NECESSITY OF TESTING FURNITURE MATERIALS WITH A CONE CALORIMETER

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ABSTRACT

It is proposed and demonstrated in this paper that fire-safe furniture must be developed with appropriate tests. A cone calorimeter should be the minimum requirement, though some full-scale burning tests are necessary. The component materials of a typical furniture foam sofa commonly used in Hong Kong were selected for assessing the fire behaviour with a cone calorimeter. A high radiative heat flux of 50 kWm^{-2} was used to consume all materials in the tests. The sustained ignition time, peak heat release rate, average heat release rates in 60 s and 180 s after ignition, total heat release rate, mass loss percentage, total smoke release, carbon monoxide and carbon dioxide yields of the component materials in the arrangement, were measured. These data can be applied for assessing the possibility to flashover and making recommendations on what should be considered in selecting furniture. Further, the importance of protecting the foam by fabric and cotton covering; and treating the foam with fire retardant should be considered. Results are useful for the Authority to set up regulations on fire-safe furniture.

1. INTRODUCTION

Big accidental fires due to burning furniture or cushion foam had raised public concern on using fire-safe furniture in Hong Kong since 1997 [e.g. 1]. This is important for public entertainment places like those karaokes with partition walls made of timber product [2,3]. The heat release rates of burning furniture and their contributions to a compartment fire at the preflashover stage should be clearly understood [e.g. 4,5]. As reviewed recently on furniture fires [e.g. 6], heat released from a burning foam might be strong enough to ignite adjacent items which are not easy to ignite accidentally by electric sparks or cigarettes. In fact, the government has set up some regulations to specify 'fire-safe' furniture [e.g. 7,8] by following overseas practices [9,10]. But without knowing the fire behaviour of common furniture and their constituting materials, it is difficult to convince the citizens that such regulations can really give fire-safe furniture. Now, regulations might not be passed by the Legislative Council so easily as before, especially there are cost implications. The recent Karaoke Establishments Bill [11] is an obvious example and there are numerous concerns [3]. Full-scale burning tests must be carried out to support the argument. An experimental rig, known as the PolyU/HEU Assembly Calorimeter [12], is now developed in China as a collaboration project between The Hong Kong Polytechnic University (PolyU) and Harbin Engineering University (HEU).

There have been extensive studies on upholstered furniture over the past years [e.g. 13-19]. One of the recent biggest projects is perhaps the project on Combustion Behaviour of Upholstered Furniture (CBUF) in Europe [17-19]. Upholstered furniture is quite complicated with several fuel elements including cover fabric, seat cushion material and the padding. How these would burn depends [20] on the material composition, thickness and density.

As reported in the literature, results measured from a cone calorimeter [e.g. 4,13,21,22] would be useful in understanding the fire behaviour, both heat and smoke aspect, of the materials including sandwich panel [23]. Results from cone calorimeter should be taken as a 'yardstick' for assessing whether the furniture is safe in a fire, in complementary with full-scale burning tests. Therefore, local furniture materials should be tested at least, by a cone calorimeter [e.g. 4,13,22,24]. A ranking system [21,25] should be worked out for 'grading' the materials concerned. Reporting how to get cone calorimeter results becomes the objective of this paper.

Materials for a typical local furniture foam sofa arrangement were selected to demonstrate how a cone calorimeter can be used for assessing the fire behaviour. The heat release rate Q(t) (in kWm^{-2}), smoke release rate S_R (in s^{-1}), carbon monoxide (CO) and carbon dioxide (CO_2) generated under an incident heat flux of 50 kWm^{-2} of the component materials and the furniture arrangement were measured. Using such a high heat flux could ensure that all the materials would be burnt out. Eleven parameters [e.g. 4,13,21,22] commonly deduced from cone calorimeter results were calculated. Finally, the smoke aspect [22] was also analysed.

2. KEY PARAMETERS MEASURED IN A CONE CALORIMETER

Transient heat release rate per unit area Q(t), CO concentration, CO_2 concentration, smoke release rate, mass loss rate of the samples, and smoke extinction area curves of the component materials and the furniture arrangement for typical foam sofa were measured under a radiation heat flux of 50 kWm^2.

