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Flammability tests for regulation of building and construction materials

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10.1 Introduction

The regulation of building materials and products for flammability is critical to ensure the safety of occupants in buildings and other structures. The involvement of exposed building materials and products in fires resulting in the loss of human life often spurs an increase in regulation and new test methods to address the problem. Flammability tests range from those in which the sample is ground to a powder prior to testing to the full-scale room comer test. Variations in test methods include the specific measurement of flammability parameters being considered, the intensity and characteristics of the fire exposure, the relative scale of the test specimen, and many other factors. As a result of specific details such as specimen orientation and fire exposure intensity, some existing regulatory test methods have been shown not to classify a type of building material or product in a manner consistent with full-scale tests that simulated actual conditions. Such failures have resulted in the development of alternative test methods for specific applications or products. As a result there is a wide range of tests used to classify building materials and products for flammability or reaction to fire.

Unfortunately, the results of flame-spread tests are often characteristics of the test procedure (Clark, 1981). In a 1970s comparison of international test methods for flammability, the ranking of materials by the different regulatory methods was little better than a random number generator (Emmons, 1974; Karlsson *et al.,* 2002). To achieve harmonization within the European Union, it became necessary to develop a new test - the Single Burning Item test. The scope of this chapter is limited to those flammability test standards that are relevant to the regulation of building materials and products. As such, it is only a subset of the many fire tests that have been used or are being used to evaluate building materials (Tewarson *et al.,* 2004; Eickner, 1977). This chapter focuses on the compliance criteria used in the regulatory classifications of building materials for flammability. More details on many of the applicable test methods can be found in other chapters of the book.

10.2 United States flammability requirements

The regulations for building materials and products to address the hazards associated with their flammability and related characteristics are found in the International Building Code and other building codes, the National Fire Protection Association (NFPA) 101 Life Safety Code, and other such documents. Acceptance criteria and classifications in this section generally refer to provisions of the International Building Code, which is the dominant model building code in the United States. Two main sets of requirements address the combustibility and the flame spread characteristics of building materials. These two main tests are described in the standards of ASTM International: ASTM E136 for combustibility and ASTM E84 for flame spread. The ASTM E84 test method also addresses the regulation for visible smoke characteristics. To address certain materials or applications, other test methods are also used in the regulation of building materials in North America.

10.2.1 Combustibility

The classification of a material as a non-combustible material is based on ASTM E136 Standard test method for behavior of materials in a vertical tube furnace at 750 °C. In the test, a dry 38 mm × 38 mm × 51 mm specimen is heated in a small vertical tube furnace. A material is accepted as non-combustible, if the material passes the criteria of ASTM E136. ASTM E136 requires that three of the four specimens must pass the criteria. If the weight loss of the test specimen is 50% or less, the criteria are (i) the specimen surface and interior temperatures during the test do not increase more than 30°C above the temperature measured on the surface of the specimen prior to the test and (ii) no flaming from the specimen after the first 30s. If the weight loss is greater than 50%, the criteria are no temperature rise above the stabilized temperature measured prior to the test and no flaming from the specimen at any time during the test. The commentary in ASTM E136 standard discusses the development of the test method and the rationale for the criteria.

As noted by Carpenter and Janssens (2005), one important limitation of ASTM E136 is that the test method does not provide a quantitative measure of heat generation or combustibility, but only a pass/fail result. The ASTM E136 is a severe test in that composite materials with even a small amount of combustible component will often fail to satisfy the criteria. Thus, materials such as mineral wood insulation with combustible binder, cinder concrete, cement and wood chips, and wood-fibered gypsum plaster are all classified as combustible (Institute for Research in Construction (IRC), 1995). The core of gypsum wallboard will satisfy the criteria for non-combustible. Paper-faced gypsum wallboard does not pass the non-combustible flaming criteria (Canadian Wood Council, 1991). As a result, prescriptive provisions to the codes are needed to permit the use of paper-faced gypsum in non-combustible construction. Fire-retardant treatment of a combustible material is not a viable option to satisfy the requirements of ASTM E136 and be classified non-combustible. Tewarson *et al.* (2004) considered E136 to be capable of providing quantitative data for the performance-based fire codes for the assessment of fire hazards associated with the use of products and protection needs.

