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FIRE TESTING OF LOW SLOPE ROOF ASSEMBLIES AN INTERNATIONAL REVIEW

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ABSTRACT

Knowing the fire behaviour of roofs is important when deciding on the fire safety strategy and risk analysis for buildings. Consequently appropriate fire test methods, which provide information about the fire behaviour of roofs, are needed.
Over the years many different test methods have been developed which address the fire behaviour of roofs. Some are developed by national standardisation organisations such as ASTM in the US or DIN in Germany while others are developed by the insurance industry. For each test method the results are linked to the fire scenario, which the test method is attempting to simulate. Some of the existing test methods focus only on surface spread of flame on the top of the roof, others address both surface spread of flame and penetration of fire from above, as well as the issue of fire spreading through the roofing system when exposed to a fire from within the building.
This paper provides a thorough review of fire test methods for roof assemblies, which currently are available in Europe and North America. The underlying fire scenario, the test parameters and the test results will be discussed.

INTRODUCTION

Consideration of fire spreading over and possibly through the roof of buildings lead to the banning of traditional straw roofs in major cities a long time ago and replaced these with e.g. slate and tile roofs. The development of more modern roof membranes in the 20th century as well as the use of these in combination with insulating products and/or wood boards led to the development of fire tests for roofs to determine that these would not cause an unwanted risk for fire spread.

The fire problem presented by roofing materials was among the first to be recognised in North America. Two prominent fire test methods, that are still being used today, were under development in 1903. One of these was developed by Underwriters' Laboratories, Inc. This fire test designed for the protection of urban buildings from fire included evaluations for ignition, fire spread, and penetration of exterior roofing materials. The fire test method was adopted in 1910 by the National Fire Protection Association for the classification of roof coverings. This test has been in use for about 100 years and has been updated with advancements in technology and is currently ASTM E108, Standard Test Methods for Fire Tests of Roof Coverings. Test methods in this standard are utilized in the protection of buildings and homes, the latter particularly in communities where wildland/urban interfaces exist.

Roof assemblies become involved in fire either by ignition of the external surface of the roof or a fire from within the building impinging on the underside of the roof assemblies. Life safety codes around the world focus primarily on the behaviour of roof assemblies when exposed to an ignition source on the outside. This is considered the scenario where the threat to life and property is greatest. Fire from

within the building, which develop into a fire of a size big enough to implicate the roof assembly, most often occur either after occupants have evacuated the room of origin, or conditions have become untenable and survival is no longer a possibility. These two scenarios, as well as the tests developed to represent them, will be discussed in the following.

EXTERNAL EXPOSURE TO FIRE

External fire spread on a roof system can be caused by fire in adjacent building components, neighbouring buildings, wild land fires ("flying brands") or hot work on the roof.

The term "flying brand" is used to describe the fire phenomenon of falling burning components or embers on a roof from a fire in the immediate vicinity of the roof.

External fire on a roofing system can spread to the interior and exterior of the building. Some combustible roofing materials can generate flowing burning droplets which may penetrate through the roofing system spread to exterior facades, or may initiate new fires by ignition of other exposed combustibles. Combustible building components are especially vulnerable during construction or renovation period when the tested system is incomplete. It is vitally important that sub-contractors using torch-welding or any hot installation work have an understanding of the fire risks from all exposed roofing system components.

These risks are tested by exposing the roof-decking material and the underlying insulation to radiation heat and/or to a small fire load consisting of an open flame and an air flow across the surface. Roofing systems are qualified and limited by the maximum slope of the roof system tested. The following lists test methods, which are currently used in Europe and North America. Table 1. provides further details of each test method.

ASTM E108[1]

This test method is used primarily in North America. UL790-4, NFPA 256-03 and CAN/ULC-S107-03 are functionally identical to ASTM E108.

Scenario

Four separate fire tests are used to provide 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.

Test specimen

The width of the deck is 1.0 m and the length of the deck is 4 m for Class C, 2.7 m for Class B and 2.4 m for Class A.

