An Experimental Study of on the Combustion Properties of Lobby Chairs in Open Space and in ISO Room Compartment

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ABSTRACT

Performance-based design should reflect initial fire phenomena properly. For this purpose, necessary data are being accumulated through combustion tests. It is reported that the maximum heat release rate and the fire growth rate are significantly increased by thermal radiation feedback effects from a smoke layer and a wall in a compartment in comparison with burning in an open environment [1-2]. In this study, a series of burning tests were carried out using lobby chairs to compare burning behavior in open environment and in a compartment. The measured items were heat release rate, mass loss rate, heat flux and vertical distribution of temperature in the compartment and above the center of combustibles. The cause of flame spread to adjacent chair was different between in an open space and in a compartment. In an open space, flame spread was mainly caused by direct contact of flame with adjacent chair. However, the main cause of the flame spread in a compartment was thermal radiation. As a result, heat release rates in open space and in a compartment significantly differ in shape. In a compartment, heat release rate slowly decreases after it reaches at the maximum level. In open space, heat release rate increased and decreased as flame spread to adjacent chairs successively. Heat flux showed similar patterns with that of heat release rate. Both maximum heat release rate and maximum heat flux increased as the number of chairs were increased. Measured values in a compartment are 2-4 times larger than that in an open space. Fire growth rate was increased by hot smoke layer. However, the relationship with the number of chairs was not clear. In addition, it was confirmed that the air temperature around chairs was higher than that in an open space.

KEYWORDS:

Burning in a Compartment; Flame spread; Fire growth; Lobby chairs

NOMENCLATURE LISTING

| Symbol | Definition |
|--------|------------|
| HF     | Heat flux (kW/m²) |
| Q      | Heat release rate, HRR (kW) |
| T      | Temperature (°C) |
| t      | Time (s) |
| α      | Fire growth rate (kW/s²) |

| Subscripts | Description |
|------------|-------------|
| grow       | Growth      |
| max        | maximum HRR |
| 0          | incubation  |
INTRODUCTION

It is recommended that performance-based design consider the initial fire phenomena properly. For this purpose, basic data sets necessary to predict behavior of a fire are being accumulated through combustion tests. It is reported that the maximum heat release rate (Hereinafter, HRR) and the fire growth rate are significantly increased due to thermal radiation feedback from a smoke layer and from enclosure walls in case of fires in a compartment [1-2]. For example, the maximum HRR of upholstered furniture is increased by 20 % in a compartment compared to that in an open space [1]. According to a study conducted using polyurethane foam blocks, the maximum HRR is increased by 80 % in an ISO room corner compartment. At a corner, 10-20% of additional increase was observed [2]. However, basic data and quantitative research on fires spreading to adjacent combustibles are not sufficient yet. Therefore, the purpose of this research is to examine the behavior of fire spread to adjacent combustibles quantitatively. The experiments were carried out using lobby chairs both in an open space and in a compartment. The influence on the initial fire growth and maximum HRR was investigated.

EXPERIMENTAL METHODS

The dimension of a lobby chair was W600 x D550 x H680 mm. The weight of each lobby chair is in the range 10.23-10.80 kg. As a result of disassembling one lobby chair, main constituent materials were natural wood frame 7.635 kg, polyurethane foam 0.46 kg for cushion materials with thickness 5-25 mm, PVC 0.765 kg for covering material and stainless steel 1.26 kg for legs. The estimated total heat release (THR) was 157.7 MJ [3]. An iron plate with the thickness of 1.6 mm is installed between the cushion part and the leg part before conducting a combustion experiment.

Fig. 1 and Fig. 2 show experimental methods in open space and in a compartment. An experiment is separately conducted in an open space (OS1-OS3) and in a compartment (CS1-CS3). For experiments in a compartment, ISO9705 room corner test facility was used [4]. Lobby chairs were arranged side by side. The distance between chairs was 40 mm. An ignition point was located at the center of the cushion part. A piece of ceramic blanket, 30 x 30 mm, was absorbed with a small amount of ethanol and ignited. HRR was measured by an oxygen consumption method [5].

Vertical temperature distribution was measured by using type K thermocouples of diameter 0.32 mm. Total heat fluxes were measured using Circular-foil gauges (Gordon gauge). Mass loss was measured by a load cell. The mass loss was measured only in open space experiment. As for heat release rate measurements, delay time was adjusted by preliminary experiments using methanol pool fires.