To accommodate materials that are of low combustibility, alternative test methods have been developed. One such method is the test for potential heat of building materials, NFPA 259. The potential heat is the difference in the gross heat of combustion (oxygen bomb calorimeter) of the original material and the material after a two-hour exposure in a furnace at 750°C. In the NFPA 101 Life Safety Code, the test is used as a criterion for limited-combustible materials. The criterion is a potential heat less than 8,140 kJ/kg. The use of the cone calorimeter as a test for combustibility has also been investigated (Carpenter and Janssens, 2005). As noted by Carpenter and Janssens (2005), one of the biggest obstacles to the use of the cone calorimeter for combustibility is the implementation of a classification system that does not disrupt the status quo.

10.2.2 Interior finish flammability

The main test for surface burning characteristics of building materials in North America is the 25-foot (7.6m) Steiner tunnel. The standards are ASTM E84, NFPA 255, and UL 723. A 1.35 m long test flame at one end provides the ignition source and the fire exposure. The test provides measurements of the surface flame propagation and a measure of the optical smoke density. Based on the observations of the flame propagation, a comparative dimensionless flame spread index (FSI) is calculated from the areas under the flame spread distance-time plot. For the purpose of the calculations, the flame front is assumed to never recede. The comparative smoke developed index (SDI) is calculated from the area under the smoke density-time plot. The areas for reinforced cement board (SDI = 0) and red oak flooring (SDI = 100) are used in the calculation of the smoke developed index. Historically, both the flame spread index and the smoke development index were based on red oak flooring being 100 and asbestos board being zero. The times for the flames to reach the end of a red oak flooring specimen is still used to calibrate the equipment but the results for red oak flooring are no longer part of the calculation of the flame spread index. With the specimen located on the top of the rectangular test furnace, the question of mounting methods has been a controversial aspect of the test method. A non-mandatory appendix of the ASTM E84 standard provides a guide to mounting methods. Tewarson *et al.* (2004) consider the major limitation of E84 (and likewise for E648) to be that it is very difficult to assess the fire behaviors of products for heat exposures and environmental conditions and shape, size, and arrangements of the products other than those used in the test. For the purpose of research and development of new products, the correlation of other test methods to the ASTM E84 results is an area of continuous interests (Eickner, 1977; Stevens, 1998; White and Dietenberger, 2004).

Based on the ASTM E84 FSI, three classes of interior finish are specified. Class A (or I) requires a FSI of 25 or less. For Class B (or II), the FSI must be 26 to 75. Class C (or III) has a FSI range of 76 to 200. Materials not meeting the upper limit of Class III are considered unclassified and not permitted where the flammability of the material is regulated. The requirement for the SDI is 450 or less for all three classes. The primary purpose of the fire-retardant treatment of combustible materials is to reduce the flame spread index classification. Values for flame spread index can be found in Galbreath (1964), American Forest & Paper Association (2002), and the publications of listing services such as Underwriters' Laboratory, Underwriters' Laboratory Canada, and Intertek. Non-fire-retardant paints and other thin coatings can have a negative or positive effect on the flame spread index. The effect is usually not sufficient to change the classification unless the classification of the uncoated material is low or marginal. For example, the classification of brick, concrete, aluminum, and gypsum plaster goes from FSI of zero unfinished to 25 with the application of a 1.3 mm alkyd or latex paint or one layer of cellulosic wallpaper (IRC, 1995). The FSI classifications of 150 for lumber and various types of plywood and 25 for gypsum wallboard do not change with the application of a 1.3mm alkyd or latex paint or one layer of cellulosic wallpaper (IRC, 1995).

As noted by Belles (2003), materials that may not be adequately evaluated in the tunnel test include foam plastics, textile wall coverings, and vinyl film with foam backing. The large-scale room-comer tests of NFPA 265 and NFPA 286 provide an alternative to the tunnel test. These tests are similar to the standard ASTM and ISO room-comer tests that use a 2.4 m × 3.6 m × 2.4 m room with a single door opening for ventilation. A single propane burner is placed in a comer of the room.

