Measurements on the Fire Behaviour of PVC Sheets Using the Cone Calorimeter

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ABSTRACT

A kind of commercially available PVC sheets in the Chinese market have been tested using the Cone Calorimeter at different heat fluxes (25 kW/m^2, 35 kW/m^2 and 50 kW/m^2). Two kinds of thickness of PVC sheets (3 mm and 8 mm) were used in this study. The test results show that the thickness of specimens has a significant effect on their fire behaviour.

INTRODUCTION

Polyvinyl chloride (PVC) is inherently flame-retardant due to its high chlorine content; and thus it is widely used in many sectors of industry, especially building and household industries. The combustion of PVC materials, however, emits large amounts of toxic hydrogen chloride gases and smoke [1, 2]. These gases can rapidly condense in the presence of water into hydrogen chloride acid, which is trapped into the smoke particles causing serious damage to firemen and building occupants in a PVC-containing fire. Great concern with the use of PVC products has arisen for decades, but it is still difficult to completely prohibit their use as they have many outstanding properties, including low price, self-extinguishing, and a broad scope of mechanical properties. Therefore, it is worthwhile investigating the properties of PVC products in fires.

The Cone Calorimeter [3] is a modern instrument for the fire testing of building materials, furnishing products and different material combinations. It is based on the oxygen consumption principle [4,5], which means for most materials, commonly encountered in fires, e.g. plastics, wood and paper, when related to a unit of oxygen consumed, their heats of combustion are approximately same and are close to 13.1 kJ per gram oxygen consumed with an accuracy of ±5%. Many researchers [6,7,8] have reported that the results obtained from the Cone Calorimeter correlate well in many ways with ones of large-scale fire tests, and that its data could be useful in predicting real fire performance of combustible products.

A kind of commercially available PVC sheets in the Chinese market was selected to test its behaviour using the cone calorimeter. This work is a part of the project funded by the Chinese Science and Technology Committee, which is concentrated on the fire characteristics of typical materials commonly used in the structures with a big space, such as cinemas, theaters and supermarkets.

EXPERIMENTAL

The Cone Calorimeter (Rheometric Scientific) tests were carried out according to the ISO 5660 and ASTM E 1354. The sample (100 mm × 100 mm) with the bottom and sides wrapped in aluminum foil was mounted horizontally. A metal grid was used during the experiments because this kind of material exposed the radiation became intumescent very seriously and the foamed material nearly touched the spark igniter. The external heat fluxes in this study are 25 kW/m^2, 35 kW/m^2 and 50 kW/m^2. For the 8 mm sheet at 50 kW/m^2, the spark was not removed until the entire test was completed because the flame extinguished in less than 60 s after turning off the spark. The data collection intervals in all cases is 3 s.

RESULTS AND DISCUSSION

The test results are presented in Table 1, which includes time to piloted ignition (t_i), rate of heat release (RHR) and specific extinction area (SEA). Additional data, such as mass loss rate, effective heat of combustion, CO_2 (carbon dioxide) and CO (carbon monoxide) yields are not reported herein. From Table 1, it can be seen that at the irradiances of 25 kW/m^2 and 35 kW/m^2 the 8 mm thick PVC sheet took two to three times long to ignite, compared with the 3 mm one, whereas the ignition times of the both are almost same when the heat flux was raised to 50 kW/m^2. This is expected because at high heat fluxes the heat loss through conductivity within the sample and by means of the backed material is not important.

According to the suggestion about the treatment of ignition data proposed by Mikkola and Wichman [9], the relationship between ignition time and incident heat flux is as follows:

Table 1. The Cone Calorimeter test results

Fire parameter		heat flux (kW/m^2)	PVC sheet (3 mm)	PVC sheet (8 mm)
mean time to ignition (s)		25	216	524
		35	67	181
		50	37	36
mean peak values	RHR (kW/m^2)	25	88	76.4
		35	103	99
		50	133	142
	SEA (m^2/kg)	25	1891	1275
		35	1884	1305
		50	1925	1380
mean values from t_i to 180 s	RHR (kW/m^2)	25	65	63
		35	80	85
		50	85	108
	SEA (m^2/kg)	25	1025	992
		35	950	856
		50	1042	897
mean values from t_i to 360 s	RHR (kW/m^2)	25	37	54
		35	47	67
		50	48	75
	SEA (m^2/kg)	25	963	931
		35	921	884
		50	1006	922

