PRELIMINARY STUDIES ON THERMAL SENSITIVITY OF FUSABLE LINKS WITH A WIND TUNNEL

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ABSTRACT

This is a report on a joint feasibility study with the Fire Services Department on exploring how thermal sensitivity of fusable links can be assessed. Five samples of fusable links provided were tested by following UL-33 on "Heat responsive links for fire-protection service" with a modified wind tunnel.

A wind tunnel for studying the thermal response of sprinkler heads at The Hong Kong Polytechnic University was used. In the test, the fusable link samples were loaded under 0.4 kgf. The work-section of the tunnel was set at air temperature of 135ºC and air speed of 2.54 ms^{-1}.

Results suggested that it is feasible to assess the thermal sensitivity of fusable links by following UL-33.

1. INTRODUCTION

There are interests in assessing the thermal sensitivity of fusable links made locally. For quality control, a common test is to measure the activation temperature of fusable links by a hot water bath. However, the result of this test can only assess whether the fusable link can be activated at the specified temperature. There is no indication on how long the fusable link will be activated. In other words, thermal sensitivity of the fusable link has to be tested.

There are overseas standards on assessing the thermal sensitivity of fusable links with a wind tunnel. Examples are UL-33 on "Heat responsive links for fire-protection service" [1] and AS 1890-1999 on "Preliminary studies on thermal sensitivity of fusable links" [2]. The Fire Services Department (FSD) is interested in investigating whether such testing procedure for fusable links can be carried out in Hong Kong.

A joint feasibility study project of testing the thermal sensitivity of fusable links was then worked out with Professor W.K. Chow, Chair Professor of Architectural Science and Fire Engineering at The Hong Kong Polytechnic University (PolyU) in September, 2005. A team was then set up with some engineers from FSD as in Fig. 1.

In fact, thermal sensitivity of sprinkler heads has been studied by Professor Chow for 20 years. After a series of meetings with the engineers from FSD, it is agreed that UL-33 will be followed. It is possible to test fusable links in Hong Kong by following this standard as a wind tunnel can be developed easily. Five samples of fusable links were delivered to Professor Chow and assessed.

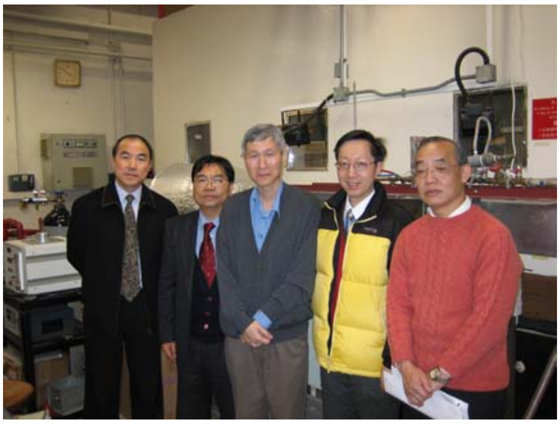


Fig. 1: The team and wind tunnel test on 25 January 2006

2. TESTING PROCEDURE

A wind tunnel was constructed under the supervision of Professor Chow at PolyU after his training at Fire Research Station (FRS), Borehamwood, UK in September 1986. That was one of the research and development outcomes of attachment exercise at the golden age of polytechnic. Advices from discussion with the pioneer expert, Mr. C. Theobald at FRS, on assessing the thermal sensitivity of sprinkler were applied to build the tunnel at PolyU in 1988. Detailed descriptions were reported in the literature

[3,4]. A schematic diagram of the wind tunnel is shown in Fig. 2.

