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OBSERVATION ON THE TWO RECENT BUS FIRES AND PRELIMINARY RECOMMENDATIONS TO PROVIDE FIRE SAFETY

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ABSTRACT

Consequent to two recent fires in double-deck buses which burnt away almost everything within 10 minutes, some citizens in Hong Kong are now questioning whether they are safe while travelling on a bus. Key points for consideration on providing fire safety in local buses are discussed. Possibilities of flashover will be analyzed with reference to materials fire safety. By using tested results on a sandwich panel sample commonly used in the construction industry with a cone calorimeter, how incident thermal radiation heat flux would affect the fire behaviour of the materials will be studied. It is recommended that tests on those sandwich panels with or without fire retardants treatment under higher external heat fluxes, say at least 20 kWm^{-2} for a flashover fire, should be developed to understand how the materials would behave in a fire. Before such tests are agreed by the interested parties, immediate actions to take on fire safety management are recommended.

1. INTRODUCTION

Consequent to two big bus fires happened recently [e.g. 1,2], people in Hong Kong are wondering about whether they are safe while travelling on a bus. It was reported that only part of the bus envelope wall and the engine chassis were left after the fire had started in a double-deck bus in just 10 minutes [e.g. 2]! Fire safety for buses should be understood more and being pointed out in this short article.

The percentage by weight of plastics for modern vehicles had been increased up to 13% by weight for private cars as reviewed in 1994 [3]. Modern buses also used quite a lot of composite materials with adhesive resins. To provide proper fire safety protection to a bus, those combustible items must be selected carefully. Upon ignition of combustible materials by accident such as electrical fault, a bus fire is similar to a compartment fire which happens at least in three stages: the growth stage; the development stage upon transition to flashover; and the decay stage. Air-conditioned buses are of enclosed structure, smoke generated would fill up the space quickly as reported earlier which is another point of concern to be addressed separately. Those bus envelopes are made of thermal insulation materials such as glass fibre reinforced plastics. The organic resins can be over 50% by weight eventhough the surface of the panel might be metallic. The overall heat transfer coefficient [4] of those modern bus envelopes during a fire will be much lower than those values for traditional buses with sheet metal, giving easier conditions to flashover. There should be higher expectation on fire resistance requirement of the bus wall, especially on satisfying the stability and integrity criteria.

Fire safety in double-deck bus had been reported in the literature [5-9] as such a bus fire started from the engine at the rear happened two years ago [e.g. 10]. Desired fire protection goals [11] for a bus had been outlined and the following were discussed [5-9]:

- Fire safety materials.
- Bus fire scenarios.
- Smoke filling in the bus compartment.
- Brief review on the heat release rate of a burning bus.

As there were no other bus fires since then [e.g. 10], nobody was interested in that incident anymore. However, two big bus fires happened recently within 2 months [1,2] and more citizens are now questioning about bus fires. The objective of this paper is to clarify several points as raised by the media [2].

2. COMBUSTIBLES FOR BUS

Apart from the fuel and its associated system, combustible items are envelope as lining materials, seating materials and materials for air ducts for air-conditioned buses and plastics components of the vehicle. The amount of combustibles and their orientations are important in affecting how the materials would be burnt. That is why some fire tests are specified on testing not only the materials, but also their assemblies. Flammability, smoke emission and toxicity of those materials are the key factors to be evaluated. For example, tests commonly referred to in America [12,13] are on flame spread – ASTM E162 or ASTM D3675; smoke density chamber – ASTM E662; floor covering – ASTM E648; fire endurance test – ASTM E119; and bench-scale 'Bunsen burner' tests – FAR-25.853. Only those plastic materials with suitable fire retardants (FRs) [14] to give low smoke and toxic gas emission rates are allowed to be used in some countries, based on some specified tests on the FRs themselves [15].

However, as reported by Peacock et al. [12,13] on studying fire protection for passenger rail transportation vehicles, the random ability of current bench-scale material tests to predict actual fire behaviour was pointed out. The same conclusion should be drawn for fire protection in buses. A multi-faceted fire safety approach to include the vehicle design, material selection, detection and suppression systems and emergency egress is proposed. As described in there [12,13], the heat release rate of the fire must be understood.

It is proposed that the bus envelope materials should be tested, at least, by using the 'cone calorimeter' [16,17] under different radiation heat fluxes. This is a bench-scale test giving the time to ignition; heat release rate; mass loss rate of the tested sample; concentration of carbon monoxide, carbon dioxide and soot; and optical smoke density. Further support by full-scale burning tests such as the SP Industry Calorimeter [e.g. 18] of the Swedish National Research Laboratory, Sweden; the Large Exhaust Hood [19] at the Building and Fire Research Laboratory, National Institute of Standards and Technology, USA; and the PolyU/HEU Assembly Calorimeter [20] of The Hong Kong Polytechnic University (PolyU) and Harbin Engineering University (HEU), is necessary.