For non-textile wall and ceiling finishes, the room-comer test of NFPA 286 is an alternative method to achieve Class A classification. In NFPA 286, the burner protocol is 40 kW for five minutes followed by 160kW for ten minutes. The test materials fully cover the three walls and/or the ceiling depending on the intended application of the material being tested. The acceptance criteria are (i) no flame spread to ceiling during 40 kW exposure, (ii) no flame spread to the outer extremity of sample wall or ceiling and no flashover during the 160kW exposure, and (iii) total smoke released must not exceed 1,000 m^2. The criteria for flashover are heat release rate of 1 MW, heat flux to floor of 20 kW/m^2, average upper air layer temperature of 600°C, 'flames out door' and ignition of paper targets on floor.

Alternative acceptance criteria for Class A textile wall coverings are based on NFPA 265. In NFPA 265, the burner protocol is 40kW for five minutes followed by 150kW for ten minutes. Method A is a comer test in that the test material only covers portions of the two walls adjacent to the corner burner. Method B is like NFPA 286 in that the test material fully covers the three walls. No test material is on the wall with the door in either method. Observations needed for the acceptance criteria of NFPA 265 include flame spread to the outer extremity of the test material, observation of burning droplets, observation of flashover, and peak heat release rate. Criteria for flashover include 25 kW/m^2 to floor, average upper air temperature of 650°C, 'flames out door', and ignition of paper targets on floor.

Besides the slight difference in the burner protocol, a second difference between NFPA 286 and NFPA 265 is that the burner is directly placed against the wall in NFPA 286 while it is 51 mm (2 in.) from the wall in NFPA 265. The NFPA 265 is considered unsuitable for the testing of ceiling materials since the flame from the burner alone will not touch the ceiling. The involvement of the ceiling in the NFPA test is somewhat due to the higher energy release rate of the NFPA 286 burner, but primarily due to the NFPA 286 burner being in direct contact with the walls, thereby reducing the area over which the flames can entrain air and increase the overall flame height (Janssens and Douglas, 2004). For decorative materials or other materials in a hanging configuration, one of the two tests described in NFPA 701 is used to determine the acceptance of the materials as flame-resistant materials. Selection of the specific test depends on the type of fabric or film being used.

The critical radiant flux apparatus is used to regulate carpets and other floor covering materials. Floor coverings such as wood, vinyl, linoleum, and other resilient non-fiber floor coverings are exempt from such requirements. The standard designations are ASTM E648 and NFPA 253. Because of the 30" incline of the radiant panel, the radiant heat flux profile on the test specimen ranges from 11 kW/m^2 to 1 kW/m^2 along the length of the specimen. The critical radiant flux is the flux that corresponds to the maximum distance of the flame front. As noted by Blackmore and Delichatsios (2002), the flooring radiant panel characterizes opposed flow horizontal flame spread and the pyrolysis is induced by both the external heat flux and convection/conduction from the flame at the front. The classes are Class 1 for a critical flux of 4.5 kW/m^2 or greater and Class 2 for a critical flux of 2.2 kW/m^2 or greater. Units of W/cm^2 are used in the U.S. codes and standards. The ASTM D2859 'pill test' is used as the least restrictive requirement. In the 'pill test' a small methenamine tablet is ignited in the center of a 230 mm square sample of the carpet. The specimen passes the test if the charred portion of the carpet does not extend beyond a 178 mm circle around the center of the sample. Requirements for carpets are also specified by the U.S. Federal Consumer Product Safety Commission (CPSC). The flooring radiant panel test is also part of the European regulations for floor coverings.

The duration of the standard ASTM E84 test is ten minutes. As a performance requirement for fire-retardant treated wood, the test is extended to 30 minutes. Fire-retardant-treated wood is required to have a FSI of 25 or less and show no evidence of significant progressive combustion when the test is continued for the additional 20 minutes. In addition, the flame front must not progress more than 3.2 m beyond the centerline of the burners at any time during the test. For fire-retardant-treated wood intended to be exposed to weather, damp, or wet locations; the listed FSI must not increase when tested after being exposed to the rain test of ASTM D2898.

