International Journal on Engineering Performance-Based Fire Codes, Volume 6, Number 4, p.295-300, 2004

A NEW STRATEGY ON ASSESSING FLAME SPREAD OVER MATERIALS IN HONG KONG

C.W. Leung
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

ABSTRACT

Existing regulatory requirements in Hong Kong on flame spread over materials was found to be inadequate. Studying the flame spread phenomenon and defining a new set of workable fire safety regulations are essential. A survey on common building materials in the local industry and review on standard flame spread tests were completed. Development of a suitable mathematical model with validation by full-scale burning tests is recommended.

1. INTRODUCTION

Fire development from a single ignition source to a large extent of area is controlled by the rate of flame spread. It plays an important role in affecting the heat release rate (HRR) in the room, the fire size, the time to flashover and the available safe egress time for occupants. These are key parameters to be considered when engineering performance-based fire codes [1] are implemented, especially for complex projects, green buildings, infrastructures and other new generation of architectures in which the concepts of building structural designs and other building services systems are contradictory to the fire safety objectives. As reviewed [2,3], the local specifications [4-7] on the assessment of flame spread over materials were inadequate. A new set of tests should be specified to ensure the protection of life and property. In doing so, an important task is to identify the types of materials concerned. A survey was carried out on the construction materials most commonly used in Hong Kong for identification of their fire properties [8]. Standard tests [9-13] on flame spread were reviewed [2]. The ISO full-scale burning test [13] was recommended to the local government [3]. A mathematical model for numerical prediction of flame front position and flame spread rate was developed [14]. Further development of the model for simulation of full-scale data would be the end-up strategy for the assessment of flame spreading properties of materials.

2. SURVEY ON PARTITIONING MATERIALS

According to a previous survey [8], partitions used in the local industry are basically classified as wet and dry partitions. Wet partitions are mainly noncombustible compartmentation walls or construction for security purposes. Common materials include bricks, concrete, lime, cement and mortar. Dry partitions are usually constructed in non-residential buildings for division of open areas into private zones. Ordinary systems include gypsum wallboard (GWB), calcium silicate board partition, timber stud or plywood partition, fire-rated partition, relocatable panel, operable wall and "lightweight" block wall. GWB is the most popular partitioning material due to its low cost, simple and standard installation works, high flexibility, light weight and noncombustibility. Plywood partitions was the major partitioning design until around six years ago when GWB were widely used. Plywood panels can still be found in old offices and in places with low requirements of sound insulation and simple partitioning purposes. These partitions are of fire concern. According to field surveys and interviews with building professionals, wood panels are commonly used for covering of compartmentation walls for fast and easy alignment. This shortens the time required for surface rendering and reduces the cost for workmanship and time. Sandwich panels and composite materials are prevailing partitioning design in commercial buildings and karaokes. They are constructed by two panels with insulating materials or acoustic linings in between for better sound isolation. The panels might be steel sheets, gypsum board or timber products. Timber products might not be ignited very easily. However, surface finishing materials such as wallpaper, paint and other organic materials are always applied on the surface of partitions for decoration. Those materials with short ignition time can give out a high HRR, though it might only last for a short period of time, which would be good enough to ignite adjacent combustibles in the compartment, such as curtain, foam sofa or alcoholic drinks in karaokes. The strong HRR from those big burning objects would be sufficient to ignite the timber panels. A t^2-fire is likely to occur with maximum HRR up to 5 MW within three minutes [15].

3. REVIEW ON FLAME SPREAD TESTS

In the local prescriptive codes [4-7], only the old British Standard test, BS476: Part 7 [9] is specified in the FSI code [4] published by the Fire Services Department. No specification was issued from the Buildings Department. BS476: Part 7 is a bench-scale test for a small specimen size of 0.885 m by 0.27 m (0.24 m^2) with a limitation of 0.05 m thickness, as shown in Fig. 1. This allows testing of a single building component only and it might not be adequate for testing of building assemblies made of more than one material like sandwich panels. Even if the assembly can be fit into the specimen holder, the insulating materials exposed in the cut ends and edges might be ignited and the overall testing results would be affected. Due to the small scale, the flame over the material is fairly developed. Radiation cannot be scaled down and the small flaming part of the material is not sufficient to show the important contribution of the radiative feedback to the material itself. An electrical radiation panel was designed to apply an external radiative heat flux on the material. Materials to be tested should be attached vertically perpendicular to the heat panel under a steep thermal gradient of 32.5 kWm^{-2} to 5 kWm^{-2}. Only lateral spread of flame is simulated along the material length. Tests are carried out in an open space and ambient temperature. All the heat and combustible vapour generated during the combustion process are lost to the surrounding. No scientific results or physical properties of materials are obtained from the test. Tested materials are classified into Classes 1 to 4 based on the extent of flame spread as shown in Table 1. As specified in the FSI code, for premises including basements, commercial buildings, domestic buildings, hotels and institutional buildings, Class 1 or 2 rate of flame spread should be provided, or be brought up to that standard by the use of an approved fire retardant product for all linings for acoustic and thermal insulation purposes in ductings and concealed locations, and all linings for acoustic, thermal insulation and decorative purposes within the protected means of escape. This is an arbitrary comparison between materials only and it is not a representative reflection of the fire growth potential of materials in actual installations. It was even established [16] that no known bench-scale test is directly correlated with the data on flame spreading of real products. A new testing strategy should be proposed.

