Intermediate-Scale Tests Of Ventilated Facades With Aluminium-Composite Claddings

Eric GUILLAUME*1, Talal FATEHB, Renaud SCHILLINGER2, Roman CHIVA3, Sebastian UKLEJAB, Roy WEGHORSTC

1 Efectis France, France
2 Efectis UK-Ireland, United Kingdom
3 Kingspan B.V., Netherlands
Roman.chiva@efectis.com

ABSTRACT

The fire behaviour of a building façade is dependent on the overall system’s performance, rather than the performance of the individual components. A façade system includes the cladding and the insulant’s characteristics, but also the cavities, cavity barriers, mounting and fixings, substrate and any singularities, such as window frames. Aluminium-Composite-Materials (ACM’s) are increasingly commonly used as cladding when designing building facades nowadays, but different types of cladding can achieve very different levels of performance.

Assessment of a particular façade system’s fire performance can be undertaken using large-scale testing such BS8414-1, but there is currently no commonly accepted method of extending the scope of a large scale tested system, to account for variances from the configuration that has been tested; it is therefore proposed that intermediate testing could allow a route for assessing the significance of different system configurations and components to extend the scope of large scale tested systems.

The test protocol proposed for such intermediate level testing, is a façade fire propagation test according to the ISO 13785-1 standard, with additional heat release rate and gases analysis using FTIR. Tests results have been compared to real-scale data available to estimate measurement relevance of such intermediate-scale tests.

In order to appreciate the variability of different system configurations, as well as the effect of different interactions between panels and insulants, a test campaign of 9 combinations of cladding and insulants was performed using intermediate level testing, this involved 3 different Aluminium Composite Material (ACM)-based cladding systems in combination with 3 different insulants within each system.

KEYWORDS:
Flame spread; fire growth; façade fire; ignition.
INTRODUCTION

The global market for façade insulation and especially ventilated facades, is growing quickly and likely to double in size by 2024 [1]. In this growing market, the proportion of Aluminium-Composite-Materials (ACM) is currently estimated as 25% of the market share for US and the same level for Europe [2]. Such global and increasing use of ACM’s requires proper risk evaluation. Façade systems have been implemented on a great many commercial and residential buildings, providing a good level of energy efficiency, weather resistance and improved aesthetics. ACM cladding is generally followed by a cavity, then the insulant, over the face of a building structure (often either a steel frame or masonry or concrete framed substrate). The construction products used as external façade assemblies may include combustible insulants and combustible claddings. As stated in Table 1, there have been several significant fires over the last decade involving rainscreen facades; a large proportion of these have involved to the use of a combustible ACM-based cladding. Such fires are described in the references [3], [4] and [5] and have involved massive fatalities and property losses. According to the table, propagation through the cladding and penetration from the outside to the inside are the most important parameters driving these fires and their consequences.

| Date       | Place                        | Circumstances and consequences                                                                 |
|------------|------------------------------|-------------------------------------------------------------------------------------------------|
| 1/10/2010  | Wooshin Golden Suites, Busan, South Korea | No fatalities, 5 injured. Fire from apartment, propagated by the façade.                        |
| 14/5/2012  | Rousbaix, France             | Dwelling building fire, 1 fatality, 20 apartments (over 94) destroyed. Initiated from apartment fire, propagated through decorative ACM panels on balconies |
| 17/7/2012  | Polat Tower, Istanbul, Turkey | Fire caused by a faulty air conditioning unit, no fatalities.                                   |
| 18/11/2012 | Tamweel (Al Seef) Tower, Dubai, UAE | No fatalities. The building was made uninhabitable by the fire, and is expected to be reconstructed |
| 3/4/2013   | Hotel and Business Center, Grozny, Chechnya | Fire completely destroyed the plastic trimming used on the building’s exterior, but the interior remained untouched. |
| 25/11/2014 | Lacrosse Tower, Melbourne, Australia | No fatalities or serious injuries. Levels six to twenty-one were affected by fire and many more were affected by water damage. |
| 21/2/2015  | Marina Torch Tower, Dubai, UAE | 7 injuries. The fire started in the middle of the building and spread rapidly due to falling flaming debris and high winds. External cladding was charred from the 50th floor (over 82) to the top of the tower |
| 19/5/2015  | Dwelling building, Baku, Azerbaijan | 16 fatalities, 63 injuries. Fire propagated on façade after a renovation.                      |
| 1/10/2015  | Nasser Tower, Sharjah, UAE    | 19 injuries. Fire started on the third storey and moved up through façade.                      |
| 31/12/2015 | Hotel The Address, Dubai, UAE  | No fatalities. Fire started outside the 20th floor of the hotel but didn’t spread inside.       |
| 14/06/2017 | Grenfell tower, London       | 71 fatalities. Initiated from an apartment fire, rapid propagation to the façade and penetration from the outside to the other storeys. |
| 4/8/2017   | Marina Torch Tower, Dubai, UAE | Second fire on the same tower. No fatalities. Debris from the fire falling to the ground and starting a second fire in the streets below. |
| 22/12/2017 | Dwelling building, Jecheon, South Korea | 29 fatalities. Initiated from a car fire in underground car park, then propagated to the cladding |