Due to difficulties in the fire testing of foam plastic insulation that melt, specific requirements beyond those based on ASTM E84 test are specified for all foam plastic insulation. For foam plastic insulation that is part of a classified roof-covering assembly, testing according to FM 4450 or UL 1256 is an option. For exterior walls with foam plastic insulation, test methods include NFPA 268 and NFPA 285. In the NFPA 268 ignitability test, a 1.2 by 2.4 m test specimen is exposed to a 12.5 kW/m^2 heat flux and a piloted ignition source for a 20 minute test period. The NFPA 285 test is an intermediate-scale, multi-storey test apparatus with a minimum 4.6 m height. Large-scale tests such as FM 4880, UL 1040, NFPA 286, or UL 1715 are options to satisfy the provisions for foam plastic via special approval. FM 4880 is a 25 foot or 7.6 m high comer test. For light-transmitting plastics, tests include ASTM D1929 for self-ignition temperature, ASTM D2843 for smoke-development index, and ASTM D635 for combustibility classification (Class CC1 and CC2).

Exposed insulation is also tested using ASTM E84 for flame spread and smoke development. For loose-fill materials that cannot be mounted in the standard ASTM E84 tunnel without a screen or other artificial supports, the Canadian tunnel test for floors (CAN/ULC S102.2) is used to evaluate for flame spread. The Canadian flooring tunnel test 'addresses the question of testing of loose-fill insulation by placing the test specimen on the floor of the ASTM E84 test furnace and turning the burners down towards the test specimen. Another test for exposed attic floor insulation is the critical radiant flux test described in ASTM E970. It is similar to ASTM E648. The requirement for exposed attic insulation is a critical heat flux of 0.12 W/cm^2 or greater. Cellulose loose-fill insulation requirements are specified by the US Federal Consumer Products Safety Commission requirements that include the test of ASTM E970.

The standard test methods for roof coverings are in ASTM E108 (UL 790). Four separate fire tests for a relative comparison of roof coverings subjected to exterior fire exposure are part of ASTM E108: intermittent flame exposure test, spread of flame test, burning brand test, and flying brand test. The details of the tests are a function of the three classes (A, B, and C). Class A is the most restrictive. While the roof covering tests are primarily considered fire-resistance tests in terms of preventing penetration of the fire to the interior of the structure, there are requirements for surface flammability. The spread of flame test consists of a luminous gas flame burner at the edge of a 1 m wide inclined roof deck and an air current of 5.3 m/s. The length of the deck is 4 m for Class C, 2.7 m for Class B and 2.4 m for Class A. The gas flame and air current is applied in the Class A and B tests until any flaming of the test specimen recedes from its point of maximum flame spread, but no longer than ten minutes. If the test is run to obtain the Class C classification, the gas flame and air current is applied for four minutes. In the spread of flame test, the flaming cannot spread beyond 1.8 m for Class A, 2.4 m for Class B and 4.0 m for Class C. No significant lateral spread of flame from the area directly exposed to the test flame is permitted.

10.3 Canadian flammability requirements

The Canadian Commission on Building and Fire Codes is responsible for the National Building Code of Canada. Administrative and technical support for this model code is provided by the Institute for Research and Construction of the National Research Council of Canada. A new objective-based code is planned for 2005. The fire tests used in the Canadian codes for building materials requirements are similar to those in the United States. The test standard for determination of non-combustibility is CAN4-S114-M80. The tunnel test is CAN/ULC-S102-M88 in the Canadian standards. In addition, there is the tunnel test in which the test specimen is placed on the floor of the tunnel (CAN/ULC-S102.2-M88). It is intended for materials that (i) are intended for horizontal applications in which only the top surface is exposed, (ii) would require supports not representative of those used in actual applications to test the specimen on top of the tunnel (e.g. loose-fill insulation), or (iii) are thermoplastic. Because of melting or dripping, thermoplastics will have lower flame spread index in the ASTM E84 tunnel test with the material on the ceiling of the tunnel than in the Canadian flooring tunnel test (Canadian Wood Council, 1991). The Canadian flooring tunnel test addresses the question of testing of loose-fill insulation by placing the test specimen on the floor of the ASTM E 84 test furnace. Except for a few specific applications, the upper limits for the flame-spread rating are 25, 75, or 150. When regulated, the limits on the smoke developed classification are for values of 50, 100, 300, and 500. The standard for roof covering is CAN/ULC-S107-M87. More recently, the cone calorimeter was proposed as a standard test method for degree of combustibility (ULC-S135-04) (Richardson and Brooks, 1991; Richardson, 1994; Carpenter and Janssens, 2005).

