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Flame Spread Characteristics of Inclined Extruded Polystyrene Thermal Insulation Material

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Abstract

A set of small-scale flame spread experiments was conducted to explore the effects of sample orientation on the flame spread characteristics of extruded polystyrene (XPS) insulation material. The obtained data were employed to show the variation law of flame angle, pool fire zone length and flame spread rate when the tilt angle of XPS material changes from -90° to 90°. The flame angle decreased when the inclined angle increased from -90° to 90° and there are two different variation trends of flame angle in different inclined angle ranges. Meanwhile, both pool fire length and flame spread rate of the inclined XPS material depend on gravity controlled flow of flammable and molten drops produced by heating XPS material. Furthermore, the fitting relationship between flame spread rate and tilt angle was put forward when the tilt angle was less than or equal to 0°. This work is a supplement to the fire risk study on the XPS insulation materials and system.

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Keywords: insulation materials, XPS, inclination effects, flame spread rate.

Nomenclature

d	distance between the fixed positions of gypsum board (cm)
ΔH	enthalpy change of per unit mass between the virgin fuel and the fuel in its ignition temperature (J/kg)
L_a	average pool fire length of XPS sample (cm)
L_t	pool fire length of XPS sample at t moment (cm)
q_v	net heat flux accepted by the unburned material at flame front (W/m^2)
q_{sc}	heat flux from the flame to the unburned material through the solid material (W/m^2)
q_{gc}	convective heat flux from flame to the unburned material through gas (W/m^2)
q_{fr}	radiative heat flux from flame to the unburned material (W/m^2)
q_{sr}	radiation loss of the solid surface (W/m^2)
t	flame spread time (s)
v_f	flame spread rate (cm/s)
$\overline{v_f}$	average of flame spread rate (cm/s)
v_b	burnout rate (cm/s)
$\overline{v_b}$	average of burnout rate (cm/s)

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Greek symbols	
α	tilt angle of XPS material (°)
β	flame angle (°)
ρ	density of material (kg/m^3)
Subscripts	
b	burnout
f	flame

1. Introduction

As a kind of material exhibits excellent thermal insulation property, easy processing performance and tolerance capability to environment, the polystyrene (PS) foams which contain extruded polystyrene (XPS) and expanded polystyrene (EPS) have been widely used in thermal insulation project of building's exterior wall. However, PS material is flammable with high calorific value, it could be ignited under certain external conditions even after flame retardant treatment. Plenty of heat and poisonous smoke would be generated once PS material had been ignited, followed by a rapidly spreading flame due to production of molten drops during combustion process [1]. Owing to mentioned above, PS material is considered to be of high fire risk. Several fire accidents related to PS material have happened in the past years, and caused heavy casualties and property losses. For instance, in the fire disaster of the house for the elderly in China's Henan Province on May 25, 2015, high temperatures caused by poor electrical contact ignited PS material, and then the molten drops exacerbated the rapid spread of the flame, resulted in 39 people killed and 6 injured.

Some researchers have reported the flame spread characteristics of PS material influenced by the width, thickness and density of sample as well as altitude while horizontal placement [2-4]. Nevertheless, accompanied by the continuous progress of construction technology and architectural design, buildings with sloping facades are increasingly found. Accordingly, the effects of material inclination angle on the flame spread characteristics of PS material have become a pressing problem in practical engineering applications. Zhang et al. [5] and Xu et al. [6] indicated that the melt flow behavior of PS material and other thermoplastic materials is an important factor in vertical flame spread. Huang et al. [7] pointed out that the flame spread rate of EPS material increased with angle increased when the tilt angle in the range of -30° ~ 30° both on plateau and plain while the flame spread rate of XPS material decreased based on a series of experiments.

It can be seen that previous researches were mostly focus on the horizontal or vertical placement flame spread characteristics of PS material and other thermoplastic materials more than inclined placement. Inclination angle of sample in some experiments (-30° ~ 30°) mainly considered the inclination of the building's roof, but not the common inclination angle of the exterior wall [7]. Therefore, by carrying out the small-scale fire spread experiment with XPS material board under the inclination angle of -90° ~90°, the influences of tilt angle on flame spread characteristics of XPS material such as flame angle, pool fire length, flame spread rate and the contributing factor of some phenomena during the flame spread process have been further discussed in this work.

2. Experimental apparatus and methods

Table 1 lists the properties of XPS samples used in this work. The experimental installation as given in Fig. 1(a) was used to conduct the flame spread experiment of horizontal and the slanted XPS sample. The tilt angle of the 1 cm-thick thermal insulation gypsum board for loading the XPS sample can be changed by adjusting its fixed positions on two brackets and the distance between the fixed positions *d*. Meanwhile, XPS samples should be fixed on the vertical steel holder surface in the vertical flame spread experiment as Fig. 1(b) shown.

The flame spread process of XPS samples were monitored from the side view by a color digital video camera. Measures taken during the experiment contributing to ensuring characteristic parameters of flame spread (e.g. flame front position, pool fire length, flame angle) were not only sets of parallel lines drawn at 5 cm intervals on which surface facing the camera of each sample, but also a steel ruler fixed parallel with the long side of the XPS sample. Each XPS sample was ignited at the center of one end in a breezeless environment.

Table 1. Properties of XPS samples

Material	Length (cm)	Width (cm)	Height (cm)	Density (kg/m^3)	Specific heat (J/kg· K)	Conductivity (W/m· K)
XPS	60	2	2	36.46	1500	0.03