Ignition source

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. A Burning Brand test and Intermittent Flame test are also conducted for roof assemblies installed over combustible decks. The Brand test simulates various sizes ranging from 9.25 g to 2000 g (depending upon the Class of roof covering sought) of burning embers landing on the surface of the roof covering. The Intermittent flame test is a series of on/off flame exposures over a specified period of time. Both tests are designed to evaluate the propensity of the roof covering to prevent burn through to the underside of the combustible deck.

1. External exposure to roofs - Test details

	ASTM E108-07a	**CEN TS 1187**			
		Test 1	**Test 2**	**Test 3**	**Test 4**
Fuel Source	Flame of spread test: Gas Burner Burning Brand test: Class A: 1 brand 2000g. Class B: 2 brands 500g. Class C: 20 brands 9,25g	650±50 g of wood wool in a steel mesh basket suspended 10 mm from surface	Wood crib consists of eight pieces 10x10x100 mm nailed together. Total weight 40g	Brands made from fiberboard 250 kg/m3, 4 pieces 55x16x25 mm soaked in Heptane. Weight of wood crib alone 82g	Brand consisting of a gas flame (stage 1) and the radiant panel (stage 2)
Heat flux on surface from Radiant Panel				12.5±0.5 kW/m^2	12+1,5 kW/m^2
Airflow across specimen	5.1-5.5 m/s	Natural convection	2.0 or 4.0 m/s	3.0 m/s	
Length and width of test rig/specimen	Intermittent flame/burning brand: 1.0 x 1.3m, Spread of flame: A = 1.0 x 2.4 m B = 1.0 x 2.7 m C = 1.0 x 4.0	1800 x 800 mm	1000 x400 mm	3000 x1200 mm	840 x 840 mm.
Slope of deck	Max slope specified by manufacturer or Max 416mm/m	15° apply to a slope of 0 – 20°. 45° apply to a slope greater than 20°	30°	15° apply to a slope of 0 – 10°. 30° apply to a slope greater than 10°.	0° apply to a slope of 0 – 10°. 45° apply to a slope greater than 10°.
Type of deck	Combustible or noncombustible decks	The specimens shall be representative, in all details of practical application (except for standard supporting deck)	The specimens are normally attached to a standard substrate.	The specimens shall be representative in all details.	The specimen shall be representative of the complete roof assembly including deck and supporting structures

Duration of test

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 lowest Class C classification, the gas flame and air current is applied for four minutes. The airflow is maintained afterwards until no evidence of flame, glowing or smoke.

Classification criteria
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.

Under Class A, B and C exposures: at no time during intermittent flame, spread of flame or burning brand tests can

- any portion of roof blow off in form of flaming or glowing brands that continue to glow after reaching floor,
- the roof deck become exposed (except for non combustible decks),
- portions of roof deck fall away that continue to glow when reaching floor.

At no time during intermittent flame or burning brand test can there be sustained flaming under the deck.

CEN TS 1187[2]

This test standard is used in the European Union. It consists of four different tests, as it was not possible to find one test method, which could satisfy the requirements of the European regulators. The member states can determine which of the four test methods they will refer to in their national codes. The four tests are based on previously national test methods. Test 1 is based on the German test, Test 2 is based on the Scandinavian test, Test 3 is based on the French test and Test 4 is based on the British test. The classification criteria for all 4 tests are given in EN 13501-5[3]. These are shown in table 2.

CEN TS 1187, Test 1, Scenario
The test simulates a roof exposed to a burning brand only and with no imposed airflow over the roof.

CEN TS 1187, Test 1, Test specimen
The test specimen is 0.8 m wide and 1.8 m long and shall be representative in all details of the practical application except for the use of a standard supporting deck. Joints shall be present in all the layers of the test specimen.

CEN TS 1187, Test 1, Ignition source
The ignition source simulates a burning brand and consists of a metal basked filled with 650 g of wood wool positioned 10 mm above the surface of the test specimen. The basket is located with its centre 800 mm from the bottom edge of the specimen and 400 mm from the side of the specimen.

CEN TS 1187, Test 1, Duration of test
The test duration is 60 minutes measured form the ignition of the wood wool. If surface flames are still present 30 minutes after the start of the test these shall be extinguished in such a way that it does not interfere with the rest of the roof construction. After the test the roof assembly shall be opened to check for glowing combustion within and penetration through the test specimen.

