FIRE SAFETY PERFORMANCE OF MEMBRANE STRUCTURES

ETFE in particular

In any subject area related to the provision of safety, failure is typically the most effective mechanism for evoking rapid reform and an introspective assessment of the accepted operating methods and standards within a professional body (1). When it comes to fire safety, lessons can be learned from the reaction of the cladding system - the roof and/or the façade – in case of a fire inside the building.

A good example has been a fire at Condor Campus, the headquarter of Condor at Frankfurt International Airport in western Germany, in 2016. The Headquarter was opened in March 2013 and is certified as a LEED Gold project. On December 29, 2016, a flight simulator had caught fire in the Condor office building at Frankfurt airport. The simulator, much of which burned out, contained a replica passenger cabin. Some 200 people were forced to evacuate the office building. Fire fighters were alarmed at 11:52. They managed to extinguish the flames within 45 minutes. At 12:30 the fire was extinguished. At 13:20 it was announced that the whole building was smoke-free and that the employees were allowed to return to their workplaces. Due to the fact, that the roof of the hall of the flight simulator was cladded by an ETFE foil system heat and smoke were released immediately after the foils were melted and therefore the roof was entirely open towards the outside. ETFE foil claddings just retract to the extrusions when temperatures exceed 200°C. Thus, the fire fighters had direct access to the source of fire. The primary steel supporting structure was kept in place. Additionally, there was no risk of parts falling down from the roof.

The classification systems for building products

This specific response of a membrane cladding system is not taken into account by actual classification systems. Only the reaction to fire of the building cladding material is analysed, neither the building cladding system nor whole the building structure. Today, typical parameters are fire resistance and flammability. In particular, the national standards like DIN 4102 *Fire behaviour of building materials and building components* (2), BS 476 *Fire tests on building materials and structures* (3), NFPA 701 *Fire tests for flame propagation of textiles and films* (2019) (4), or ASTM E 84 *Standard Test Method for Surface Burning Characteristics of Building Materials* (2020) (5), focus on the material performance. Consequently, the European classification system EN 13501 *Fire classification of construction products and building elements* (6) categorises the fire performance according to the fire performance of a specific building product. Each product is tested according to the procedures given in EN 13823 *Reaction to fire tests for building products* (7), and EN ISO 11925-2 *Reaction to fire tests - Ignitability of products subjected to direct impingement of flame* (8). The test results in accordance with EN 13 823, clause 9, provide good evidence of the contribution of the building material under investigation regarding fire growth (FIGRA – fire growth rate), smoke growth (SMOGRA – smoke growth rate), and flaming droplets/particles. The reaction-to-fire test according to EN ISO 11925-2 provides good evidence regarding the ignitability of the building material. For membranes, the ignitability is analysed for both surface exposure and edge exposure. Additionally, the ignition of filter paper placed below the test sample indicates, whether potentially burning droplets might cause ignition of the filter paper.

The classification is carried out in accordance with clause 11.6 of EN 13 501-1:2010 (6). Without going too much into details, the norm differs between five classes A, B, C, D and F regarding flammability and ignitability. Products classified A2, B, C, D obtain an additional classification s1, s2, and s3 regarding the smoke production and an additional classification of d0, d1 or d2 regarding the production of flaming droplets and/or particles. Just as an example, ETFE (ethylene tetrafluoroethylen) foils are classified as B-s1-d0 (9).

However, the background information concerning the reaction to fire classification of a product given in Annex A of the EN 13 501-1 (10) states under clause A.2.2, that the validation of the classification of products in terms of their contribution to fire growth and post flashover fires is based on a large scale scenario. As a reference scenario for the definition of class limits the test procedure published in ISO 9705-1:1993 *Fire tests – Full scale room test for surface products* (11). The method does not evaluate the fire resistance of products. Thus, fire classes defined according to EN 13 501-1 cannot be understood without detailed knowledge gained from a full-scale test of whole the cladding system. Up to now, the building industry has set focus on comparison between the fire classes achieved by performance tests of the cladding material only, not on the fire performance of different building cladding systems. For membrane structures, the actual constricted perception does mislead the valuation regarding reaction to fire performance of membrane cladding systems. Unfortunately, the reference standard for a full-scale room test cited in EN 13 501-1 is not suitable for membrane cladding systems. In close cooperation with RISE, the Research Institute of Sweden nearby Gothenburg, Vector Foiltec has identified ISO 13784-1 *Reaction to fire test for sandwich panel building systems – Part1: Small room test* (12) as perfect for a test of the reaction to fire performance of membrane structures, ETFE building cladding structures in particular. The scope of ISO 13 784-1 is a "test for determining the reaction to fire behaviour of sandwich panel building systems, and the resulting flame spread on or within the sandwich panel building construction, when exposed to heat from a simulated internal fire with flames impinging directly on the internal corner of the sandwich panel building construction". According to Per Thureson, fire expert at RISE Research Institute of Sweden, this method is similar to ISO 9705-1, which is a small room scenario of the same size as ISO 13784-1. The main difference is that ISO 9705-1 has a room enclosure in which the product is mounted and in ISO 13784-1, the product itself forms the room scenario without any outer enclosure (13).

