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Qiyuan Xie[a]; Heping Zhang[a]; Liang Xu[b]
[a] State Key Laboratory of Fire Science, University of Science and Technology of China, Anhui, Hefei, P.R. China [b] Fire Bureau of Zhejiang Province, Hangzhou, China

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Large-scale Experimental Study on the Effects of Flooring Materials on Combustion Behavior of Thermoplastics

QIYUAN XIE,[1] HEPING ZHANG,[1] and LIANG XU[2]

[1]*State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, P. R. China*
[2]*Fire Bureau of Zhejiang Province, Hangzhou, China*

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The effects of flooring materials on the combustion behavior of thermoplastics is investigated. Based on the ISO 9705 fire test setup, an experimental rig was designed. Full-scale experiments of PP combustion were carried out using five flooring boards, namely gypsum, steel, wood, ceramic tile and PVC. The experimental results indicate that the flooring boards play an important role in the heat release rates of typical thermoplastics combustion. Specifically, the time for the sharp increase of heat release rate is generally later for the flooring boards with larger thermal conductivity, except for the case of PVC. Preliminary analyses suggest that the reason for the exception of PVC is the expansion and carbonization of PVC at high temperature. In addition, experimental results also show that the corresponding peak heat release rate of thermoplastics combustion would be generally smaller for the flooring board with a larger thermal mass, except for the case of gypsum. The primary cause for the exception of gypsum may be the heat absorption by the crystal water released from the gypsum during the burning of hot pool oil.

Keywords: combustion behavior; flooring boards; pool fire; heat release rate; fire risk

1 Introduction

The demand for decoration in residences and offices is increasing fast as a result of the developing of social and life needs of people (1). The used lining materials, such as wood and furniture, are generally combustible although they bring comfort to home life and efficiency to work. In addition, various kinds of thermoplastics are increasingly encountered in dwellings, offices, laboratories and industrial premises, since they are light weight, modified conveniently, inexpensive and corrosion resistant (2, 3). However, the potential fire hazards of these thermoplastics in fires are a matter of great concern. Most thermoplastics are combustible and result in lots of heat, heavy smoke and various toxic gases, which may bring great damage to the occupants and fire fighters. In addition, since most thermoplastic materials melt under fire conditions, this behavior will inevitably influence the flame spread. The melting behavior is one of the most distinctive combustion characteristics for these plastics in fires. The induced flowing pool fires of molten thermoplastics will bring some different behaviors of fire spread, such as a quick downward fire spread. Although the combustion behavior of thermoplastics plays an important role in the safety protection of the above mentioned applications, rather few attempts have been carried out to study it in detail. Additionally, most of the previous polymer burning models have not taken melting behavior into account and generally ignored its effects on the burning process (4–7). Sherratt and Drysdale, Ohlemiller et al. and Zhang Jun et al. have conducted some experiments to preliminarily analyze the melting behavior of thermoplastics in fires (8–12). They indicated that the induced pool fire during the combustion of thermoplastics is the most distinctive feature and is important for fire spread. In the application of thermoplastics, floor boards made with different materials may be used. The type of bottom board, on which the pool fire is formed, will play an important role in the pool development since they will have different thermal properties. In the present paper, focusing on the typical thermoplastics used in various applications, large-scale experiments were carried out with the help of the ISO 9705 fire test apparatus. A commercially available polypropylene (PP) with a thickness of 5 mm was employed to analyze the effects of floor boards on the formation and development of pool fire. The combustion behavior and the most important parameters for model development, such as heat release rates, were analyzed.

Address correspondence to: Qiyuan Xie, State Key Laboratory of Fire Science, University of Science and Technology of China, Jinzhai Road 96, Anhui, Hefei 230027, P. R. China. Tel.: 86-551-3602631; Fax: 86-551-3606981; E-mail: xqy@ustc.edu.cn

2 Experimental

As shown in Figure 1, all the full-scale experiments were carried out based on a ISO 9705 fire test apparatus (13). To examine the melting and dripping behavior of PP in combustion processes, a corresponding experimental rig was designed and located under the 3 m × 3 m × 1 m high hood but outside the room. This experimental rig was composed of three parts. A supporting frame was used to support a thermal insulation board (1.2 m width and 2.4 m height), which simulates a vertical wall. Floor boards (1.2 m width and 1.2 m length) made with different materials were used to analyze the effects of flooring materials on the development of pool fires. The test sample material was fixed vertically on the thermal insulation board for experiments. For each test, ignition was achieved by means of a BS No.7 wooden crib, which was placed at the center bottom of the test sample sheet. The whole test process was monitored with a video recorder, which is used in the ISO apparatus. The products of combustion were collected and exhausted by the hood. The O_2, CO_2 and CO concentrations, as well as the smoke density in the combustion products, which are sampled at the exhaust duct, could be continuously measured. The temperature, different pressure and flow rate could also be measured at the exhaust duct. Heat release rate for the combustion of thermoplastics was measured through an oxygen depletion calorimeter. At the end of the exhaust duct, there is an axial flow fan to exhaust all combustion fumes.