CEN TS 1187, Test 1, Observations during test
During the test the following observations are made: External fire spread, fire penetrations and openings and extend and nature of internal damage. The classification criteria are provided in the standard EN 13501-5.

CEN TS 1187, Test 2, Scenario
The test simulates a roof exposed to a burning brand only and with an imposed airflow over the roof of either 2,0 m/s or 4,0 m/s.

CEN TC 1187, Test 2, Test specimen
The test specimen is 1000 mm long and 400 mm wide. The specimens are normally attached to a standard substrate according to the following:

- Combustible but not treated with Fire Retardant: Either wood particleboard or EPS
- Non-combustible: Either calcium-silicate board or mineral wool.

The specimens may also be tested on a non standard substrate in which case the test result is only valid for that substrate.

The test specimen shall as far as possible conform to the end use of the product.

CEN TS 1187, Test 2, Ignition source
The ignition source is a 40 g wood crib made of eight pieces of pine wood with no knots and dimensions 10 mm x 10 mm x 100 mm. Six of these pieces are nailed to the remaining two with a distance of 8 mm between each of them. The burning wood crib is positioned centrally on the specimen and with its centre 100 mm from the lower edge of the specimen.

CEN TS 1187, Test 2, Duration of test
The test is terminated by extinguishing the fire on the test specimen

- either 15 minutes form the time the burning wood crib was positioned on the test specimen or
- when the flame front has reached the upper edge of the specimen.

CEN TS 1187, Test 2, Observations
The following observations shall be made:

- The length of the damage material of the roof covering and the substrate measured from the centre of position of the wood crib.
- When required for regulatory purposes or classification also damaged area in square mm of the roof covering and substrate respectively and the maximum depth of the damage on the specimen in mm.

CEN TS 1187, Test 3, Scenario
The test simulates a roof exposed to a burning brand as well as radiation and with an imposed airflow over the roof of 3,0 m/s.

CEN TS 1187, Test 3, Test specimen
The test specimen is 3000 mm long and 1200 mm wide. The specimens shall be representative, in all details of practical application with regard to both the support and also the type and number of layers of roofing materials (including any insulation, vapour barriers, etc.), and with regard to the joining of those layers.

CEN TS 1187, Test 3, Ignition source
The burning brand consist of a 82 g wood crib constructed of four pieces of fibreboard 250 kg/m^3 with dimensions 55 mm x 16 mm x 25 mm forming a grid 55 mm x 55 mm x 32 mm and soaked in Heptane. The brands shall be positioned with their centres 500 mm from the lower edge of the specimen and 370 mm apart and equidistant from the specimen longitudinal centre line.

The radiation is provided by a radiant panel positioned in a plane parallel to the surface of the specimen and at a distance of 500 mm providing a heat flux of 12,5 kW/m^2. The specimen is exposed to radiant heat for 3 minutes before the burning brands are placed according to the above.

CEN TS 1187, Test 3, Duration of test
The test shall be terminated and the fire extinguished if any of the following occurs:

- Fire spreads on the underside of specimen after penetration.
- 30 minutes has passed since beginning of the test.

- Risk of safety to personnel or impending damage to the equipment.