for thermally thin sample,

$$t_i = rcL_0 (T_i - T_o)/q,$$

for thermally intermediate sample,

$$t_i = rc (kL_0)^{-1/2} [(T_i - T_o)/4q]^{3/2}$$

for thermally thick sample,

$$t_i = prk (T_i - T_o)^2/4q^2$$

where r is density, c is specific heat, L_0 is sample thickness, k is thermal conductivity, T_i is ignition temperature, T_o is ambient temperature, and q is net heat flux. The thickness of samples used in our experiments is in the range 3-10 mm, but

it has been found that the ignition data for the 3 mm sheet fall very nearly on a single straight line when t_i^{-1} is plotted versus incident heat flux Q, and the correlation factor, R^2 is 0.9953 (Figure 1). In the case of the 8 mm sheet, Figure 2 shows that the correlation between $t_i^{-1/2}$ and Q is again very good ($R^2 = 0.9724$), whereas $t_i^{-2/3}$ is plotted versus Q ($R^2 = 0.9564$). From the plots, if the extrapolation has been made to $t_i = \infty$, the minimum heat fluxes for ignition of the 3 mm sheet and 8 mm sheet are ca 19 kW/m^2 and 18 kW/m^2, respectively.
Ignitability data alone cannot be used to assess the fire behaviour of a material, much more information is required. For example, RHR is usually adopted by many researchers in assessment of a fire since it greatly affects fire growth and spread. Generally, the RHR peak is an important factor. Table 1 shows that the peak RHR values increase with the increase of heat fluxes, and that the effect of the thickness of samples on the RHR peak is not significant (the variation is within 10 %). The shapes of RHR curves with different thickness are different. For the 3 mm sheet, there are two distinct peaks (Fig. 3 (a)), but for the 8 mm sheet, only one broad peak appears in the RHR curve (Fig. 4 (a)). The difference of the mean RHR between t_i and t_i +180 s for the both sheets is minor (except for the irradiance of 50 kW/m^2, whereas there exits a great difference of the mean RHR from t_i to t_i +360 s between the two kinds of sheets.

The smoke obscuration in the Cone Calorimeter tests is expressed in the terms of specific extinction area (SEA). The average SEA obtained during the test is given as follows:

$$SEA_{avg} = å_i V_i k_i Dt_i / (m_i - m_f)$$

where k_i is smoke extinction coefficient, V_i is volume exhaust flow rate, Dt_i is sample time interval, m_i is initial specimen mass, and m_f is final specimen mass.
Fig. 3(b) and Fig. 4 (b) show a significant amount of smoke abscuration occurred before ignition. The SEA peaks appeared as the RHR was subsiding. From the data presented in Table 1, it can be seen that the peak SEA values are about 50% higher for the 3 mm sheet than for the 8 mm one, but that the average values are just a bit higher.

The smoke measurements in the Cone Calorimeter are conducted in a well-ventilated atmosphere (dynamic).This is not the case in an enclosed space where smoke generation (cumulative) is usually in a reduced oxygen atmosphere. Moreover, the measurements do not take into the rate of smoke production in the Cone Calorimeter. Therefore, SEA has its limitations in the prediction of the smoke production of an enclosed fire.

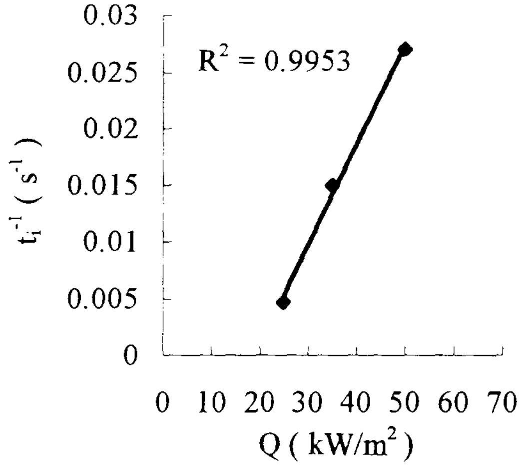


Fig. 1 Effect of heat flux on igntion time of PVC sheet (3mm)