Fig. 1. Combustion experiments of lobby chairs in an open space
EXPERIMENTAL RESULTS

Combustion behaviors in an open space (OS1-OS3) and in a compartment (CS1-CS3) are shown in Fig. 3. In an open space, fire spread horizontally to the back of a chair in a circular shape. In a compartment, fire also spread to the back of a chair and a wall in a circular shape, but the spreading speed was much faster in the direction toward a wall. In addition, fire spread to the adjacent chair when chair were placed side by side. In an open space, flame spread to an adjacent chair by direct flame contact. In a compartment, flame spread to adjacent chair by thermal radiation without direct contact of flame. Flame spread time in a compartment is relatively shorter than that in an open space. After 15 minutes, burning was reduced because only the burning of wood frame continues.

| Time    | OS1          | OS2          | OS3          | CS1          | CS2          | CS3          |
|---------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1'00"   |              |              |              |              |              |              |
| 3'30" (growth period) | | | | | | |
| 5'00"   |              |              |              |              |              |              |

Flame spread A to B

- 6'42" by contact of flame
- 6'29" by contact of flame
- 5'40" by radiation
- 5'05" by radiation

Flame spread B to C

- Not happened yet
- 5'51" by radiation

10'00"

Flame spread B to C

- already spread

Fig. 2. Combustion experiments of lobby chairs in a compartment
The results of HRR are shown in Fig. 4. The maximum HRR was significantly increased as the number of chairs increased. HRR’s in an open space and in a compartment differ considerably. In an open space, the number of HRR peaks is the same as the number of chair. The maximum HRR occurred at the second peak. In compartment, the maximum HRR is quickly increased to the maximum. Then, the HRR decreased gradually. Compared to CS1, the values of total heat release (hereafter, THR) of OS1 were smaller because wood frame did not burn completely.

The heat flux (hereafter, HF) are shown in Fig. 5. The change of HF was similar to that of HRR. HF in compartment is significantly larger than that in an open space.

The height of a smoke layer was determined by using vertical temperature distribution measured by a thermocouple tree apart from flame (TC3). The smoke layer height was defined as the height where temperature increase was 10% of the maximum temperature increase [6]. Change of the smoke layer height and the temperatures of smoke layer and air layer are shown in Fig. 6 (a). The smoke layer interface descends during 300 and 400 seconds but maintains stable position after 400 seconds. The height of the smoke layer was about 800-1000 mm from the bottom. The smoke layer height was lower as the number of chairs was
increased. The smoke layer temperature was significantly increased when smoke layer height was low. The maximum temperature occurred at around 400 seconds. Thereafter, the temperature of the smoke layer gradually decreased.

The flame tip height was obtained from temperature distribution measured by a thermocouple tree installed above the chair (TC1). The flame tip height was defined as the point where the temperature decreased to 290°C [7]. Fig. 6 (b) indicates the measured results of OS1 and CS1. Comparing the flame size in an open space with that in a compartment, the flame grew more quickly in a compartment. The flame tip in a compartment was twice as high as that in an open space.

DISCUSSIONS

To compare between experiments, maximum $HRR$ and time to maximum $HRR$ were extracted from measured data and plotted in Fig 7. Both in an open space and in a compartment, the maximum $HRR$ increases as the number of chair increases. However, it is revealed that the degree of increase is significant in a compartment than in an open space.

Maximum $HF$'s obtained by each test are shown in Fig. 8. $HF$ in a compartment is larger than that in an open space. The $HF$ in a compartment was larger than that in an open space, about 2 times in case of one chair burning, about 2.7 times in case of 2 chairs, about 4 times in case of 3 chairs.

The initial fire growth rate (hereinafter, fire growth rate) $\alpha_i$ (kW/s²) was obtained from the result of $HRR$ [7] using

$$\alpha_i = \frac{Q_{grow}}{(t_{grow} - t_0)^2}, \quad t_0 < t_{grow} < t_{max} \tag{1}$$

where $Q_{grow}$ is the maximum $HRR$ (kW) in the regression section, $t_{grow}$ is the duration of the maximum $HRR$ (s), $t_0$ is incubation time (s). Fig. 9 shows the relationship between fire growth rate and smoke layer temperatures. Here, the smoke temperature is the maximum temperature in the fire growth period. The graph also contains data on polyurethane foam blocks in ISO room corner test compartment [2]. According to the experiment results, the fire growth rate increases as the smoke layer temperature increases. The fire growth rates in a compartment are roughly twice as large as those in an open space. Compared to the results of experiments on corners in previous studies, it shows relatively larger fire growth rates overall. For a lobby chair, it is assumed that mutual thermal feedback between heated sides is a cause of increased fire growth rate because the cushion part and the back part of a chair burned simultaneously.

CONCLUSIONS

Burning experiments were conducted in an open space and in a compartment using lobby chairs. One to three specimens were set at a separation distance of 40 mm. The results were as follows;
The cause of flame spread to an adjacent chair was the contact of flame in open space and thermal radiation in a compartment.

The history of HRR was largely different between in an open space and in a compartment. In a compartment, the HRR gradually decreased after quickly reaching to the maximum value. In an open space, the increase and decrease of the HRR repeated due to successive spread to adjacent combustibles.

History of HRR and HF were similar in shape. Maximum HRR and maximum HF increased with increasing number of chairs. The measured values in a compartment were about 2 to 4 times of those in an open space.

The fire growth rate increased with the increase in the smoke layer temperature. In a compartment, the lower layer temperature around the chair also increased with the temperature increase in the smoke layer.

Fig. 7. maximum HRR and time to maximum HRR
Fig. 8. Comparison of maximum Heat flux
Fig. 9. Smoke layer temperature and fire growth rate [2]

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