After the Grenfell tragedy in June 2017 [5], the UK government commissioned seven large-scale BS8414-1 [7] tests in order to determine which types of insulation could safely be used with different cladding types. These tests were performed by the BRE, according to criteria from BR135 document [8]. The test campaign involved 3 types of cladding: ACM with a polyethylene dominated core from here on referred to as “ACM PE” (this is the type that was used on Grenfell tower), Fire retardant ACM cladding, with a better fire performance, hereafter referred to as “ACM FR” and ACM cladding with a mineral core filling of limited combustibility, hereafter referred to as “ACM A2”. These cladding types were initially tested in combination with a PIR insulation as used at Grenfell and a Mineral wool insulant. Test results [9][10][11][12][13][14][15] are summarized in Table 2. None of the ACM PE based compositions passed the test. Unfortunately, BS8414 tests gives very little quantitative information for further interpretation of fire behaviour of these systems. Moreover, the tests were extinguished as soon as BR135 criterion failed, making a complete fire scenario (growth, possible plateau and decay of the fire) impossible to assess. An additional test was undertaken with ACM-FR and phenolic insulation [16]. The rationale for this was that not all plastic foams are alike. It was conceivable that a phenolic insulant could pass the test with FR-grade cladding, even if PIR did not. The phenolic did perform a little better than the PIR - but it still failed. The phenolic was deemed to have failed the test after 28 minutes. The equivalent PIR test lasted just 25 minutes, both met all temperature criteria set out in BR135 however they both failed due to “flames on top of the rig”. Looking at the reports test pictures, it is
clear that, although, it passed, the mineral wool insulation with the ACM FR barely only passed the criteria “flames on top of the rig”.

Table 2. Results of BRE tests after Grenfell disaster.

| BS8414-1 tests            | With combustible insulant (PIR) | With mineral wool insulant |
|---------------------------|---------------------------------|----------------------------|
| Aluminium with mineral core (ACM A2) | Pass                           | Pass                       |
| Aluminium with fire-retardant core (ACM FR) | Fail at 25 min                | Pass                       |
| Aluminium with polyethylene core (ACM PE) | Fail at 8 min                 | Fail at 7 min              |

FM Global recently undertook a series of tests on ACM-based panels, according to a 16 feet parallel panel test stated in ANSI/FM4880 [17]. Results were then compared with NFPA 285 [18]. A large number of façade systems were evaluated. The results were sufficient for FM Global to take a view that the ANSI/FM 4880 parallel panel test method was discriminant enough to identify hazardous assemblies. Compared to NFPA 285, several compositions that complied with this standard didn’t pass the parallel panel test, mainly because of lower heat exposure in the NFPA 285 test compared to realistic façade fire scenarios. Large-scale and real-scale façade experiments such BS8414-1 are however expensive and take a long to prepare. As a consequence, there is a need for an intermediate test method able to be correlated with a large scale reference test to account for variations from what is tested at a larger scale. An example of application is to extend reference tests with small changes in geometry or thicknesses of a component, and to validate this extended application using a scientifically based assessment. The test campaign described hereafter in this publication intends to cover this need, consider sensitivity and identify whether an intermediate-scale test method can be discriminant enough.