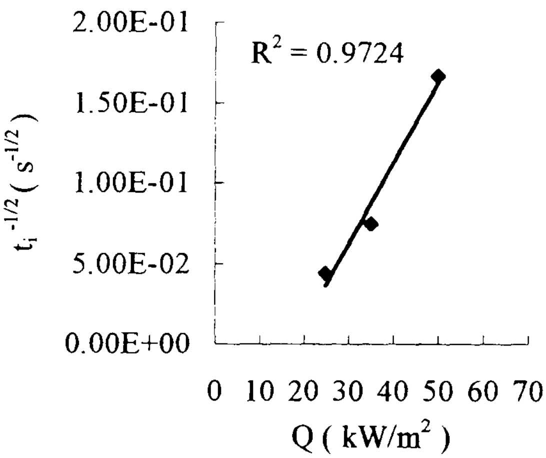
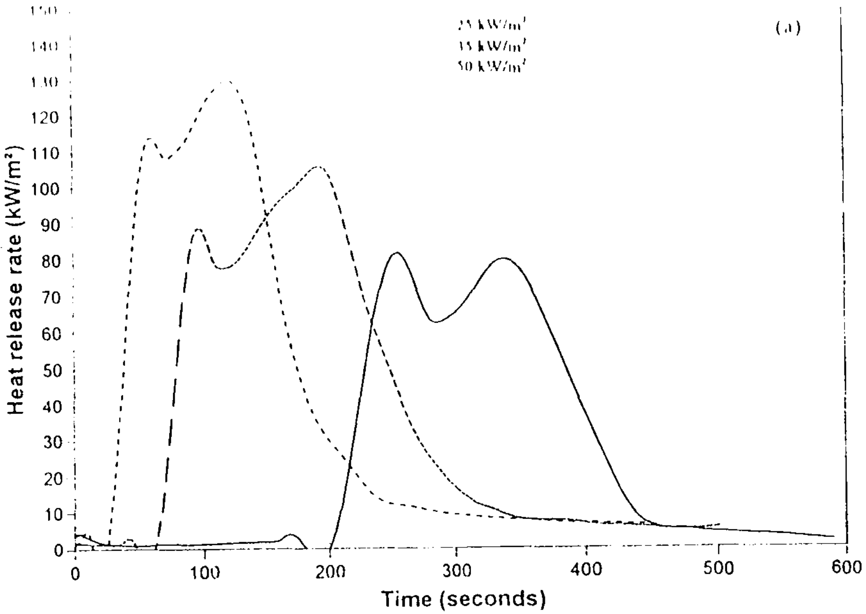
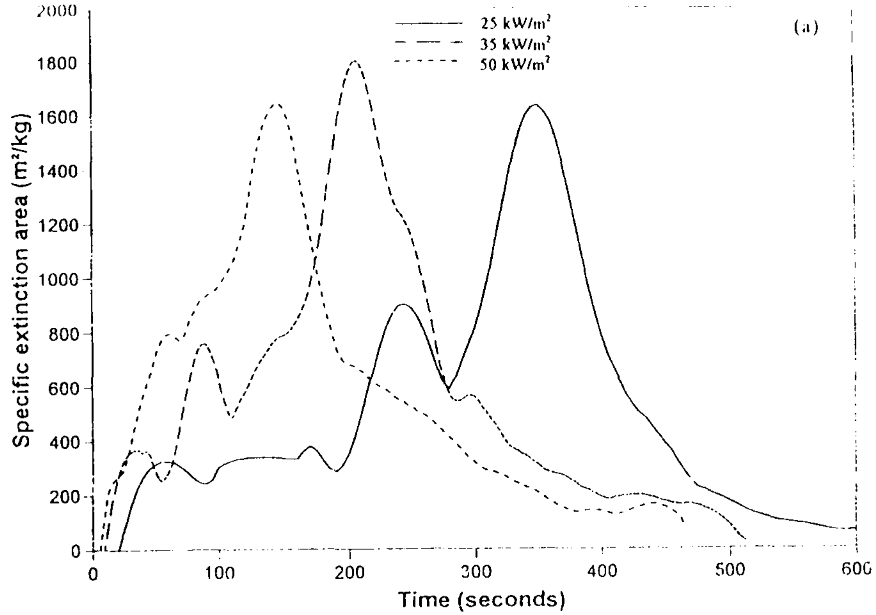


