is 70 mm; the electric resistance of the core wire is 5.5 Ω/m. The resistance is the value under room temperature, which is used to calculate the Joule energy, E, generated in the core wire under a given electric current. In the tests, the length of time the current is applied, t_a, was varied in the range from 0.2 to 1.5 s to simulate delays in the circuit breaker activation. Oxygen concentration and supplied current values were also varied in the tests. Microgravity experiments were conducted at the MGLAB (Microgravity Laboratory of Japan) in Gifu, Japan, which provides a microgravity environment of $10^{-5}g_0$ (g_0: gravity level on the ground) for around 4.5 s and at the COSMOTORRE in Hokkaido, Japan, which provides $10^{-3}g_0$ environment for around 2.7 s. When light emission in gas phase is observed in the video images, it is defined as "ignition" in the experiment and the "Ignition delay", t_{ig} is defined as the time after the start of current supply till the moment of ignition.

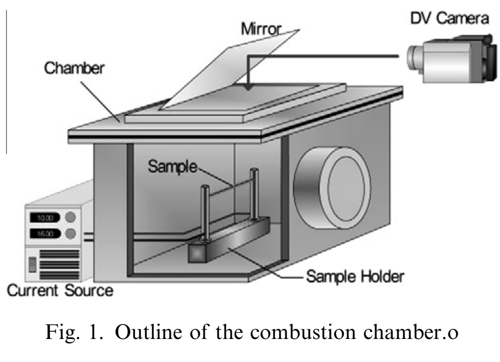

Fig. 1. Outline of the combustion chamber.o

Fig. 2. Schematic details of the sample wire.o

2.1. Method of the numerical calculations

The numerical calculations are carried out with a model on a one dimensional cylindrical coordinate system. Fig. 3 is a schematic illustration of the ignition model. At the start of the experiment (time zero) current is supplied to the core wire and insulation starts to degrade to emit pyrolysis gas into the oxygen-containing atmosphere. The evolved gas mixes with the ambient oxygen to form a hot combustible mixture eventually leading to spontaneous ignition. The assumptions adopted for the calculations were as follows:

1. Both core wire and insulation are thermally thin.
2. The solid fuel thickness is held at the initial value throughout the course of the calculations. The density decreases with time as the reactions degrading the solid phase proceed.
3. Gas generated by the degradation is ethylene.