Previous works show that the burning, flowing material induced, pool fire plays an important role in the development of the total thermoplastic combustion. Namely, the increasing pool fire increases the whole heat release rate and, therefore, the radiant flux supplied to the vertical material feeding the pool. This loop mechanism increases the flow rate into the pool and the burning rate of the pool fire. The pool fire forms and develops on the flooring board. The characteristics of the flooring boards, such as thermal conductivity, would show effects on the development of pool fires. Therefore, full-scale experiments were carried out using five types of typical flooring boards, namely gypsum board, steel sheet, wood board, ceramic tile and PVC sheet. In this way, an appropriate kind of flooring board may be chosen for a certain application to reduce the fire risk of thermoplastics. Here, the flow velocity in the exhaust duct was set at 2.5 m/s through controlling the axial flow fan for each test. The calibration of heat release rate, etc. was carefully done before each experiment was conducted according to the operating instructions of the ISO 9705 code (13).

3 Results and Discussions

As indicated above, the pool fire on the flooring board is a characteristic and important part for thermoplastics combustion. The pool fire area means the area of the pool with combustion flame, which represents, relatively, the intensity of the pool fire. The pool fire areas during each set of experiments were recorded using a camera.

Figure 2 shows the development of the pool fire area for PP with different types of flooring boards. It should be noted that for the case of a wood flooring board, after combustion of the PP sheet fully develops, the fire is so strong that experimenter can't stay nearby for taking photos of the pool fire. Therefore, only the early data of pool fire area was obtained. For each set of experiments, the pool fire areas increases slowly at first after the PP is ignited with the BS No.7 wooden crib fire. With the development of PP combustion, the pool area increases sharply until a peak value is reached. They then start to decrease as the PP is being consumed. As can be seen from Figure 2, for the various type of flooring boards

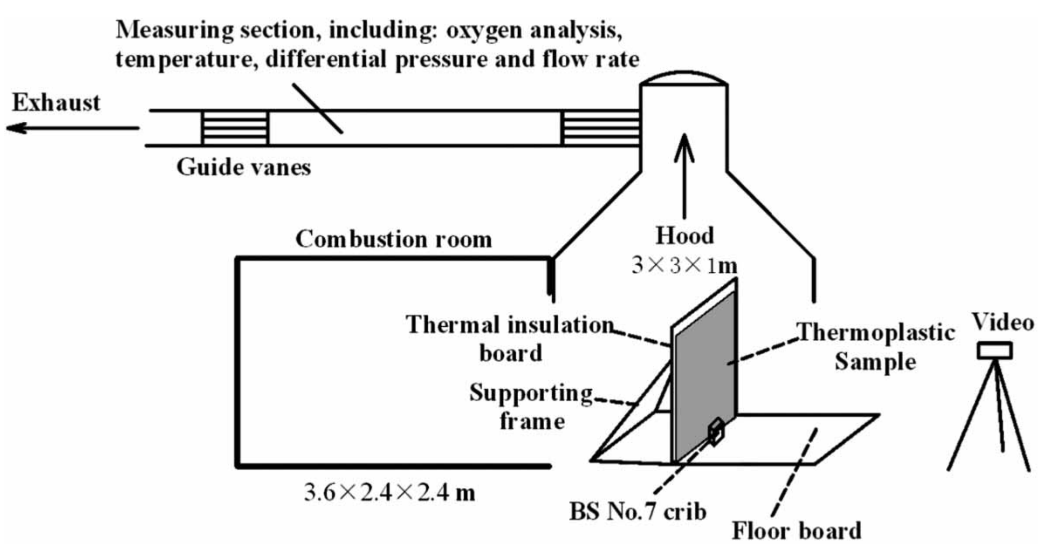

Fig. 1. Schematic of ISO 9705 full-scale test setup and experimental rig for thermoplastics.

