Recommendation on assessing flame spreading of materials using ISO 9705

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Abstract Fire safety provisions for buildings in Hong Kong can be designed with the "engineering approach", though the performance-based fire code is not yet available. To cope with the use of new building materials, flame spread tests on materials and components should be specified. After reviewing four standard tests in the literature, i. e. ASTM E1321-97a, BS476 Part 7: 1997, ASTM E84-99/NFPA 255 and ISO 9705: 1993(E), the ISO 9705 is recommended to the local government for assessing the spread of flame over materials.

Key words flame spread; ISO 9705; full-scale burning test

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1 Introduction

Spread of flame over lining and finishing materials is one of the key elements to be considered in providing fire safety. Rapid upward flame spread along wall linings followed with horizontal flame development beneath a combustible ceiling give short time to flashover. In Hong Kong, the passive building design on fire safety and the provision of fire services installations are governed by prescriptive codes issued by the Buildings Department and Fire Services Department[1] of the local government. Restriction on flame spreading of materials was not clearly described in the local codes for passive building design. There, only the fire resistance period of compartmentation walls is specified. BS 476: Part 7[2] on surface spread of flame test was specified in the fire service installations code[1]. This test is designed basically for assessing building materials, but not on the entire building element. Suitable tests on flame spread should be considered for assessing modern materials and components, especially for implementing engineering performance-based fire codes (EPBFC). At the moment, EPBFC is not yet available but the government would consider the designs of fire safety provisions based on the "engineering approach"[3].

Heat release rate of materials is very important in fire safety assessment. By studying the relationship between flame spread and heat release rate, the material fire properties can be assessed. The term "fire properties" used by Cleary and Quintiere[4] refers to input material data for fire modelling. Values might not be unique but depend on environmental conditions. To test the actual behaviour, appropriate tests with mathematical model have to be used.

An obvious local example is the building control set up on karaoke establishments after a big karaoke arson fire. Tests on flame spread were not yet specified. Note that karaokes are typically partitioned into many boxes with long corridors. Previous survey studies[5] indicated that timber products were commonly used as decorative partitioning materials before 1995 when gypsum plasterboard was not popular. The current local building codes[1,3] require a fire resistance period of 1 hour for compartmentation walls. This is not too sufficient and it does not cover the use of internal partitions which can be ignited easily, especially for those timber products. Upward and horizontal flame spread over those wallboards might give a heat release rate high enough to cause flashover. Further, the partition wall might fall down and block the escape route. Items placed adjacent to the flaming partition might be ignited and cause fire spread from its origin. On the other hand, although some lining materials might be ignited easily in a fire, there is some degree of fire safety if the flame cannot be sustained after removing fire source. Therefore, clearer specification on flame spreading of materials is strongly recommended.

Previously, four standard tests on flame spread were reviewed[6] to see whether recommendations can be made to the Authority on specifying the flame spread behaviours of materials and components. Those four standard tests are:

° ASTM E1321-97a, Standard test method for determining material ignition and flame spread properties[7], also referred to as the Lateral Ignition and Flame Spread Test or LIFT.

° BS476: Part 7: 1997, Method of test to determine the classification of the surface spread of flame of products[2].

° ASTM E84-99 or ANSI/NFPA 255-2000, Standard test method for surface burning characteristics of building materials[8,9].

° ISO 9705: 1993(E), Fire Tests-Full-scale room test for surface products[10] Both ASTM E1321 and BS476: Part 7 are bench-scale experiments. ASTM E84/NFPA 255 is a relatively large test and the ISO 9705 is a full-scale burning test. These four standard tests were developed from different principles with behaviours of materials under various conditions being compared. Arbitrary ranking or classification systems were designed from the testing results. An attempt[6] was made on relating the testing results measured in the four tests by surveying flame spread data, though the tests are basically different. However, the data available in the literature are not yet good enough for deriving correlations for the results tested on the same materials under the four tests. There is no established pass/fail criterion for the ignition and flame spread test results generated in the ASTM E1321. Material parameters obtained can be used in mathematical models for fire growth and prediction of performances of materials. Materials are classified into Classes 1 to 4 depending on the extent of flame spread with time in BS476: Part 7. In ASTM E84/NFPA 255, travelling distances of the flame front are measured. A flame spread time-distance curve can be obtained to determine the Flame Spread Index. This index can be compared with the benchmark to provide a relative ranking. No official classification or product rating scheme was defined in the ISO 9705 standard. Proposed systems in overseas are discussed in the later section.

