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REVIEW OF THE FIRE PERFORMANCE OF FLOOR COVERINGS

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ABSTRACT

A series of 13 commercial flooring products were chosen for fire testing. All the floor coverings were tested using a cone calorimeter to determine the peak rate of heat release and the time to ignition. An investigation of a suitable heat flux density in the cone calorimeter for assessing floor coverings was made, and was determined to be 35 kW/m^2. Each material was also subjected to the hot metal nut test (BS 4790, 1987).

It was found that the floor coverings showed a wide range of fire performance, including a factor of four in the peak rate of heat release and time to ignition. It was not possible to correlate the results obtained from the cone calorimeter with the hot metal nut test nor with a radiant panel test (flooring radiant panel test or AS 1530.3). A four stage classification scheme is presented for the fire performance of floor coverings, based on parameters determined in the cone calorimeter test method.

INTRODUCTION

Fire Engineering and Floor Coverings

For fire engineering design it is vital to determine the extent to which flooring materials contribute to the development of hazardous conditions within a building as a result of fire, and whether the floor coverings are likely to endanger the life safety of building occupants. The work described here complements that previously completed at BRANZ to provide a comprehensive and scientific understanding of flame spread and smoke development contribution from walls, ceilings, external wall claddings and floors in buildings, and their contribution to development of hazardous conditions in buildings. More importantly, this greater understanding will ensure better regulatory controls for the specification of combustible finishes in buildings.

Floor coverings have been shown to contribute to fire growth and will contribute to the hazard to life in building fires. There is a need to control the use of floor coverings in certain circumstances to reduce the hazard to life. The Approved Documents[1] of the NZBC[2] recognised this by providing limitations on the use of materials for floor coverings in exitways and SC (Sleeping Care) or SD (Sleeping Detained) facilities. It is unclear whether the adopted method, the hot metal nut test[3], is able to eliminate materials that may contribute to rapid fire spread. The test method involves placing a hot metal nut on the surface of the flooring material and measuring the radius of the fire effect. The hot metal nut test does not provide any measure of performance to a flaming ignition scenario, or where development of a hot layer in the building causes the flooring to be subject to pre-heating effects. To provide a realistic assessment of the fire hazard potential of flooring materials and floor coverings these latter scenarios should also be considered.

Fire Hazard from Floor Coverings

There are three ways in which fire, irrespective of the products involved, can lead to harm to people, property or business operations. These are; 1) The heat or flames spreading from the item first ignited to other products, 2) the production of smoke which can obscure vision and possibly hinder the escape of trapped victims, and 3) the generation of toxic products in smoke which can be inhaled by victims and cause injury or death.

Fire hazard is associated with a number of different fire properties including ignitability, flame spread, and toxicity. However, it has now been established that the single most important property is the peak rate of heat release[4], and to quote from (Hirschler, 1992)[5]-

> *"In fact, the importance of heat release as the measure of fire hazard vastly exceeds those of ignitability, flame spread, or toxicity. The heat release rate governs not only the burning rate (and mass loss rate) of the product being consumed, but also the amounts of other products (present in the fire compartment or in other compartments) which will be ignited and burn."*

It is essential that a fire test method that measures the fundamental properties of burning items in a real fire is used to assess the fire hazard of floor coverings. The best approach is to estimate the rate of growth of a real fire based on measuring, in a small-scale test, the peak rate of heat release for materials and products. The modelling process requires measurements of yield factors to give the amounts of heat, smoke and toxic gases generated per unit mass burnt.

REVIEW OF FIRE TEST METHODS

Fire Testing of Floor Coverings

In broad terms a test method will be used to assess one or more properties of a material or system exposed to a particular condition. The aim of a test method should be to provide information for an analysis that can determine whether a particular functional requirement of a system is achieved or not. For fire tests the aim has generally been to provide a method for predicting the behaviour of a system in an actual situation so that risk of damage to buildings and people can be minimised. However, a critical analysis of most test methods for floor coverings would reveal the above aim is not often achieved.

The following requirements of a sound fire test method are based on concepts presented by Nordtest[6] for standard fire resistance testing and have been adapted for use with a more general assessment of fire test procedures.

