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Experimental Study on Upward Flame Spread Behaviors over Thin Fabric Fuels

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Abstract

Experiments were conducted on cotton fabric to study the characteristics of upward flame spread including flame front, pyrolysis front, flame height, pyrolysis height. Samples of cotton fabric were 1.80 m high and 1.35m wide, with thickness of 0.44 mm, 0.42 mm, 0.28 mm and 0.30 mm. It shows that: the evolutions of flame front, pyrolysis front, burnout front conform to a non-linear relation, and the speed of upward flame spread is not constant, but inconstantly accelerated. The flame height and pyrolysis height have a relation with the thickness of the thin fuels. A linear relation between flame height, pyrolysis height and time was observed appreciably in the two former tests, a power function with power value of 1.4~1.7 in the two latter tests, which accords with the fact that the upward flame spread of the thinner cotton fabric is faster than that of the thicker ones. The correlation between flame height and pyrolysis height is consistent with the power function $Hf = \alpha Hp^n$ .In the four upward flame spread experiments, the coefficient α varies within the range of 1.4 ~1.7 and the power coefficient n is equivalent to 1 approximately. Not affected by the thickness, the correlation between flame height and pyrolysis height is a linear function approximately.

Keywords: upward flame spread, thin fabric fuel, flame height, pyrolysis height.

1. Introduction

Upward flame spread over thin fabric fuels have been becoming a particularly important issue in fire research because it is always most rapid and hazardous, easy to form an out-of-control overall fire. Thus, many experts had been carrying out a series of experiments on solid materials to study the upward flame spread behaviors, particularly PMMA、XPS、PU. E.g. Brehob [1], J.L. Consalvi [2] et al. established a numerical model to predict the speed of upward flame spread; Ali s. Rangwala [3], y. Pizzo [4] et al. put forward the concept of lateral diffusion to illuminate width effect on the early stage of upward flame spread; James G. Quintiere [5], M.J. Gollner [6], Huang [7] tried and took into account effects of altitude and sample orientation on upward flame spread; T. Ohlemiller [8], Tsai [9], J.L. Consalvi [10], Isaac T.L eventon [11] et al. accounted for other influencing factors on upward flame spread, especially ignition conditions, definition of flame height, heat flux feedback. However, only few of studies took into account upward flame spread on thin fabric materials, which only emphasized on flame front and rate of flame spread, not pyrolysis front, flame height, and pyrolysis height. Markstein and de Ris [12] experimentally studied the upward flame spread over thin cotton fabric and established a theoretical model to predict the upward flame spread. Quintiere [13] studied the flame spread over polyethylene terephthalate (0.2 mm) and paper (0.17 mm), and developed a theoretical analysis to predict the flame length and the upward flame spread rate.

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The process of upward flame spread over thermally thin materials is illustrated in 错误!未找到引用源。. The flame height Xf is the dimension measured from the bottom edge of solid fuels to the flame front and the pyrolysis height *X* is the dimension measured from the bottom edge to the pyrolysis front. Once local extinction at the bottom edges of fuels appears, burnout starts to occur. The burnout length is Xb. The pyrolysis zone Hp is determined by Xp minus Xb, in which the solid fuel is pyrolyzing.

In present paper, the behaviors of upward flame spread including flame front, pyrolysis front, flame height, pyrolysis height, etc., were discussed from the results of cotton fabric experiments, which provided theoretical basis for upward flame spread model.

2. Experimental setups and materials

2.1. Experimental setups

The experimental setup is shown schematically in Fig 2. Designed to hold the sample, the holder was attached vertically to the tension-compression sensor connected to the FUTEK USB data acquisition module recording the mass loss rate in flame spread process.

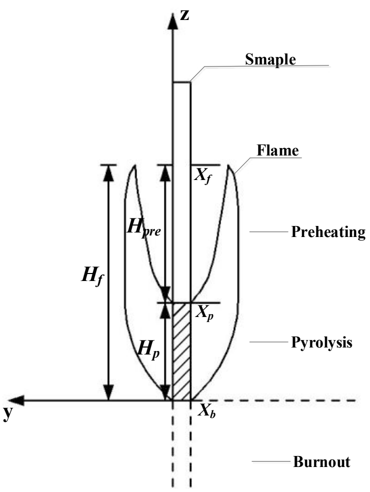

Fig. 1. Schematic diagram of flame spread

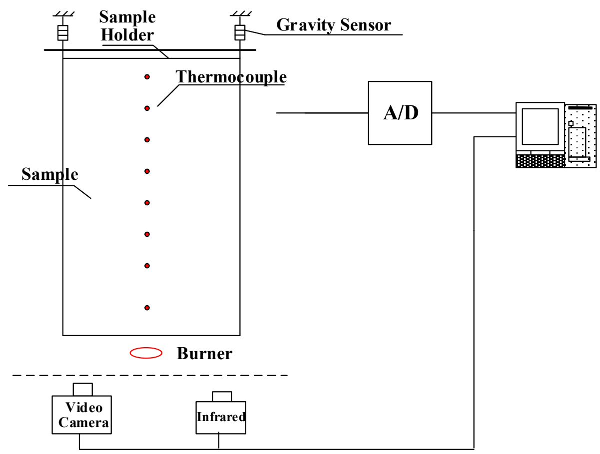

Fig. 2. Schematic diagram of experimental apparatus

A HD video camera was set at the front of the samples to track the flame front and record the visible size of the flame. The camera is capable of imaging a 20 frame burst in 1 s. Each image was converted to gray levels (0-255) and all values were averaged leading to an average image[2]. The position of the flame was quantified by statistical analyses on the images. Rangwala et al. [14] applied gray technique to obtain the flame length and the experimental error in flame length was less than 5%.

A high-frequency thermal IR imager (MAGNITY-MAG32HF), set at the front of the test samples, was used to obtain the samples surface temperature, by which the pyrolysis height and burnout height were determined. Liang et al. [15] performed experiments on PMMA slabs to study the effects of altitude and intersection angle on the flame spread behaviors and pyrolysis characteristics along corner walls by a thermal IR imager.

Fuel ignition was achieved using a Φ 160 mm pool fire at the free bottom middle of the fuel sample. Once sample ignited, the ignition power was removed immediately. The timescale of each test was shifted such that burner removal corresponded to t = 0 s. Each test was repeated three times at some moisture level in order to verify the repeatability of the experimental data.

2.2. Materials

Selection of materials for upward flame spread experiments should consider the properties of the fuels, specifically melting, deformation and homogeneity. These properties are all swept into thermal parameters: T_{ig} and k, and c. For example, a curling material could accelerate flame spread. The experimental materials was selected in these fuels widely