Energy and Buildings 82 (2014) 243–249

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Correlation study between flammability and the width of organic thermal insulation materials for building exterior walls

Lin Jiang, Huahua Xiao, Weiguang An, Yang Zhou, Jinhua Sun*

University of Science and Technology of China, State Key Laboratory of Fire Science, Hefei, Anhui 230026, China

ARTICLE INFO

Article history:
Received 24 February 2014
Received in revised form 7 June 2014
Accepted 9 June 2014
Available online 8 July 2014

Keywords:
Thermal insulation
Polyurethane
Extruded polystyrene
Fire safety
Flame propagation
Width effects

ABSTRACT

Considering the sustainable energy strategy for buildings, external wall insulation system is expected to play an important role in building energy conversation. And higher energy efficiency drives our demands for much thicker thermal insulation materials. However, it does not mean that the thicker the better, especially considering various requirements and properties. Among these are materials mechanical strength, aging durability, water resistance, construction difficulty and even fire safety performance. In the following paper to explore fire safety of organic thermal insulation, polyurethane foam (PUF) and extruded polystyrene (XPS) were selected to carry out a series of lab-scale tests over a wide range of widths. What is more, some fire safety aspects have been studied and compared: temperature variation in solid and gas phase, heat and mass transfer process, flame propagation over material surface, flame height, material melting and charring, etc. The aim of exploring relationship between material flammability and width is to help to select a proper width when considering fire safety, and lay a foundation for us to conduct real fire disaster of external insulation system in following study.

1. Introduction

With the background of world energy crunch, thermal insulation treatment to building exterior wall is the key to enhance the building energy effectiveness [1]. Currently, given the cost and construction sequence [2], organic thermal insulation materials are usually adopted as the frequently used ones. Among them, polyurethane foam (PUF) and extruded polystyrene (XPS) are the quintessential examples. PU belongs to thermosetting materials while XPS is thermoplastic. What is more, they behave entirely different thermal characteristics.

As thermal insulation materials, both PU and XPS have very low thermal conductive coefficients. At 300 K, coefficients of PU and XPS are 0.026 W m^{-1} K^{-1} and 0.029 W m^{-1} K^{-1} [3], respectively. However, oxygen indexes (OI) [4] of both materials are very low. Without any flame retardants, the OI of XPS is only 17 and PU is 21. Both are very combustible [3,4] and could generate large quantities of toxic gases [5]. Once being ignited, the whole fire could develop hastily. Eventually, released heat and poisonous gases cause deaths.

In February 9, 2009, a fire disaster of China Central Television (CCTV) caused by unlicensed fireworks display made this new site building notorious, resulting in 163 million RMB economic losses and one person dead. Soon after that, another fire disaster occurred at high rise apartment house in Shanghai Jing'an District caused unstandardized welded construction, resulting in 58 people dead and at least 70 people injured. One crucial reason for both disasters was the large scale employment of flammable organic thermal insulation materials. Once these materials caused fire by any ignitor, flame could spread rapidly from the ignited source to the whole building. Therefore, it is significant to research the heat transfer mechanism of these kinds of low thermal conductive materials during combustion and flame propagation process.

As to fire hazardous behaviors of thermal insulation materials, there have been lots of qualitatively described studies, mostly about melting down behaviors of polystyrene [6–8]. There were, to the knowledge of the authors, seldom investigations involved in horizontal width effects [9,10] and heat transfer study during flame propagation [4,11].

Zhang [9,10] has studied flame propagation behaviors of XPS on plateau and in plain, respectively. And he found that there was a transition of heat transfer mechanism with different sample width. The flame was controlled by convection transfer initially. With the flame size increased, it would be controlled by radiation heat flux. Huang [12,13] and Jiang [14] researched the different behaviors of XPS and expandable polystyrene (EPS) on combustion behavior. When this research was begun, although lots of quantitative conclusions had been observed, they were only qualitative observations. What is more, as another frequently-used thermal insulation

* Corresponding author. Tel.: +86 551 63606425; fax: +86 551 63601669.
E-mail address: sunjh@ustc.edu.cn (J. Sun).

http://dx.doi.org/10.1016/j.enbuild.2014.06.013
0378-7788/

material, PU behaves completely different thermal property with XPS and EPS. Few researches about flammable characteristic of PU had been published.

Mahlia has studied the correlation between thermal conductivity and the width of thermal insulation materials [15]. In this paper, PUF and XPS with different width were selected to conduct a series of bench-scale experiments, aiming at exploring relationship between material flammability and sample width. We hope final conclusions would lay a foundation for us to investigate width effects on real fire disaster of insulation system in further study.

2. Experimental

2.1. Apparatus

The whole apparatus designed in our experiment is illustrated in Fig. 1. METTLER electronic scale was used to measure the real-time mass of materials during test. The scale range is up to 10 kg with an accuracy of 0.01 g. Sony HDR-XR200 V digital video camera was placed at 1.5 m far away from the apparatus to monitor and record materials' flame propagation behavior, flame height and pool fire length.

