International Journal on Engineering Performance-Based Fire Codes, Volume 8, Number 4, p.166-169, 2006

WILL TWO FIRE SHUTTERS OF FIRE RESISTANCE PERIOD 2 HOURS EQUAL TO ONE WITH 4 HOURS?

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(Received 18 July 2007; Accepted 22 August 2007)

ABSTRACT

There are proposals on using two fire shutters of 2 hours fire resistance period instead of one with 4 hours as specified in the fire codes. This point will be discussed in this paper. Argument will be supported by the equal temperature-time exposure concept or t-equivalent rule commonly applied in consultancy on performance-based design projects. However, using temperature is not adequate. Thermal radiation heat flux, the other parameter describing a thermal system, should be included.

1. INTRODUCTION

There are proposals of installing fire shutters of 2-hour fire resistance period (FRP) instead of 4-hour as required [1]. Such cases of not complying with the codes have to go through the fire engineering approach (FEA) [2,3] in Hong Kong. FEA is similar to performance-based design (PBD) practising elsewhere [4]. Normally, fire safety is demonstrated by FEA to be equivalent to what specified in the codes. There are many other requests on providing fire resisting constructions with lower ratings [1,5].

The equal area hypothesis or t-equivalent rule [6] will be applied to study whether two fire shutters of 2-hour FRP is equivalent to one with 4-hour FRP. However, thermal radiation acting on the construction element [7,8] is not included. Applying the equal area hypothesis on the temperature-time curve would only give a rough estimation. Importance of including thermal radiation [9] will further be pointed out in this paper.

2. FIRE RESISTANCE PERIOD

The FRP of structural elements for premises in Hong Kong are required to be examined by British Standard fire tests [5,10,11] as specified in the local Fire Resisting Construction (FRC) code [1]. Fire resistance is defined in BS 476 Part 20 [5] as:

"The time for which an element of building construction is able to withstand exposure to a standard temperature/time and pressure regime without a loss of its fire separating function or loadbearing function or both".

The test specimen is to be accommodated in a furnace with heat and stresses (for load bearing elements only [10]) applied. The heating conditions will be controlled by limiting the input rate of fuel to follow the standard temperature-time curve. Reviews on fire resisting construction are available in the literature [8,12].

The mean furnace temperature T (in °C) is expressed in terms of the initial furnace temperature T_0 (lying between 0 to 30 °C and taken to be 20 °C in this study) and the heating time t (in minutes) as:

$$T = T_0 + 345 \log_{10}(8t + 1) \qquad (1)$$

Three performance criteria, including loadbearing capacity, integrity and insulation, are used to examine the fire resistance of construction and structural elements. Part of the criteria might not be required for some applications as specified in the local FRC code [1]. Examples are the thermal insulation criterion for fire shutters; and the integrity criterion for columns.

3. THE EQUAL AREA HYPOTHESIS

The "equal area hypothesis" or the t-equivalent rule [6] was commonly applied to estimate the equivalent time that an element can stand by relating the fire load and fire severity. It was demonstrated that equal areas under two temperature-time curves (with respect to a reference value [12]) will have identical fire severity [13,14] as shown in Fig. 1.

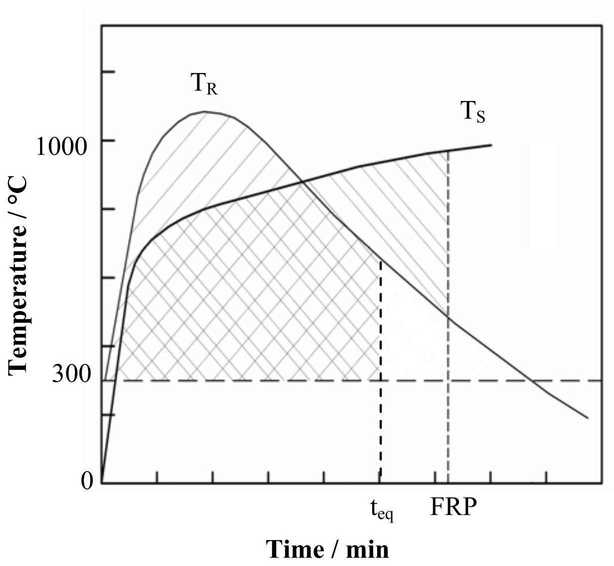

Fig. 1: The equal area hypothesis

The fire severity and the required FRP of an element can be determined from the temperature-time curve T_R of a real fire scenario by comparing with the standard temperature-time curve T_S with reference to a temperature, say 300 °C in the literature [e.g. 13].

The equivalent time t_{eq} that an element of certain FRP can protect can be expressed as:

$$\int_0^{t_{eq}} \left(T_R - 300\right) dt = \int_0^{FRP} \left(T_S - 300\right) dt \qquad (2)$$

Note that the heat flux received by the construction elements was not taken into account. The fire severity is considered as a function of temperature only. Under a small fire with temperature-time curve lower than the standard curve [e.g. 5], such proposal might work.

4. TWO FIRE SHUTTERS

For a fire resisting construction element of 2-hour FRP, integrating equation (1) will give the area A_2 under the temperature-time curve:

$$A_2 = \int_{0.69}^{120} [T_0 + 345\log(8t+1)]\, dt - \int_{0.69}^{120} 300\, dt \qquad (3)$$

Note that integrating the natural logarithm function on t (ln t) over t from 0 to x would be:

$$\int_0^x \ln t\, dt = (t\ln t - t)\Big|_0^x \qquad (4)$$

Therefore, the value of A_2 is 72101 °C·min. Note that integration starts from 0.69 min, not from 0 min to allow T_s rising up to 300 °C.