For a fire test method to provide hazard assessment for international acceptance it must fulfil certain essential requirements:

- **Representative exposure**
  The test simulates the characteristics of a real fire scenario; including ignition source and fire intensity.
- **Representative test object**
  The sample tested is representative of a practical application of the test object.
- **Broad application for fire scenarios and flexibility in application**
  With a minimal variation in the test method it can be applied to a range of fire scenarios and material applications - in walls, ceilings and floors, as well as external claddings.
- **Records a well defined property**
  The test must provide a record of a releVant, defined physical or chemical property, e.g. ignitibility, rate of heat release, or rate of smoke production.
- **Good reproducibility and repeatability**
  Good reproducibility between different laboratories and good repeatability within the same laboratory.

- **Uncomplicated test conditions**
  The preparation and test execution time should be reasonable for the scale of test required. For example a small-scale test should require no more than half a day to complete, including replicates.
- **Wide applicability of reporting**
  The results from the fire test in one country are applicable for fire classification in another country.

Fire Test Methods for Floor Coverings

There are three specific tests that have been developed to measure the fire performance of floor coverings: 1) The flooring radiant panel test, measuring a critical radiant flux, 2) the hot metal nut test, and 3) the methenamine tablet test.

Many other tests are also relevant particularly if the sample is exposed in the horizontal orientation. In particular we will address the following test methods: 4) AS 1530.3 (samples are tested in the vertical orientation only), 5) the cone calorimeter (allows testing of both horizontal and vertical samples), and 6) the Nordtest FIRE 007 method (flooring sample is tested on an inclined plane).

The fourth test AS1530.3[7] is of interest as it is currently used in Australia and New Zealand for the fire performance of wall linings and for external wall claddings. It is also used for floor coverings in Australia. The fifth method, the cone calorimeter is not currently used anywhere in the world for the evaluation of floor coverings, but is known to provide valuable data in the assessment of fire hazard of building materials.

Other test methods, including full-scale room fire tests, such as those developed by the American Society of Testing and Materials[8] and the International Standards Organisation[9] are not considered suitable for regulatory purposes as they can be very expensive, provide relatively poor reproducibility and are time consuming to perform. Some full-scale test methods[10,11] are often ad-hoc in nature and are essentially research tools. They provide useful data for studies that compare results from small scale tests with the full-scale test method but are often restricted to a single country or even laboratory.

1. Flooring radiant panel test

ASTM E648: 1986 Standard Test Method for Critical Radiant Flux of Floor-Covering Systems
Using a Radiant Heat Energy Source (flooring radiant panel test)

Equivalent tests DIN 4102, ISO 9239-1

In this test, a horizontally mounted floor covering is exposed to radiant energy from a gas/air fuel radiant panel mounted above one end of the sample and inclined at 30° to the horizontal mounted floor covering specimen. The radiant panel generates a heat profile along the length of the sample. A gas-fired pilot burner is used to ignite the sample, and the distance the floor covering burns to extinguishment is converted to Watts per square centimetre (W/cm^2). This value is reported as the Critical Radiant Flux (CRF) and is the minimum radiant energy needed to sustain flame propagation in the test. The United States National Bureau of Standard (NBS) carried out full-scale corridor burn tests with a wide range of floor coverings and obtained a good correlation between the flooring radiant panel test and full-scale tests.

2. Hot metal nut test

BS 4790 : 1987 Determination of the effects of a small source of ignition on textile floor coverings
(hot metal nut method)

Equivalent tests none

This British Standard is intended to assess the ease with which a textile floor covering would ignite under certain practical conditions, e.g. when a burning cigarette, a hot coal, or a similar source of ignition is dropped on it. The standard makes it very clear that it is not intended for assessment of the contribution a textile floor covering will make to an established fire. Nor does it take any account of smoke and toxic fumes that may be produced. BS 5287: 1988 Assessment and labelling of textile floor coverings tested to BS 4790 is provided for labelling of textile floor coverings for contract use. The test measures the radius of effect of an M16 stainless steel nut when heated to 900 °C and placed on the flooring sample. A low radius of effect is considered less than 35 mm.

3. Methenamine tablet test

BS 6307 : 1982 Determination of the effects of a small source of ignition on textile floor coverings (methenamine tablet test)

Equivalent tests ISO 6925, ASTM D2859

Like the hot metal nut test the methenamine tablet provides a small ignition source flammability test for textile floor coverings. Unlike the Hot Metal Nut, this test introduces a flaming ignition source in the form of a flaming methenamine tablet. The test standard makes it clear these two tests are to be used together where the flaming tablet is important in the assessment of upper surface characteristics and the glowing ignition source of the metal nut allow it to sink through any surface pile to the substrate.