In addition, eleven parameters were studied [25] for assessing the materials:

- Time to ignition, TTI (in s)
- Peak heat release rate, pk RHR (in kWm^{-2})
- Time to pk RHR after ignition, t_{fp} (in s)
- Average heat release rate in 60 s after ignition, $\overline{Q}_{60}$ (in kWm^{-2}), given by:

$$\overline{Q}_{60} = \frac{1}{60}\int_{TTI}^{TTI+60} Q(t)dt \qquad (1)$$

- Average heat release rate in 180 s after ignition, $\overline{Q}_{180}$ (in kWm^{-2}), given by:

$$\overline{Q}_{180} = \frac{1}{180}\int_{TTI}^{TTI+180} Q(t)dt \qquad (2)$$

- Total heat released, THR (in MJm^{-2}), calculated from:

$$THR = \int_{0}^{\infty} Q(t)dt \qquad (3)$$

- Mass loss percentage of sample, m_L (in %)
- Average effective heat of combustion, ΔH_c^{av} (in $MJkg^{-1}$)
- Total smoke released at the end of the test, TSR (a non-dimensional quantity), calculated by integrating the curve of rate of smoke release S_R (in s^{-1}) over time:

$$TSR = \int_{t=0}^{t_\infty} S_R\, dt \qquad (4)$$

- CO yield (in $kgkg^{-1}$): the mass of CO produced relative to the mass loss rate of the specimen
- CO_2 yield (in $kgkg^{-1}$): the mass of CO_2 produced relative to the mass loss rate of the specimen

Smoke extinction area SEA (in kgm^{-2}) is a basic measurement on smoke with value computed from the optical density on a fuel-mass-loss basis [e.g. 4]:

$$SEA = \varepsilon \left(\frac{k}{C}\right) \qquad (5)$$

where ε is the smoke yield, i.e. the fraction of fuel mass loss converted to soot; C is the mass concentration of smoke particles (in kgm^{-3}); and k is the light extinction coefficient (in m^{-1}) given by:

$$k = \frac{1}{L}\log_e\left(\frac{I_0}{I}\right) \qquad (6)$$

Attenuation of light (reducing incident intensity from I_0 to I) by soot particles is proportional to the projection area (in m^2) of particles blocking the distance L (in m) between the light source and the receiver. SEA is a measure of this value normalized by the fuel mass. This characterizes the 'smokiness' of fuel per unit mass of fuel burnt.

3. TESTS ON LOCAL FURNITURE MATERIALS

A typical furniture foam arrangement commonly used in the local furniture industry was selected for safety evaluation. This sample was constructed of two pieces of fabric of thickness 1 mm with cotton of thickness 20 mm at the two surfaces, and two pieces of foam of thickness 25 mm glued together as in Fig. 1a.

There were six sets of testing combination of the component materials as shown in Figs. 1a to e:

- T1: The furniture arrangement.
- T2: Fabric only.
- T3: Cotton only.
- T4: Foam only.
- T5: Fabric, cotton and foam; with the fabric size exposed to heat.

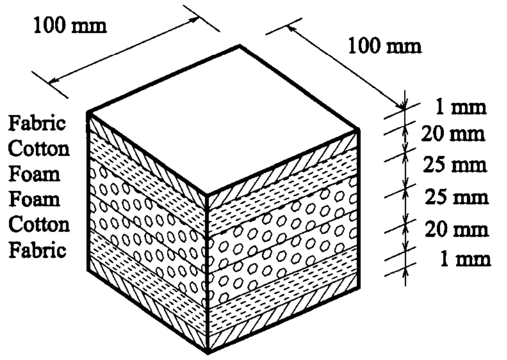
A cone calorimeter was used to measure the heat release rate curve, the CO and CO_2 concentration curves, the S_R curve and the SEA curve under an incident radiative heat flux of 50 kWm^{-2}. Results on averaged heat release rate per unit area Q(t) (in kWm^{-2}), CO (in ppm of dry air), CO_2 (in % of dry air), mass lost of the testing samples (in g), S_R (in s^{-1}) and SEA (in m^2kg^{-1}) for tests T1 to T5 are shown in Figs. 2 to 7.

From those curves, values of the eleven parameters are calculated and shown in Table 1.