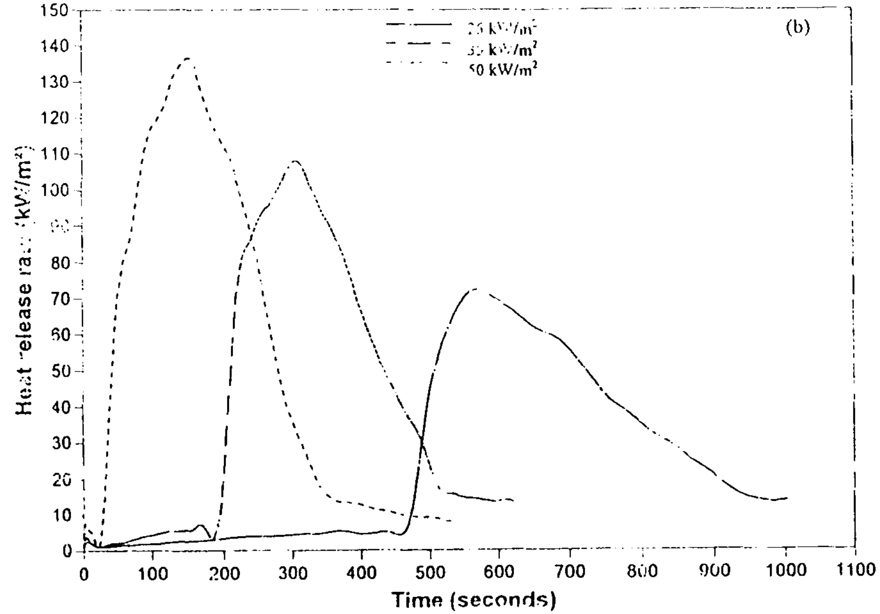
Fig. 2 Effect of heat flux on ignition of PVC sheet (8mm)

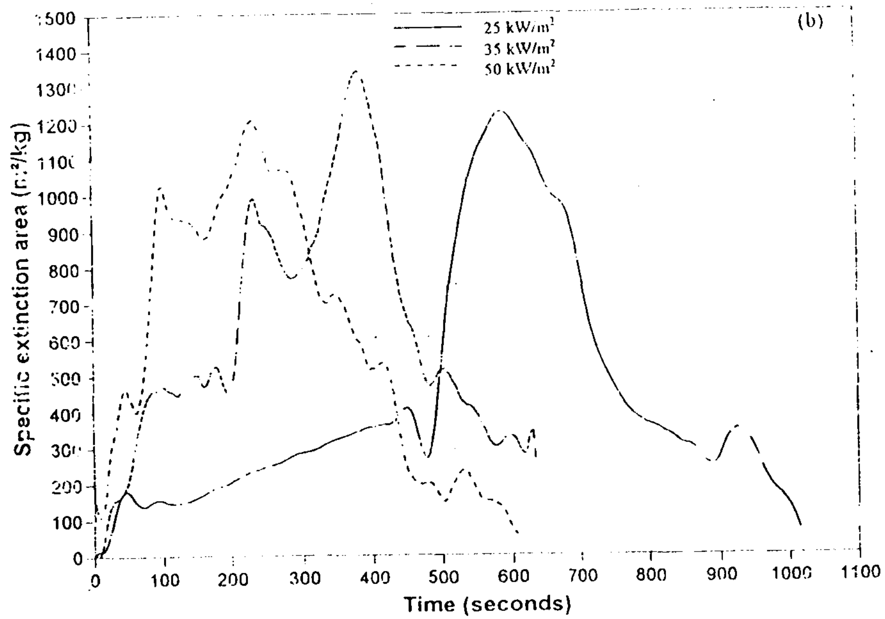
CONCLUSIONS

1. The ignition time is longer for the 8 mm PVC sheet to be ignited than for the 3 mm one, especially, at low heat fluxes, but at a high flux of 50 kW/m^2, the


(a)
25 kW/m²
35 kW/m²
50 kW/m²
Heat release rate (kW/m²)
Time (seconds)


(a)
25 kW/m²
35 kW/m²
50 kW/m²
Specific extinction area (m²/kg)
Time (seconds)


(b)
50 kW/m²
Time (seconds)


(b)
25 kW/m²
35 kW/m²
50 kW/m²
Time (seconds)

ignition times for the both kinds of sheets are almost same.

2. The minimum heat flux for ignition obtained from the extrapolation of the plots of t_i^{-1} (for thermally thin specimens) or $t_i^{-1/2}$ (for thermally thick specimens) vs. heat flux might be used to assess the ease of PVC materials. The minimum fluxes for the 3 mm and 8 mm sheets are ca 19 kW/m^2 and 18 kW/m^2, respectively.

3. The combustion of PVC sheets emits a large amount of smoke during the test. The smoke obscuration expressed as SEA in the Cone Calorimeter (well-ventilated) might not be consistent with the smoke generation of a material in real fires, especially in an enclosed fire (a material is usually in a reduced oxygen atmosphere).

4. The thickness of the sheets has a great effect on the peak SEA, whereas the effect of the thickness of specimens on the peak RHR is not significant.

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