4. AS 1530.3

AS 1530: 1989 Methods for Fire Tests on Building Materials, Components and Structures-Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release.

Equivalent tests none

This test exposes a vertical specimen to a gradually increasing heat flux up to a maximum of about 30 kW/m^2 by moving the specimen closer to a radiant panel over a period of 20 minutes. AS 1530.3 is used in Australia for regulation and specification of floor coverings, however the test is run in the vertical orientation and provides dubious results for floor coverings. The ignitability index requirement of the Australian Building Code requires that ignition is limited under the test conditions. Although ignitability is an important factor influencing flame spread, in this case, the heat flux level and the gradual heating conditions may be considered not severe enough to represent a developing fire. AS 1530.3 has been criticised[11] for yielding results which do not correlate with full-scale fire scenarios.

5. Cone calorimeter

ISO 5660: 1995 Fire Tests - Reaction to Fire - Rate of Heat Release from Building Products

Equivalent tests ASTM 1534

The cone calorimeter[12] developed at NIST provides a small-scale test method for measuring the rate of heat release. Data from the cone calorimeter can be used in fire models to predict development of a potential fire. The cone calorimeter has been shown to provide the best correlation with real scale fire test results.

6. NT FIRE 007

NT FIRE 007, 1985, Floorings: Fire spread and smoke generation

Equivalent tests none

The Nordic test method for floor coverings has been developed from a test for roof coverings. The 1000 mm x 400 mm specimen is mounted at an angle of 30° to the horizontal plane. Forced air flow of 2 ms^{-1} is passed over the exposed surface. A burning wooden crib exposes the underlying surface to a heat flux of 20 - 75 kW/m^2 and ignites it. There is no external heat radiation. Damage inflicted to the specimen is observed and recorded as a flame spread length.

Summary

Table 1, below, summarises the performance of selected fire test methods and the suitability for floor coverings against the criteria of a good fire test outlined previously.

Table 1: Fire Test Methods for Floor Coverings

	Representative fire exposure	Representative test object	Broad fire scenarios and flexibility in application	Records a well defined property	Good reproducibility and repeatability	Complication of test conditons	Application of reporting
Full scale							
ISO Room Fire	V.Good	V.Good	V.Good	V.Good	Good	Poor	V.Good
CSIRO Room-Corridor	V.Good	V.Good	V.Good	Good	NA	Poor	NA
SP Room-Corridor	V.Good	V.Good	V.Good	Good	NA	Poor	NA
Intermediate scale							
none							
Small scale							
Multiply parameter test							
NT FIRE 007	Good	V.Good	Poor	Good	NA	Good	NA
AS 1530.3	Poor	Poor	Good	Good	Poor	Good	Poor
Cone Calorimeter	V.Good	Good	V.Good	V.Good	V.Good	V.Good	V.Good
Small scale							
Single parameter test							
Flooring Radiant Panel Test	Good	V.Good	Good	Good	Good	V.Good	Good
Methenamine Tablet	Poor	V.Good	Poor	Poor	V.Good	V.Good	V.Good
Hot Metal Nut	Poor	V.Good	Poor	Poor	V.Good	V.Good	V.Good

The two small ignition source test methods, the hot metal nut and the methenamine tablet provide useful information for a particular ignition scenario. They do not allow an assessment of the contribution of floor coverings to fire growth and therefore hazard to life, property or industry.

The radiant panel tests (flooring radiant panel test and AS1530.3) allow for a more complex flammability ignition and heat flux fire scenario but fall short of providing an equivalent full-scale fire scenario for a developing fire. The flooring radiant panel test has been shown to give good correlation with full-scale tests involving wind-opposed flame spread. AS 1530.3 has yet to be correlated with any full-scale test method. The inclined plane and forced air flow of the NT FIRE 007 provides the more severe wind-aided scenario of flame spread, and as explained above, gives results which can be correlated with rate of heat release data.

The cone calorimeter provides measurements of actual physical properties of materials at various imposed heat flux densities. Data from cone calorimeter testing can be used to predict the performance of building materials, including floor coverings, in full-scale fire testing.