A 4-hour fire resisting construction will give an area A_4:

$$A_4 = \int_{0.69}^{240} [T_0 + 345\log(8t+1)]\, dt - \int_{0.69}^{240} 300\, dt \qquad (5)$$

The value of A_4 is 168925 °C·min.

Let the values of equivalent times that 2-hour and 4-hour FRP elements can protect under a real fire be t_2 and t_4 respectively. The difference in equivalent time ($t_2 - t_4$) between elements of 2-hour FRP and 4-hour FRP is as shown in Fig. 2:

$$\int_{t_2}^{t_4} \left(T_R - 300\right) dt = 96824a \text{ °C·min} \qquad (6)$$

This can explain why two fire shutters with 2-hour FRP is not equivalent to a 4-hour FRP shutter. The area ($2A_2$) under the temperature-time curve for two fire shutters with 2-hour FRP is only 144202 °C·min. The area (A_4) under the temperature-time curve for a fire shutter with 4-hour FRP is 168924 °C·min.

In fact, the equivalent time that the second 2-hour fire shutter can stand after the first shutter collapsed t_{S2} is:

$$\int_{120}^{t_{S2}} [T_0 + 345(8t+1) - 300]\, dt = A_2 \qquad (7)$$

Value of t_{S2} is less than 120 minutes as the second fire shutter would be exposed to higher initial temperature.

Therefore, installing two fire shutters of 2-hour FRP in parallel is not equivalent to a fire shutter of 4-hour FRP.

5. THERMAL RADIATION

Gas temperature is only one of the two parameters describing the thermal fire system. The other parameter is the heat flux. As proposed by Harmathy [15], heat transfer from fire gases to the compartment boundaries is by thermal radiation. Note that radiative heat flux is proportional to temperature to the power four.

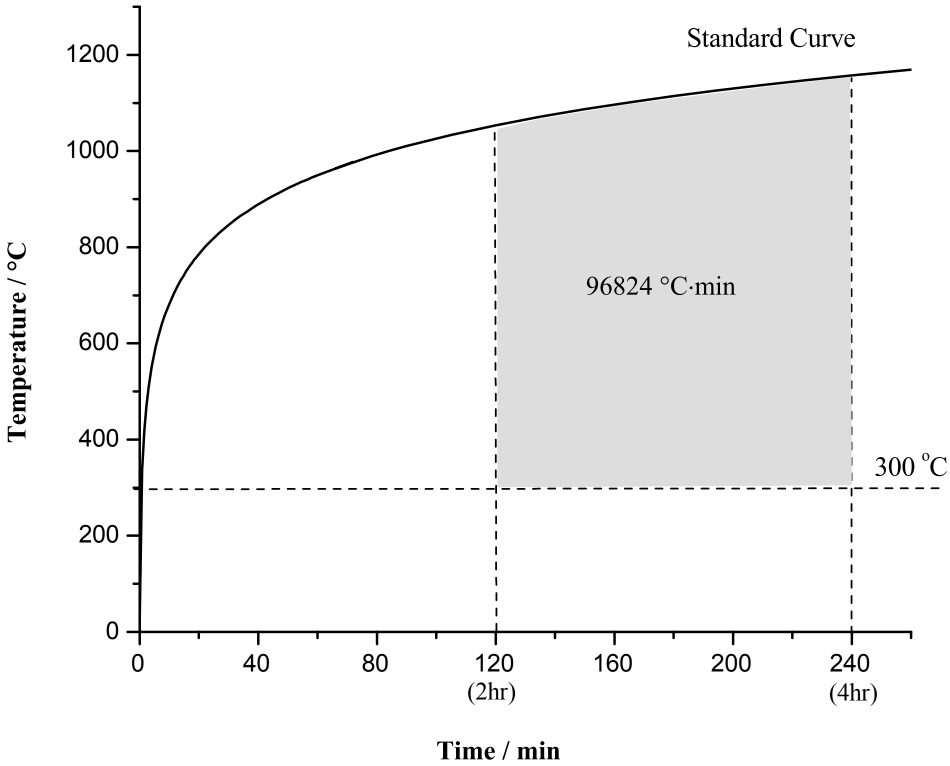

Fig. 2: Difference in fire resistance

Possible impact of thermal radiation was also discussed by Law in her set of paper collection [16]. Exposing the element to hot gas temperature does not necessarily correspond to the actual situation. Therefore, heat flux due to convection and radiation acting on the structural or building element concerned should be considered in fire resistance test.

Heat flux at different parts of the furnace in full-scale and intermediate-scale fire resistance tests were compared by Sultan and associates [e.g. 17]. Although similar values up to 150 kWm^{-2} were measured for furnace temperature following the standard temperature-time curve, value might be very different under bigger fires. Inadequacy [7,16] of using only the gas temperature had been further discussed and demonstrated by preliminary full-scale burning tests on fire shutter [9,18]. It is necessary to carry out more full-scale burning tests under post-flashover fires [19] to give temperature-time curves higher than the standard ones.

6. CONCLUSIONS

Providing construction elements with fire resistance rating lower than the code specification was discussed in this paper. The equal area hypothesis on temperature-time curve [6] with respect to the standard value was commonly adopted in performance-based design. It is obvious that installing two fire shutters with 2-hour FRP is not equivalent to one with 4-hour FRP, even when using only gas temperature in the equal area hypothesis.

Thermal radiation is important and has to be considered in fire hazard assessment [7-9,16]. Including the other parameter on heat flux for a thermal system would give much lower equivalent protection time when the fire resistance element is exposed to bigger fires. Tests with post-flashover fires of higher heat release rate [18-19] have to be carried out to justify the equivalent fire resistance period.

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