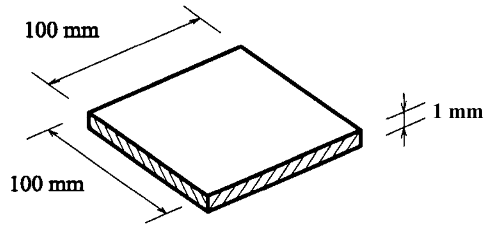
4. THERMAL ANALYSIS

It is observed that under this high radiative heat flux of 50 kWm^{-2}, i.e. much higher than the flashover heat flux of 20 kWm^{-2}, all samples were ignited within 3 s. Note that pk RHR of T4 was the highest among the five tests. This is a good demonstration that exposing foam to high heat flux without adequate covering would be very dangerous. An alternative approach is to treat the foam with fire retardants.

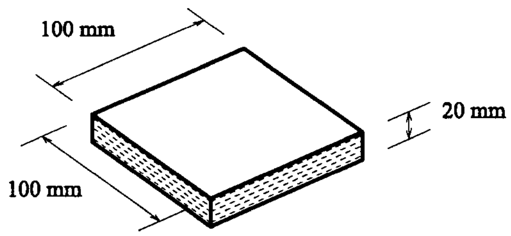
As discussed by Petrella [21], two parameters, the ratio of pk RHR to TTI (in $kWm^{-2}s^{-1}$) and THR are useful to assess the contribution of materials to flashover. That was discussed for assessing local furniture materials in detail elsewhere [25]. From that analysis [25], materials arranged as T1 to T5 are ranked as having high contribution to flashover.