REVIEW OF FIRE RESEARCH

Recent Studies of Fire and Floor Coverings

Prior to the 1960's floor coverings were customarily exempted from coverage in the building codes[13] regulating life safety from fire. Since 1960 a small number of significant fires have indicated that carpets can be the prime material involved in the development and spread of a fire. In the US, during the 1970's, the Steiner Tunnel test was used to assess the "flame spread index" for floor coverings. Criticism of the suitability of the Steiner Tunnel test for the assessment of floor coverings lead to the concept of critical radiant flux. In their work[14, 15, 16, 17] on model corridor fire tests the National Bureau of Standards (now NIST) found that the radiant energy impacting on a floor covering had a significant influence on the propagation of flame across the floor covering. As a result of their work the flooring radiant panel test was adopted in 1978 as ASTM E648. *Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source.* There have been no recent studies from NIST as to the contribution of floor coverings to fire development, and as Ohlemiller[18] notes; "*the relatively minor (research) activity level in this category of fire hazard seems justified*". More recently Europe, through the EC, has moved towards adopting the flooring radiant panel test for floor coverings even though current research as outlined below, indicates it may not be the most suitable method of determining the fire hazard of floor coverings.

Small scale fire tests for floor coverings

The European Community (EC) has mandated the ISO/TC92 committee to prepare test methods which will support the aim of removing technical obstacles to trade for products in the construction field. The working group, WG3 Surface Spread of Flame Test of the sub committee SC1 Reaction to Fire, have investigated the suitability of the methenamine tablet test and a spread of flame test for floor coverings based on the flooring radiant panel test, ISO 9239-1 for regulating floor coverings. The later test has been modified to incorporate a line burner which improves the repeatability and reproducibility of the test method. This work is ongoing and at this stage does not consider the cone calorimeter or any full-scale fire test methods.

The Wool Research Organisation of New Zealand (WRONZ) have completed studies comparing the AS 1530.3 Spread of Flame indices with the flooring radiant panel test[19]. They conclude that the flooring radiant panel test should be used for specifying the flammability performance of floor coverings due to its demonstrated correlation with full-scale fire test scenarios.

WRONZ report that full-scale corridor burn tests by the United States National Bureau of Standards on a wide range of floor coverings obtained a good correlation between the flooring radiant panel test and full-scale testing. WRONZ also concludes that the AS 1530.3 test is not suitable for the flammability assessment of floor coverings.

Small scale fire testing and comparison with cone calorimeter

Tomann[20] makes a detailed study on the assessment of floor coverings using three different methods; the cone calorimeter, the Nordtest floor coverings test NT FIRE 007[21] and the radiant panel method. Some degree of correlation was found between the results of the cone calorimeter and the intermediate scale NT FIRE 007 test. Between the other methods, Tomann concludes, no correlations seem to exist. Tomann also provides a formulation for flame spread distance in the NT FIRE 007 test based on the cone calorimeter parameters; ignition time, maximum rate of heat release and the duration of burning. This solution is presented as Equation 2.

Östman and Mikkola[22] provide a specialised comparison of the performance of wooden floors to the proposed ISO test method (the radiant panel method as discussed in 2.5.1), the Nordtest FIRE 007 test and the data from the cone calorimeter. Their results indicate a slight correlation between the cone calorimeter and the other test methods and a confirmation of the Tomann study with a slightly higher correlation with the Nordtest NT FIRE 007 method.

Cone calorimeter test parameters and fire performance classification

Hirschler[5] provides detailed comparison of cone calorimeter and flooring radiant panel test methods with a series of 22 commercial carpet tiles selected for testing. He concludes that 25 kW/m^2 provides the optimum radiant heat flux density for repeatability in the cone calorimeter and that no correlation was observed between the cone calorimeter and the flooring radiant panel test parameters. Hirschler points out that the cone calorimeter provides the best correlatable test with full-scale fire test results.

Hirschler also presents a classification scheme based on material performance in the cone calorimeter. The scheme is based on the ratio of the time to ignition (in seconds) and peak rate of heat release (kW/m^2). It is desirable for a flooring material to exhibit a high value for this ratio.

Full-scale testing, cone calorimeter data and mathematical modelling

The Commonwealth Scientific and Industry Research Organisation (CSIRO) Australia have begun a program to consider the relationship between the current Australian assessment method, AS 1530.3, and their own newly established full-scale room-corridor test facility. McArthur[11] concludes that the AS 1530.3 test provides a poor correlation to a full-scale fire scenario for floor coverings. He also suggests the full-scale test method could be used to provide a suitable tool for assessing the validity of small-scale testing suitable for regulating the fire performance of floor coverings. McArthur recognises the value of the flooring radiant panel test as representative of a well developed fire scenario.