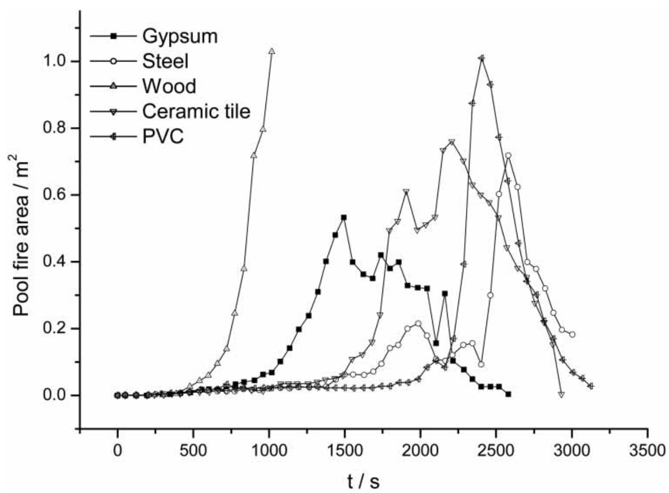

Fig. 2. Pool fire areas for a PP sheet with different types of flooring boards.

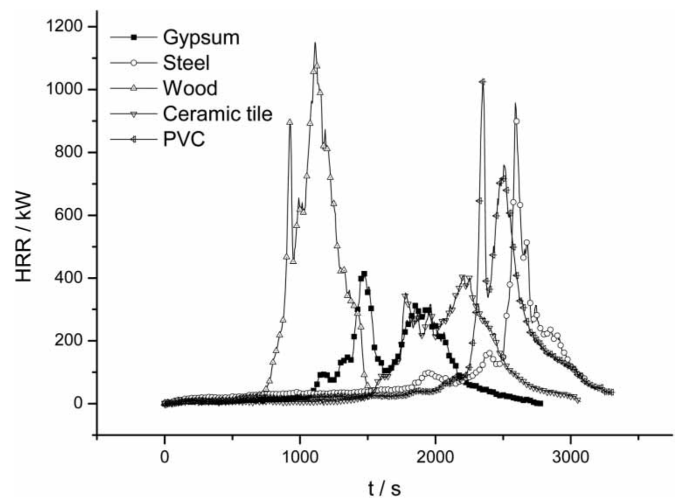

Fig. 3. Heat release rates for PP with different types of flooring boards.

there are obvious different characteristics of pool fire development. The pool fire from PP combustion increases sharply soon after ignition of the wooden crib fire with the wood flooring board although only part of the data was obtained. There is only a short period of slow development. For the cases of flooring boards of PVC and steel, the corresponding time for the sharp increase of pool fire was rather late& there is a relatively long period of slowly developing combustion. The time to the sharp increase of pool fire is in the middle for the experiments using flooring boards of gypsum and ceramic tile. The main reason for the fast development of pool fire in the case of wood flooring board is that the wood board itself is combustible. In addition, another important reason is that the thermal conductivity of wood is relatively small but PVC is small also, as is gypsum. On the contrary, the thermal conductivity of steel is rather large, which is the reason for the slow development of corresponding pool fire. The heat of the pool fire on the steel flooring board is easy to transfer away even though the fire is on top of molten PP which has low conductivity. In this case, the development of pool fire would be more difficult. On the other hand, the reason for the slow development of pool fire with PVC flooring board is the expansion and carbonization of the PVC sheets, which is disadvantage for the development of pool fire. More detailed relationships between the thermal properties of the flooring materials and the developments of pool fires will be shown in the following discussions.

Figure 3 shows the heat release rates of PP sheet combustion under the conditions of different flooring boards. It is illustrated that the flooring boards play a remarkable role in the HRR of PP combustions. Not only the time for increase of HRR, but also the maximum HRR are different for the various flooring boards. The time for sharp increase of HRR using different flooring boards is similar to the development of pool fire. Namely, the corresponding time for different flooring boards can be sorted from early to late as follows: wood, gypsum, ceramic tile, PVC and steel. In addition, Figure 3 shows that the maximum HRR in the cases of flooring boards of PVC and steel are obviously larger than those of gypsum and ceramic tile.

For more detailed analyses of the effects of thermal properties of the different flooring boards on the combustion behavior of PP sheets, Table 1 gives the time for sharp increase of HRR, maximum HRR, thermal conductivity and thermal mass. The thermal mass $\rho c\delta$ is the product of density, heat capacity and thickness of flooring board material. Figure 4 shows the relationship between time for a sharp increase of HRR and the thermal conductivities of the different types of flooring boards. It is suggested that the time for sharp increase of HRR is generally later for the flooring board with larger thermal conductivity, except for the case of PVC. Equation (1) can be used to fit the relationship between the time for sharp increase of HRR and thermal conductivity of flooring boards with R^2 of 0.984.