10.4 European flammability requirements

The national fire regulators of the European Union countries developed a new flammability classification system in 2001. The new system is expected to replace the large number of different tests and classification systems used across the European Union. Two classification systems were developed; one for floor coverings (Table 10.1) and the other for all other construction products (Table 10.2). Suffix ‘FL’ is used to denote the floor covering classifications. This classification system is published in the *Official Journal of the European*

Table 10.1 European Union classification system for floor coverings

Class	Test method	Classification criteria
$A1_{FL}$	ISO 11 82 and ISO 1716	$T \leq 300°C$ and $m \leq 50\%$ and $t_f = 0$ and, $PCS \leq 2$ MJ/kg and $PCS \leq 1.4$ MJ/m^2
$A2_{FL}$	ISO 1182 or ISO 1716 and ISO 9239-1	$T \leq 500°C$ and $m \leq 50\%$ and $t_f = 20$ s or, $PCS \leq 3$ MJ/kg and $PCS \leq 4$ MJ/m^2 and, Critical flux ≥ 8 kW/m^2
B_{FL}	ISO 9239-1 and ISO 11925-2	Critical flux ≥ 8 kW/m^2 and $Fs \leq 150$ mm within 20 s following 15 s exposure.
C_{FL}	ISO 9239-1 and ISO 11925-2	Critical flux ≥ 4.5 kW/m^2 and $Fs \leq 150$ mm within 20s following 15s exposure.
D_{FL}	ISO 9239-1 and ISO 11925-2	Critical flux ≥ 3 kW/m^2 $Fs \leq 150$ mm within 20s following 15 s exposure.
E_{FL}	ISO 11925-2	$Fs \leq 150$ mm within 20 s following 15 s exposure
F_{FL}	No requirement	

Communities (OJ L50, 23.2.200, P.14) and published as EN 13501-1. The reference scenario used as the basis for the classification system is a fire starting in a small room and growing to reach flashover subject to a contribution from the room lining material. The reference test protocol is standardized as ISO 9705.

Table 10.2 European Union classification system for building products other than floor coverings

Class	Test method	Classification criteria
A1	ISO 11 82 and ISO 1716	$T \leq 300°C$ and $m \leq 50\%$ and $t_f = 0$ and, $PCS \leq 2$ MJ/kg and $PCS \leq 1.4$ MJ/m^2
A2	ISO 11 82 or ISO 1716 and EN 13823	$T \leq 500°C$ and $m \leq 50\%$ and $t_f = 20$s or, $PCS \leq 2$ MJ/kg and $PCS \leq 1.4$ MJ/m^2 and, $FIGRA \leq 120$ W/s and $THR_{600s} \leq 7.5$ MJ
B	EN 13823 and ISO 11925-2	$FIGRA \leq 120$W/s and $THR_{600s} \leq 7.5$ MJ and $Fs \leq 150$ mm within 60s following 30s exposure.
C	EN 13823 and ISO 11 925-2	$FIGRA \leq 250$ W/s $Fs \leq 150$ mm within 60s following 30s exposure.
D	EN 13823 and ISO 11925-2	$FIGRA \leq 750$ W/s and $THR_{600s} \leq 15$ MJ and $Fs \leq 150$ mm within 60s following 30s exposure.
E	ISO 11925-2	$Fs \leq 150$ mm within 60s following 30s exposure.
F	No requirement	

The following series of tests are used for classification.

ISO EN 1182 Non Combustibility Test: identifies products that will not contribute significantly to a fire. Used for classification in Class Al, A2, $A1_{FL}$, $A2_{FL}$.

ISO EN 1716 Calorific Value: determines potential heat release by a product under complete combustion. Used for classification in Class A1, A2, $A1_{FL}$, $A2_{FL}$.

EN 13823 Single Burning Item Test: evaluates the potential contribution to fire growth with a single burning item in a room corner. Used for classification in Class A2, B, C and D.

ISO EN 11925-2 Ignitability: evaluates the ignitability of a product when subject to a small flame. Used for classification in Class B, C, D, E, B_{FL}, C_{FL}, D_{FL} and E_{FL}.