Van Hees and Vandevelde[23] makes it clear that the traditional assumption of wind-opposed flame spread for floor coverings is no longer valid. He points out the possibility of both wind-aided and wind-opposed flame spread on floor coverings. Van Hees has been able to complete a large number of full-scale room corridor tests conducted at the Swedish National Testing and Research Institute. He concludes that the flooring radiant panel test, which has been validated for wind-opposed flame spread of floor coverings, is unable to predict the more severe wind-aided flame spread scenario. He suggests modifications to the radiant flooring panel which allow prediction of wind-aided flame spread.

Van Hees[10] provide two types of mathematical model for the prediction of wind-aided flame spread on floor coverings validated with full-scale testing. Both models rely on cone calorimeter data for input. The first gives an analytical solution for the flame spread as a function of time. The second model is a numerical simulation. The first model can be used for a specific scenario and gives a good estimate of the possible risk of floor coverings. The second model can be used for zone or field models as input for growth of the fire as a function of time. Thus providing the user with an ability to calculate the flame spread in a wider range of fire scenarios.

Van Hees suggests limits based on acceleration of flame front leading to flashover in a full-scale room-corridor fire test facility. He presents four groupings of behaviour in the full-scale test as floor coverings with;

- no flame spread in the corridor, N
- a short but fast flame spread, SF
- a slow but continuous flame spread and SC
- flashover in the corridor. F

He also provides an analytical model for wind-aided flame spread on floor coverings that shows a strong correlation for prediction of flashover between the full-scale test performance and data from the cone calorimeter. The model provides flame spread accelerations for two situations; firstly for the time from ignition to burnout and secondly for the time greater than burnout of the floor sample. The following cone calorimeter parameters are required; ignition time, average rate of heat release and the duration of burning (expressed as time to burnout). This solution is presented as Equation 3, Equation 4 and in Table 3.

Summary

It appears that the United States and the European Community still consider the flooring radiant panel test a suitable method for the assessment the flame spread on floor coverings. In contrast more recent work involving full-scale room-corridor fire tests indicate that the Flooring Radiant panel test method is unable to predict the behaviour of floor coverings in the wind-aided flame spread scenario. The flooring radiant panel was developed with consideration of the less severe wind-opposed flame spread scenario only.

The single most important parameter in determining fire hazard from burning materials is now clearly established as the rate of heat release. Of all the fire test methods currently available the cone calorimeter provides a small scale, economical test method that is now well established and provides data which can be used to predict the full-scale performance of floor coverings and building materials.

A series of flooring materials, representing three different types of floor coverings in the New Zealand market, have been assessed using the cone calorimeter and hot metal nut methods.

EXPERIMENTAL INVESTIGATION

Thirteen floor covering materials, representing three different types of floor coverings in the New Zealand market, were selected for assessment using the cone calorimeter and hot metal nut test methods. Four textile carpets, six thin floor coverings and three wood based floorings were used. Details of the tested floor coverings are given in Table 3.

Cone Calorimeter

The cone calorimeter test equipment used for this study was specified in the standard ISO 5660[24]. The equipment included a laser smoke-measuring device according to ASTM E 1354[12]. All tests were carried out in the horizontal orientation with the retainer frame, the grid was not used. All samples were wrapped in aluminium foil on the unexposed sides. The wrapped sample was placed in the sample holder over a mineral fibre blanket. The heat flux density was set at 25, 35 and 50 kW/m^2 and results averaged from three replicates. Tests were conducted at the stated heat flux levels for at least 15 minutes from the start of the test.

The following parameters from the cone calorimeter test were recorded: t_{ig}, Time to ignition (sec), $\dot{Q}''_{\max}$, Maximum Rate of Heat Release (kW/m^2), $\dot{Q}_{tot}$, Total Heat Released (kJ), m, Total mass loss during the burning phase (g) and t_b, the duration of burning (sec).

Hot Metal Nut

The following parameters from the hot metal nut test were recorded: t_f , Time to flaming (sec), t_g, Time of afterglow (sec), r, Measured radius of char (mm) and R, Radius of effect (mm).

Test Results

According to the results of the hot metal nut tests, all materials meet the New Zealand requirements (having a low radius of effect of ignition) for use in exitways for all purpose groups, or any space occupied by purpose groups SC or SD. The cone calorimeter is not currently used anywhere in the world for the evaluation of floor coverings, and therefore, no test requirements exist to deem a product acceptable or not acceptable.