Experimental materials were horizontally placed on an asbestos board (1.2 m in length, 0.25 m in width and 0.5 cm in thickness) for the simulation of insulation boundary condition at the rear surface. Two thermocouples were located in the material inner to monitor the temperature variation in solid phase. One was placed 1 cm underneath its upper surface, and another was at the bottom surface, especially for melting temperature. A thermocouple tree (measurement range: 0–1000 °C, response time: 0.3 s, resolution: 0.4% T, with diameter of 0.5 mm) was settled above the asbestos board surface, and the position has been illustrated in Fig. 1. The frame and joint are all made by aluminum alloy to reduce the apparatus weight.

Experimental materials were ignited by self-made linear ethyl alcohol igniter. During test, we only focused on the stabilization stage of the flame propagation, for the initial stage was largely influenced by ignition behavior. All data, including time, mass and temperature, were collected at a frequency of 1 Hz. Each test with the same condition was repeated at least 3 times to reduce laboratory errors.

2.2. Materials

XPS and PU were both 1 m in length and 2 cm in thickness. Selected widths in our experiments were 4 cm, 6 cm, 8 cm, 10 cm, 12 cm, 14 cm and 16 cm, respectively. As XPS could melt and generate residue stuck to asbestos board when burning, aluminum foil was adhered on the board surface to keep asbestos board clean, which was changed for every test. XPS and PU in our experiments were prepared without any flame retardant.

3. Results and discussion

3.1. Essence of flame propagation

Theoretical modeling of flame propagation has been explored by many researchers [11,16,17]. Williams [11] established the concept of heat transport models, considering that flame spread rate was mainly controlled by heat transfer through the cross section

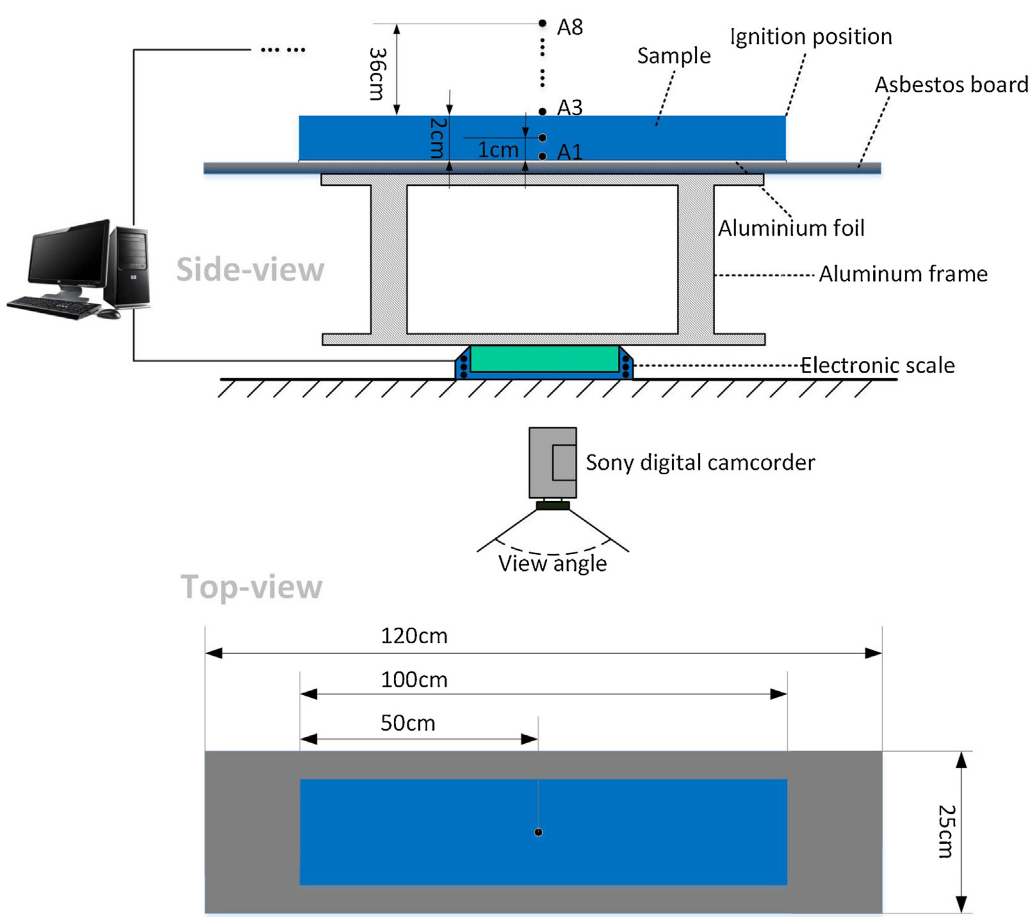

Fig. 1. Experimental apparatus for horizontal flame propagation over XPS and PU surface.