In this paper, the ISO 9705 is recommended for assessing flame spreading over materials for local use with explanations outlined.

2 Brief summary on the four tests

Comparison of the four tests was reported[6] with a summary as follows:

° Both ASTM E1321 and BS476: Part 7 are bench-scale tests for assessing specimens of smaller size relative to the actual construction. It is difficult to use such tests to assess full-scale effects such as structural performance of a material or construction component in real fires. Thermostructural failures and falling of non-structural members in actual fires might affect the flame spread. Radiation cannot be scaled down. An external heat panel was designed to compensate the little radiation feedback from the small fire over the burning part of the specimen to the material itself.

° Horizontal flame spread under opposed flow is tested with materials mounted in standing position for ASTM E1321 and BS476: Part 7. However, vertical flame spread dominates over walls and there might be significantly distinct fire behaviours if the materials are mounted horizontally. In ASTM E84/NFPA 255, materials are tested in ceiling position. Some materials might melt or fall down and the flame propagation would be affected.

° ASTM E1321, BS476: Part 7 and ASTM E84/NFPA 255 access flame spread in one direction only. Three-dimensional problems cannot be studied. In actual fires, there would be radiative feedback from the hot gas layer and flame might spread across walls and the ceiling, which would give a faster flame spreading rate.

° A wall surface exposed to an advancing heat and flame front is simulated in BS476: Part 7. The fire is fairly well developed. It only provides a measurement of the rate of flame development across the material which is not the first items ignited and no thermal feedback from ignition is considered.

° The lengthy preheat time of specimen in ASTM E1321, say from 7 to 10 minutes, might allow surface pyrolysis. This might cause changes of the specimen from its actual conditions before the test is started. Such changes can lead to poor ignition of the material and the burning behaviour might be affected. This can be evidenced by the propensity for oscillating flames rather than sustained flaming, after ignition[11]. Assessment of flame spread depends on the consistency of flame propagation. Erratic flame fronts might lead to uncertain sets of data and affect the repeatability of the test. It was recommended[11, 12] to run the tests using the International Maritime Organisation (IMO) Res. A653(16) or ASTM E1317 surface flammability test protocol, which operates at a higher heat flux level without preheating the specimen, and then to apply the ASTM E1321 procedures for further testing.

◦ For ISO 9705, wall and ceiling materials can be tested in their normal mounted conditions. Flame spread from one region or falling flaming objects to adjacent surfaces can be observed. From the experiments reported on investigating the burning behaviours of materials under different configurations[13], the results of testing the walls and ceiling separately and putting them together are different. Heat release rate curves of plywood and fire-retarded plywood ceiling and walls are shown in Figure 1. With the fire retardant treatment, only a delay in the heat release is observed, except for the case of fire-retarded ceiling where a much lower peak is shown. This gives an overall picture on the performance of the fire retardant and this can only be illustrated from the ISO 9705 results. Fire behaviours of the same material might change with different substrates. Experimental studies in ISO 9705[14] showed that wallpaper burned with extremely fast fire growth rate over glass wool, while only a small amount was burnt when it was placed over a concrete substrate. A possible explanation is the different thermal properties of the two substrates, giving different thermal inertia. Therefore, testing the materials under end-use conditions is necessary.