Three standard tests including ASTM E1321 (the LIFT test) [10], ASTM E84 [11]/ NFPA 255 [12] and ISO 9705 [13] on flame spread were reviewed and compared with BS476: Part 7. It was found that the corresponding experimental setup, ignition source, application of external heat, configuration, geometry, orientation, installation method, environmental conditions, measurements, observations and classification systems are distinct. No significant correlations between testing results were found [2]. Materials passing one test do not necessarily fulfill the requirements in the others. Most of the conventional tests do not seem to have clear relevance with real fires [17].

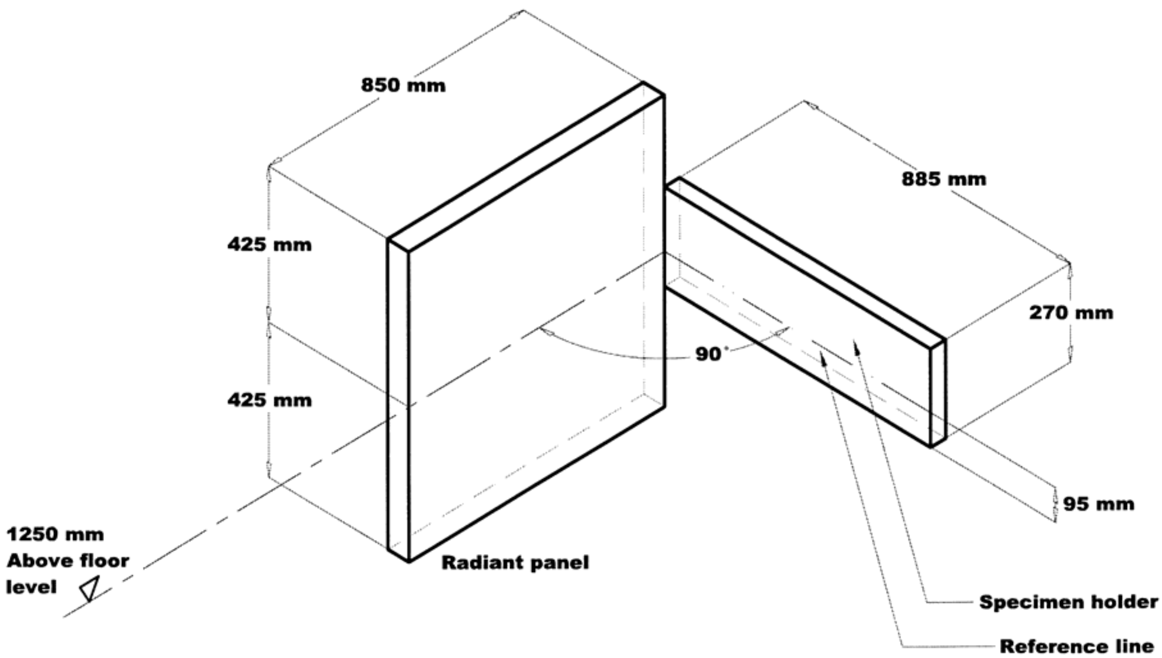

Fig. 1: Configuration of BS476: Part 7

Table 1: Classification of flame spread under BS 476: Part 7

Class	Spread of flame / mm			
	At 1.5 min.		Final	
	Limit	Limit for one specimen	Limit	Limit for one specimen
	5 out of 6	Remaining specimens*	5 out of 6	Remaining specimens*
Class 1	165	165 + 25	165	165 + 25
Class 2	215	215 + 25	455	455 + 45
Class 3	265	265 + 25	710	710 + 75
Class 4	Exceeding the limits for Class 3			

*Note: A minimum of six and a maximum of nine test specimens shall be provided, and they shall be representative of the exposed surface of the product [9].