3. COMPARISON OF BUS ENVELOPE MATERIALS

A heat balance equation [e.g. 21,22] for bus fires can be set up to understand flashover by considering the heat gain due to the fire Q_f (in W); heat lost through the bus envelope Q_L (in W); and the heat carried out of the enclosure by air and smoke determined by the flowing rate m_g (in kgs^{-1}), temperature rise in the bus compartment ΔT (in °C) and the specific heat capacity of air and smoke C_p:

$$m_g C_p \Delta T = Q_f - Q_L \quad (1)$$

From the heat balance equation, different bus wall materials had been analyzed theoretically. As a summary, the heat release of a fire Q_f depends on the ventilation factor and the heat lost Q_L depends on the overall heat transfer coefficient, which in turn depends on the material properties. Possibility to flashover can be judged by comparing the heat lost of different materials. The following materials of thickness 1 cm and 0.5 cm with physical properties ρ_w, C_w and k_w listed in Table 1 were tested before [7]:

- Glass panels
- Steel
- Glass fibres with organic bonds

Values of Q_L and ΔT for 3.18 MW fire (typical in a furniture fire) are also shown in Table 1. Key points observed are:

- Steel is a good thermal conductor and so most of the heat generated by the fire lost rapidly through the walls.
- Glass fibres with organic bonds have very low heat lost, giving higher chance to flashover.
- Glass materials with better thermal insulation are used for energy conservation in air-conditioned buses. However, this would keep the heat generated from a fire, and flashover would occur easily.

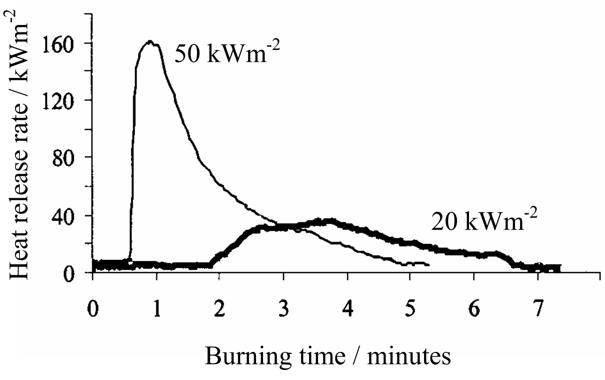
Table 1: Properties of common bus envelope materials

Materials	Thermal conductivity $k_w/Wm^{-1}K^{-1}$	Density ρ_w/kgm^{-3}	Specific heat capacity $c_w/Jkg^{-1}K^{-1}$	Q_L/MW		ΔT/°C	
				0.5 cm thick	1 cm thick	0.5 cm thick	1 cm thick
Glass	1.2	2500	750	2.61	2.22	270	450
Steel	48	7854	559	3.16	3.15	10	20
Glass fibres with organic bonds	0.038	32	835	0.39	0.21	1300	1390

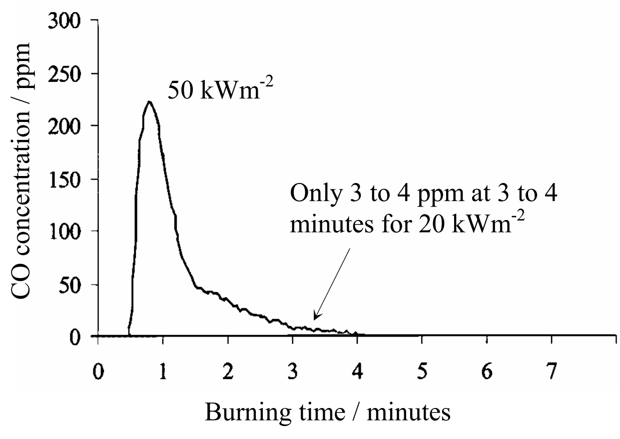
4. SANDWICH PANELS TESTED BY CONE CALORIMETER

The envelope of the bus burnt previously was reported to be made of sandwich panels [2] with metallic surface treated with FRs coating. Since no sample was provided, it is difficult to judge the fire behaviour of those panels. However, similar type of sandwich panel made of polyurethane (PU) foam commonly used for constructing temporary accommodation units had been evaluated [23] as in literature [e.g. 24,25]. The panel is constructed of colourful galvanized steel sheets with PU hard foam to give good thermal insulating properties. Samples were tested by a cone calorimeter [16,17] to assess its fire behaviour under incident radiative heat fluxes for flashover of 20 kWm^{-2} and another high value at 50 kWm^{-2}.

The sandwich panel was cut into samples of surface area 10 cm by 10 cm, and thickness 50 mm. One of the metal surfaces was exposed to thermal radiation in the test. The edge of the panel, i.e. the PU foam, was exposed to outside air without insulation. The time to ignition, TTI (in s), transient heat release rate, carbon monoxide CO concentration and others [15] were measured.