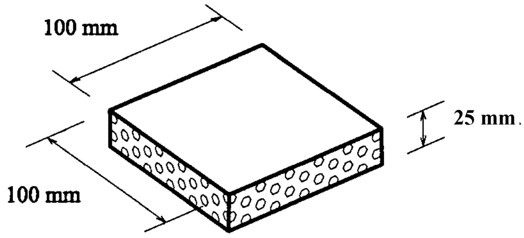
(a) T1: Furniture arrangement



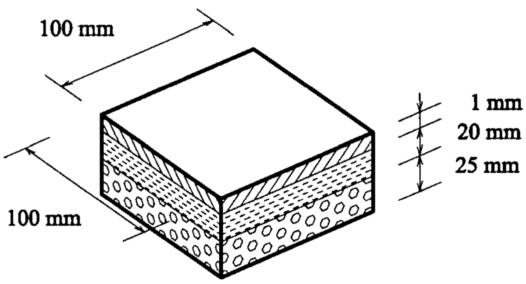
(b) T2: Fabric only



(c) T3: Cotton only



(d) T4: Foam only



(e) T5: Fabric, cotton and foam

Fig. 1: Geometry of the testing samples

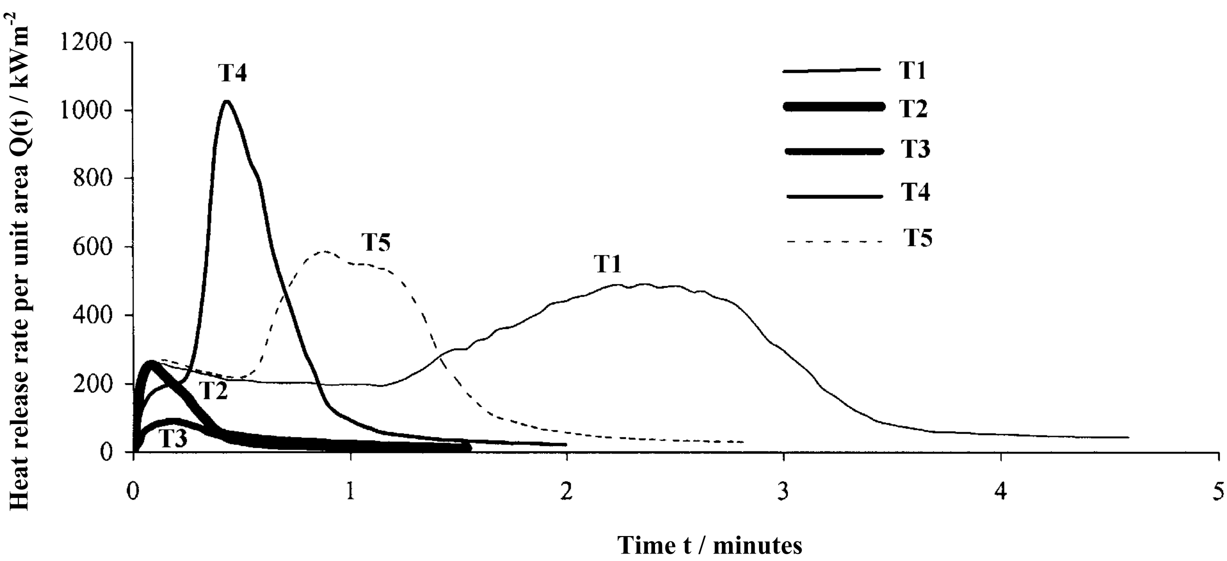


Fig. 2: Heat release rate curves

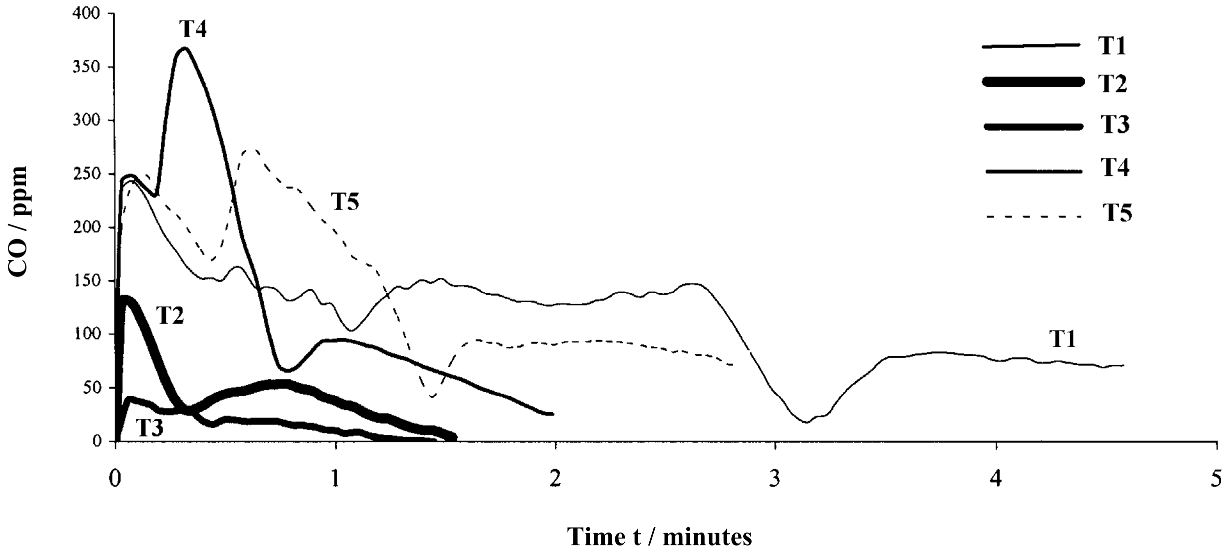


Fig. 3: Carbon monoxide concentration

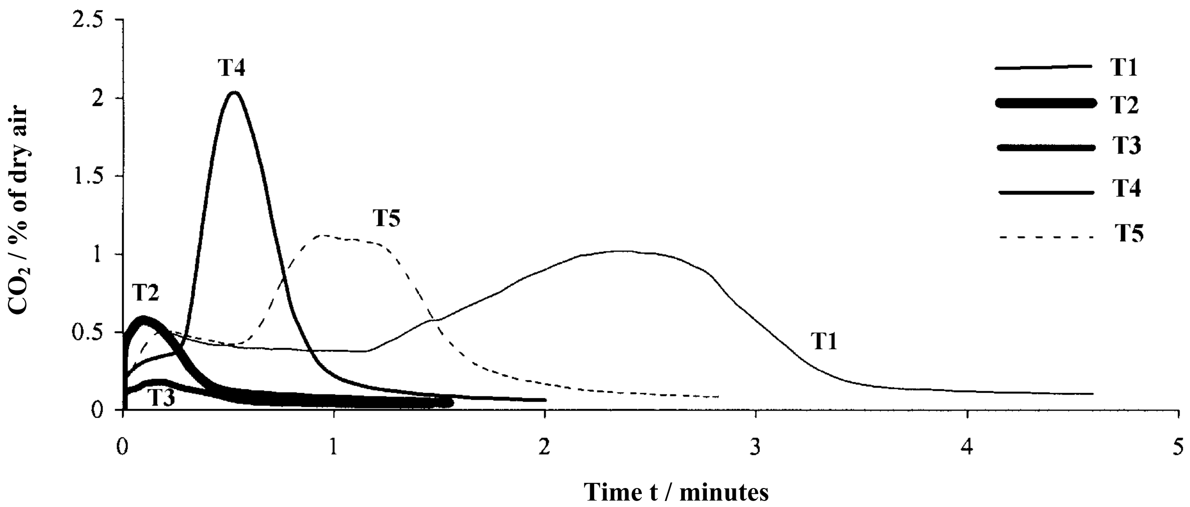


Fig. 4: Carbon dioxide concentration

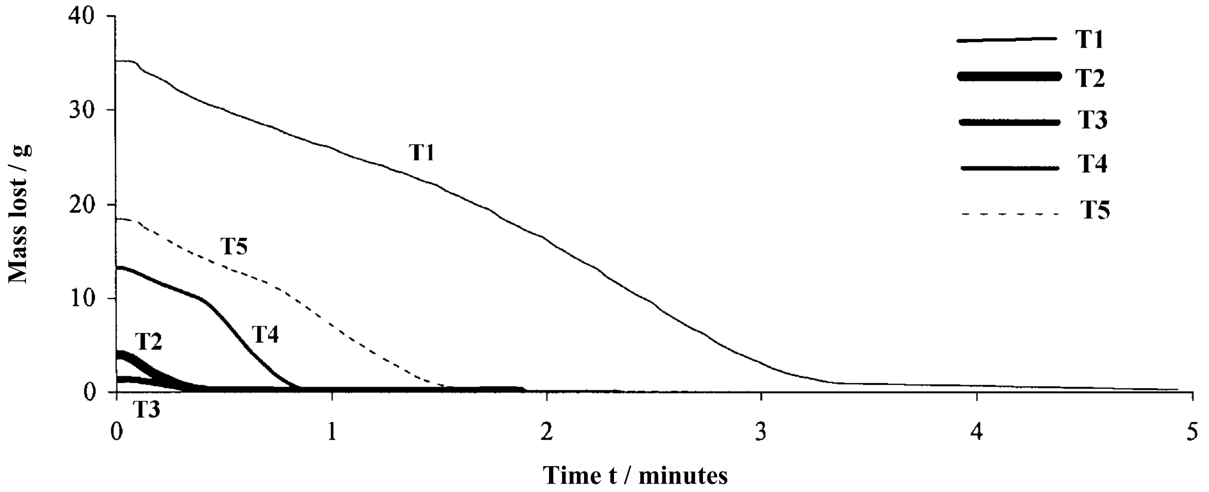


Fig. 5: Mass lost of testing samples

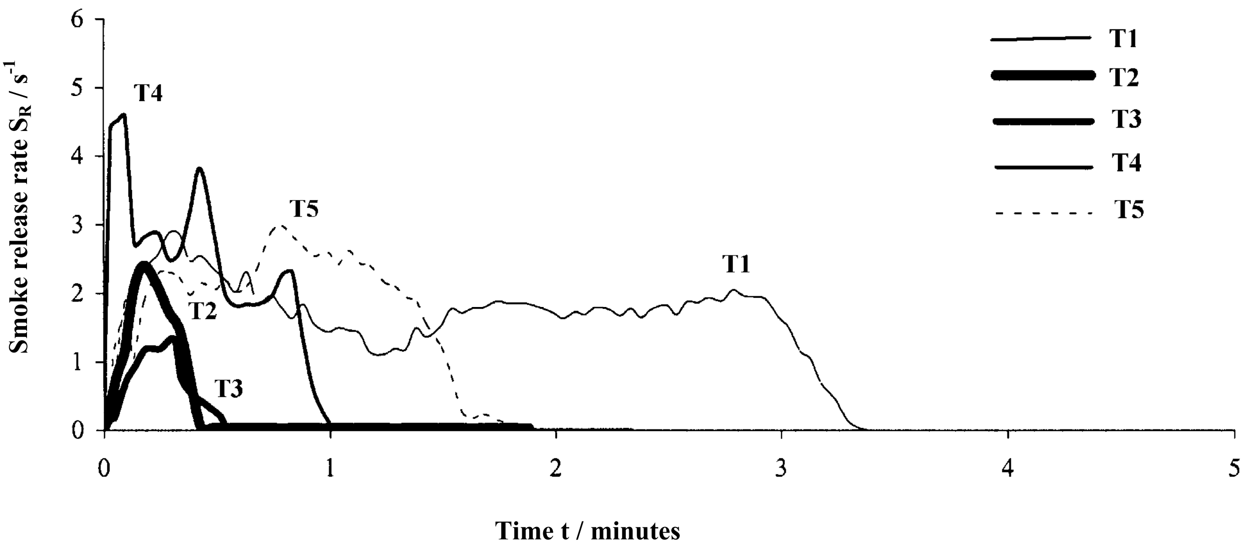


Fig. 6: Smoke release rate

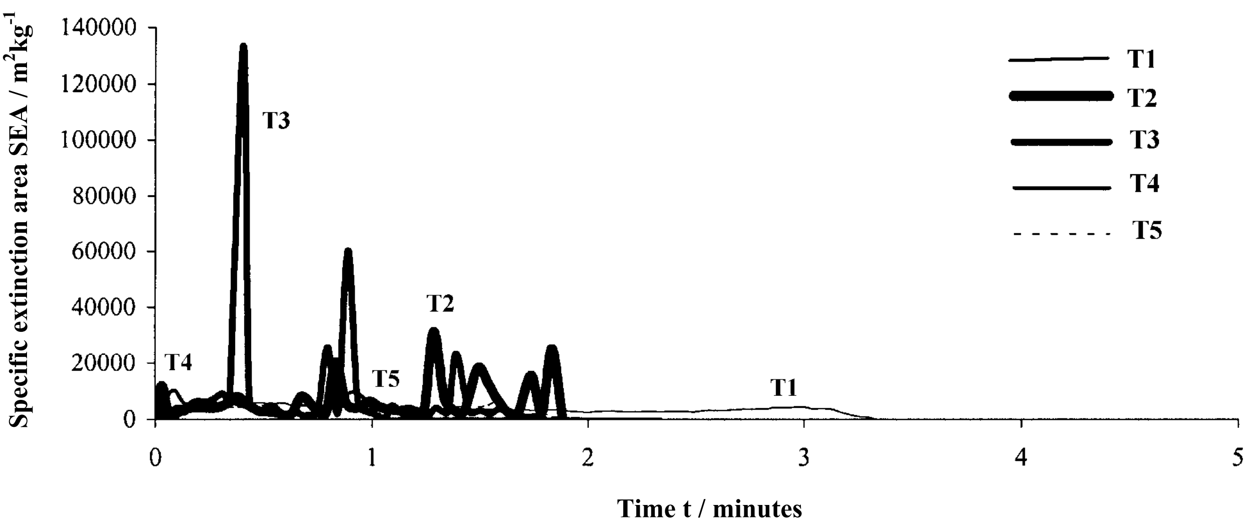


Fig. 7: Specific extinction area

Table 1: Test results

	Parameters	T1			T2			T3			T4			T5		
		Test 1	Test 2	Mean value	Test 1	Test 2	Mean value	Test 1	Test 2	Mean value	Test 1	Test 2	Mean value	Test 1	Test 2	Mean value
Derived data	TTI /s	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	pk RHR $/kWm^{-2}$	292	226	259	299	209	254	110	83	93	1092	959	1025	280	571	426
	Q_{60} $/kWm^{-2}$	241	192	217	100	83	92	41	37	39	425	385	405	360	337	348
	THR $/MJm^{-2}$	71.3	61.6	66.5	6.04	5.55	5.8	2.68	2.7	2.7	29.7	27.1	28.4	38.9	38	38.5
	m_L /%	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	ΔH_c $/MJkg^{-1}$	20.3	17.4	18.9	14.9	14.4	14.7	20.1	19.2	19.7	22.6	20.5	21.6	11.1	20.7	15.9