3 Recommendations of using ISO 9705

The ISO 9705 is a suitable testing method for assessing flame spreading for local use. More realistic fire performance data instead of testing

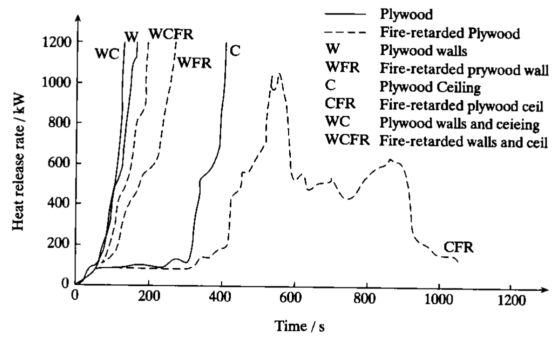

Fig. 1 Heat release rate curves of plywood with and without fire retardants under three configurations[13]

results for individual components can be obtained. Justifications are as follows:

◦ Measurement of heat release rate and smoke production—The answer to the question "How big is a fire?" is on estimating the heat release rate from burning the building materials. This was identified to be the most important parameter in hazard assessment. Smoke production rate should be considered carefully as most people killed in a fire were due to smoke. These two parameters are key measurements in the ISO 9705. Gas temperature, thermal radiation, concentration of gases and production of toxic gases can be measured continuously and accurately. For other tests giving a relative ranking or an arbitrary number, properties of the material itself are not given. The results cannot be taken for further scientific use.

◦ Possibility of flashover—Whether flashover can occur is critical in fire safety. Flame spreading governs the rate of fire growth from a small ignition source to a big fire releasing a large amount of heat. In this test, time to flashover can be measured. The assessment of flame spread over material is changed from the arbitrary limitation on the surface spread performance to the limitation on the contribution to fire growth in terms of heat release rate as a function of time. Note that the room size for the ISO 9705 test is very similar to the size of a small typical compartment. A lining fire might develop faster in a larger room.

◦ Scale of test and orientation—Flame spread depends on surrounding ambient conditions. Some substrates might behave as a heat sink because of their porosity and thermal properties. With ISO 9705, it is possible to test composite materials and sandwich panels with lining and surface finishing products which cannot be tested properly in smaller scale tests due to the dimensional limits. Materials can be tested in different orientations, such as wall and ceiling, under their actual conditions in sites. Ignition of the exposed insulating materials in cutting edges of sandwich panels would affect the overall flame spread results in bench-scale tests. No such problem exists in the ISO 9705.

4 Review on classification systems based on ISO 9705

There are recommendations on classifying and rating products based on the ISO 9705. A ranking system can be derived by evaluating performance of some fire aspects. For example, the peak heat release rate, total heat release, time to flashover and amount of smoke evolution can be used to study the hazards of materials.

By using time to flashover as the criterion for classification[15], ability of a material in sustaining flame spreading and its contribution to fire growth can be assessed. Four levels of room fire performance, A, B, C and D were suggested for controlling materials:

- A: for fire-isolated passageways (exits), no flashover after 10 minutes
- B: for assembly areas and corridors providing access to exits, flashover after 6 minutes
- C: for general areas, flashover after 4 minutes
- D: not permitted, flashover in less than 4 minutes

Efforts were made in the Nordic countries on evaluating a proposed five-scale classification system by and Göransson[16]. It is compared with BS 476 Part 7 as shown in Table 1. In the classification system, both the peak and average values of the heat release rate were considered. A limit was put on long lasting fires which give off a significant amount of total heat. Credits were given to those products that burn out quickly even with high peak heat release. To evaluate the system, eleven products were tested and classified under the proposed system. The results were compared with the regulations used in England, France, Germany, Italy and Denmark under their EUREFIC programme. It was found that there was no general agreement between the classification systems, except for Class A products, plasterboard and plywood. This classification system should be further assessed. Having five classes in a new classification system might not be practical, but this can give flexibility[16] on differentiating various products and to be related to other existing national systems.