2. Classes of external fire performance for roofs/roof coverings tested to CEN TS1187

Test	Class	Classification criteria
1	B_{ROOF} (t1)	All of the following conditions shall be satisfied for any one test: • external and internal fire spread upwards < 0,700 m; • external and internal fire spread downwards < 0,700 m; • maximum burned length external and internal < 0,800 m; • no burning material (droplets or debris) falling from exposed side; • no burning/glowing particles penetrating the roof construction; • no single through opening > 25 mm^2; • sum of all through openings < 4500 mm^2; • lateral fire spread does not reach the edges of fire measuring zone; • no internal glowing combustion; • maximum radius of fire spread on 'horisontal' roofs, external and internal < 0,200 m.
	F_{ROOF} (t1)	No performance determined.
2	B_{ROOF} (t2)	For both test series at 2 m/s and 4 m/s wind speed: • mean damaged length of the roof covering and substrate ≤ 0,550 m; • max. damaged length of the roof covering and substrate ≤ 0,800 m.
	F_{ROOF} (t2)	No performance determined.
3	B_{ROOF} (t3)	$T_E \geq 30$ min and $T_p \geq 30$ min.
	C_{ROOF} (t3)	$T_E \geq 10$ min and $T_p \geq 15$ min.
	D_{ROOF} (t3)	$T_p \geq 5$ min.
	F_{ROOF} (t3)	No performance determined.
4	B_{ROOF} (t4)	• No penetration of roof system within 1 hour. • In preliminary test, after withdrawal of the test flame, specimens burn for < 5 min. • In preliminary test, flame spread < 0,38 m across region of burning.
	C_{ROOF} (t4)	• No penetration of roof system within 30 min. • In preliminary test, after withdrawal of the test flame, specimens burn for < 5 min. • In preliminary test, flame spread < 0,38 m across region of burning.
	D_{ROOF} (t4)	• Roof system is penetrated within 30 min. but is not penetrated in the preliminary test. • In preliminary test, after withdrawal of the test flame, specimens burn for < 5 min. • In preliminary test, flame spread < 0,38 m across region of burning.
	E_{ROOF} (t4)	• Roof system is penetrated within 30 min. but is not penetrated in the preliminary test. • Flame spread is not controlled
	$F_{ROOF\ (t4)}$	No performance determined.

CEN TS 1187, Test 3, Observations

The following shall be observed:

- Progress of sustained flaming at the base (and not at the 'flame envelope'),
- The time when the sustained flaming has reached 100, 300, 500, 700, 900, 1100, 1300, 2000 mm from the edges of the brands and upper edge of measuring zone.
- Time where sustained flaming has progressed downwards 100,300,500 mm.
- Time of burning droplets or debris.
- Penetration and internal damage.
- T_E = Time for external fire spread to the edge of the measuring zone.

- T_p = Time to fire penetration.

CEN TS 1187, Test 4, Scenario
The test is done in two stages with a preliminary test with only a burning brand and then a penetration test with burning brand, radiant heat and wind. Unlike test 2 and 3 the wind is not simulated by airflow over the test specimen but instead a wind speed of 6,7 m/s is simulated by applying suction to the underside of the test specimen.

CEN TS 1187, Test 4, Test specimen
The specimen shall be representative of the complete 'end use' roof construction including the deck and supporting structures and at least one specimen containing joints used in practice.

CEN TS 1187, Test 4, Ignition source
The burning brand is a gas flame 230 mm long. For the preliminary test it is applied for one minute at the centre of the test specimen and directed up the slope.

The radiation is provided by a 915 mm square radiant panel positioned in a plane parallel to the surface providing a heat flux of 12 kW/m^2. For the penetration test with burning brand and radiant heat the test specimen is exposed to radiant heat for 5 minutes before the burning brand is applied for 1 minute moving once up and once down the centre of the specimen.

CEN TS 1187, Test 4, Duration of test
The preliminary test is terminated after the 1 min flame exposure in the event no ignition or penetration of the specimen occurs. If ignition occurs the test is continued until all flaming ceases or until the flame spread has been reached 0,38 m.

The penetration test is continued for 1 hour in the event no penetration has occurred. If penetration occurs the test is terminated.

CEN TS 1187, Test 4, Observations
For the preliminary test the following is observed:
- Duration of flaming.
- Extent of flame spread in any direction.
- The time and nature of any penetration.

For the penetration test the following is observed:
- The time at which any penetration occurs.
- Occurrence of melting of the test specimen and the production of molten droplets flaming and/or non-flaming.
- Any mechanical failure or development of holes without penetration by fire.

INTERNAL EXPOSURE TO FIRE

Exposure to fire from the underside of a roof assembly occurs when there is a significant fire exposure within rooms or concealed spaces below the assembly. It is possible that such an exposure can penetrate roof assemblies thus spreading the fire laterally within the roofing materials. The fire can also penetrate through the roof to the outside thus spreading across the top of the roofing system and potentially spreading to nearby buildings via radiation and/or burning brands. There have been several big fires caused by fires spreading to the roof assembly from the inside of the building. The most notorious would be the fire at the General Motors transmission plant in Livonia, Michigan in 1953 and the KamAz factory fire in Russia in 1993.