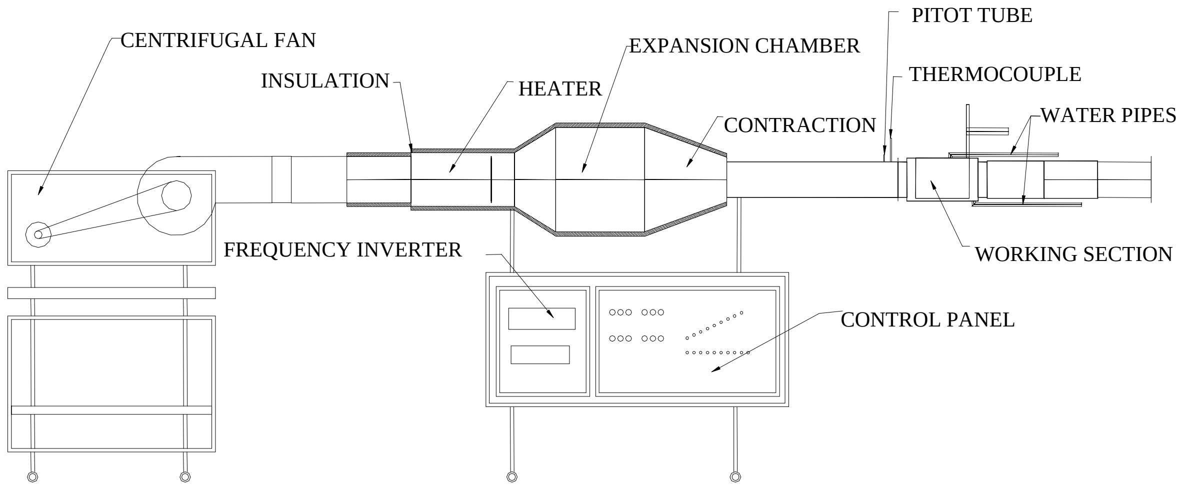
Each fusable link would be placed in the working section of the wind tunnel as in Fig. 3. There, the air temperature and speed can be adjusted. In following UL-33, the air temperature has to be adjusted to 135ºC, and air speed to 2.54 ms^{-1}.

Five samples of fusable links of 68°C rating were supplied by FSD. Four of them are shown in Fig. 4. An external loading of 0.4 kgf was applied to the fusable link as in Fig. 5.

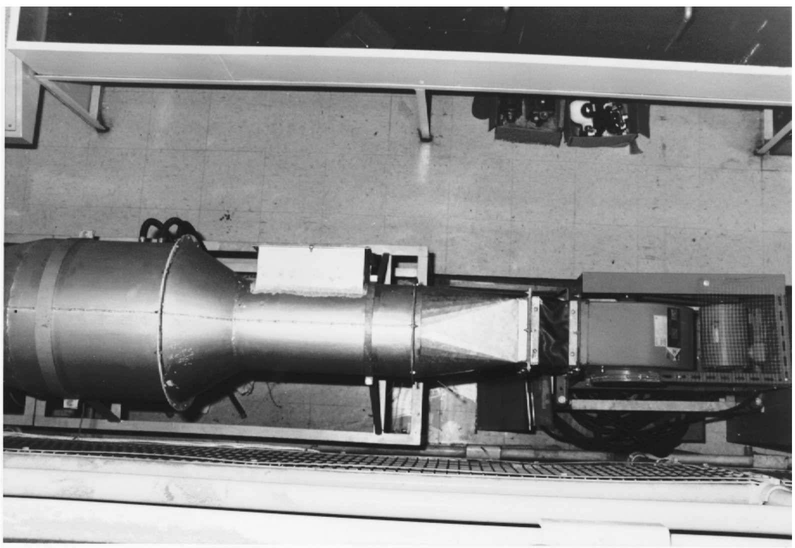
A trial run on one sample was conducted on 20 January, 2006. The other four samples were tested together with three engineers from FSD and one fire expert on 25 January, 2006. The plane of the fusable links was orientated either along or perpendicular to the air flow. This would change the heat transfer process slightly. The appearances of those four samples after testing are shown in Fig. 6.

3. RESULTS

The testing conditions and results on the measured activation times are shown in Table 1. It is observed that the 68°C-rated fusable links would be activated at 30 s to 73 s, all lying within the range of UL-specification from 19.7 s to 86.1 s under the loading of 0.4 kgf, when plunged by hot air at 135°C and speed 2.54 ms^{-1}.