4. THE NEW ASSESSING STRATEGY

The ISO 9705 is proposed as a suitable assessment tool [3]. It is considered as a full-scale burning test and the results from the test were found to be comparable to real fire data [18]. A standard room of 3.6 m by 2.4 m and 2.4 m (H) with a 0.8 m by 2.0 m (H) doorway as shown in Fig. 2 represents a minimum room size in buildings [17]. Materials should be attached on the ceiling and walls excluding the one with the doorway based on the actual on-site installation methods. A 0.17 m by 0.17 m propane gas burner should be placed on the floor at the rear wall corner, giving out a heat output of 100 kW for 600 s and 300 kW for a further 600 s if no flashover occurred. Sandwich panels and building assemblies can be tested in full-scale under their on-site orientation and geometry. Upward flame spread from the primary ignition source along walls, flame spread along the ceiling jet region, lateral flame spread along vertical walls and interface between the walls and ceiling, followed by downward flame spread on the walls can be simulated. Combustible vapours and heat generated are trapped in the room and substantial radiative feedback from the hot gas and smoke layer are included. Radiation, combustion and turbulence inside the compartment provide a severe environment comparable to real fire scenarios. Most importantly, the HRR can be measured accurately using the duct section and oxygen consumption method. Time to flashover can be taken by defining a criterion as floor heat flux of 20 kWm^{-2}, flame emerging from doorway, or upper layer gas temperature of 500 to 600 ^oC. Thermocouples can be attached for the measurements of surface temperature which can be compared with the ignition temperature of materials for monitoring the rate and extent of flame spread. Smoke and gases including carbon monoxide and carbon dioxide concentrations can be measured for necessary assessment of materials. No official classification system is established in the ISO standard at the moment. Average HRR, total HRR, peak HRR, time to flashover, amount of smoke evolution and limitations on falling of flaming debris are key parameters in the proposed ranking systems [e.g. 19-24]. Although the ISO 9705 is well recognized, its complexity and high cost and demand of time make regulators, developers and material producers hesitate to introduce this test into regulatory tool. Associated environmental legislation problems with the large production of smoke, soot and possible toxic gases also make it difficult to put the test into practice in large cities. Installation of smoke treatment plant and developing a facility in a remote area might be possible solutions, but the long-term potential health hazards to residents and operators should not be neglected.

The HRR of the primary ignition source is the most important single variable in the spread of a developing fire [25]. Time to flashover can be affected greatly by the changes in heater size and output schedule [26]. Sensitivity of the fire growth to the ignition source and the boundary conditions lead to uncertainty on the effects from different combinations of ignition source, room size, geometry and ventilation conditions. Experimental results can be applied to the specific scenario only.

In view of that, development of a mathematical model based on bench-scale test results for assessing the flame spread of materials is essential before drafting workable fire safety regulations for recommendation to the government. Models for various fire aspects are available in the industry including zone models, field models and airflow network models. However, good predictions of flame spread [27] are rarely found in those models. Further experimental verifications are still required and the accuracy of the modeling results is still an uncertainty. Reviews of models reported in the literature had identified an approach of using bench-scale testing data to predict the flame spread results [28] such as those generated by the LIFT test. Cone calorimeter [29] results including ignition time, critical surface temperature for ignition, HRR and flame duration are the input data. With assumptions on the flame configuration, flame duration and emissivity, the total heat flux on the material taking into account the external radiative heat flux, burning part of the material and heat loss to the ambient air was calculated to define the transient surface temperature of the material, and thus ignition and extinction. In the existing model, the flame was treated as a planar surface only and it is limited to be used as a practical tool for fire safety assessment. The model was further developed [14] with a more realistic two-dimensional radiative transfer model and a simplified model of the luminous flame emissivity was used to simulate the radiative heat transfer from the flame to the unburned surface. The basic geometry is shown in Fig. 3. Simulation results on ignition time, flame front distance and extinction time agree well with experimental data. This improved model can be taken as the first step for modeling the flame spread over materials with a simple approach. The next step should be applying the methodology for the ISO full-scale burning test.

