ASSESSING FIRE BEHAVIOUR OF MATERIALS BY STANDARD TESTS

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ABSTRACT

Consequent to so many big building fires in Hong Kong, there are concerns on new materials used. How fire behaviour of materials should be assessed is discussed in this short note. The current tests required in Hong Kong are briefly reviewed. The fire tests desired are then discussed. The importance of testing the materials properly is pointed out.

1. INTRODUCTION

The number of fires due to accidents or whatever causes appears to increase recently. The Garley Building fire was the first terrible one in Hong Kong since 1996 [1]. After that, there were other residential fires due to burning furniture and a big karaoke arson fire. The Garley Building fire, together with the underground railway fire in South Korea [2] might be regarded as the two biggest ones in the Far East from 1996 to 2003.

There are different views [e.g. 3] on those incidents, either on inadequacy of fire safety regulations or improper safety management. Anyway, people are quite worried about building fire safety, especially in those new architectural features such as supertall buildings where evacuation with lift will take at least 30 minutes [4]! The occupant loading in shopping malls, public transport terminals, multi-purpose commercial buildings and even offices can be very high. Observed values can be even higher than the design figures specified in the local codes on means of escape [5]. This suggests that fire safety management should be implemented properly, a separate issue to be reported later.

An accidental fire started from igniting a small heat source might lead to hazardous consequences if the fire safety provisions, both hardware passive building construction or active fire engineering system and software safety management, are not adequate. Further, many new materials such as sandwich panels [e.g. 6-8] are used for thermal and sound insulation partitions. Their fire behaviour should be watched carefully as their central core might be made of cellular plastics such as polyurethane foam. Accidental fires that had burnt up the whole double-deck bus made of sandwich panels are good examples in demonstrating the potential hazard [9]. Everything except the engine chassis in three such fires disappeared within 15 minutes.

Standard tests on assessing the fire behaviour of materials specified by the local government departments [5,10-12] taking care of fire safety were developed years ago. British Standards 476 on test of ignitability [13], non-combustibility [14], surface spread of flame [15] and fire resistance [16,17] are referred to. Apart from some fire resistance tests, the others are on smaller samples of materials with a single component. They are not appropriate for testing materials with several components such as sandwich panels [6-8]. These older tests on materials are for assessing whether the materials can be ignited by a pilot flame without radiation heat flux [13]; whether there is combustion under a small chamber with a certain thermal environment [14]; and flame spreading under a standard furnace [15]. The standard fire tests [16,17] on fire resistance are for assessing stability, integrity and insulation of construction elements. All these are based on thermal aspects, say from the temperature-time curves with wood. As pointed out before [18,19], updated tests and standards should be recommended to assess the fire behaviour of materials. This cannot be achieved without in-depth investigations.

The materials should be tested, at least on whether it is easy to ignite when heat supplied from external sources is higher than the heat lost [20], on the heat release rate [20-22], the amount of smoke and combustion products generated [20,22], smoke toxicity [23] and flame spread [24].

2. FIRE TESTS DESIRED

Updated standard tests for assessing the fire behaviour of materials should be properly reviewed first. Feasibility studies of the tests are then assessed before recommending the suitable ones for use in the codes. However, as pointed out recently [25], combustibility of materials had not yet been studied thoroughly in the Far East. It is obvious that the following areas should be considered and studied in detail:

- Ignition under radiation heat flux
- Heat release rate
- Smoke emission rate
- Smoke toxicity
- Flame spreading
- Acceptance criteria
- Data for fire safety design

The heat release rate of burning materials [21,22] is believed to be the basic element in understanding how big is the fire. This can be assessed by a cone calorimeter under a wider range of heat fluxes [20,22]. Further, full-scale burning test such as the ISO room-corner fire test is recommended for measuring fire spread. The single burning item (SBI) test [26] should also be considered. Experimental studies, both full-scale burning tests and bench-type experiments, should be carried out. Statistical analysis on the measured burning parameters and derivation of correlation relations among them can then be achieved.

3. COMPARTMENT FIRE

When a fire starts in a compartment with walls, floors and ceilings made of materials which are difficult to ignite or even classified as 'non-combustible' following British Standards BS-476 [14], only a small amount of combustibles would be burnt. The initial heat release rate from an accidental fire is small.

