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Procedia Engineering 62 (2013) 283 – 291

Procedia Engineering

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The 9th Asia-Oceania Symposium on Fire Science and Technology

An experimental study on fire spread over polyurethane block receiving heat feedback from adjacent walls

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Abstract

An experimental study on fire spread was conducted using a solid polyurethane block receiving heat feedback from adjacent walls. Near-wall and near-corner configurations were applied to investigate the heat feedback effects from wall depending on the separation distance between polyurethane block and walls. Oxygen consumption method was used to measure the heat release rate (HRR). Flame spread rate was measured by video records of flame front for the each surface. The results show that in the case of insulation walls made of ceramic fiber board walls, maximum HRR was increased up to 20% for the near-wall and 40% for the near-corner configuration, respectively, as compared with burning in open configuration. Maximum HRR was increased as separation distance is increased to a certain value. After reaching the peak value, maximum HRR was decreased as the separation distance is increased. The heat feedback effects could be confirmed through flame spread rate both top and vertical surfaces, but more clearly appears in vertical surfaces.

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Keywords: Fire spread; Heat feedback; Heat release rate; Solid combustibles; Walls

Nomenclature

d	separation distance between combustibles and walls (mm)
Q	heat release rate (kW)
Q_{max}	maximum heat release rate (kW)

1. Introduction

For the purpose of building fire safety design, it is important to know the growth of fire in the initial stage of fire quantitatively for a given combustibles and their arrangements. Concerning with the prediction methods, there are some earlier studies on the burning characteristics in open arrangement. Tsukuda et al. [1] proposed the fire spread model to predict the effects of combustibles size and interaction with polyurethane blocks of various sizes. Shintani et al. [2] extended the model to take into account of the effect of external radiation from smoke layer, ceiling and near wall surfaces to combustibles surfaces. Polyurethane block was burnt under smoke layer. Acceleration due to external radiation was quantified.

But the effect of vertical wall is left to be solved. If a combustible item burns close to a wall or close to a corner of wall, interaction between wall surface and flame would take place. If flame adheres to wall surfaces, flame length is extended to

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1877-7058
Selection and peer-review under responsibility of the Asian-Oceania Association of Fire Science and Technology
doi:10.1016/j.proeng.2013.08.066

create large emitting surface. Flame adhesion to wall may alter the air flow around combustibles from that in open configuration. For the accurate prediction of burning characteristics of solid combustibles in compartment fire, it is very important to identify the mechanisms of heat feedback effects. In this study, the experiments were performed to examine the flame spread and heat release characteristics of polyurethane block close to wall and close to corner. Flame spread routes and heat release rate were measured and compared with those in open configuration.

2. Experimental methods

2.1. The configurations of specimens

The experimental configurations are shown in Fig. 1(a) and 1(b). The walls materials were heat-resistant glass or ceramic fiber board, respectively. Burning behavior was observed as increasing of separation distance with combustibles and walls. The size of polyurethane block was 500 × 500 × 500 mm and density was 15.6 kg/m^3. The size of heat-resistant glass and ceramic fiber board were 1000 × 1000 × 8 mm (thickness) and 1800 × 900 × 50 mm (thickness), respectively.

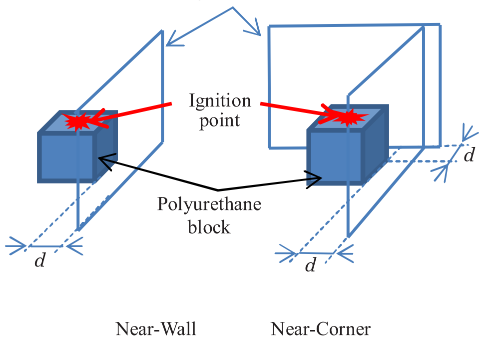

Fig. 1(a). Schematic of experimental apparatus.

Fig. 1(b). Photo of experimental arrangement in case of near-corner configuration with no separation distance (experiment 5b).

Table 1. Experimental conditions

Experiment No.	Configuration	Separation distance, *d* [mm]	Wall materials
1a	Open	-	-
1b		-	-
2	Near-wall	0	Heat-resistant glass
3	Near-corner	0	
4a	Near-wall	0	Ceramic fibre board
4b		10	
4c		50	
4d		100	
5a	Near-corner	0	
5b		10	
5c		50	
5d		100	

(a) Open (experiment 1a)

(b) Near-wall, no separation distance (experiment 4a)

(c) Near-corner, no separation distance (experiment 5a)

Fig. 2. Burning behavior in open, near-wall and near-corner configurations.

