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

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(Received 17 August 2006; Accepted 15 November 2006)

ABSTRACT

This is a report on a joint feasibility study with the Fire Services Department on exploring how thermal sensitivity of fusible links can be assessed. Five samples of fusible 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 fusible link samples were loaded under 0.4 kgf. The work-section of the tunnel was set at air temperature of 135°C and air speed of 2.54 ms⁻¹.

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

1. INTRODUCTION

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

There are overseas standards on assessing the thermal sensitivity of fusible 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 fusible links” [2]. The Fire Services Department (FSD) is interested in investigating whether such testing procedure for fusible links can be carried out in Hong Kong.

A joint feasibility study project of testing the thermal sensitivity of fusible 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 fusible links in Hong Kong by following this standard as a wind tunnel can be developed easily. Five samples of fusible 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.
A schematic diagram of the wind tunnel is shown in Fig. 2.

Each fusible 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 135°C, and air speed to 2.54 m/s.

Five samples of fusible 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 fusible 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 fusible 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 fusible 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 m/s.

![Diagram of the wind tunnel](image1.png)

(a) Diagram

![Picture of the wind tunnel](image2.png)

(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
Table 1: Test results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Testing Date</th>
<th>Orientation with Air</th>
<th>Tg/°C</th>
<th>Tf/°C</th>
<th>Vg/ms⁻¹</th>
<th>Activating Time t/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 January 2006</td>
<td>Along</td>
<td>135</td>
<td>17.1</td>
<td>2.54</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>25 January 2006</td>
<td>Along</td>
<td>135</td>
<td>15.8</td>
<td>2.54</td>
<td>73</td>
</tr>
<tr>
<td>3</td>
<td>25 January 2006</td>
<td>Perpendicular</td>
<td>135</td>
<td>15.8</td>
<td>2.54</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>25 January 2006</td>
<td>Along</td>
<td>135</td>
<td>15.8</td>
<td>2.54</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>25 January 2006</td>
<td>Along</td>
<td>135</td>
<td>15.8</td>
<td>2.54</td>
<td>38</td>
</tr>
</tbody>
</table>

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:

$$M_s C_s \frac{dT}{dt} = h_s A_s (T_g - T)$$

Rearranging:

$$\frac{dT}{(T_g - T)} = \frac{h_s A_s}{M_s C_s} dt$$

This can be rewritten in terms of a time constant $\tau$:

$$\tau = \frac{h_s A_s}{M_s C_s}$$
Solving it would give the activation time \( t_a \), when heated up to \( T_a \):

\[
\int_{t_a}^{T_a} \frac{d(T - T_s)}{T_s - T} = \int_0^{t_a} \frac{dt}{\tau}
\]  
(4)

or

\[
(T_a - T_s) = (T_s - T_a) \left(1 - e^{-\frac{t_a}{\tau}}\right)
\]  
(5)

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

\[
RTI = \tau \sqrt{h_s}
\]  
(6)

In this way, RTI is a property of the thermal sensing element only. \( T_s \) is then given by:

\[
(T_s - T_a) = (T_s - T_e) \left(1 - e^{-\frac{t_a}{\tau}}\right)
\]  
(7)

This can be arranged as:

\[
t_a = RTI \left[\frac{1}{\sqrt{h_s}} \ln \left(\frac{T_s - T_a}{T_s - T_e}\right)\right]
\]  
(8)

Let

\[
x = \frac{1}{\sqrt{h_s}} \ln \left(\frac{T_s - T_a}{T_s - T_e}\right)
\]  
(9)

This gives:

\[
t_a = RTI \cdot x
\]  
(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:

\[
t_a = 117.4 \cdot x
\]  
(11)

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

5. CONCLUSIONS

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

REFERENCES


APPENDIX A: HEAT BALANCE EQUATION

(1) The heat balance equation is:

\[
M_s C_s \frac{d(T - T_s)}{dt} = h_s A_s (T_s - T)
\]  
(A1)

Defining \( \tau \):
\[ \tau = \frac{M C_p}{h A} \quad \text{(A2)} \]

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

\[ \int_{t_a}^{t} \frac{d(T - T_e)}{(T - T)} = \int_{0}^{t_a} \frac{dt}{\tau} \quad \text{(A3)} \]

(2) Dimension of \(\tau\):

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

(3) Integrating LHS of equation (A3):

Let

\[ T_e - T = 0 \quad \text{(A4)} \]

\[-dT = d0 \]

\[ \int \frac{d(T - T_e)}{(T - T)} = \int \frac{dT}{0} = -\ln\theta + C \]

\[ = -\ln(T_e - T) + C \]

\[ \int_{t_a}^{t} \frac{d(T - T_e)}{(T - T)} = \left[ -\ln(T_e - T) + C \right]_{t_a}^{t} \]

\[ = -\left[ \ln(T_e - T_a) - \ln(T_e - T_o) \right] \]

\[ = -\ln\left( \frac{T_e - T_a}{T_e - T_o} \right) \]

(4) Integrating RHS of equation (A3):

\[ \int_{0}^{t_a} \frac{dt}{\tau} = \frac{t_a}{\tau} \]

(5) LHS = RHS:

\[ -\ln\left( \frac{T_e - T_a}{T_e - T_o} \right) = \frac{t_a}{\tau} \]

\[ \ln\left( \frac{T_e - T_a}{T_e - T_o} \right) = -\frac{t_a}{\tau} \]

\[ \frac{T_e - T_a}{T_e - T_o} = e^{-\frac{t_a}{\tau}} \quad \text{(A5)} \]

Rearranging:

\[ T_e - T_s = (T_e - T_o) e^{-\frac{t_a}{\tau}} \]

\[ -T_s = -T_e + (T_e - T_o) e^{-\frac{t_a}{\tau}} \]

\[ T_s = T_e - (T_e - T_o) e^{-\frac{t_a}{\tau}} \]

\[ T_s - T_o = (T_e - T_o) - (T_e - T_o) e^{-\frac{t_a}{\tau}} \]

\[ (T_s - T_o) = \left( T_e - T_o \right) [1 - e^{-\frac{t_a}{\tau}}] \quad \text{(A6)} \]

\[ \text{RTI} = \tau \sqrt{V_e} \quad \text{(A7)} \]

\[ (T_s - T_o) = \left( T_e - T_o \right) [1 - e^{-\frac{\text{RTI}}{\sqrt{V_e}}}] \quad \text{(A8)} \]

(6) Rearranging:

\[ \frac{(T_s - T_o)}{(T_e - T_o)} = 1 - e^{-\frac{\text{RTI}}{\sqrt{V_e}}} \]

\[ e^{-\frac{\text{RTI}}{\sqrt{V_e}}} = 1 - \frac{T_s - T_o}{T_e - T_o} \]

\[ e^{-\frac{\text{RTI}}{\sqrt{V_e}}} = \frac{T_e - T_s}{T_e - T_o} \]

\[ -t_a = \frac{\text{RTI}}{\sqrt{V_e}} \ln\left( \frac{T_e - T_s}{T_e - T_o} \right) \]

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

\[ t_a = \text{RTI} \left[ \frac{1}{\sqrt{V_e}} \ln\left( \frac{T_e - T_s}{T_e - T_o} \right) \right] \quad \text{(A9)} \]

\[ \downarrow \quad \downarrow \quad \downarrow \]

\[ y \quad \text{slope} \quad x \]

The slope is RTI.