Study of Downward Flame Spread and Fire risk Evaluation of the Thermoplastic Materials

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1 Abstract

This paper focuses its attention on the combustion characteristics and fire risk evaluation on the downward flame spread of polypropylene (PP) and polymethyl methacrylate (PMMA). Many characteristic parameters have been measured under different widths, such as flame spread rate， flame height etc. It is shown that the flame spread mode of PP and PMMA are different because of different pyrolysis mechanism. Based on the Analytic Hierarchy Process (AHP), the evaluation of fire risk has been conducted. The flame height, flame spread rate and toxic gas generation rate are selected as the basic evaluation index parameters to establish a comprehensive evaluation model of fire risk. The fire risk of PP is greater than PMMA.

Keywords: thermoplastic materials; downward flame spread; melting; comprehensive evaluation; the analytic hierarchy process

2 Introduction

The thermoplastic materials have characteristic of easy to melt and burn, accelerating the fire spread, and generating a large amount of toxic gases, which seriously affect people's life, property and social stability. Much studies have been focused on the thermoplastic material for its fire hazards. Current researches have focused on the upward flame spread of thermoplastic materials, but downward flame spread is an important pattern of flame spread. Mechanism of downward flame spread of thermoplastic materials and its influence factors are not yet clear. In this paper, based on downward flame spread experiments of typical thermoplastic material, the evaluation of thermoplastic material in the downward flame spread process has been conducted, which aims at exploring the law of thermoplastic materials, and evaluating the fire risk in downward flame spread.

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3 Experimental

Experimental system

A schematic illustration of the experimental system for downward flame spread is shown in Figure 1, which consists of combustion system and data collection system. A gypsum board with area of 30cm*15cm is fixed on the insulation board. A ruler is set on one side to record the experimental parameters. Samples of different widths are tied closely on center of the gypsum board. The whole system is placed on a horizontal insulation board of 30cm*30cm. A smoke analyzer (Testo340) is placed around 15cm over the top edge of sample. The smoke analyzer mainly collects the volume fraction of CO, at the frequency of one data per second. The combustion process is recorded with a digital video camera.

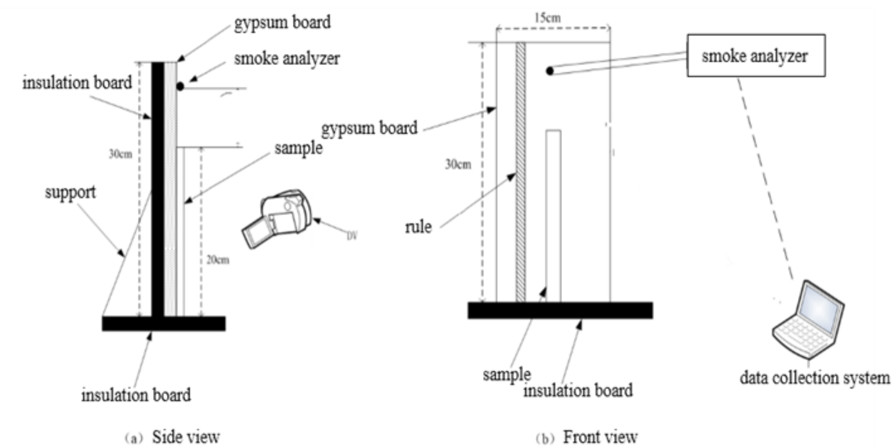

Fig.1 Schematic diagram of the experiment

Experimental sample

The size of Polypropylene (PP) and Poly Methyl Methacrylate (PMMA) is 20cm in length and 0.3cm in thickness, the width is 1cm, 2cm, 3cm, 4cm, 5cm respectively. At the start, the sample top edge is ignited by the gas igniter. Each combustion test has been repeated for 3-4 times.

Analytic Hierarchy Process

Qualitative and quantitative analysis of fire hazard can be carried out with AHP by 3 steps to conduct a comprehensive evaluation model. First, establish a multi-level analytic hierarchy structure. Then, make quantitative descriptions of the importance of each level factors (judgment matrix). Finally, check the consistency.

Table1: Ratio scale in AHP

Ratio scale a_{ij}	Implication
1	i and j are equally important
3	i is more important than j slightly
5	i is more important than j
7	i is more important than j strongly
9	i is more important than j extremely
2,4,6,8	The middle value between the scale above

4 Results and discussion

Flame spread mode

Samples of 2cm width are selected as example to illustrate the downward flame spread process.