2.2. Experimental conditions

The conditions of experiments are shown in Table 1. Experiments 1a and 1b are to confirm the characteristics of fire spread in an open configuration. Experiments 2 and 3 are to observe the flame spread near wall and near-corner configurations, respectively. The walls are made of heat resistant glass, which can easily penetrate the heat to unexposed side. Condition 4a and 5a are the same with experiments 2 and 4, but the walls are made of ceramic fiber board in order to investigate the effect of insulating characteristics of wall materials. Condition 4b ~ 4d and 5b ~ 5d are to investigate the effects of separation distance between wall surfaces and specimen surfaces. The ignition point is center of top surface in all the experiments.

(a) 10 mm (Experiment 5b) (b) 50 mm (Experiment 5c) (c)100 mm (Experiment 5d)

Fig. 3. Burning behavior in near-corner configurations with 10, 50 and 100 mm of separation distances.

2.3. Measurements

Combustion products were collected and measured in the ventilation hood to obtain the HRR with oxygen consumption method. The progress of flame front on all surfaces was recorded by video cameras.

3. Experimental observations of burning behavior

3.1. Comparison of burning behavior in open, near-wall and near-corner configurations

Photographs of experiments in open (1a), near wall (4a) and corner (5a) configurations are shown in Fig. 2 at every 90 seconds. In the open configuration, the flame which is ignited at center of top surface spread in the shape of circle and reach to the edge of top surface at about 90 seconds. And then, flame spread downward on the side surface, and reached to the bottom about 330 seconds. In the near-wall and corner configurations, small changes appeared from 60 seconds after ignition. After about 60 seconds, flame grew to tilt toward the wall and the spread was accelerated. This acceleration was more increased at the side surface than top at surface, and consequently, the side surface adjacent wall was most rapidly burned.

3.2. Change of burning behavior due to the separation distance to wall

Photographs of burning behavior at every 90 seconds are shown in Fig. 3 for the near-corner configurations according to the separation distance (5b~5d). The flame ignited at center of top surface spread in the shape of circle and was accelerated by tilt of flame. The flame spread downward on vertical surface up to its bottom. After about 120 seconds, it grew to increase the intensity of flame in case of 100 mm, so the fastest burning was appeared about 210 seconds, but completion time of combustion was almost same in these experiments.

4. Heat release rate

4.1. Comparison of open, near-wall and near-corner configurations with no separation distances

The measured HRR for experiments using heat-resistant glass wall (experiments 2 and 3) are shown in Fig. 4 in comparison with those of open configuration (1a and 1b). There were almost no differences in the initial fire growth rate when the flame is spreading over top surface. The initial peak of HRR was increased by 15% in case of near wall configuration, 20% in case of corner configuration. After the initial peak, the HRR is slightly decreased for a while. After the second peak, HRR decayed gradually. In both cases, the burning area was limited by wall surfaces which prevent the fresh air to contact with burning surface. However, burning rate in the part in contact with air might be increased. As a result, the change in HRR was minor.

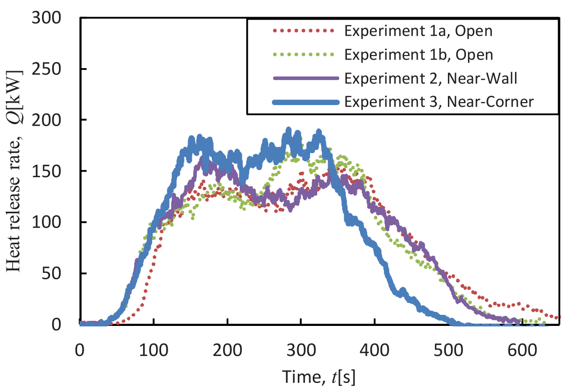

Fig. 4. The comparison of heat release rate in case of open, near-wall and corner configuration (Heat-resistant glass).

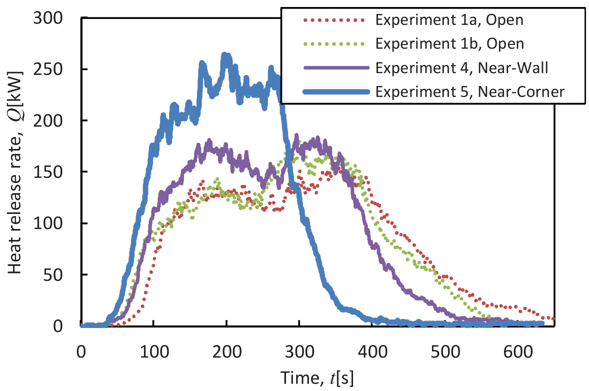

Fig. 5. The comparison of HRR in case of open, near-wall and corner configuration (Ceramic fiber board).