	TSR	386	294	340	47	32	39	37	13	25	170	113	142	235	162	199
	CO yield $/kgkg^{-1}$	4.2	2.1	3.2	3.5	6.5	5.0	6.3	0.6	3.5	16.5	9.5	13.0	4.7	9.2	7.0
	CO_2 yield $/kgkg^{-1}$	122	100	111	90	199	145	174	48	110	136	352	244	73	355	214
Smoke	Peak [CO] /ppm	279.3	233.5	256.4	144.2	116.2	130.2	60.3	44.7	52.5	399.8	334.1	366.9	268.5	277.6	273.1
	$FED = \frac{[CO]}{5000}$	0.056	0.047	0.051	0.029	0.023	0.026	0.012	0.009	0.011	0.080	0.067	0.074	0.054	0.056	0.055

5. SMOKE ASPECT

Concerning smoke, it is observed from Table 1 that the mean yields of CO emitted varied from 3.2 to 13 kg per kg of sample burnt under different arrangements T1 to T5. The mean yields of CO_2 varied from 110 to 214 kg per kg of sample. Again, both CO yield and CO_2 yield were observed to be the highest in T4, taking values up to 13 $kgkg^{-1}$ and 244 $kgkg^{-1}$ respectively.

Since only CO and CO_2 were measured, the peak Fractional Effective Dose (FED) [20,22] was calculated from the peak concentration of CO and CO_2 denoted by [CO] and [CO_2] and their toxic potency LC_{50} denoted by LC_{CO} and LC_{CO_2} :

$$FED = \frac{[CO]}{LC_{CO}} + \frac{[CO_2]}{LC_{CO_2}} \qquad (7)$$

Since LC_{CO_2} is very large, following Babrauskas [23], FED is given by taking LC_{CO} to be 5000 ppm:

$$FED = \frac{[CO]}{5000} \qquad (8)$$

Values of FED for arrangements T1 to T5 are shown in Table 1.

6. CONCLUSION

In this paper, fire aspects of typical samples for local furniture materials were assessed by a cone calorimeter. Note that T4 was on testing the sample by exposing the foam to high heat flux without covering protection by fabric and cotton arrangement. High peak heat release rate was reached within a short time, say less than 0.5 minutes after ignition, as shown in Fig. 2. But covering the foam (as in tests T1 and T5) with appropriate fabric or cotton would reduce the peak heat release rate and delay the time to attain the value. Therefore, exposing the furniture foam without covering to heat flux is dangerous. Fire retardants should be used to give fire-safe foam. This point must be considered carefully by the government in setting up regulations on fire-safe furniture [7,8].

Parameters deduced from the cone calorimeter might be useful for helping the Authority to set up regulations for assessing the propensity to flashover and total heat release rate. Arbitrary scale as proposed by Petrella [21] and discussed for local use [24] would be a good starting point to design full-scale burning tests to support the regulations.

There are many studies on fire behaviour of furniture, especially on the heat release rates. Those work should be reviewed before agreeing on what are 'fire-safe' furniture. Existing experience such as the CBUF project [17-19] should be referred to. It is difficult to convince the Legislative Council by specifying guidelines [e.g. 7,8] from some overseas practices [e.g. 9,10] without support from in-depth studies on local materials and living style of citizens. Results on the full-scale tests, particularly the furniture calorimeter [e.g. 4], should be included, together with cone calorimeter results as in above, in the local regulations. A database on fire behaviour for local materials should be developed by carrying out similar types of full-scale burning tests as in the CBUF project [17-19]. Correlation relations with the bench-scale tests should then be derived [e.g. 26,27], so that the cost for assessing new products would not be too high.

As reported in the CBUF project [17-19], modelling the heat release rate of furniture based on the burning area-convolution technique through the heat release rate per unit area of the composite samples in a furniture measured by a cone calorimeter is a good choice. This will be studied in detail with the PolyU/HEU Assembly Calorimeter [12] and the results will be reported later once available.

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