$$y = 284.2\ln(x) + 1433 \tag{1}$$

The reason can be analyzed as follows. The heat of the pool fire is easier to transfer away for a flooring board with a larger

Table 1. Comparison of characteristic combustion parameters for different flooring boards

Bottom board	Time for sharp increase of HRR/s	Max HRR/ kW	Thermal conductivity/ W.m.k	Thermal mass ($\rho c\delta$)/kj/m^{2}k
Gypsum	1080	414	0.2	9
Wood	735	1144	0.13	6.62
Ceramic tile	1495	403	1.1	18.75
PVC	2235	1024	0.17	7.93
Steel	2475	957	42	10.4

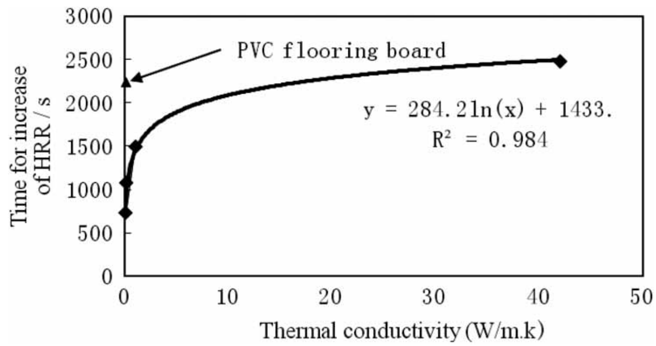

Fig. 4. Relationship between time for sharp increase of HRR and thermal conductivities of different flooring board.

thermal conductivity. The relatively lower temperature of the pool oil would generally slow the development of pool fire. For the case of PVC flooring board, as indicated above, the expansion and carbonization of PVC flooring board during the PP combustion is the main cause for the slow development of pool fire.

Figure 5 shows the relationship between peak HRR and thermal mass of different flooring boards. It is suggested that the peak HRR of PP combustion would be generally smaller for the flooring boards with a larger thermal mass, except for the case of gypsum. Equation (2) can be used to linearly fit the relationship between the peak heat release rates and thermal mass of flooring boards with R^2 of 0.989.

$$y = -60.00x + 1537 \quad (2)$$

The reason is that more heat would be absorbed by a flooring board with a larger thermal mass. The temperature of the pool fire would be relatively lower for a flooring board with a larger thermal mass. Therefore, the corresponding peak HRR may be smaller. However, as shown in Table 1 and Figure 5, although the thermal mass of gypsum flooring board is small, the corresponding peak heat release rate is surprisingly the smallest among the cases of the five flooring boards. We suggest the reason is as follows. The main component of gypsum is $CaSO_4 \cdot 2H_2O$, which contains about 20% crystal water. With the development of pool fire, the crystal water in the gypsum would be released with the heat absorbed from pool fire. In this case, the temperature of the pool fire would be relatively low. It is suggested that the chemical reaction of gypsum at high temperatures depresses the peak heat release rate.

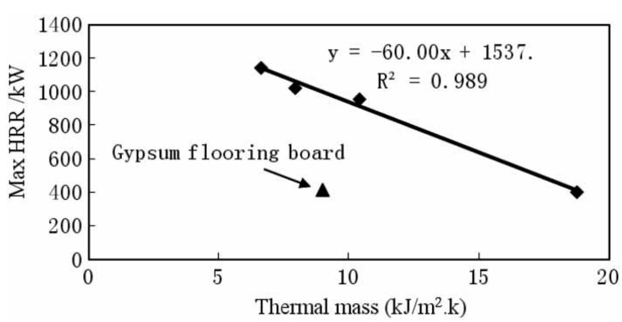

Fig. 5. Relationship between max HRR and thermal mass of different flooring boards.

4 Conclusions

In this paper, focusing on the interesting burning flowing pool fire of thermoplastics, full-scale experiments were conducted to analyze the effects of flooring boards on the combustion behavior using gypsum, steel, wood, ceramic tile and PVC. The main conclusions that can be drawn from the experimental results are as follows:

The flooring boards play a remarkable role in the HRR of typical thermoplastics combustion. Not only the time for increase of HRR, but also the maximum HRR are different for various flooring boards.

The time for sharp increase of HRR is generally later for the flooring board with larger thermal conductivity, except for the case of PVC. The main reason for the exception of PVC is the expansion and carbonization of PVC at a high temperature.

The corresponding peak heat release rate of thermoplastics combustion would be generally smaller for the flooring board with a larger thermal mass, except for the case of gypsum. The main cause for the exception of gypsum is the release of crystal water from the gypsum to the burning formed hot pool oil.

5 Acknowledgments

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