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Experimental study on the width and pressure effect on the horizontal flame spread of insulation material

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ABSTRACT

Organic insulation materials such as polyurethane foams are widely used as buildings' façade wall insulation materials in China. However, they are highly flammable and of great fire hazard by the chemical nature. In this paper, a series of laboratory scale experiments using rigid polyurethane foam were conducted and theoretical analysis was applied to evaluate the real fire performance of such materials under different situations. Temperature profiles in both solid and gas phases were obtained. This work provides basic correlations of flame spread characteristic of polyurethane foams regarding to width and pressure changes. Theoretical analysis on heat transfer of width and pressure effects was also provided. Good agreement of changing trends was found between experimental results and theoretical calculation.

1. Introduction

With the increasing of high-rise buildings, rapid growth of energy consumption and widely spread of energy saving concept, the need for exterior wall insulation materials is growing. Because of the good insulation property and relatively low price, the rigid polyurethane (PU) insulation material is widely used, especially in developing countries such as China. However, PU foam is of great fire hazard when not properly treated. It is easy to ignite. Once ignited, flame spread could be remarkably fast in some situations. And large amount of toxic smoke would be released. For example, the residential building fire in Shanghai, China, 2010, which resulted in 58 fatalities and 71 injuries, was one of the fires in which rigid PU external insulation materials was the main fuel. Moreover, characteristics such as heat release rate and the emission of smoke and toxic gases are influenced by the flame spread rate. Thus it is very important to understand the flame spread characteristics of PU insulation materials in order to evaluate fire risks.

Polyurethane as a kind of polymer has received much attention and been studied intensively, including fire tests. Lefebvre et al. [1] had performed comprehensive study on fire characteristics of PU foam under different standards. Their work provided basic knowledge on fire performance of flexible PU foam. However, the standard fire tests results could be very different from real applications, considering that the fire performance would be influenced by many factors such as material sizes and ambient conditions. Many works reported that the fire performance of insulation materials (including polystyrene and polyurethane) would change obviously under different situations: The flame spread characteristics on thermal insulation materials under different environmental conditions (pressure and oxygen concentration) were studied experimentally in plateau and plain by Huang et al. [2]. It was concluded that the changes in the average length of the pool fire, flame spread speed, average flame height, and length of preheating zone were larger in plain than those in plateau, indicating that the fire hazard in plain would be higher than that in plateau if insulation materials of the same size were used. Zhang et al. [3] also conducted a series of comparative laboratory-scale experiments in plateau and plain to investigate the characteristics of flame spread over XPS thermal insulation material. The results showed that the temperature change as a function of time could be divided into three stages: the preheating stage, the melting stage and the pyrolysis stage. It was also reported that two different regimes were found in flame spread behavior with sample scale at both altitudes: The spread rate decreased with sample scale in convection regime and rose in radiation regime. In another paper, Zhang et al. [4]

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investigated the effects of sample width (W) on flame spread over horizontal charring solid surfaces in plateau. Their results showed that the flame spread rate was influenced by the combined effects of convection heat transfer and flame radiation. Moreover, two regimes similar to previous work [3] were found. To reveal flame spread characteristics of the insulation material with different thicknesses under different environmental conditions. Experiments were carried out in the plateau and plain by Huang et al. [5]. It was found that with the increase in sample thickness, the values of flame spread rate, average pool fire length, and average maximum flame height increased in both plateau and plain. And these values in plain were all larger than those in plateau. An et al. [6] performed experimental study on the effect of sample width and inclined angle on flame spread across expanded polystyrene (EPS) surface in plateau and plain. It was found that the surface flame height, flame spread rate and preheating zone length in plain were larger than the results obtained in plateau and the experimental results agreed well with theoretical analysis. Jiang et al. [7] also studied the mechanisms of horizontal flame spread over thermal insulation foam surfaces (extruded polystyrene and expanded polystyrene foams) through a series of experiments with different sample widths. In their work, the flame spread rates of both materials first decreased and then increased with increasing sample widths. The minimum flame spread rates were found at widths of 8 and 10 cm for extruded polystyrene and expanded polystyrene, respectively, resulted from the relative differences between convection and radiation heat flux, which were different for the two foams. The experimental results agreed well with theoretical deduction. Zhou et al. [8] measured the sample surface temperature, spread rate, and height of flame in a series of comparative experiments in plateau and plain to investigate the effects of sample width and ambient pressure on horizontal flame spread over rigid polyurethane foams. Experimental results showed that the horizontal flame spread rate decreased as the sample width increased in a negative power law at both two altitudes and the flame spread rate in the plain was larger than that on the plateau of the same width.

