

Some comments on the use of cone calorimeter data

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Abstract

The cone calorimeter has become one of the most important and widely used instruments for the research and development of fire retarded polymeric materials. The paper addresses three important ways in which the principal setup influences the results — factors which sometimes do not receive due consideration when drawing conclusions. The paper discusses in detail the impact on cone calorimeter results of the choice of external heat flux, the influence on the peak of heat release rate of sample thickness and thermal feedback from the back of the sample, and the influence on irradiance of the horizontal and vertical distances from the cone heater.

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1. Introduction

The cone calorimeter is a performance-based bench scale fire testing apparatus [1,2]. Sample plates 100 mm × 100 mm in size are investigated under forced-flaming conditions [3]. The sample size is of the smallest order of magnitude discussed in fire engineering and of the largest used in polymer analysis. Hence, the cone calorimeter constitutes an important link between fire engineering and polymer science, which is crucial in the interdisciplinary area of fire science. Furthermore, it provides comprehensive insight into not only fire risks such as heat release rate, total heat release, and time to ignition, but also fire hazards such as smoke release and CO production. The cone calorimeter setup [4] was developed thoroughly to target the properties of materials [5] rather than to correspond to a special full-scale scenario of a real fire. Cone calorimeter investigations

can be used as a universal approach to ranking and comparing the fire behaviour of materials. Therefore, it is not surprising that the cone calorimeter is finding increasing implementation as a characterization tool in the research and development of fire retarded polymeric materials.

However, each experimental setup defines a specific fire scenario. As is typical for all fire tests, samples' performance in the cone calorimeter depends on the specific characteristics of the test, including ignition source, ventilation, irradiance (external heat flux), temperature, and the geometry of the specimen. Strictly speaking, the cone calorimeter test characterizes the performance resulting from an interaction of material properties, specimen, and the defined fire scenario. The meaning of the results may have little relevance for other fire scenarios or fire tests that differ in their essential setup. Some of the crucial setup characteristics are obvious, such as horizontal sample positioning, melt dripping prevention, and well-ventilated combustion, and the effects of these characteristics on the results are well known. However, some cone calorimeter characteristics are less obvious and are sometimes neglected

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detrimentally in performing cone calorimeter tests or discussing their results. The author was encouraged to submit this paper as a consequence of discussions on cone calorimeter experiments and data at the ACS meeting in Fall 2004. This paper addresses three different points concerning the performance and evaluation of cone calorimeter tests on polymeric materials.

2. Experimental

A cone calorimeter (Fire Testing Technology, East Grinstead, UK) was used in accordance with ISO 5660 [6]. Samples were measured in the horizontal position using the retainer frame. The data were evaluated using the decreased surface area of the sample (88.36 cm^2). Temperatures were measured using NiCr–Ni thermocouples of type K. Irradiances were measured using the Schmidt–Boelter heat flux meter (GTW-10-32-485A, Meditherm Corporation) of the cone calorimeter equipment.

3. Results and discussion

3.1. Heat flux and temperature

In the cone calorimeter experiment a constant external heat flux is applied, resulting in heating of the sample surface, in some cases in phase transitions in the interphase, and in the formation of a pyrolysis zone where endothermic decomposition of material occurs. Fig. 1 shows the surface temperature of a ceramic fibreboard plotted against time for different external heat fluxes between 10 kW m^{-2} and 70 kW m^{-2} . Since the ceramic and polymer specimens have similarly low

thermal conductivities, the plot shows the approximate temperature curve expected for a polymer surface if no decomposition and thus no ignition occur. The surface temperature increased quite rapidly at the early stage of the tests and levelled off to a steady state as soon as the re-radiation of the surface and the heat transport from the sample plate to the surrounding was equal to the input at its surface. It became clear that — if no ignition occurs — the typical external heat fluxes used for investigations on polymers ($25\text{--}50 \text{ kW m}^{-2}$) lead to maximum temperatures far below those reached in fires characterized by similar heat fluxes.

Reaching surface temperatures above the decomposition temperature results in the formation of a pyrolysis zone, so that ignition subsequently occurs, at the critical temperature or at the corresponding critical mass loss rate. The highly exothermic reactions in the flame zone are the source of an additional heat flux affecting the sample surface. During a cone calorimeter test, external heat flux, flame heat flux, and re-radiated heat flux are all of the same order of magnitude [7]. In contrast to the surface temperature without decomposition, which is illustrated in Fig. 1, the pyrolysis temperature is determined by a complex equilibrium during the fire performance of the sample, controlled by external heat flux, heat transfer, endothermic polymer decomposition, gasification, mass loss rate, effective heat of combustion, thermal feedback of the flame, and re-radiation of the surface. Typical surface temperatures during a cone calorimeter test were reported [8,9] and characterized by increase until decomposition temperature is reached, ignition occurs at time to ignition (t_{ig}), and the temperature soars up to the pyrolysis temperature. The discontinuity in temperature indicates the crossover from an ignition scenario to a forced-flaming scenario. It also marks the difference between ignitability and flammability. Ignition occurs when the heat flux resulting from the difference of external heat flux and re-radiated heat flux results in a mass loss rate that exceeds the critical mass loss rate of a distinct ignition scenario. A sustained flame (flammability) is detected if the differences in external heat flux, heat flux from the flame, and re-radiated heat flux result in a mass loss rate that exceeds the critical mass loss rate of extinguishing. Fig. 2 shows a rather rough scheme of the surface temperature and effective heat flux behaviour at the surface according to the results reported in the literature [8,9] and based on a number of simplifying assumptions. Indeed, Fig. 2 is a description reasonable only for a thermally thick sample of a non-charring material that is characterized by a steady-state burning after ignition. Hence, the system can be described in terms of constant heat release rate, mass and heat transfers, and temperatures. Three main zones characterize the system: the flame zone, the pyrolysis zone, and the polymer. In a rough approximation, the pyrolysis zone is characterized by a constant

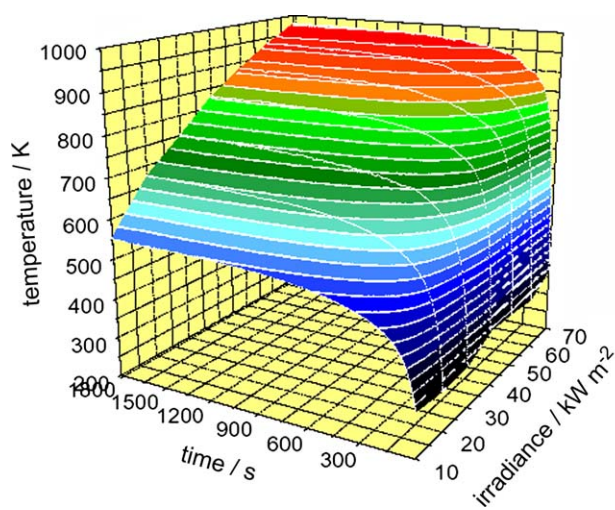


Fig. 1. Surface temperature of a ceramic plate plotted against the external heat flux applied and the time in a cone calorimeter test run.

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