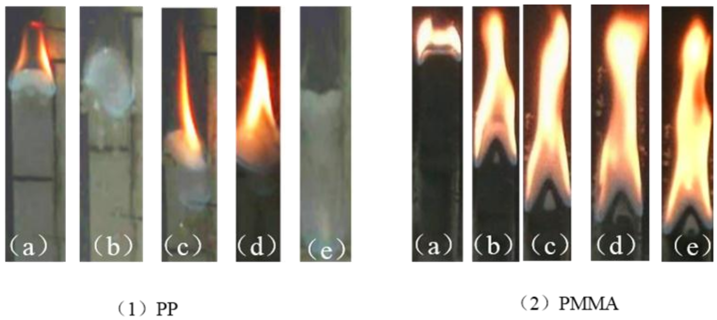

Fig.2 Combustion process of PP and PMMA with 2cm width
（a）8s（b）116s（c）260s（d）434s（e）623s

After the ignition of PP, a small yellow flame occurs on the top of the sample, but the flame is mainly presented in blue during the burning process. Droplets are generated after the PP have been heated, the melt liquid flows on the surface of PP. After the steady burning, the samples covered by the melt liquid also begin to melt and drop off for the second time, at the bottom of sample within 6cm. The combustion process is basically same for PP samples in the different widths.

There are no droplets in the combustion of PMMA, and a steady yellow flame above the sample has been observed, and flame height increases continuously. The flame front is presented as inverted V-shape.

The pyrolysis of material is an important factor of the flame spread mode of thermoplastic material. Generally there will be a dominant pyrolysis mechanism for materials. For PMMA, the dominant pyrolysis mechanism is depolymerization reaction[1], so the flame spread mode of PMMA is solid surface burning. The dominant pyrolysis mechanism of PP is random scission[1], so the flame spread mode of PP is melt burning.

Analysis of characteristic parameters of downward flame spread

Flame spread rate

Flame spread rate is defined as the derivative of pyrolysis front on time. In Figure 3, flame spread rate of PP is greater than that of PMMA, the flame spread rate increases with the increase of width except the PP sample with width of 1cm.

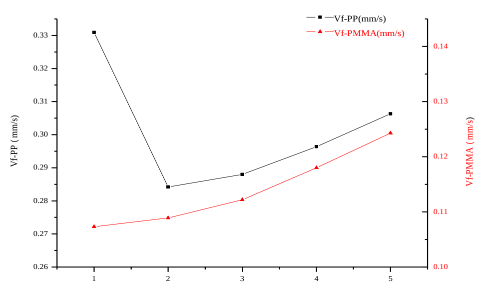

Fig.3 Flame spread rate of PP and PMMA with different widths

Flame height

In the study, the flame height is defined as the vertical distance from flame front to the horizontal plane where the continuous flame zone lies. Figure 4 and Figure 5 are the flame height and dimensionless flame height of samples with different widths.

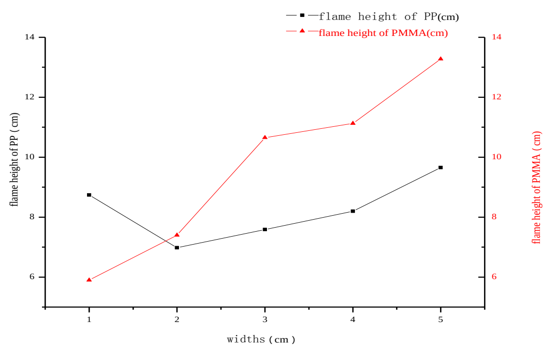

Fig.4 Flame height of PP and PMMA with different widths

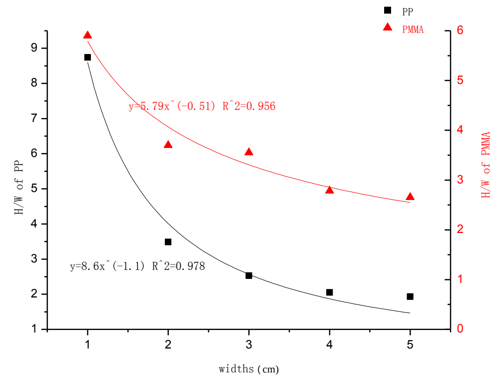

Fig.5 Dimensionless flame height (H/W) of PP and PMMA with different widths

With the width increasing, the mixed speed of pyrolysis gas and air goes upward increases. Besides, more pyrolysis gas required for combustion can be provided, the temperature of surrounding increases faster, the density flame density difference between flame inside and outside is larger, so the flame height increases. The flame height is larger for PP sample with width 1cm. This is due to the dropping off appears three times in combustion process.

CO volume fraction

The volume fraction of CO is measured by smoke analyzer. Figure 6 is the curve of CO volume fraction with different width for PP and PMMA.