The HRR of experiments using ceramic fiber board are shown in Fig. 5. The initial growth was quick in the case of corner configuration. Even in the initial spread over top surface, thermal feedback effect can be recognized due to the flame inclination to corner and possibly due to radiation from wall surface to specimen surface. The maximum HRR was significantly increased. In case of near-corner configuration, maximum HRR was about twice of those in open configuration. In case of near wall configuration, HRR was increased by 20%.

4.2. *The effects of separation distance*

Figure 6 shows the comparison of HRR by separation distance to wall surfaces in case of near-wall configurations. Compared with no separation distance case, initial growth and maximum HRR are increased in all the cases. Initial growth rate is almost the same for all the experiments with more than 10mm separation distance. It implies that the burning of vertical surface in the gap is increased by the thermal feedback even with small separation distance as long as the minimum air for combustion enters into the gap between wall surface and specimen. The maximum HRR varied slightly by the separation distance. In the case of 50 mm separation distance, maximum HRR was largest. In the case of 100 mm separation distance, maximum HRR is slightly decreased. As the separation distance is increased, the degree of thermal feedback is decreased and the air entrainment pattern would be close to open configuration.

The results of near-corner configurations are shown in Fig. 7. The effect of separation distance is obvious. During the initial growth period, increase of HRR is large when the separation distance is small. This is due to the strong thermal feedback effect at the corner between wall surface and vertical surface of specimen. However, the increase of HRR was reduced afterwards. As the burning area spreads, the increase of HRR is limited by the inflow of air to the gap. As a result, maximum HRR is increased as the separation distance is increased.

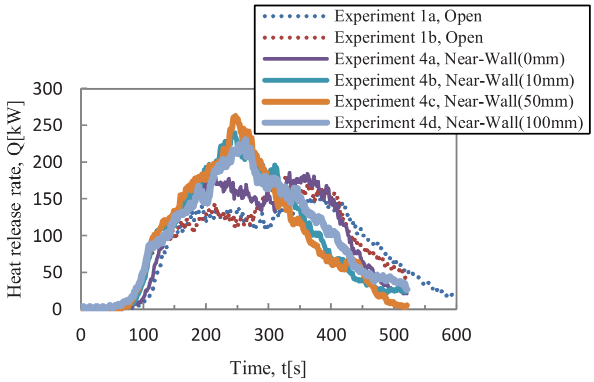

Fig. 6. The effects of separation distance in the side wall on the heat release rate (Ceramic fiber board).

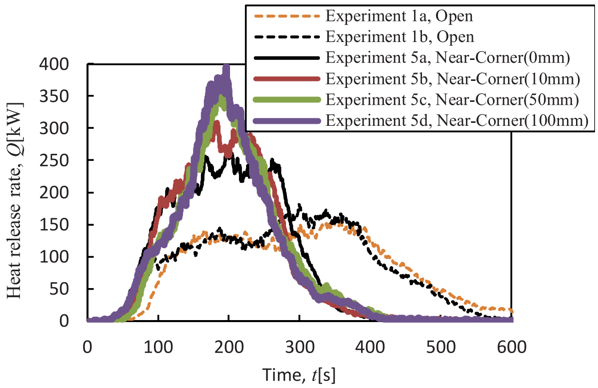

Fig. 7. The effects of separation distance in the corner wall on the heat release rate (Ceramic fiber board).

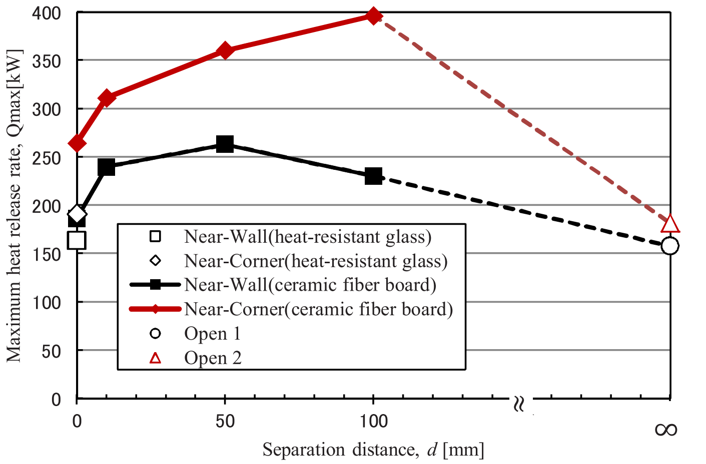

Fig. 8. Maximum heat release rate according to the separation distance.

