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Experimental and theoretical research on the fire safety of a building insulation material via the ignition process study

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ABSTRACT

A series of experiments were carried out on extruded polystyrene (XPS) foam using a vertical thermal radiator. Measurements were taken for the ignition time, the pyrolysis mass and the temperature distribution. Two kinds of XPS foam with flame retardant levels of B1 and B2 were tested in the experiments and the incident heat fluxes were set as 20, 30, 35, 40, 50 and 60 kW/m^2. For the XPS shrinks to a thin layer under the thermal radiator heating, thus the classical ignition theory may be improper and the new functions relationship between the ignition time and the radiant heat flux was derived in theory and experiment. What's more, the pyrolysis mass increases with the radiant heat flux, while the extent of increasing reduces as the radiant heat flux increases. And the result of temperature distribution indicated that under high incident heat flux the flame retardant treatment becomes less effective. The research results were useful for the theory and the experimental study on the fire characteristic of foamed polymer under vertical radiation condition.

1. Introduction

Extruded polystyrene (XPS) was widely used as a core material of the external thermal insulation composite systems (ETICS) for improving energy efficiency. The features of XPS as a kind of polymer material, such as low conductivity, lightweight, high strength and multifunctional, have drawn increasingly attentions in both scientific and industrial communities [1,2]. The flammable property of XPS foam has been leading to the potential hazards of the high-rise building, what's more the XPS foam could yield amount of heat, heavy smoke and toxic gasses in fire accident. Thus the ignition process of the XPS should be investigated with experiment and theory.

Radiant ignition is one of the most important subjects regarding fire behaviors and it has been widely studied in fire research [3–8]. Liang et al. [3] study of vertically upward flame spread over polymethyl-methacrylate slabs at different altitudes. An et al. [4] analysis of sample thickness, heat flux, and cone calorimetry test data of polystyrene foam. Yang et al. studied the pyrolysis process of charred material exposed to weak external heat fluxes [5], the spontaneous ignition process under variable heat flux [6], the effect of distance between radiator and sample [7] and the altitude effects on spontaneous ignition process [8]. But most of above studies were focused on the normal combustibles without melting phase change.

There is also a significant amount of studies that have been carried out on XPS. The ignition of expandable polystyrene foam by a hot particle were conducted to assess the risk caused by hot particles from fireworks and welding processes [9,10]. The XPS was found to generate high heat release rate, heavy smoke and high toxicity in previous study [11]. The sandwich panels with a polystyrene core was studied by ISO9705 test [12]. The thermal degradation [13], composite materials with XPS under radiation [14],

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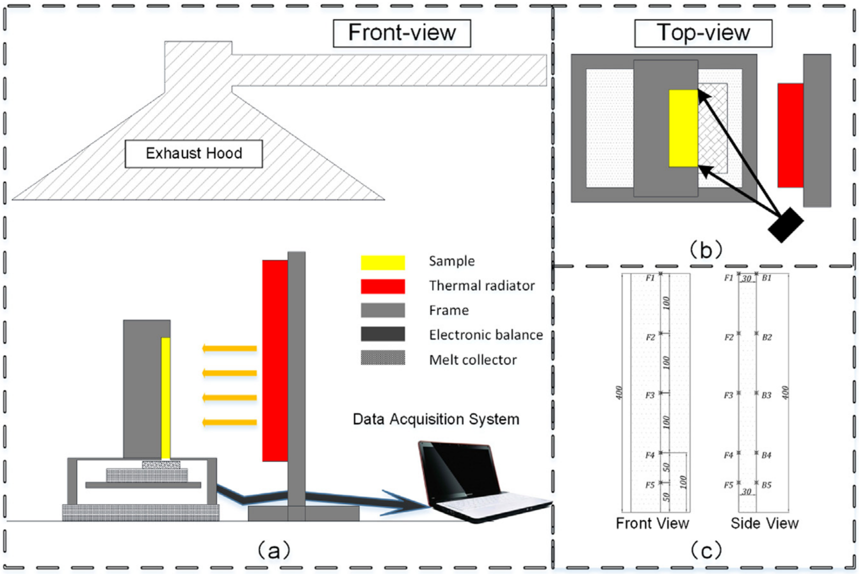

Fig. 1. Vertical radiation experimental apparatus (a) Schematic of the experimental system. (b) Applied position of cameras. (c) Arrange point of the thermocouples.

physical and kinetic models [15] on XPS foams were also studied. However, the majority of previous studies have focused on the horizontal layout meanwhile the melting and dripping of material were not taken into account. The melting and dripping processes would have led to obvious differences between the horizontal and vertical experiments. As an insulation core of the ETICS, majority of the XPS used in the ETICS are applied vertically at the external walls of buildings. Since the melt and drip properties of XPS will strongly affect the fire hazard of the pool induced by polymer melt flow [16], the fire behaviors at vertical direction are worth studying.

Nowadays, little research has been conducted on the vertical ignition of XPS foam under external radiation, which is regarded as a common trigger of fire spread in high-rise buildings. When subjected to thermal decomposition, the XPS foam becomes soft at approximately 120 °C, melts at 160 °C, and completely decomposes between 470 and 500 °C. In this paper, a set of experiments were carried out under a vertical radiator and some important parameters including the time to ignition, pyrolysis mass and temperature distribution were measured and analyzed.

2. Experiment and materials

2.1. Experiment apparatus

Fig. 1 presents the vertical radiation experimental apparatus for XPS foam. As shown in Fig. 1(a), a collector was used to collect the melt generated by the sample during the experiment. Two electronic balances were used to record the mass loss histories of the sample and the melt respectively. The XPS foam was fixed on the frame vertically, which is similar to the thermal insulation material in ETICS. The thermal radiator was also located vertically, and the distance to the XPS foam could be adjusted according to the required heat flux intensity. The experimental condition for XPS was different from previous studies conducted in Cone Calorimeter and some other similar apparatuses. The experiments were conducted under a smoke hood by which the gaseous products from burning were exhausted. In the experiment, a digital camera was used to record the experimental process, as shown in Fig. 1(b). Three sets of thermocouples (K-type, 1.0 mm in diameter) with 2 each set were installed in the sample. The ones installed at the front surface and back surface were labeled using respective letter “F” and “B”, as shown in Fig. 1(c). The thermocouples were positioned at the centerline of the sample with 100 mm spacing.

2.2. Radiation panel

The radiation panel contains of fifteen Quartz Heater sticks, which is a half gold-plated tube powered electrically. The radiation panel was 300 mm wide and 725 mm high, which is much larger than the sample, thus the incident radiation flux at the sample surface is fairly uniform during the experiments. For example, a radiant panel temperature of 1000°C approximates to a radiation heat flux of 50 kW/m^2 at the sample surface while the distance between the panel and the sample was 150 mm. Additionally, to ensure the uniformity of the incident radiation flux at the sample surface, three water-cooled radiation flux gauges were used to monitor the incident radiation flux.

The water-cooled radiation flux gauge was manufactured by Huxseflux Thermal Sensor B.V.T. As shown in Fig. 2(a), the incident