ISO EN 9239-1 Burning behavior of floor coverings exposed to a radiant heat source: evaluates the critical radiant flux at flame extinguishment over a horizontal surface. Used for classification in Class $A2_{FL}$, B_{FL}, C_{FL}, D_{FL} and E_{FL}

10.5 Japanese flammability requirements

Japan uses the Cone Calorimeter test results to classify the interior finish materials. The test method referenced is ISO 5660-1 at a radiant exposure of 50 kW/m^2. The three class classification system is summarized in Table 10.3.

Table 10.3 Japanese classification system for interior finish materials

Class	Test method	Classification criteria
Non-combustible materials	ISO 5660-1 with 50 kW/m^2 exposure for 20 mins	THR $\leq$ 8 MJ/m^2 and PHR $\leq$ 200 kW/m^2
Quasi non-combustible materials	ISO 5660-1 with 50 kW/m^2 exposure for 10 mins	THR $\leq$ 8 MJ/m^2 and PHR $\leq$ 200 kW/m^2
Fire-retardant materials	ISO 5660-1 with 50 kW/m^2 exposure for 5 mins	THR $\leq$ 8 MJ/m^2 and PHR $\leq$ 200 kW/m^2

Exception: Peak heat release rate is allowed to exceed 200 kW/m^2 provided the time interval where the heat release rate stayed above 200 kW/m^2 is less than ten seconds.

10.6 Chinese flammability requirements

China has established a non-combustible test and a three-class classification system for combustible wall and ceiling interior finishes. They have also established a two-class classification system for combustible floor coverings. The following test methods are used for the purpose of classification.

GB 5464-99: non-combustibility test method of building materials. This test is similar in principle to ISO 1182 and ASTM E136. Used for classification in Class A.

GB 8625-88 Combustibility test of burning materials. This test is based on the German fire test apparatus *Brandschacht* (DIN 4102-15) and is used for classification in Class B1 and B2 for wall and ceiling linings.

GB 8626-88: Flammability of building materials. This test is based on the *Kline burner* and is used for classification in Class B3 for wall and ceiling linings.

GB 11785-89: Determination of thermal transfer of flooring material-radiant heat method. The test method is similar in principle to ASTM E648 and ISO 9239-1. Floor coverings with a critical radiant flux $\geq$ 4.5 kW/m^2 are classified B1 while those between 4.5 and 2.2 kW/m^2 are classified B2.

10.7 Future trends

Various drivers will continue to push innovations in fire testing and the adoption of improved test methodologies for flammability of building materials. The first driver is the increased level of engineering involved in the fire protection profession. The increased use of fire models to demonstrate that acceptable levels of fire safety will increase the demand for fire tests that provide suitable test results to use either as input to the models or provide validation data for the models. Tests that provide only a comparative measure of fire performance under specified and limited test conditions will become less acceptable. In the future, Belles (2003) noted that we may use fire models to link the actual hazards created by the use of a product in a specific situation to regulatory limits.

In synergy with increased fire protection engineering is the international movement toward performance-based or objective-based building codes. Many of the traditional tests for flammability that have been acceptable in a prescriptive code environment will hinder the potential benefits of the performance-based codes. For harmonization and reliable assessment of fire resistance of materials, Tewarson *et al.* (2004) noted it is necessary to use quantitative measurements, rather than visual observation. Even if the goals of performance-based codes are not achieved in the near term, Beyler (2001) believes that there is the need to rationalize our prescriptive fire safety requirements by using these methods for assessing fire safety performance.

Grayson and Hirschler (1995) noted (i) the recent trend to replace older tests that only rank materials with new standard fire tests that can provide input into mathematical fire models and fire hazard assessment, and (ii) the use of real-scale tests for validation of the small-scale tests and the models. However, as noted by Karlsson *et al.* (2002), the validity of the models must be demonstrated for a wider range of materials and the models must be made more user friendly and widely available to engineers before there can be widespread performance-based design of interior finish materials. As is happening within the European Union, world globalization of markets will drive the harmonization of regulatory test standards for products. Tewarson *et al.* (2004) expects further harmonization of test methods as many regulatory agencies are considering augmenting or replacing the prescriptive-based fire codes (currently in use) by performance-based codes. FORUM for International Cooperation on Fire Research (Croce, 2001) supports this movement away from *ad hoc* approval tests and towards scientifically based tools (accurate data, tests, and models) as a basis for equitable performance levels.