The correlations between separation distance and maximum HRR are shown in Fig. 8. In the case of heat-resistant glass walls, there were no significant differences from the open configuration. In the case of near-wall configuration, maximum HRR is decreased as the separation distance is increased up to 50 mm. In case of 100 mm separation distance, the maximum

HRR is slightly decreased. In case of near-corner configuration, the effect of separation distance is obvious. The maximum HRR is increased monotonically up to 100 mm separation distance. It implies that the heat feedback effect in the near-corner configuration is stronger than that in near-wall configuration. Thus large distance is needed for the feedback effect to vanish.

5. Spread of burning surfaces

5.1. The spread of burning front according to the time

The shape of flame front was captured from pictures of video camera at every 30 seconds. The results are plotted on the planar figures. The results of experiments 5a to 5d are shown in the Fig. 9. In case of experiment 5a (0mm separation distance), burning surface spreads on top surface. The spread is not uniform to all the directions, but the spread towards corner is a bit faster than other directions. After spreading down on vertical surfaces, burning front spreads faster at the part of close to wall.

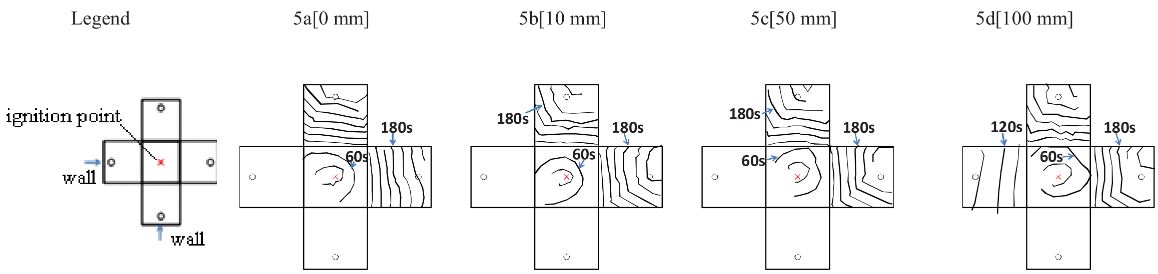

Fig. 9. The spread of burning front with time for experiments from 5a to 5d (near-corner configuration, ceramic fiber board).

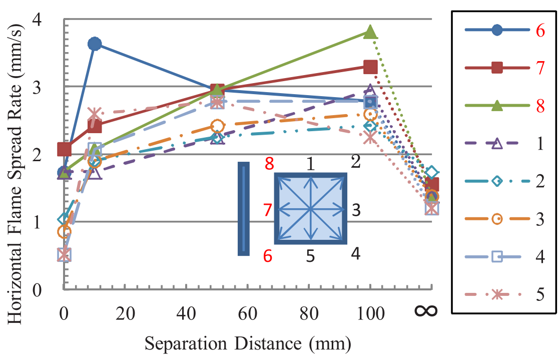

Fig. 10. Horizontal flame spread rate according to the separation distance in the near-wall.

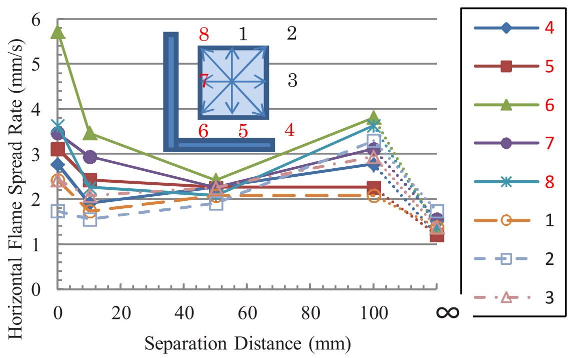

Fig. 11. Horizontal flame spread rate according to the separation distance in the corner-wall.

5.2. Horizontal Flame spread rate on the top surface

Using the shape of burning front, horizontal flame spread rate over top surface was calculated. The results are shown in Fig. 10 for near-wall configuration. The results of open configuration are plotted at infinite separation distance ($d=\infty$). In legends, the number of 1 to 8 represents the direction of spread on the top surface. Flame spread rate increases to the directions 6, 7 and 8, which corresponds to the direction towards wall. This is because of the inclination of flame toward wall surface, which increases the radiation heat flux to top surface. In the other directions, the increase is small or rather decreased in case of small separation distances.