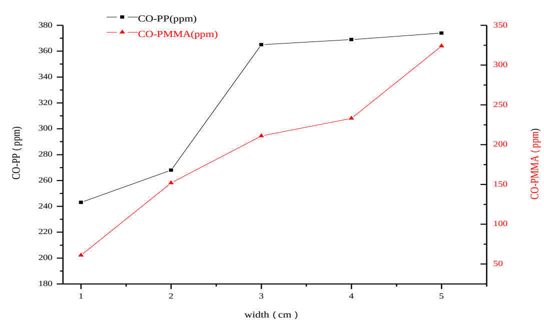

Fig.6 CO volume fraction of PP and PMMA with different widths

As the width increases, the CO volume fraction of PP and PMMA increases. For PMMA, the CO volume fraction of sample with width 3cm and 4cm are similar, which means during a certain width range, CO volume fraction will get to a stable value. For PP, the width effect on CO volume fraction is not obvious. In every width condition, CO volume fraction for PP is larger than PMMA.

Evaluation of downward flame spread for thermoplastic material

Based on the analytic hierarchy process (AHP) and the experiment data, we put forward a new fire risk evaluation method. In this study, the flame spread risk and the toxicity are chosen to analyze. The evaluation index parameter such as the flame height (a1) and flame spread rate (a2) have been describe above, the value of the flame height and flame spread rate are bigger, the fire risk is greater. The definitions of toxic gas generation rate (a3) are in the replace of CO generation rate.

The multi-level analytic hierarchy structure is established as figure 7, according to the table 1, the ratio scale and judgment matrix of a1， a2， a3 are shown in the table 2.

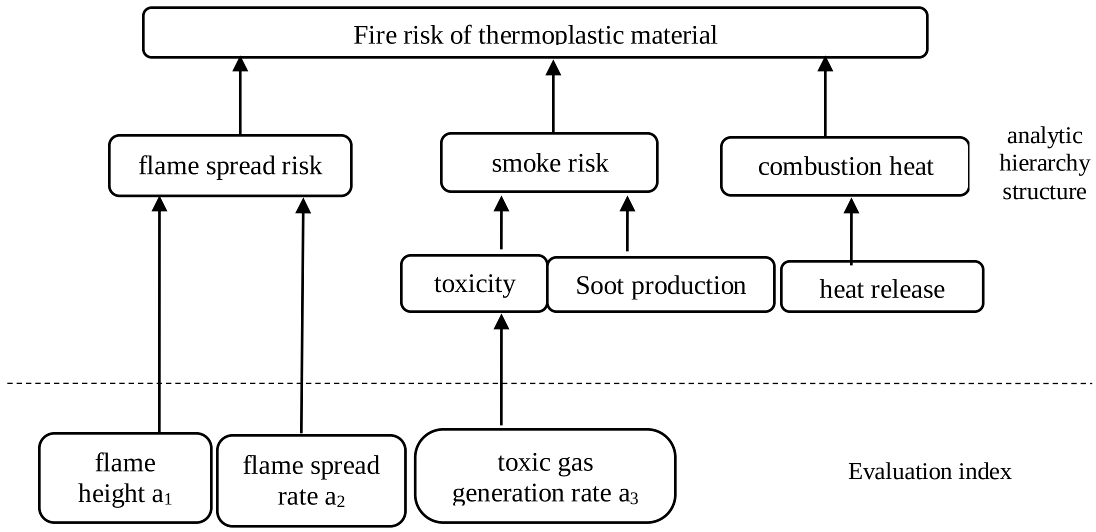

Fig.7 Fire risk evaluation structure of thermoplastic material

Table 2 Ratio scale of evaluation index parameter

Matrix	Flame height a_1	Flame spread rate a_2	Toxic gas generation rate a_3
Flame height a_1	1	2	3
Flame spread rate a_2	1/2	1	2
Toxic gas generation rate a_3	1/3	1/2	1

The comprehensive evaluation index of PP and PMMA with different widths is shown in table 3.

Table3 Evaluation index of PP and PMMA with different widths

Samples/widths(cm)		Evaluation index I	Samples/widths(cm)		Evaluation index I
PP	1	0.592	PMMA	1	0
	2	0.529		2	0.141
	3	0.442		3	0.374
	4	0.591		4	0.535
	5	0.864		5	0.673

The table shows that in these widths, the greatest fire risk is PP with width 5cm, the least fire risk is PMMA with width 1cm.The comprehensive evaluation index I increases with the width increasing for PMMA. For PP, the comprehensive evaluation index I decreases first and then increases.

5 Conclusion

A series of experiments was conducted to investigate the flame spread behavior characteristics and fire risk evaluation of thermoplastic materials in this paper. Conclusions have been reached as follows:
1. The flame spread mode of PP and PMMA are different. The dominant pyrolysis mechanism of PMMA is depolymerization reaction so the flame spread mode of PMMA is solid surface combustion. The

dominant pyrolysis mechanism of PP is random scission, and the flame spread mode of PP is melting combustion.

2.The characteristic parameters have been analyzed for the samples under different widths. The flame spread parameters are influenced by the width and flowability. With the increase of width, flame spread parameters of PP vary complexly, but that of PMMA increased only.

3. Based on analytic hierarchy process and experiments results, the fire risk evaluation on the downward flame spread is conducted. The fire risk of PP is greater than PMMA because of effect of flowability.

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