Another classification system for the ISO 9705 was established in the USA[12]. The High Speed Craft Code (HSC) was implemented on 1 January 1996 as part of the Safety of Life at Sea on the construction of high-speed crafts using combustible materials. Bulkhead linings, compartment linings and ceiling materials should be tested using the ISO 9705. Materials with low flame spread characteristics, limited rate of heat release and low smoke production are classified as fire restricting. Otherwise, they are classified as non-fire restricting. The acceptance criteria as published in the resolution MSC. 40(64) of the IMO should be met[12]:

- Average heat release rate over the entire testing time shall not exceed 100 kW,
- Maximum 30-second average heat release rate shall not exceed 500 kW,
- Average smoke production rate shall not exceed 1.4 $m^2 \cdot s^{-1}$,
- Maximum 60-second average smoke production rate shall not exceed 8.3 $m^2 \cdot s^{-1}$,
- No flaming 'droplets or debris' may reach the floor, except in the area within 1.2 m from the corner.
- No flame spread to the area below 0.5 m from the floor at a distance greater than 1.2 m from the corner, and

Some shortcomings on the ISO 9705 test and the IMO failing criteria were identified[11]. Except the examination of the effect of the duct flow rate (at 300 kW only) in the calibration procedure, no clear specification on the exhaust duct volumetric flow rate or range of flow rates is defined in the standard. There should be effects of the exhaust volumetric flow on the measurements of heat release rates, especially when the flow rates and heat release values were low. Rapid increase in the duct flow rate was found when there was a sudden increase in smoke production rate. The heat release rate might give unreal spikes when the duct volumetric flow rate was suddenly increased.

Table 1 Proposed EUREFIC classification system for ISO 9705 and comparison with BS 476 Part 7[16]

Class	Minimum time to flashover / min	heat release Burner excluded Peak	heat release Burner excluded Avg	rate / kW Burner included Peak	Corresponding material and typical examples	Classification in BS 476: Part 7 and examples
A	20	300	50	60	Products showing very limited burning (e.g. Mineral wool; Gypsum plaster board)	Class 1 (Painted gypsum paper plasterboard; Melamine faced high density non-combustible board; Plastic faced steel sheet on mineral wool; FR particle board)
B	20	700	100	1 000	Products approaching but not giving flashover during the entire 20 minutes test period (e.g. Light wall-papers on gypsum plaster board)	
C	12	700	100	1 000	Products leading to flashover but only after more than 2 minutes of exposure to the increased burner output of 300 kW; Fire resistant coating on wood (e.g. Gypsum plaster board on polystyrene foam)	
D	10	900	100	1 000	Products flashing over shortly after increasing the burner output to 300 kW (e.g. Heavy wallpaper)	Class 3 (Textile wallcovering on gypsum paper; FR particle board type B1; PVC wallpaper on gypsum paper plasterboard)
E	2	900	–	1 000	Products flashing over after more than 2 minutes at a burner output of 100 kW (e.g. Solid wood products)	Class 3 (Ordinary plywood; Plastic faced steel sheet on polyurethane foam)
Unclassified						Class 4 (Combustible faced mineral wool) Invalid (FR extruded polystyrene foam)

The IMO failure criterion on the extent of flame spread was criticized as not representative in the results of nine composites including a range of fire restricting and non-fire restricting materials. The upper limits on smoke production and heat release rate were usually exceeded before the flame spreads to the 0.5 m level when flashover occurred[11]. On the other hand, the flame was usually confined to the wall and ceiling areas in the immediate vicinity of the burner flame if there was no flashover throughout the 20 - minute testing period. Only some finishing materials like thin wallpaper might have rapid flame spread with a small amount of heat and smoke released. Some lining materials might separate from the substrate when burning and fall on the ground. Such materials are classified as non-fire restricting according to the IMO criterion on flaming debris. However, the quantity of flaming debris might be very small and it might cease in seconds. This would not produce any significant hazard. Those two flame spreading criteria were suggested to be re-examined. A room partially filled with wall-covering materials was suggested[11] to be good enough for assessing fire-restricting materials. It was observed that only the panel sections adjacent to the burner, at the top of the side walls and on the ceiling were burnt in most cases. Remainders of the materials did not contribute significantly to the fire. Such partially lined room would reduce the testing cost and the amount of materials to be provided by manufacturers.

