Differences between Free and Compartment Burning of Furniture

Part 2 Maximum Heat Release Rate and Fire Growth Rate

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1. INTRODUCTION

As a sequel to Part 1, based on the experimentally obtained time history of the heat release rate of the flammable material, this report presents the change of the heat release rate of flammable materials, such as a legless chair and a sofa in free burning (open space) and compartment burning (enclosed space) conditions.

Regarding the curve of the heat release rate (hereinafter, HHR curve), the increasing heat release rate can be expressed by the fire growth rate and the maximum heat release rate. However, it is uncertain how the fire growth rate and the maximum heat release rate change when the burning occurs in open space and inside a compartment. Therefore, in this report, a method for estimating the increased portion of the fire growth was developed in order to create a simplified model of the heat release rate curve, such as determining the calculation method of the fire growth and the maximum heat release rate. This method makes use of a variable defined as the radiative heat transfer from the smoke layer and the compartmental walls due to the combustion of a legless chair and a sofa inside the compartment.

2. EXPERIMENTAL RESULTS FOR HEAT RELEASE RATE

Figure 1 shows the results for the heat release rates obtained with test object S in the free burning and the compartment burning conditions. In compartment burning case (Sc-1), the time elapsed until the peak of the heat release was reached was 7 min 15 s, and the maximum heat release rate was 1645 kW. In the free burning case (Sf-1), the time elapsed until the peak of the heat release was reached was 8 min 19 s, and the maximum heat release rate was 1245 kW. In the compartment burning case, the heat release rate reached its maximum when the entire test object was burning. In contrast, in the case of the free burning, the heat release rate reached its maximum when only the seating part and back rest were burning. In addition, the time elapsed until the maximum heat release rate was reached is 1 min shorter in the compartment burning case as compared with the free burning, and the value was 400 kW greater in the

compartment burning case. As presumed in Part 1, this was possibly triggered by the heat radiation from the smoke layer and the surrounding walls.

Figure 1 Heat flux of test object S (Sofa)

3. SIMPLIFIED HEAT RELEASE RATE MODEL

In order to estimate the HHR curve for a flammable material in a simple manner, the method described in Figure 2 was considered. It assumes that after ignition the heat release rate increases proportionally to the square of the time until the heat release rate reaches a maximum.

$$Q = \alpha t^2 \quad 0 \leq t \leq t_{\max} \quad (1)$$

After the heat release rate has reached a maximum, it is assumed that the peak burning continues and subsequently burning will be completed. However, the duration of the peak burning (t_c) needs to be calculated in a way such that it is equal to the total heat release rate (THR), which can be calculated as the product of the weight of the flammable material and the heat of combustion (ΔH_c) per unit weight. Therefore, the duration of the peak burning was calculated by subtracting from THR the heating value of the duration where it increases at an initial rate of αt_2 , and then dividing the resultant value by the maximum heat release rate.

$$Q = Q_{\max} \quad t_{\max} \leq t \leq t_{ex}$$

$$t_c = \frac{THR - \alpha t_{\max}^3 / 3}{Q_{\max}} \quad (2)$$

Figure 2 Simplified model of the heat release rate curve

3.1 Relation between fire growth rate and density

Based on the simplified model described above, the fire growth rate which needs to be used in the simplified model is derived.

By assuming that the burning area spreads concentrically, the heat release rate can be calculated by taking the product of the burning area and the heat release rate per unit time. In theory, the flame propagation speed of the flammable material is inversely proportional to the density of the flammable material.[1] Therefore, the fire growth rate can be approximated by the inverse of the proportion to the square of the density of the flammable material.

Given this factor, the fire growth rate for each experiment was calculated. However, the fire growth rate α was calculated as the increase by αt_2 between 2 points: the time needed to reach the maximum heat release rate and the time needed to reach 10% of the heat release rate, based on the experimental results. As a comparison, with the same method, another fire growth rate was calculated based on the results obtained in reference [2]. *Figure 3* shows the relation between the fire growth rate and the density. According to *Figure 3*, the range of the fire growth rate of the legless chair is 0.01 to 0.1 kW/s². As mentioned earlier, in the case of two-dimensional burning, the fire growth rate is theoretically inversely proportional to the square of the density of the flammable material, but it is difficult to assess the fire growth rate with respect to the density if the burning object is three-dimensional, such as a legless chair.

Figure 3 Relation between fire growth rate and density

3.2 Relation between maximum heat release rate and surface area

According to the observation record of this experiment, the heat release rate reached a maximum when the exposed area of the front face of the object was completely covered by flames. Taking this factor into account, the relation between the maximum heat release rate and the exposed area of the front face of the sofa and the legless chair is presented in *Figure 4*, together with the result based on Reference [2].

As shown in *Figure 4*, the maximum heat release rate increases in both cases (legless chair and sofa) as the surface area increases, although in one case the maximum heat

release rate remarkably increased more than that of Reference [2]. Other than that, as a result of calculating the heat release rate per unit, where the maximum heat release rate was divided by the surface area, the average of the heat release rate per unit area became 339.6 kW/m^2 (legless chair) and 500.2 kW/m^2 (sofa).

Figure 4 Relation between maximum heat release rate and surface area

4. CHANGE OF FIRE GROWTH RATE IN THE CASE OF COMPARTMENT BURNING

In the previous section, the experimental results for free burning were given. This section investigates how fire growth rates change when the same flammable materials are burned inside a compartment for the purpose of making a comparison with the free burning case.

The fire growth rate was calculated by using the experimental results for the compartment burning. Comparing the average fire growth rates of the legless chair (Cw), it was 0.070 kW/s^2 in the free burning case, while it reached 0.082 kW/s^2 during the compartment burning, which is an increase of approximately 10%. In the case of the sofa, the average fire growth rate was 0.059 kW/s^2 in the case of free burning, while it was 0.073 kW/s^2 in the case of compartment burning, which is an increase of approximately 20%. Thus, it was confirmed that the fire growth rate increases in the case of the compartment burning. This indicates that the radiative heat transfer from the smoke layer and the surrounding walls, influenced the increase in the fire growth rate. Considering this factor, based on the values of the heat flux obtained in this experiment, the increase rate of the fire growth is evaluated.

Figure 5 was plotted based on the incoming heat flux at the time the heat release rate has reached maximum. The x-axis indicates the portion of the incoming heat flux which has increased in the compartment burning case as compared to the free burning case, and the y-axis is the fire growth rate. It should be noted that the value of the heat flux is taken from meter (2), which is placed above the center (refer to Part 1 for detail). As shown in Figure 5, the fire growth rate increases as the incoming heat flux in the compartment increases.

Figure 5 Relation between fire growth rate and incoming heat flux

5. CONCLUSIONS

The following findings were obtained from burning experiments involving a legless chair and a sofa in free burning and compartment burning conditions.

- In the experiment involving a sofa, the time elapsed until the peak of the heat release was reached was 1 min shorter, and the maximum heat release rate was 400 kW greater in the compartment burning case than in the free burning case.
- The range of the fire growth rate of the legless chair is from 0.01 to 0.1 kW/s².
- The maximum heat release rate increases in proportion to the surface area. The heat release rate per unit area was 340 kW/m² in the case of the legless chair and 500 kW/m² in the case of the sofa.
- Both the values of the fire growth rate and the values of the maximum heat release rate are greater in the compartment burning case than in the free burning case. The increase ratio of burning between the compartment burning case and that of the free burning case can be calculated by using the incoming heat flux as a variable. However, further research is needed to assess the influence of the incoming heat flux.

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