(a) Diagram



(b) Picture

Fig. 2: Schematic of the wind tunnel

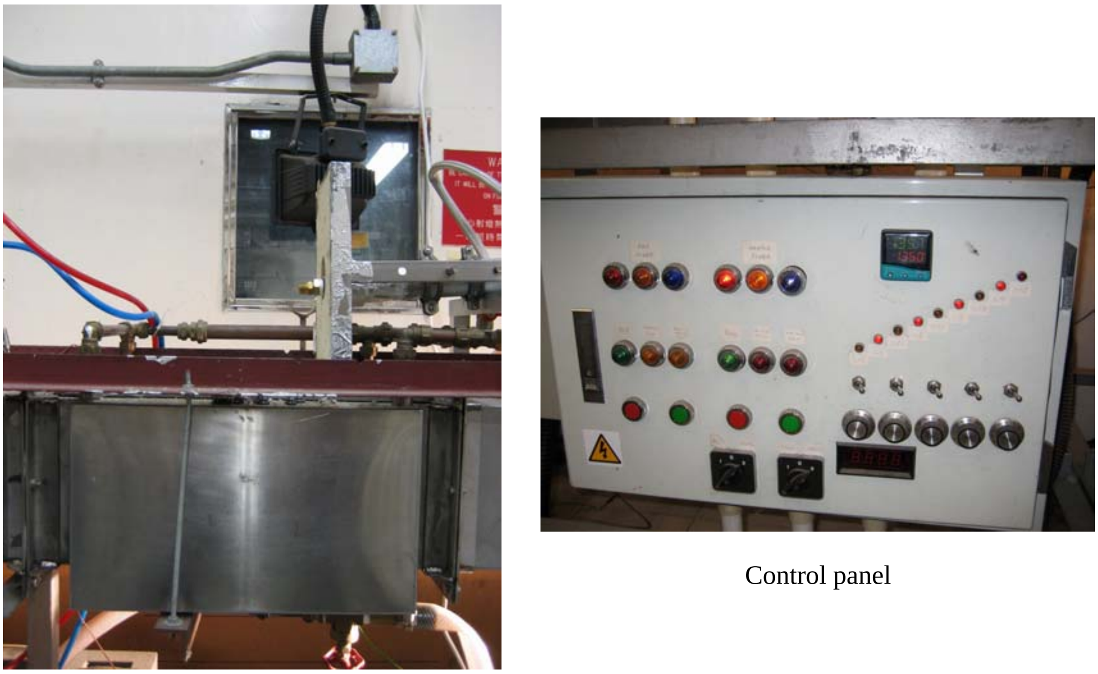


Fig. 3: Work-section of the Wind Tunnel

Fig. 4: The four fusible links tested on 25 January 2006

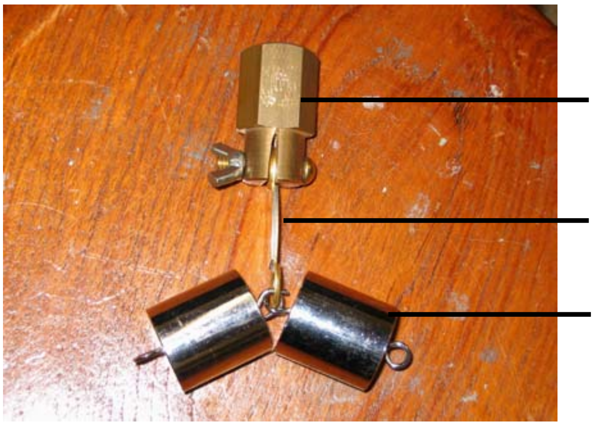


Fig. 5: Fusible link under loading of 0.4 kgf

(a) Sample 2

(b) Sample 3

(c) Sample 3

(d) Sample 4

Fig. 6: Appearance of the samples tested on 25 January 2006

Table 1: Test results

Sample	Testing Date	Orientation with Air	T_g/°C	T_o/°C	V_g/ms^{-1}	Activating Time t_a/s
1	20 January 2006	Along	135	17.1	2.54	30
2	25 January 2006	Along	135	15.8	2.54	73
3	25 January 2006	Perpendicular	135	15.8	2.54	31
4	25 January 2006	Along	135	15.8	2.54	41
5	25 January 2006	Along	135	15.8	2.54	38