The following provide a description of the only two specific internal exposure to roof tests, which are used in Europe and North America.

DIN 18234[4]

Most regulations in Europe deal with fires from the inside only through requirements to the reaction to fire properties of products and fire resistance capabilities of structures. There is no specific test in the harmonised European system specifically fire addressing fire spread caused by the exposure to roof assemblies from the inside. There is a German standard for internal fire exposure to roof assemblies (DIN 18234-2), which is used for testing flat roofs to be used in industrial buildings with an area of at least 2500 m^2.

Scenario
The test simulates a natural fire happening in the room below the roof. The test room is 4,5 m wide, 11 m long and 4 m high. The building has an opening at one of the short sides.

Test specimen
The roof of the test room consists of the roof assembly to be tested. The specimen shall be representative of the complete 'end use' roof construction.

Fire source
The fire is a natural fire with a fuel consisting of 6 wood cribs made of pine and weighing a total of 400 kg. The wood cribs are positioned on scales in order to estimate the fire development within the room.

Duration of test
There is no set duration for the test.

Classification criteria
The roof assembly is deemed to fail the test in one of the following occur:

- Max. 0,25 m² burned area at the surface (open flames).
- Partly of fully collapse of the steel sheet.
- Fire spread inside the roof with open flames at the front and with open flames in the voids (flames smaller than 30 cm is not taken into account).
- Droplets in the area from 5 m from the back wall to the front end.
- Flames under the curtain at the front end.
- Continuous glowing combustion when opening the roof 1 hour after the test.

FM 4450[5]/NFPA 276[6]

The only specific internal exposure to roofs test used extensively is the Factory Mutual Construction Material Calorimeter. This was originally described in the Factory Mutual Approval standard 4450 but it is now available as NFPA 276. This test was correlated to FM's White House test, which was developed following the fire at the GM plant in Livonia. The White House test is no longer in use by FM.

Scenario
The test simulates a fire from below. The test operates under the principle of direct fuel substitution. The roof assembly to be tested is exposed to a liquid fuel fire for 30 minutes. During the test the time temperature curve in the flue is recorded. The test is terminated after 30 minutes and then a similar test is made using a non-combustible panel taking the place of the roof assembly. The 30 minute test is repeated under identical conditions adding auxiliary fuel to obtain the same time temperature curve

in the flue as that obtained with the roof assembly. The auxiliary fuel added represents the actual fuel originally contributed by the test specimen.

Test specimen
The specimen size is 1,2 m x 1,2 m and shall be representative of the complete 'end use' roof construction.

Fire source
The fire exposure is provided by heptane fuel adjusted to a rate of 27.875 KJ/Min for the entire 30 minutes of the test with the roof assembly in place.

Duration of test
30 minutes.

Classification criteria
The roof assembly when subjected to the test shall not exhibit fuel contribution rates in excess of 410 Btu/ft2/min at 3 minutes, 390 Btu/ft2/min at 5 minutes, 360 Btu/ft2/min at 10 minutes and an average 285 Btu/ft2/min. There shall be no dropping of flaming particles into the furnace or uncontrolled flaming on exterior of the sample.

UL 1256 Part 1[7]

UL 1256 Part I describes the large scale fire test method used to evaluate roof deck constructions which, by experience in actual installations, were known to have contributed extensively to underdeck fire spread or, conversely, were regarded as being eligible for classification from this standpoint. It is similar to FM's White House test.

Scenario
The test simulates a fire from below. The test room is 6.1 m wide, 30.5 m long and 3.1 m high. The building has an opening at one of the short sides. At the opposite end is located an ignition source burner assembly.

Test specimen
The specimen size is 6.1 m wide by 30.5 m long and is to be representative of the complete 'end use' roof construction.

Fire source
The fire exposure is designed to produce a fire exposure condition within the first 6.1 m from the burner that is representative of the standard time-temperature curve in the Standard for Fire Tests of Building Construction and Materials, UL 263. It is provided by heptane fuel for the entire 30 minutes of the test with the roof assembly in place.

Duration of test
30 minutes.