The Small Room Test according to ISO ISO 13784-1

In order to form a basis for a new technical fire classification for membranes, Vector Foiltec has requested a test of a standard ETFE cushion systems at RISE Safety – Fire Research. The test was performed on February 13, 2019. The nominal external dimensions of the test room were 3.7m by 2.5m by 2.5m (length by width by hight). A standard Vector Foiltec Texlon® F16 aluminium frame system was attached to the structural steel framework of the test room in order to hold the ETFE foil cushions. The setup of the foil cushions was a standard 3-layer ETFE foil system comprising an outer foil of 250μm thickness, a middle foil of 100μm, and an inner foil of 250μm. The individual layers were welded together at the edges. They were stabilised to approximately 250Pa by means of a low-pressure air supply system. The outer foil was coated by a dark print pattern that covers 92% of the cushion area with highly pigmented ink (DH 9:92 dark, aluminium pigments).

Smoke gases were vented and air was let into the small room through a door opening. The ignition source was a gas burner, placed close to the left rear corner on the back of the wall. The burner heat output was 100kW for the first 10 minutes and then 300kW for another 10 minutes. The smoke gases coming out through the doorway and through the joints of the sandwich panel system was collected by a hood and exhaust system (in accordance with method 2, clause 9.4.2) from where samples were taken for gas analysis. Heat release and smoke production rate were measured continuously.

The heat from the gas burner in phase 1 (100kW output) caused the foil material of both wall panels next to the flame to melt and form holes. When the heat energy was increased to 300kW after 10 minutes, the foil cushion panel in the roof corner started to melt and form a hole, also (Fig. 1).
Figure 2 shows both the damage of the rear and left wall panels as well as the damage of the roof panel. Two holes of 1.5m² each were formed in the walls and a hole of 0.5m² was formed in the roof corner.

Figure 1. Flame after increase to 300kW.
Figure 2. After the test holes of 1.5m² were formed in the façade foil cushions and a hole of 0.5m² was formed in the upper left corner of the roof cushion.

The observations are summarised in Table 1.

TABLE 1: OBSERVATIONS	
Ignition of specimen	No
Flames emerging through the doorway	No
Opening joints and flaming from joints	No
Flaming debris/droplets	No*
Smoke and flames outside the room through joints	No
Flame spread through core of specimens/panels	Yes**
Flashover	No
Collapse of structure	No

* *Droplets were not burning.*
** *Some panels were burned through all of the three foil layers.*

Figure 3 shows the heat release rate HRR during the test. No contribution from the cladding system was found. The gas burner was switched off at 20:00 minutes and the test was terminated at 30:00 minutes.

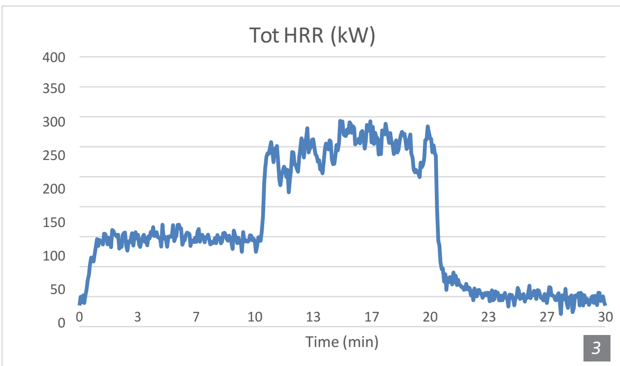

Figure 3. Heat release rate HRR during test, including burner heat output.

Figure 4 shows the smoke production rate. After the test the lenses of the smoke measurement system showed some contamination, causing the photometric signal not to return to the base-level. Therefore, the measured smoke production most likely can be seen as a worst-case performance.

Figure 5 shows the gas temperatures in different height in the centre of the door opening. The height is indicated in table 2.

The heat from the gas burner caused the foil material to melt. There were holes in all three of the foil layers of the ceiling panel and of both wall panels in the corner next to the burner.

