
One and Two Face Burning of Thin PMMA

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Abstract

A pervious study has reported effects of spacing on vertical burning of thin PMMA. However, one and two face burning of PMMA is not considered. The present study has revisited this topic by performing experiment using 300 mm height, 50 mm width, and 2 mm thickness PMMA sheets with one and two face burning cases. The steady state heat balance theory of one and two face burning is proposed. The flame height, pyrolysis height, and burnout length were measured by video image analysis. The results show that the values of flame height, pyrolysis height, and burnout length for two face burning are 1.4 times that of one face burning. The relationships between flame height and pyrolysis height, as well as flame spread rate and effective heating length are analyzed.

Keywords: PMMA, thin material, vertical burning, flame spread rate

Nomenclature

- \( c_g \): heat capacity of the gas (kJ/g)
- \( E \): activation energy (kJ/mol)
- \( L_p \): length of pyrolysis zone (m)
- \( q_e^p \): external radiant flux (kW/m²·s)
- \( \dot{Q}^p \): rate of heat release per unit width (kW/m)
- \( T_f \): flame temperature (K)
- \( T_s \): sample surface temperature (K)
- \( V_p \): pyrolysis spread rate (m/s)
- \( X_p \): pyrolysis height (m)
- \( \delta_f \): effective heating length (m)
- \( d \): the thickness of sample (m)
- \( h \): convective heat transfer coefficient (kW/m²·K)
- \( m \): the mass flow (kg/m²·s)
- \( Q_e \): the heat of gasification (J)
- \( R \): the gas constant
- \( T \): ambient temperature (K)
- \( t_\text{igt} \): the ignition time (s)
- \( X_f \): flame height (m)
- \( X_b \): burnout length (m)
- \( \sigma \): Stefan-Boltzmann constant

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1. Introduction

Many slab-like materials are used everywhere in life such as clothing, draperies, paper, etc. These slab-like materials are expected to approach thermally thin behavior during combustion, which have a special fire hazard. By thermally thin materials are meant that heat absorbed on one face of sheet will penetrate its thickness sufficiently rapidly, so that there will be no significant temperature gradient through the material depth[1]. In the fire research community, it is thought that a thin material may be more dangerous for its easy ignition and rapid fire development.

Previous studies have reported the vertical burning behavior of thin materials. Quintiere[2] studied the effects of the angular orientation of flame spread over thin metalized polyethylene terephthalate (0.20 mm thickness) and paper (0.17 mm thickness), but the thermally thin fuels were heated from one side by a flame plume. An empirical flame spread parameter obtained from bench-scale tests was used to correlate the flame spread behavior of thin rooflight materials in large-scale tests by Khan and Alpert[3]. Kleinhenz et al.[4] as well as Ohlemiller and Shields[1] reported that in the flame spread phenomena of a thermally thin composite cotton/fiberglass fabric, one-sided flames are smaller in size than their two-sided counterparts and propagate at half the speed. Thomas and Webster[5] demonstrated that for thermally thin materials, the flame spread is faster for suspended cotton fabric strips. Drysdale and Macmillan[6] studied the difference in the mechanisms of upward flame spread for thin and thick fuels. Using a semi-empirical analysis, Markstein and de Ris[7] demonstrated that an accelerating spread rate asymptotically attains a steady state if the length of a cotton fabric is infinite. Zhu[8, 9] et al. reported effects of spacing on vertical burning of thin PMMA, the results shown that as the spacing increased, the front flame height, back flame height, pyrolysis height, and burnout length showed the same trajectory, first increased and then decreased.

Although many studies have been reported for upward flame spread along vertical surfaces focusing on thin material as a wall-fire model, sometimes two face burning for the thin material, as shown in Figure 1. The flame height of PMMA is \( X_f \), the pyrolysis height is \( X_p \), and the burnout length is \( X_b \). The length of pyrolysis zone is \( L_p = X_f - X_p \). The effective heating length is \( \delta_f = X_f - X_p \). Fuel vapors are released from the pyrolysis surface and participate in the flame, which is confined to the buoyancy-induced boundary layer. The regions \( (X_f - X_p) \), where the flame extends beyond the pyrolysis length is known as the preheating zone, and the heat transferred from this region to the virgin fuel above \( X_f \) is responsible for the upward spread of the flame[10]. Clearly, in the first case, the preheating zone receives heat from one side. However, in the second case, the preheating zone receives heat from both the front and back sides.

In this study, a series of experiments for 300 mm height, 50 mm width and 2 mm thick PMMA (Acrylite GP) were carried out to compare the characteristics of one and two face burning on upward flame spread in the laboratory. The flame height \( X_f \), pyrolysis height \( X_p \), burnout length \( X_b \), and pyrolysis spread rate \( V_p \) were investigated.

2. One and two face burning (theory)

When slab-like materials with vertical orientation are ignited at the bottom, upward flame spread becomes one of the most important mode of flame spread. The surface of the thin materials absorb the flame heat flux, which penetrate the material thickness without a temperature gradient immediately. For the fire safety engineering, the fire risk of the two face burning of the thin materials at the same time is significantly greater than the one face burning conditions. Therefore, the thin combustible materials should be tested on one and two face of the fire characteristics.
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