The increased use of heat release rate measurements to quantify the flammability of building materials is likely to continue. Innovation in building materials will continue to be a driver for improvements in the testing of building products for flammability. One potential impact of a new material or product, such as foam plastic in recent history, is to illustrate the inadequateness of an existing test method to prevent high-hazard materials from the market. It is expected that the introduction of new and improved low-hazard materials will increase the pressure to develop and implement methodologies for degrees of combustibility that will not require prescriptive lists of exceptions to the current noncombustibility requirements.

10.8 Sources of further information and advice.

10.8.1 Standard organizations

ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428 2959, USA, www.astm.org

D 2843 Test for density of smoke from the burning or decomposition of plastics.
D 2859 Test method for ignition characteristics of finished textile floor covering materials.
D 2898 Test method for accelerated weathering of fire-retardant-treated wood for fire testing.
E 84 Test methods for surface burning characteristics of building materials.
E 108 Test methods for fire tests of roof coverings.
E 136 Test method for behavior of materials in a vertical tube furnace at 750 °C.
E 648 Test method for critical radiant flux of floor-covering systems using a radiant heat energy source.
E 970 Test method for critical radiant flux of exposed attic floor insulation using a radiant heat energy source.

Consumer Product Safety Commission. 4330 East West Highway, Bethesda, MD 20814-4408, USA, www.cpsc.gov

16 CFR Part 1209 Interim safety standard for cellulose insulation.
16 CFR Part 1630 Standard for the surface flammability of carpets and rugs (FF 1-70).

Factory Mutual Approvals, 1151 Boston-Providence Turnpike, Norwood, MA 02062, USA www.fmglobal.com/approvaIs

4450 Approval standard for class I insulated steel deck roofs.
4880 American national standard for evaluating insulated wall or wall and roof/ceiling assemblies, plastic interior finish materials, plastic exterior building panels, wall/ceiling coating systems, interior and exterior finish systems.

National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101 USA, www.nfpa.org

101 Life safety code
253 Test for critical radiant flux of floor covering systems using a radiant heat energy source.
259 Test method for potential heat of building materials.
265 Standard method of fire tests for evaluating room fire growth contribution of textile wall coverings.
268 Standard test method for determining ignitability of exterior wall assemblies using a radiant heat energy source.
285 Standard method of test for the evaluation of flammability characteristics of exterior non-load-bearing wall assemblies containing combustible components.
286 Standard method of fire test for evaluating contribution of wall and ceiling interior finish to room fire growth.
701 Standard methods of fire tests for flame-propagation of textiles and films.

Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096, USA, www.ul.com

723 Test for surface burning characteristics of building materials,
790 Standard test method for fire tests of roof coverings.
1040 Fire test of insulated wall construction.
1256 Fire test of roof deck construction.
1715 Fire test of interior finish material.
1975 Fire tests of foamed plastics used for decorative purposes.

Underwriters Laboratories of Canada, 7 Crouse Road, Scarborough, Ontario, M1R 3A9 Canada. www.ulc.ca

CAN/ULC-S102-M88 Test for surface burning characteristics of building materials and assemblies.
CAN/ULC-S102.2-M88 Test for surface burning characteristics of flooring, floor covering, and miscellaneous materials and assemblies.
CAN/ULC-S107-M87 Fire tests of roof coverings.

CAN/ULC-S134 Standard method of fire test of exterior wall assemblies.
CAN/ULC-S114-M80 Test for determination of non-combustibility in building materials.
CAN/ULCS135-04 Standard test method for the determination of combustibility parameters of building materials using an oxygen consumption calorimeter (cone calorimeter).

Canadian Codes Centre, Institute for Research in Construction, National Research Council Canada, Building M-23A, 1200 Montreal Road, Ottawa, Ontario, KIA OR6 Canada (Institute for Research and Construction of the National Research Council of Canada, *http://irc.nrc-cnrc.gc.ca/irccontents.html* and Canadian Commission on Building and Fire Codes *http://www.nationalcodes.ca/*)

National Building Code of Canada 1995.