Comparison of the Cone Calorimeter and the Hot Metal Nut

A comparison of the ratio of ignition time and the maximum rate of heat release to the radius of effect measured with the hot metal nut test method returned a very low correlation coefficients indicating little or no correlation exists. The best correlation occurs at the highest imposed heat flux density of 50 kW/m^2.

FLAME SPREAD MODELLING AND A PROPOSED PERFORMANCE CRITERIA

Spread of flame

Babrauskas[25] and Hirschler[5] have proposed that the ratio of the maximum rate of heat release $\dot{Q}''_{\max}$ and the time to ignition t_{ig} in the cone calorimeter test could be used as a measure of the fire hazard of a product. That is:

$$(\text{fire hazard})_{CC} = \frac{t_{ig}}{\dot{Q}''_{\max}}$$

Equation 1. Fire hazard in the cone calorimeter

The ratio of the maximum rate of heat release $\dot{Q}''_{\max}$ and the time to ignition t_{ig} from the cone calorimeter data is presented in Table 2.

Table 2. Performance of Floor Coverings

Material	Tested at 25 kW/m^2 Eqn.1 (s-m^2/kW)	Tested at 25 kW/m^2 Flame Spread (mm)	Tested at 35 kW/m^2 Eqn.1 (s-m^2/kW)	Tested at 35 kW/m^2 Flame Spread (mm)	Tested at 50 kW/m^2 Eqn.1 (s-m^2/kW)	Tested at 50 kW/m^2 Flame Spread (mm)	Classi-fication
1	0.689	165	0.033	387	0.003	852	3
2	0.286	309	0.111	431	0.030	549	4
3	0.328	313	0.121	392	0.028	575	3
4	-	-	-	394	-	-	3
5	0.559	257	0.641	244	0.076	385	2
6	0.830	200	0.241	264	0.059	374	2
7	1.446	163	0.833	200	0.040	392	2
8	0.719	297	0.259	369	0.087	449	3
9	-	-	-	157	-	272	1
10	-	139	-	-	-	340	1
11	0.162	300	0.045	409	0.025	587	4
12	0.205	293	0.058	402	0.026	494	4
13	0.773	299	0.355	340	0.150	405	3

Tomann[20] observes a reasonable correlation between the results from intermediate scale testing (NT FIRE 007 method) and the ratio of the ignition time and the heat release in the cone calorimeter. Tomann presents a correlation for the flame spread length in the NT FIRE 007 test method and the following parameters of the cone calorimeter tests; time to ignition t_{ig}, the duration of burning t_b, and the maximum rate of heat release $\dot{Q}''_{\max}$. The parameters have been selected from dimensional analysis of Thomas and Karlsson[26] and the flame spread theory of Baroudi and Kokkala[27].

A least squares fit of the cone data and NT 007 results by Tomann leads to:

$$(\text{flamespread})_{NT} = x_f = 44 \cdot \dot{Q}''^{\,0.38}_{\max} \cdot t_{ig}^{-0.19} \cdot t_b^{0.12}$$

Equation 2. Flame spread in NT FIRE 007

The flame spread determined from the cone calorimeter data using this formulation is presented in Table 2.

Tomann also presents a correlation of the cone calorimeter with the flooring radiant panel test. The results suggest that the ratio of ignition time and the maximum rate of heat release does not correlate at all with the critical heat flux in the flooring radiant panel test.

Flame acceleration and flashover

Van Hees[10] provides an analytical model for wind-aided flame spread on floor coverings which predicts flashover in the full-scale room-corridor fire test from cone calorimeter data. The model is based on two parameters that express the flame acceleration before and after burnout of the flooring sample.

If the first parameter, $C_i > 1$, then the material is likely to cause flashover.

$$C_i = k_f \cdot \dot{E}'' - 1$$

Equation 3. C_i parameter for flame spread

$$C_b = k_f \cdot \dot{E}'' - \frac{t_{ig}}{t_{bo}} - 1$$

Equation 4. C_b parameter for flame spread

where; k_f = constant relating flame length to heat release for flame geometry

= $0.01 \text{ m}^2 / \text{kW}$

$\dot{E}''$ = heat release of the material, taken as the average for the duration of the burn time.