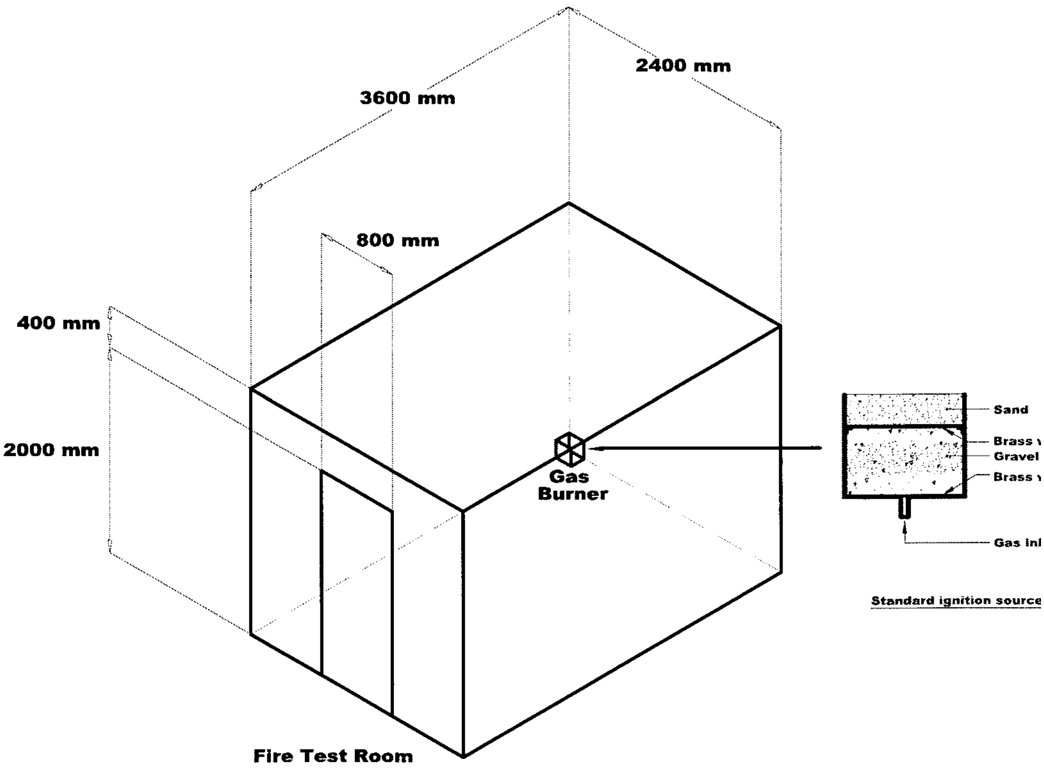

Fig. 2: Configuration of ISO 9705

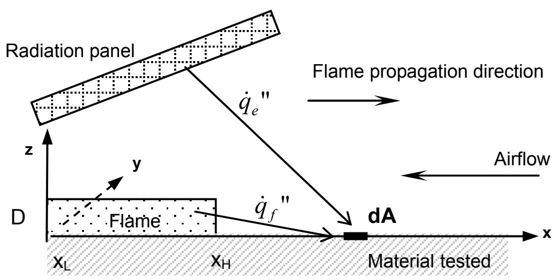

Fig. 3: Basic geometry and coordinate system of the flame spreading model

5. CONCLUSION

The specifications on the testing of flame spreading properties of materials in Hong Kong are not sufficient. The ISO 9705 was considered as a suitable testing method. However, it is reserved to specify it as the regulatory assessment tool due to its complexity and high cost. Using mathematical models for prediction, with verification from the ISO test results would be a cost-effective and scientific approach. A simple model was developed for simulating the flame spread results in a LIFT configuration. It should be upgraded to simulate full-scale results. The results from cone calorimeter have been widely proved to have good correlations with the ISO 9705 data. Using those results as input data would demonstrate a high confidence for realistic prediction. This would be the new goal on the assessment of flame spread over materials in implementing the engineering performance-based fire codes.

ACKNOWLEDGEMENT

This project is funded by a PolyU research grants under account number G-W003.

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Q & A

Q1: Does it measure the species in the smoke in the test?

Leung: There is not any analysis on smoke in the British Standard test other than the distance of flame spread. In ISO 9705, there is some measurement on production of smoke. A hood outside the doorway of the burning facility will collect all the gases and smoke produced from the burning process. This is connected to an exhaust duct where you can measure the optical density of the smoke by detecting the light obscuration with a system consisting of a lamp, lenses, an aperture and a photocell.

Q2: In ISO 9705, can composite materials be tested?

Leung: One of the major advantages of the test is that composite materials or sandwich panels can be attached on the wall because it does not have limitations on the thickness of the wall. It can test the materials under the actual installation method, configuration and geometry. You can test different materials on the same wall, but it should be considered as a particular scenario only. You cannot apply the results to other scenarios. It is better to test the same material on the wall and ceiling.

Q3: How to simulate flashover phenomenon in ISO 9705?

Leung: A gas burner is placed inside the room. The fire would develop from the ignition source and then rise upwards and move to the other area. When temperature increases up to 500 to 600 °C at the upper layer, or heat flux reaches 20 kWm^{-2} at the floor level, it is a signal of flashover.