International Organization for Standardization http://www.iso.ch/

ISO 1182: 2002: Reaction to fire tests for building products - Non-combustibility test.
ISO 1716: 2002: Reaction to fire tests for building products - Determination of the heat of combustion.
ISO 5660-1:2002: Reaction to fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method).
ISO 9239-1:2002: Reaction to fire tests for floorings - Part 1: Determination of the burning behaviour using a radiant heat source.
ISO 11925-2:2002: Reaction to fire tests - Ignitability of building products subjected to direct impingement of flame - Part 2: Single-flame source test.

European Committee for Standardization: http://www.cenorm.be/

EN 13501-1: Fire classification of construction products and building elements. Classification using test data from reaction to fire tests.
EN 13823:2002: Reaction to fire tests for building products. Building products excluding floorings exposed to the thermal attack by a single burning item.

10.9 References

American Forest & Paper Association (2002), *Flame spread performance of wood products*, Design for Code Acceptance (DCA) No. 1, Washington DC, AF&PA. (Available at *www.awc.org*).
Belles D W (2003), 'Interior finish', in *Fire Protection Handbook*, Section 12, Chapter 3, Quincy, MA, National Fire Protection Association, 12-43–12-60.

Beyler C L (2001), 'Fire safety challenges in the 21st century', *Journal of Fire Protection Engineering*, 11(1), 4-15.

Blackmore J M, Delichatsios M A, (2002), 'Flammability tests for assessing carpet performance', *Journal of Fire Protection Engineering*, 12, 45–59.

Canadian Wood Council (1991), *Wood and Fire Safety*, Ottawa, Canadian Wood Council, 266 p.

Carpenter K, Janssens M (2005), 'Using heat release rate to assess combustibility of building products in cone calorimeter', *Fire Technology*, 41, 79–92.

Clark F R S (1981), 'Fire spread tests - a critique', *Fire Technology*, 17(2), 131–138.

Croce P A (2001), 'The FORUM for International Cooperation on Fire Research: A position paper on evaluation of products and services for global acceptance', *Fire Safety Journal*, 36(7), 715–717.

Eickner H W (1977), 'Surface flammability measurements for building materials and related products', in Kolthoff I M, Elving P J and Stross F H, *Treatise on Analytical Chemistry*, Part 3, Volume 4, John Wiley & Sons (available at http://www.fpl.fs.fed.us/documnts/pdfl977/eickn77a.pdf).

Emmons H W (1974), 'Fire and fire protection', *Scientific American*, 231(1), 21–27.

Galbreath M (1964), *Flame spread performance of common building materials*. Technical Paper No. 170, NRCC 7820, Ottawa, Division of Building Research, National Research Council Canada.

Grayson S J, Hirschler M M (1995), 'Comparison of ASTM fire standards with international fire standards for building and contents', in Grand A F *Fire standards in the international marketplace*, ASTM STP 1163, Philadelphia, PA, American Society for Testing and Materials, 41-60.

IRC (Institute for Research in Construction) (1995), *National building code of Canada 1995*, Ottawa, National Research Council of Canada, Institute for Research and Construction. 571 p.

Janssens M, Douglas B (2004), 'Wood and wood products', Chapter 7, in Harper C A, *Handbook of Building Materials for Fire Protection*, New York, McGraw-Hill, 7.1–7.58.

Karlsson B, North G, Gojkovic D (2002), 'Using results from performance-based test methods for material flammability in fire safety engineering design', *Journal of Fire Protection Engineering*, 12, 93–108.

Richardson L R (1994), 'Determining degrees of combustibility of building materials- National Building Code of Canada', *Fire and Materials*, 18, 99–106.

Richardson L R, Brooks M E (1991), 'Combustibility of building materials', *Fire and Materials*, 15, 131–136.

Stevens M G (1998), 'Cone calorimeter as a screening test for ASTM E-84 tunnel test', in *Proc. 5th International conference in Fire and Materials*, London, Interscience Communications, 147–151,

Tewarson A, Chin W, Shuford R (2004), 'Materials specifications, standards, and testing', Chapter 2, in Harper C A, *Handbook of Building Materials for Fire Protection*, New York, McGraw-Hill, 2.1–2.54.

White R H, Dietenberger M A (2004), 'Cone calorimeter evaluation of wood products', in *Proc. 15th Annual BCC Conference on Flame Retardancy*, Norwalk, CT, Business Communications Co., Inc., 331-342.

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