Values of $C_b > 1$ represent a decrease in the pyrolysis front after extinction. Van Hees observes that the correlation with full-scale test result is better with cone calorimeter test data at 35 kW/m^2. Values of C_i and C_b for cone test data at 25 kW/m^2 and 35 kW/m^2 are given in Table 3. Materials 2, 6, 10 and 11 are all predicted to proceed to flashover in the SP room-corridor test. Three of these materials 2, 10 and 11 are also assessed as having the greatest flame spread by Equation 2.

Table 3. Parameters of an Analytical Solution

		25 kW/m^2		35 kW/m^2		classi-fication
Material	Description	Ci	Cb	Ci	Cb	
1	100% Wool carpet	0.50	0.06	1.58	1.56	S
2	100% Polypropylene matting	**1.08**	0.96	0.84	0.77	**F**
3	100% Polypropylene carpet	0.98	0.88	1.11	1.03	S
4	100% Nylon carpet	-	-	1.06	0.88	S
5	100% Heterogenous PVC	0.57	0.42	0.60	0.37	S
6	100% Heterogenous PVC	**1.03**	0.54	1.10	0.97	**F**
7	100% Heterogenous PVC + anti-slip addins	0.58	0.05	0.67	0.30	S
8	100% Linoleum	0.72	0.49	0.82	0.63	S
9	100% Heterogenous PVC	-	-	0.48	-0.16	N
10	100% Homogeneous PVC	0.43	-0.11	-	-	N
11	Timber veneer over Particleboard	**1.06**	0.88	1.14	1.11	**F**
12	Timber veneer over Cork	**1.08**	0.91	1.12	1.09	**F**
13	Timber veneer over Spruce	0.82	0.63	0.97	0.71	S

Classification based on predicted performance in full-scale room-corridor tests (Van Hees, 1997)

F: Flashover **S**: Steady flame spread **N:** No flame spread

Proposed classification of floor coverings

Hirschler[5] suggests that 25 kW/m^2 as an appropriate heat flux density for floor coverings (carpet tiles only) and provides a four stage classification method for fire hazard of floor coverings in the cone calorimeter test. With the wider range of floor coverings studied here, including wooden and thin floor coverings, it was found that 25 kW/m^2 did not provide a suitable heat flux density for the assessment of all floor coverings. All materials were assessed at 25, 35 and 50 kW/m^2 in the cone calorimeter.

The flame spread calculation of Tomann[20] provides a clear correlation with an intermediate test method for floor coverings. In order to use a classification based on the ratio of time to ignition and maximum rate of heat release for cone calorimeter test data at 35 kW/m^2 in was necessary to "scale up" the classification method proposed by Hirschler from data at 25 kW/m^2 to data at 35 kW/m^2. Figures 2 and 3 presents the correlations from 25 to 35, and 35 to 50 for both the ratio method of Hirschler and the flame spread method of Tomann. Figure 2 for the ratio and Figure 3 for the flame spread calculation. A high correlation can be observed and the following classification method is proposed for flooring materials assessed at 35 kW/m^2 in the cone calorimeter.

Table 4. Classification method for floor coverings

Flame Spread by Equation 2 (mm)	Class
$x_f \leq 200$	1
$200 < x_f < 300$	2
$300 < x_f < 400$	3
$x_f \geq 400$	4

A floor covering material with the highest level of hazard, Class 4, is likely to proceed to flashover in a room-corridor fire test. The lowest level of fire hazard, Class 1, is equivalent to no flame spread in a full scale test. These classifications could be used to restrict the use of materials which are likely to contribute to fire growth in exitways (say a minimum of Class 2), or in SC and SD purpose groups (say a minimum of Class 3).

Three of the materials (2, 11 and 12) were assessed as likely to proceed to flashover in a room-corridor fire test and showed a low ratio of the maximum rate of heat release $\dot{Q}''_{\max}$ and the time to ignition t_{ig} from the cone calorimeter data. They also indicated a high degree of flame spread by Equation 2. Of the three materials, only material 2 showed a radius of effect greater than 25 mm with the hot metal nut test method. None of the materials assessed failed to achieve the low radius of effect classification (35 mm).

CONCLUSIONS

1. The hot metal nut method is unsuitable for assessment of fire hazard for full-scale fire involvement in compartment fires.
2. The cone calorimeter provides a small-scale rate of heat release test that provides good correlations with full-scale fire test methods for assessing fire hazard of floor coverings.
3. A rate of heat release classification method for floor coverings is able to eliminate floor coverings which are of high fire hazard.

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