DESCRIPTION OF TEST SET-UP

A series of 9 tests were undertaken based on the ISO 13785-1 standard [19]. This test involves assessment of a medium-scale mock-up of facades. In this test façade samples are fixed over a calcium-silicate board maintained on a steel frame. All the equipment is placed with wind screens on 3 faces made of Fire-rated plasterboards. The test arrangement is similar to a one third scale of BS 8414-1 test, with a 100 kW gas burner placed at the bottom of the back wing of the sample. The burner is a sand-diffusion propane burner of 100 kW, with a length of 1200 mm and a width of 100 mm and a height of 150 mm. Its upper surface is placed 250 mm below the lower edge of the sample. The complete system is then placed under a large hood to collect effluents. For this testing, several deviations from ISO 13785-1 standardized test protocol were made:

- Test duration was systematically 30 minutes with burner on;
- Tests were performed under a large calorimetric hood. The heat release rate and smoke effluents rate was measured continuously according to ISO 24473[20];
- Smoke was collected for FTIR analysis of the effluents, according to ISO 16405 [21] and ISO 19702 [22].

Depending on the energy release, two different sizes of calorimetric hood were used. The medium one was a 3 m x 3 m hood used as per ISO 9705 standard [23]. This allows good measurement conditions for heat release rates from 100 kW to approximately 3.5 MW. The larger one was a 9 m x 9 m hood, which allows good measurement conditions for heat release rates from 500 kW to 20 MW.

DESCRIPTION OF SAMPLES

Cladding

Three different Aluminium Composite Materials (ACM) panels used as cladding were tested. References of the products are as follows: a) Alpolic A2 limited-combustibility cladding; Hereafter designed as “ACM-A2”;

b) Alpolic/fr-RF Reduced-combustibility cladding; Hereafter designed as “ACM-FR”;

c) Reynobond PE standard cladding with polyethylene core ; Hereafter designed as “ACM-PE”

Insulants

Three different insulants were used in combination with each of the cladding types for the test combinations, as follows: a) Kingspan K15 phenolic foam (50mm thick), hereafter designed as “K15”; b) Celotex RS000 PIR(50mm thick), hereafter designed as “PIR”; c) Mineral wool Rockwool Duoslab (100mm thick) hereafter designed as “MW”. Information regarding these insulants, such as density or thermal conductivity is available on product datasheets from their respective manufacturers. The different thicknesses of combustible insulants or mineral wool were chosen to achieve similar levels of thermal performance. As the total thickness is
different between organic foams and mineral wool compositions, burner position was adjusted in order to produce similar thermal attack to the cavity.

**Mounting and Fixing**

The insulant and the cladding were assembled on Calcium silicate boards (860 kg/m³) and as follows:
- Cladding made of panels of 779 x 508 mm (3 x 2 panels for back wall and 3 panels for side wall of test wing). Gaps between cladding panels are 20 mm wide;
- Cavity of 50 mm with intumescent cavity fire barrier above second rank of panels. At the position of the cavity barrier, the thickness of the cavity is reduced to 24 mm in this zone;
- Vertical frame made of aluminium profiles. Lower edge of the test frame is covered by a 2 mm thick aluminium L profile, with a 20 mm airgap at the bottom panel and the angle.

**Test Sequence**

The 9 different combinations were tested at Efectis UK-Ireland, Belfast, in indoor facilities (no wind, constant temperature). The tests using ACM-FR and ACM-A2 compositions were performed under Efectis UK-Ireland intermediate scale hood (3 m x 3 m), similar to the hood described in ISO 9705-1 standard [23]. The tests using ACM-PE claddings were performed under Efectis UK-Ireland large hood (9 m x 9 m), with a limit of 20 MW. All tests were only performed once.

**TEST RESULTS**

![Fig 1. Heat release rate.](image1)

![Fig 2. Maximum heat release rate (contribution of burner removed).](image2)

![Fig 3. Rate of smoke production.](image3)