4. RESPONSE TIME INDEX

The testing procedure under UL-33 is similar to the Factory Material (FM) plunge test [5] on assessing the thermal sensing element of sprinkler heads. Suppose hot air at constant temperature T_g and constant air speed V_g is moving toward a thermal sensing element of rating T_a, mass M_s, specific heat C_s, surface area A_s and surface heat transfer coefficient h_s. The initial temperature of the thermal sensing element is T_o. The temperature T of the thermal sensing element at time t can be obtained by solving the heat balance equations:

$$M_s C_s \frac{d}{dt}\left(T - T_o\right) = h_s A_s \left(T_g - T\right) \tag{1}$$

Rearranging:

$$\frac{d\left(T - T_o\right)}{\left(T_g - T\right)} = \frac{h_s A_s}{M_s C_s} dt \tag{2}$$

This can be rewritten in terms of a time constant τ:

$$\tau = \frac{h_s A_s}{M_s C_s} \tag{3}$$

Solving it would give the activation time t_a, when heated up to T_a:

$$\int_{T_o}^{T_a} \frac{d(T - T_o)}{(T_g - T)} = \int_0^{t_a} \frac{dt}{\tau} \qquad (4)$$

or

$$(T_a - T_o) = (T_g - T_o)(1 - e^{-t_a/\tau}) \qquad (5)$$

The time constant τ is not only a property of the thermal sensing element because h_s is related to $\sqrt{V_g}$. Therefore, τ depends on $\frac{1}{\sqrt{V_g}}$. A parameter called response time index RTI was defined by multiplying τ by $\sqrt{V_g}$:

$$RTI = \tau\sqrt{V_g} \qquad (6)$$

In this way, RTI is a property of the thermal sensing element only. T_a is then given by:

$$(T_a - T_o) = (T_g - T_o)\left(1 - e^{-\frac{t_a\sqrt{V_g}}{RTI}}\right) \qquad (7)$$

This can be arranged as:

$$t_a = RTI\left[\frac{1}{\sqrt{V_g}} \ln\left(\frac{T_g - T_o}{T_g - T_a}\right)\right] \qquad (8)$$

Let

$$x = \frac{1}{\sqrt{V_g}} \ln\left(\frac{T_g - T_o}{T_g - T_a}\right) \qquad (9)$$

This gives:

$$t_a = RTI\ x \qquad (10)$$

Plotting t_a against x would give a straight line of slope RTI.

Results on t_a are plotted in Fig. 7 with the best fitting line of correlation coefficient 0.56:

$$t_a = 117.4\ x \qquad (11)$$

The values of RTI are varying from 84.5 $m^{\frac{1}{2}}s^{\frac{1}{2}}$ to 199.6 $m^{\frac{1}{2}}s^{\frac{1}{2}}$, with a mean of 117.4 $m^{\frac{1}{2}}s^{\frac{1}{2}}$.

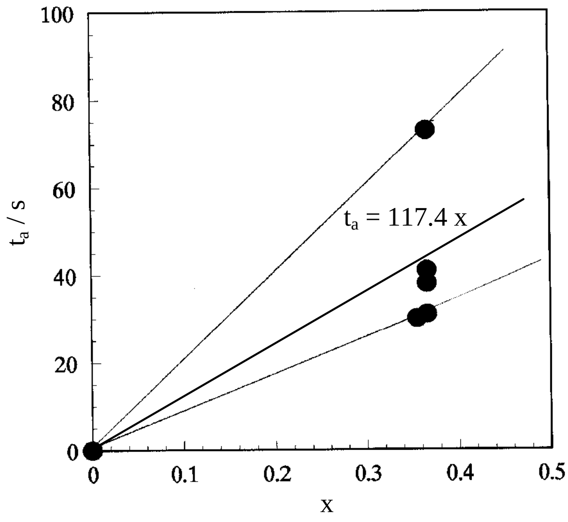


Fig. 7: Fitting for RTI

5. CONCLUSIONS

From the above study, it is feasible to assess the thermal sensitivity of fusable links by UL-33 [1]. Such a wind tunnel [3,4] can be developed early in any laboratory of Hong Kong.