(a) Heat release rate per unit area



(b) CO concentration

Fig. 1: Cone calorimeter tests on samples

The results on the heat release rate and CO concentration at 20 kWm^{-2} and 50 kWm^{-2} are shown in Figs. 1a and 1b respectively. For flashover heat flux of 20 kWm^{-2}, the sample was ignited at 126 s after starting the experiment with less than 7% of the materials burnt. The maximum CO concentration was only 3 to 4 ppm found in 3 to 4 minutes.

But for higher radiative heat flux at 50 kWm^{-2}, the sample was ignited within a much shorter time at 43 s after starting the experiment. Burning area grew up at the edge of the sample where PU foam was exposed to outside air. The first peak heat release rate of 161 kWm^{-2} was found rapidly at 13 s after ignition. The sample kept on burning up to 650 s.

It is observed that the incident radiative heat flux on the surface of sample is a key factor in assessing the fire behaviour of materials using a bench-scale test. For those materials treated with FRs [14], similar tests should be carried out to understand whether the FRs can give adequate protection.

5. TIME TO FLASHOVER

Cone calorimeter data following ISO 5660 [17] are found to be correlated with the time to flashover t_{fo} (in s) in the ISO 9705 [26] full-scale standard room fire test. t_{fo} can be expressed in terms of time to ignition at 50 kWm^{-2}, TTI_{50} (in s); total heat release in 300 s after ignition, THR_{300} (in MJm^{-2}) at heat flux of 50 kWm^{-2}; and mean density of the sample ρ (in kgm^{-3}) by the following regression equation due to Östman and Tsantaridis [27]:

$$t_{fo} = 0.07 \frac{TTI_{50}^{0.25} \rho^{1.7}}{THR_{300}^{1.3}} + 60 \qquad (1)$$

Value of THR_{300} was found to be 14.6 MJm^{-2}, density for the entire sandwich panel was found to be 194 kgm^{-3}, density for the foam was 36 kgm^{-2}, and TTI_{50} was 43 s. Taking the density of the sample to be that of the foam, putting in numerical figures gave t_{fo} to be 62.4 s.

Result indicated that radiation heat fluxes higher than 20 kWm^{-2} would be found at about 1 minute after starting a fire at the floor level in an ISO 9705 room [26] constructed of sandwich panels tested in a cone calorimeter. Most of the combustibles would be ignited to give even higher heat fluxes, igniting the sandwich panels. If the bus wall is made of sandwich panels of similar fire behaviour, that would explain why almost the whole bus was burnt out within 10 minutes in those two incidents. That was because flashover occurred at about 1 minute after starting the fire. Higher radiation heat fluxes would be emitted by igniting other combustibles. The envelope materials would then be burnt out rapidly, if the applied FRs coating could not stand such high thermal radiation.

6. RECOMMENDATION

From the above, testing the bus envelope materials with a cone calorimeter is essential to understand their behaviour in a fire. Note that the test is only a bench-scale test which should be easy to develop. Testing under radiation heat flux at flashover of 20 kWm^{-2} and higher value, say at 50 kWm^{-2}, would give a true reflection on how the materials would burn in a fire. Results will also be correlated with the time to flashover in a compartment with those materials as demonstrated in above. FRs verified by suitable tests under local conditions should be applied over the bus wall. Most importantly, sandwich panel materials with and without FRs must be tested as follows:

- Full-scale burning tests on selected seating arrangements on the furniture itself with a ‘furniture calorimeter’ [16].
- Burning a bus to understand the actual fire behaviour including the integrity of the structure and the possible heat release rate [28-30]. Results will also be important in determining the design fire while studying the fire safety provisions for tunnels [e.g. 31] and public transport interchanges.

7. CONCLUSION

There are many passengers during rush hours inside the small space volume of a bus. From the three incidents [1,2,10] of bus fires, it is obvious that active fire protection installed in a double-deck bus can be further improved so that the bus would not be burnt out completely within a short time. Water mist fire suppression system and clean agent gas protection system might be good choices. Smoke management system should be included as demonstrated [6,9] previously. Fire vents such as quick releasing panels activated by heat sensors or manual means can be considered.

Evacuation is another concern [e.g. 28] on life safety. The number of emergency exits provided is important. Care should be taken for double-deck buses where only one stair is provided for access between the two decks. Note that older double-deck buses have openable emergency exits constructed at the rear end. A good fire safety management scheme must be prepared with due consideration on this point. The only staff when the bus is moving is the bus driver, who, must be properly trained to take appropriate actions to evacuate the passengers in time.

Anyway, in-depth investigational works must be carried out on:

- Bus structure and wall materials with and without FRs.
- Active fire protection system.
- Fire management system [e.g. 6].

There are chances to get a much bigger fire due to fuel spillage [32,33] in vehicle crashing accidents. Heat might be released in a much faster rate. The fire resulted from burning liquid fuel together with those solid combustibles as discussed in above must be investigated further. Full-scale burning tests as suggested in above are strongly recommended to assess the consequences of those scenarios.

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