In this work, a series of horizontal flame spread experiments using rigid PU foam under different sample widths and ambient pressures were conducted to study the width and pressure effect on flame spread characteristics. Flame height, temperature profile, mass loss rate and flame spread rate were presented and analyzed, and theoretical analysis on width and pressure effect was performed. The aim of this study was to provide a better understanding of fire performance of rigid PU foam so that it would be helpful for fire hazard evaluation in real applications.

2. Experimental setup

2.1. Experimental apparatus

The experiments were conducted inside a low pressure facility. The facility mainly consists of two parts. One part is a sealed compartment with a dimension of 3 m × 2 m × 2 m (L × W × H). Another part is the pressure control and maintain system which has vacuum pump, a series of sensors, solenoid valves and related controllers that can pump air in the compartment out to achieve a user-set pressure. The low pressure facility can achieve and maintain a low pressure down to 30 kPa ($\approx$0.3 atm) with a fluctuation of $\pm$2 kPa. The facility also has an oxygen concentration control system which could change the oxygen concentration in the compartment but not utilized in our experiment.

The schematic of our experimental setup is shown in Fig. 1. The apparatus was composed by a sample holder, a gypsum board, an electronic balance, a digital video camera, seven thermocouples and corresponding data acquisition systems. The sample was attached to the gypsum board horizontally. In our experiments, the ambient pressures were 85, 90, 95 and 101kpa. The pressure points were chosen because an extinction limit was reached between 80 and 85 kPa without additional heat flux added to the sample surface.

For data acquisition purposes, thermocouples, an electronic balance and a digital camera were used. Seven 0.5 mm diameter sheathed K-type thermocouples were mounted vertically in both sample and air to measure solid phase and gas phase temperatures at a 10 Hz frequency. More precisely, three thermocouples were mounted inside sample with distances of 1, 2 and 3 cm from sample's upper surface, one was mounted right on the upper surface, the remainders were exposed in the air and 2, 4, 6 cm away from upper surface, as shown in Fig. 1. An electronic balance with an accuracy of 0.01 g were employed to obtain mass loss data at an interval of 1s. A full-HD 50fps camera was utilized to record experiment videos for further analysis. The experiments were repeated 4 times under each condition, while in 2 of which, thermocouples were removed to avoid the influence of force induced by thermocouple and sample deformation at high temperature on the

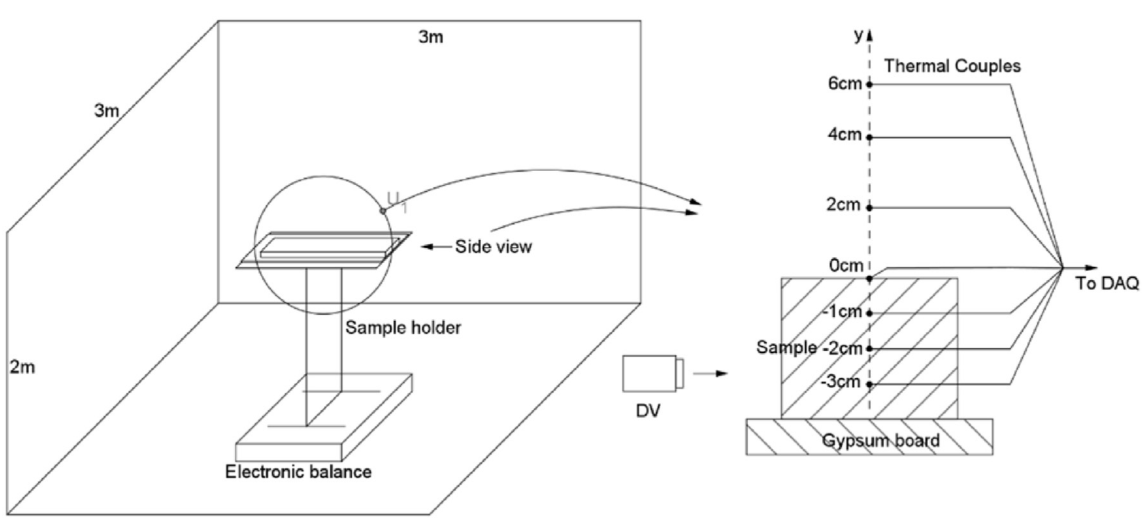

Fig. 1. Experimental apparatus.