The damage was limited to the burner corner. All external wall and ceiling thermocouples were intact in position after the test. All aluminium extrusions as well as the silicone gaskets except those next to the burner in the rear left hand corner did not show any signs of damage.

Calculation of the fire growth rate FIGRA and the smoke growth rate SMOGRA is not part of ISO 13784-1 but is defined in ISO 9705-1. As mentioned before, both tests deal with a small room scenario of the same size and can be considered to be comparable. FIGRA is defined as the peak heat release rate during the test (excluding the burner heat output) divided by the time to reach peak HRR. Since the measured HRR of the cladding product was below the systems detection limit (< 50 kW) FIGRA was set to zero (0 kW/s) (14).

SMOGRA is defined as peak smoke production rate SPR (averaged over 60s) divided by the time to reach peak SPR. If peak SPR is less than 0.3m²/s SMOGRA is set to zero. For the tested products (transparent and printed) SMOGRA can be calculated as given in Table 3:

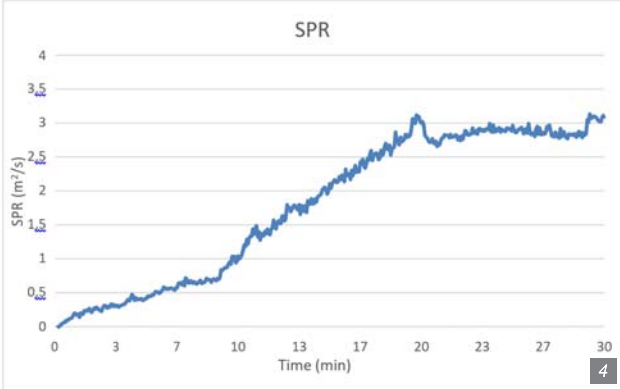

Figure 4. Smoke production rate during test including burner.

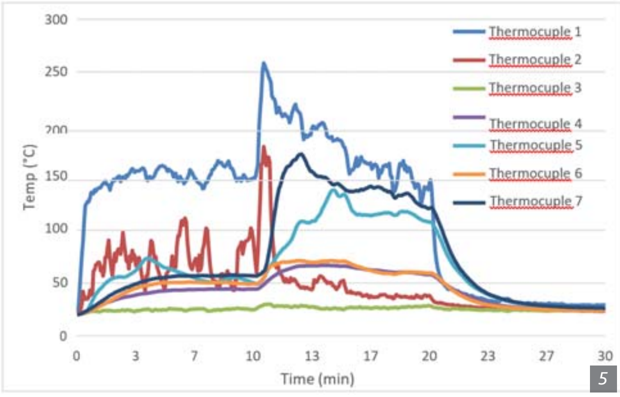

Figure 5: Gas temperatures in the door opening and temperatures on the external panel surfaces during the test. Position of thermocouples were according to table 2:

TABLE 2: SUMMARY OF THERMOCOUPLE POSITIONS

Thermocouple	Position
1	Centre of doorway at a height of 1900mm
2	Centre of doorway at a height of 1500mm
3	Centre of doorway at a height of 1000mm
4	Centre of right wall panel, external surface
5	Centre of rear wall panel, external surface
6	Centre of left wall panel, external surface
7	Centre of ceiling panel, external surface

TABLE 3: CALCULATION OF SMOGRA FOR TRANSPARENT AND PRINTED TEXLON® ETFE FOIL CLADDING SYSTEMS

Product	Peak SPR (m²/s)	Time to peak SPR (min:s)	SMOGRA 10^{-4}(m²/s²)
transparent	1.77	20:00	14.8
printed	3.12	19:44	26.4

Conclusion

The product called "Texlon® ETFE system", in relation to its reaction to fire behaviour, showed a very limited contribution to heat and smoke production during the test. No visible flaming in the material was observed. No burning droplets were seen during the test. No flash over occurred.

For classification of building cladding systems exposed to fire it is not sufficient to focus on material performance and material tests only but to understand the reaction to fire of the system. Today the significant potential and contributions to safety are not taken into account when membrane structures are discussed. The small room test published in ISO 13784-1 provides evidence regarding the response of membrane cladding systems, ETFE foil cladding systems in particular, in case of fire scenarios. Even though there are no classification criteria given in ISO 13784-1 except flash over which does not allow for a normative clause, informative advice should be given in an upcoming standard. Since the response of membrane structures is fundamentally different from stiff building cladding materials, research towards the development of criteria derived from tests of the whole cladding system according to ISO 13784-1 is strictly recommended.

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