5 Comparison with ASTM E84/NFPA 255

ASTM E84/NFPA 255 "tunnel test" is widely accepted and the FSI flame spread rating system is well understood in the USA. However, this test was not designed as a stand-alone test to describe the combustibility of a material[17]. It can be used to evaluate the FSI of interior finishes for comparison with the benchmark materials only. The behaviours of materials in their end-use applications cannot be indicated. The test might not be appropriate for assessing composite and decorative materials with unusual geometries or configurations.

Materials with low FSI rating in the tunnel test might in fact spread flame readily and have fast fire growth in realistic full- scale burning test[17]. Even the listed ratings of individual materials are acceptable, the combination of materials showed much different fire performance in actual fire conditions. The FSI rating system is adopted in the U. S. Building codes. Some restrictions on interior finishes used in a given type of construction and occupancy are specified. Textile wall coverings used in unsprinklered occupancies are required in the Model building codes and the Life Safety Code (LSC)[18] to be tested in the room /corner fire test. Complete assembly with all layers and substrates should be tested as specified in the LSC. Since the tunnel test method was not designed to test wall assemblies, the tunnel lid can be modified to ensure an adequate seal in the liquid trough and prevent the escape of heat and smoke, such that the interior finish materials can be tested on their intended substrate and wall assembly[17].

A similar tunnel test is employed in the National Standard of Canada for building materials[19]. Materials can be mounted on the ceiling or floor depending on their physical (whether it can support its own weight) and burning (melting or dripping) characteristics. This test is more flexible than the tunnel test in which samples can only be tested in the ceiling-mounted position.

As reported, carrying out an ASTM E84/NFPA 255 "tunnel test" is less expensive than the ISO 9705 room corner fire test in the USA[17]. But if a new rig is to be developed, there might not be much difference on the initial installation cost, staff training cost, operation and maintenance cost.

6 Conclusion

The ISO 9705 is recommended for testing the flame spreading of materials as explained in this paper, and earlier comparison with three other flame spreading tests[6]. As there is not yet specification on standard tests for flame spread over materials apart from the BS 476 Part 7, there would not be any disturbance to the local testing facilities as in elsewhere. The ISO 9705 should be therefore the first choice.

On ranking materials from the ISO 9705, there are classification systems proposed in other countries. However, only the IMO acceptance criteria are formally adopted in the HSC, though some decisive conditions were not agreed on[11,12]. Other systems are still open for further analysis and improvement. The local government may take those overseas experiences as references. Further in-depth studies on a wider range of different products are recommended. The results should be compared with those by BS 476 Part 7 and other recognized rankings[15,16] in order to develop the most suitable classification system for the local construction industry.

The ISO 9705 is always criticized as too expensive. But while comparing with the local cost of buildings under this economic climate, say HK$ 3, 200 (US $ 400) per square foot, the testing cost is still far below. Further, higher education institutes would serve the industry by testing the materials and components at more reasonable costs to help providing fire safety. In Hong Kong, it is difficult to have a site for full-scale burning tests. The place is so densely populated and the land cost is far too high. Products from combustion including smoke, toxic gases, ashes and odor would pollute the atmosphere, cause disturbance and ill-effects to occupants staying close to the site. Most importantly, the tight environmental protection legislations make it impossible for such real fire tests to be carried out. A site far away from the urban area should be selected with considerations including transportation of people and materials, supply of water , electricity and heating (in temperate countries).

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马宝珠 供稿

关于用ISO 9705评价材料的火焰传播

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摘 要:虽然性能化规范尚未达到通用的程度,但中国香港建筑业消防安全条款已用于“工程方法”设计中,在回顾了四个标准试验,即ASTM E 1321- 97a; BS 476: Part 1997; ASTM E84-99/NFPA 255和ISO 9705: 1993(E)之后,介绍了ISO 9705,供地方政府评估各种材料的火焰传播。为妥善处理新的建筑材料,应将材料和构件的火焰传播试验列入说明中。

关键词:火焰传播;ISO9705;全尺寸燃烧试验

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