Classification criteria

- The maximum sustained flame front progression within the structure due to underdeck flaming shall not exceed 18.3 m from the fire end during the 30-minute test period.
- The flaming of molten residue falling from the roof deck or on the floor of the structure shall not exceed 18.3 m from the fire end during the 30-minute test period.
- The maximum temperature measurements recorded at the 18.3 m location shall not exceed 760°C for a 30-second interval based on the average of any three thermocouples yielding the

highest recorded temperatures. The maximum temperature recorded at the 21.9 m location shall not exceed 760°C for a 30-second interval for any individual thermocouple.

- Intermittent underdeck flaming, tips of flaming along deck seams or flaming dissociated from the main flame front within the structure are not to exceed 21.9 m from the fire end during the 30-minute test period.
- Post test examination of the roof deck construction shall show that combustive damage (burning, charring) of the roof covering system has diminished at increasing distances from the fire end of the test structure.
- Thermal degradation (damage in the form of charring, loss of integrity) shall not have extended throughout all components of the roof covering system at the extremity (flue end) of the structure.

FIRE RESISTANCE TESTS OF ROOFS

Some countries also require Fire Resistance testing of roof assemblies most often for roofs used as part of a planned escape route. These tests are not specifically designed as tests of roof assemblies but are more generic Fire Resistance tests for horizontal elements such as floors and roofs. They provide information on the load bearing capacity, insulation and integrity of a roof assembly exposed to a fully developed fire within the building. However, they do not assess the contribution of the roof assembly to the fire load.

It is not the intention of this paper to compare the different Fire resistance tests used so they are only mentioned in order to complete the list of fire tests used for roofs:

EN 1365-2 Fire Resistance for load-bearing Elements Part 2 – Floors and Roofs.[8]

BS 476 Part 21 Section 7 Determination of the fire resistance of load bearing floors and flat roofs.[9]

LPCB Loss Prevention Standard LPS 1208 Fire Resistance Requirements for elements of construction used to provide compartmentation.[10]

A comparison of the performance of different roof assemblies in EN 1363-1 was done by M. Smolka[11]

REACTION TO FIRE TESTS OF ROOFS

Most countries have reaction to fire requirements to the inside of roof assemblies to control fire spread. However, these are focusing on ignitability and flame spread of the inside lining of the roof assembly and are not meant to address the contribution of the entire roof assembly. They will therefore not be addressed in this paper.

DISCUSSION

Unfortunately, there is very limited, if any, test data to compare the same roof assembly in all the above test methods. Thereby it is not possible to perform a direct comparison between the tests. At the European level, in the 1990's the UK Government made a study called Radar 3, at BRE and Warrington fire test laboratories for a wide variety of roof coverings and roofing systems, comparing the classifications from all European standard methods with UK standard BS 476-3. The results were not comparable for all roofing systems.

External exposure to fire

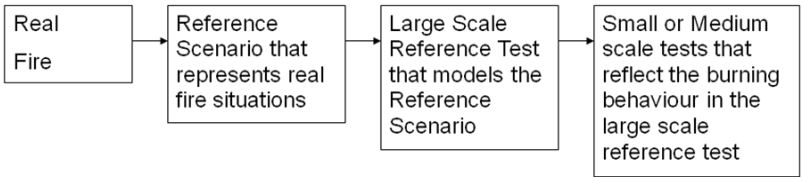
Based on our analysis of in house test results, it became obvious that especially the European test methods for external exposure to roofs more closely resemble reaction to fire (i.e. flame spread) tests of the roof covering mounted on different substrates than a test of the performance of the entire roof assembly, despite the fact that the description of the tests implies that they evaluate the fire behaviour of the entire assembly. Fundamentally, the tests appear to be designed such that the influence of the

combustibility of the layers below the roof covering do not play a significant role in the fire performance under test. Currently, the British test CEN TC1187 test 4 is the only test to consider the influence of the internal layers, but only related to penetration and not fire spreading over the roof.

Of greater concern is the fact that, in some cases, the results obtained from these tests is in contrast to experiences from real fires. This is the case for roof assemblies with thermoplastic insulation, where in some tests the fact that the insulation melts away either due to the heat flux from the radiant panel or from the burning brand gives a better result than if the same roof assembly was made with a non-combustible or limited combustible insulation.