Figure 11 presents the horizontal flame spread rate on top surface in the near-corner configurations. In case of no separation distance, the flame spread rate is obviously increased in all the directions. The flame spread rate is most increased in the direction toward corner because of flame inclination. To the other directions, increase would be due to the radiation from heated wall surface to top surface. At the 50 mm separation distance, the spread rates toward corner and walls direction decrease, however, the spread toward the direction apart from rate to other part remain unchanged. At the 100 mm separation distance, spread rate is increased.

5.3. Downward flame spread rate on the side surfaces

Similar to the top surface, downward flame spread rate was calculated using the planar figures in Fig. 9. The results are shown in Fig. 12. In the legends, symbols represent the each position on the side surfaces. There are large differences between the parts close to and far from wall surfaces. The flame spread rates close to wall parts depends on the separation distance. In case of zero or small separation distances, the spread rate is almost same with open configuration. This is due to the limitation of oxygen at the gap between wall and specimen. As the separation distance is increased up to 50 mm, the spread rate is increased. At 100 mm of separation distance, the flame spread rate is slightly decreased compared with that in case of 50 mm separation distance. The flame spread rate at far from wall parts are also increased, but the degree is small.

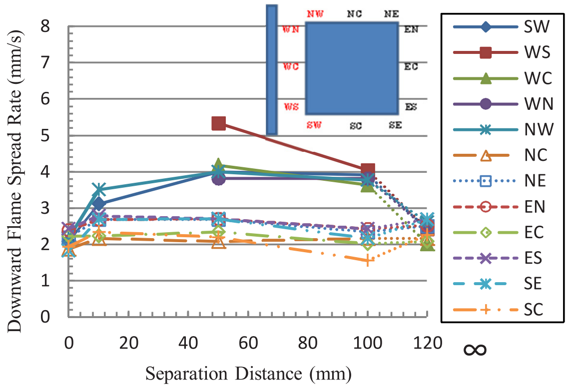

Fig. 12. Downward flame spread rate according to the separation distance in the near-wall.

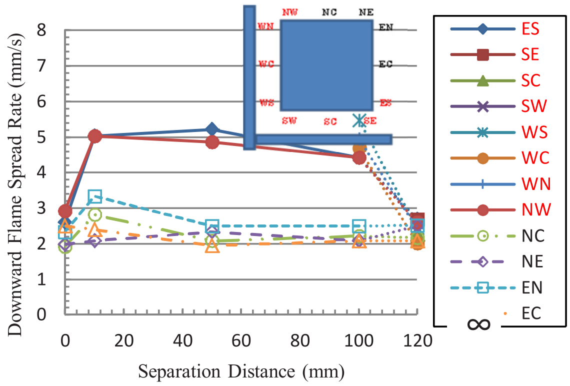

Fig. 13. Downward flame spread rate according to the separation distance in the corner-wall.

The flame spread rate on the side surfaces is shown in Fig. 13 in case of near-corner configurations. The tendency is similar to the case of near-wall configurations. But the degree is significant. Except for the case of 0 mm separation distance, the flame spread rate at near wall part is more than 2.5 times of the far wall parts. Even at 100 mm separation distance, the spread rate is still large.

6. Conclusions

This experimental study was performed to investigate the effects of thermal feedback from walls adjacent to burning polyurethane block. Experiments were carried out for open, near-wall and near-corner configurations. The major findings of this study are the followings:

(1) In the case of heat-resistant glass walls, the increase of heat release rate by heat feedback was smaller than ceramic fiber board walls in both near-wall and near-corner configurations. The large heat loss through glass to rear surface is to be considered.

(2) In case of ceramic fiber board walls, maximum heat release rate was increased up to 20% for the near-wall, 40% for the near-corner configurations, respectively.

(3) Maximum heat release rate is increased as the separation distance is increased from 0mm to 50 mm in case of near-wall configuration. At larger separation distance, maximum heat release rate was decreased. In case of near-corner configuration, maximum heat release rate was increased as the separation distance is increased up to 100 mm.

(4) The increase of horizontal and downward flame spread rate was observed. The degree of increase was significant at the vertical surface adjacent to walls.

Acknowledgements

The experiments were supported by joint usage and research with Tokyo University of Science in 2011. Part of this research has been supported by the grant-in-aid for scientific research by Japan Association for Promotion of Science (Principal Investigator: Kazunori Harada, Grant No. 23360256).

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