REFERENCES

1. UL-33, Heat responsive links for fire-protection service, Underwriter's Laboratories (2003).
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APPENDIX A: HEAT BALANCE EQUATION

(1) The heat balance equation is:

$$M_s C_s \frac{d(T - T_o)}{dt} = h_s A_s (T_g - T) \qquad (A1)$$

Defining τ:

$$\tau = \frac{M_s C_s}{h_s A_s} \tag{A2}$$

Integrating (t, T) from (0, t_a) to (T_o, T_a):

$$\int_{T_o}^{T_a} \frac{d(T - T_o)}{dt} = \int_0^{t_a} \frac{dt}{\tau} \tag{A3}$$

(2) Dimension of τ:

$$[\tau] \sim \frac{kg \cdot Jkg^{-1}K^{-1}}{Wm^{-2}K^{-1} \cdot m^2} \sim \frac{J}{W} \sim s$$

(3) Integrating LHS of equation (A3):

Let

$$T_g - T = \theta \tag{A4}$$

$$-dT = d\theta$$

$$\int \frac{d(T - T_o)}{(T_g - T)} = \int \frac{dT}{\theta} = \int \frac{-d\theta}{\theta} = -\ln\theta + C$$
$$= -\ln(T_g - T) + C$$

$$\int_{T_o}^{T_a} \frac{d(T - T_o)}{(T_g - T)} = \left[-\ln(T_g - T) + C\right]_{T_o}^{T_a}$$
$$= -\left[\ln(T_g - T_a) - \ln(T_g - T_o)\right]$$
$$= -\ln\left(\frac{T_g - T_a}{T_g - T_o}\right)$$

(4) Integrating RHS of equation (A3):

$$\int_0^{t_a} \frac{dt}{\tau} = \frac{t_a}{\tau}$$

(5) LHS = RHS:

$$-\ln\left[\frac{T_g - T_a}{T_g - T_o}\right] = \frac{t_a}{\tau}$$

$$\ln\left[\frac{T_g - T_a}{T_g - T_o}\right] = \frac{-t_a}{\tau}$$

$$\frac{T_g - T_a}{T_g - T_o} = e^{-t_a/\tau} \tag{A5}$$

Rearranging:

$$T_g - T_a = (T_g - T_o)\, e^{-t_a/\tau}$$

$$-T_a = -T_g + (T_g - T_o)\, e^{-t_a/\tau}$$

$$T_a = T_g - (T_g - T_o)\, e^{-t_a/\tau}$$

$$T_a - T_o = (T_g - T_o) - (T_g - T_o)\, e^{-t_a/\tau}$$

$$(T_a - T_o) = (T_g - T_o)\ [1 - e^{-t_a/\tau}] \tag{A6}$$

$$RTI = \tau\sqrt{V_g} \tag{A7}$$

$$(T_a - T_o) = (T_g - T_o)\ [1 - e^{-t_a\sqrt{V_g}/RTI}] \tag{A8}$$

(6) Rearranging:

$$\frac{(T_a - T_o)}{(T_g - T_o)} = 1 - e^{-t_a\sqrt{V_g}/RTI}$$

$$e^{-t_a\sqrt{V_g}/RTI} = 1 - \frac{T_a - T_o}{T_g - T_o}$$

$$e^{-t_a\sqrt{V_g}/RTI} = \frac{T_g - T_a}{T_g - T_o}$$

$$-t_a = \frac{RTI}{\sqrt{V_g}}\ln\left(\frac{T_g - T_a}{T_g - T_o}\right)$$

(7) A straight line can be obtained by plotting t_a Vs x:

$$t_a = RTI\left[\frac{1}{\sqrt{V_g}}\ln\left(\frac{T_g - T_o}{T_g - T_a}\right)\right] \tag{A9}$$

$\downarrow$ y, $\downarrow$ slope, $\downarrow$ x

The slope is RTI.