The problem with the European tests is that even though they try to simulate the different types of heat exposure and ignition sources most often seen on a roof, they have never been linked to any large scale reference test. There exists at this point no large scale reference test for external exposure to roofs. Considering that the logical steps for development of a fire test is as shown in Figure 1 it is surprising that the existence of a large scale reference test for external exposure to roofs has never been considered. If Europe was ever to truly harmonise external exposure to roofs testing it is recommended that the first step would be to consider a large scale reference test.

Figure1



The ASTM E108 test addresses flame spread over the roof as well as penetration from burning brands. The type of ignition source used for the spread of flame test combined with different sizes of test specimens as well as the different sizes of the burning brands seem to provide a more comprehensive exposure to the test specimen than what is seen in the European tests CEN TS 1187:

- Test 1 and 2 are both pass/fail tests classifying products based on the extent of flame spread.
- Test 3 evaluate flame spread and penetration from brands, but only provides one size brand combined with radiant heat to evaluate both flame spread and penetration in a combined test.
- Test 4 uses two different tests; a preliminary test with only a burning brand to measure flame time and flame spread and a penetration test using burning brand, radiation and wind suction on underside of test specimen.

Based on the above ASTM E108 is expected to better distinguish between different roof assemblies. However, the link to a large scale reference does not seem to be existing for this test either, making it difficult to relate the performance in the test to how it would be in a real fire.

Internal exposure to fire

Unlike the external exposure to roof tests the FM 4450/NFPA 276 tests are developed based on the large scale reference test known as the "White House Test". Extensive tests were done in the past showing the correlation between the two tests. However, the White house test has not been used by FM for many years and it remains to be proven if the correlation between the two tests is also valid for the type of roof assemblies which are on the market today. UL 1256 Part 1 describes a test method very similar to the White House test but this is also not used much.

Work was done by the Foam Polystyrene Alliance (FPA)[12] in the mid nineties using a test procedure similar in size to the White house test. These tests showed that a roof assembly with Polystyrene foam mounted directly on the metal deck could pass the test. This was in contradiction with the test results from the FM 4450/NFPA 276 test, which showed that a fire barrier was needed between the foam and the deck. The work of the FPA was challenged by Babrauskas et.al.[13] who also performed tests using

a procedure similar in size to the White house test but with a different fire exposure than the FPA tests. It is not clear if any of these tests followed the original protocol of the FM White house test so unfortunately they cannot be used to compare the performance of modern roof assemblies in the White house test with the FM 4450/NFPA 276 test.

Considering the small sample size used in FM 4450/NFPA 276 test it would be interesting to see if the roof assemblies used today would perform as expected if tested in a large scale reference test. Especially steel deck roofs and metal-faced sandwich panels where the performance relies on maintaining the integrity of the joints.

Performing tests in according with the FM White house test would be very expensive and the size of the test arrangement requires it to be performed outdoors, which means that it would not be allowed to be used in some countries. An interesting alternative to the White house test is the DIN 18234 test. This test is big enough to be considered a large scale test but it is not so big that it requires the test to be performed outdoors. Unfortunately no comparative testing has been done between the FM 4450/NFPA 276 and the DIN 18234 so how the same roof assemblies perform in the two tests remains to be seen.

CONCLUSION

None of the external exposure to roof tests are linked to a large scale reference test. It is therefore not possible to relate the test performance to a performance in a real fire. Based on the review above ASTM E108 appears to be the one of the external exposure tests providing the most comprehensive testing of roof assemblies and thereby being the closest to simulate real fire performance. However, without an established link to a large scale reference test any fire test becomes merely a tool for code compliance.

For the internal exposure to roofs tests the link between FM 4450/NFPA 276 and its large scale reference test the White house test is not established for modern roof assemblies.

Of all the tests in this review the most viable large scale test is the DIN 18234 test. A comparative study between FM 4450/NFPA 276 and DIN 18234 should be considered.

REFERENCES

1 E108 Standard Test Methods for Fire Tests of Roof Coverings. ASTM.
2 CEN TS 1187 Test Methods for External Fire Exposure to Roofs. CEN. January 2012.
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