A plume would be formed above the burning item. Ambient air would be entrained into the combustion region because of the buoyancy-induced turbulence. Hot smoke would rise until reaching the ceiling to form a radial plume known as the ceiling jet. It would move horizontally and entrain ambient air at the same time, until the motion is bounded by the vertical walls. Air entrainment into the ceiling jet is much less than that into the axisymmetric plume. Rebounding of the smoke front of the ceiling jet several times with the wall might lose the horizontal momentum [27]. A stable stratified hot smoke layer without (or with very little) mixing [28] across the interface would be resulted eventually.

Therefore, three regions are observed in the enclosure at the early stage of the fire, namely a hot upper smoke layer, a cool lower air layer and a plume. The phenomenon is similar to an inverted water sink with the tap turned on to get a water layer, an air layer and water discharged from the tap.

The smoke layer thickness would increase if the fire is allowed to burn. When the hot gas adjacent to the ceiling was heated up to high temperature, say 500 to 600 ^{o}C, strong radiative heat fluxes of about 20 kWm^{-2} were measured at the floor level. Higher values of 35 kWm^{-2} and 50 kWm^{-2} were recorded at the wall and ceiling respectively. Recent full-scale burning tests observed 400 kWm^{-2} [29] for some store fires. This would ignite all the combustibles and flashover would occur as a thermal transition process.

Ignition should be tested for assessing whether the material is easy to start burning. There are two types of ignition, pilot and spontaneous. The older BS-476 test on ignitability [13] is to assess the materials under a pilot flame for 10 s. Whether the materials are easy to ignite can be assessed. However, their behaviour in a compartment under fire is not known. Materials stored inside the burning compartment might be ignited spontaneously under the flashover heat flux of 20 kWm^{-2}. Using a furnace with adjustable thermal radiation flux such as that in a cone calorimeter [20] is better for assessing ignition. Not only that, the heat release rate, smoke emission rate, carbon monoxide and carbon dioxide levels under the specified burning conditions [21,22] can be measured with a cone calorimeter. This part is suggested to be studied carefully in future.

4. FLAME SPREAD

If the walls, floors and ceilings are made of combustible materials, the compartment fire would be even more complicated. Fire might spread over the lining materials if they are made of plastic products, or over carpet floors. Specifications on testing the ignitability [13], non-combustibility [14] and surface spreading of flame [15] of materials might not be applicable for new materials. Even if the materials passed the specified BS-476: Part 7 test on surface spread of flame [16] (note that this is a not a full-scale burning test), that does not mean they are safe in a fire.

There are no specifications on the new generation of fire tests in the current codes [5,10-12] yet. It would take time for updating and upgrading those fire codes to cater for the rapid development of new materials and testing standards on fire spread. Whether those testing standards such as ASTM-E84-99 [30], NFPA-255: 2000 [31] and ISO-9705 [32] commonly used overseas [e.g. 33-35] are suitable for local buildings are unknown. All the requirements should be demonstrated by good reasons or in-depth research. An obvious example is that combustible lining materials and carpets are found in karaoke establishments.

In-depth studies on flame spread over finishing materials used as floors, ceilings and walls are essential before drafting workable fire safety regulations.

5. ACCEPTANCE CRITERIA

In recommending the standard tests, acceptance criteria have to be worked out. The ignition time required under a certain radiation heat flux while carrying out tests with the cone calorimeter can be a criterion. Material samples should be selected properly and tested. Results are compiled systematically by considering repeatability and reproducibility (R & R) [36-38].

Acceptance criteria should be worked out scientifically by including those tests discussed above. Correlation expressions among measured parameters should be worked out for such purpose. Relating the peak heat release rate with the thermal contribution of the materials to the fire environment is a good example.

Flame spread results compiled from bigger-scale tests such as the ISO-9705 [32] are useful in deducing the time to flashover for typical use of buildings such as retail shops or offices.

6. CONCLUSIONS

The standard tests specified in the existing codes are not applicable for assessing the fire behaviour of new materials with more than one component such as sandwich panel. Fire behaviour of materials should be assessed with more studies on:

- Reviewing the standard tests available in the literature for assessing the fire behaviour of materials.
- Carrying out relevant experimental studies on assessing those models.
- Appropriate data analysis.
- Recommending correct drafting of local fire safety regulations related to the assessment of fire behaviour of materials.

A full-scale burning facility, the Chinese Assembly Calorimeter [39], was developed under the leadership of the author with strong supports from partners at the Harbin Engineering University (HEU). This might help the industry develop a database on heat release rate for local products. Results are important in applying the fire engineering approach [40], similar to performance-based design in elsewhere [e.g. 41].

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