![Fig 4. Maximum rate of smoke production.](image4)
Roughly, the tests involving ACM-FR and ACM-A2 present close patterns vs. time, with limited degradation sometimes visible inside the cavity but limited by the fire barrier. Maximum heat release rate from the tests with ACM-PE grew to almost 5 MW. This was similar for each of the ACM-PE tests and was more than 16 times higher than for all the other tests. This peak appears early, after only 4 minutes. The peak was of a short duration, only a few minutes. For the test involving the ACM-PE+MW, the heat release rate curve has a similar trend observed for the tests involving ACM-PE + K15 and ACM-PE + PIR, but the decay started earlier, meaning a probable small contribution from combustible insulants in the decay phase. This probably explains the difference seen between these three tests for total heat released. The peak of heat released is very intense but so short that in a test averaged for 30 minutes, the difference between the tests using ACM-FR or ACM-A2 and the ones using ACM-PE is visible but less important. The results from the tests using ACM-FR or ACM-A2 show globally the same trend, with a low heat release during the whole duration of the test, but not exceeding 300 kW. Composition ACM-A2 + MW gives the best results as expected, but the compositions with ACM-A2 + K15 and ACM-FR + MW gave close results. On total heat release, higher values for tests using PIR compared to tests using K15 (about 5% more) probably indicate that PIR contributes more than K15 to energy released. They both contribute significantly more than MW. In conclusion for heat release, the largest contributor to the peak was the type of cladding when ACM-PE was used, with a little influence from the nature of the insulant during the decay phase. For the ACM-A2 and ACM-FR compositions, the insulants behaved broadly in a similar manner, especially compared against the performance of compositions integrating ACM-PE claddings. Results on rate of smoke production reveal again the peak observed for tests with ACM-PE claddings, but the difference is less visible than for the heat release rate. It means that the combustion phase corresponding to this phase, from 4 minutes to 8 minutes when ACM-PE is used, produces less smoke in proportion than the rest of the test. This is probably linked to a very intense combustion that re-burns all the smoke. PE combustion produces less smoke in proportion. This is also visible in the results for the total amount of smoke produced, where the difference between the tests was of less importance. In these results, tests that produce the smallest quantity of smoke were on ACM-FR + K15, ACM-FR + MW and ACM-A2 + MW compositions. Tests using PIR, seem to release more smoke than those with K15 and MW, but the difference was small. Gases evolved was quantified using non-dispersive infrared analyser for carbon dioxide (CO₂) and electrochemical cell for carbon monoxide (CO). Other species have been measured using FTIR analyser and semi-quantitative analysis is presented. FTIR analysis performed during the tests has proven the presence of unburnt hydrocarbons in the smoke. Evidence of methane, ethylene, acetylene and propane was highlighted during intense combustion in tests using ACM-PE claddings, and visible for methane and ethylene. No traces of hydrogen cyanide were found in any test, or any other nitrogen-containing species. This means that contribution of insulants, and especially PIR, is not visible in terms of species production, even in the largest fires involving ACM-PE claddings.

CONCLUSIONS
Tests performed are discriminant between solutions. They highlight that, for tested compositions, the cladding is the most important parameter driving global fire behaviour. ACM-PE based cladding systems gave very different results from the other solutions tested. This was especially visible in heat release rates, where fire intensity was very high, whatever the insulant used in the system. The contribution of the insulant was only remarkable in these tests during the decay phase. The cavity barrier was largely ineffectual in the 3 tests with ACM-PE cladding, as the integrity of the cavity was not ensured. Additional gas analyses highlighted a very well-ventilated condition of combustion with the ACM-PE based cladding compositions, probably enforced by the test setup and entrainment inside the cavity. Carbon monoxide release was low in proportion. Hydrocarbon release was remarkable, but no other species was detected with in the limits of detection by the test setup and entrainment inside the cavity. Carbon monoxide release was low in proportion. This confirms BRE tests according to BS 8414-1 and supplements the results with gases evolved and heat released from the beginning to 30 minutes without external action such extinction. These tests highlight also, that the BRE tests might have developed much more higher with the ACM-PE cladding, if they had not been extinguished. For such constructive systems, use of intermediate-scale tests is a very powerful tool to complete any reference real-scale test, for example in the case of extended applications. Unfortunately, intermediate scale tests as well as the reference BS8414-1 test don’t cover all the details of a façade constructive system and single points, such as window frames, could have an important effect. Their effects on fire behaviour of the facade requires further evaluation.
REFERENCES

[1] Facades Market Analysis By Product (Ventilated, Non-Ventilated), By End Use (Commercial, Residential, Industrial), By Region (North America, Europe, Asia Pacific), And Segment Forecasts, 2014 – 2025. Published Nov 2017, Report ID: GVR-1-68038-221-1.

[2] Cladding Market Analysis By Product (Steel, Aluminum, Composite Panels, Fiber Cement, Terracotta, Ceramic), By Application, Competitive Landscape, And Segment Forecasts, 2014 – 2025. Published Jun, 2017, Report ID: GVR-1-68038-477-2.

[3] Valiulis, J., “Building Exterior Wall Assembly Flammability: Have we forgotten the past 40 Years?” In Fire Engineering Magazine, November 2015.

[4] White, N., Delichatsios, M., “Fire Hazards of Exterior Wall Assemblies Containing Combustible Components. FPRF final report”, project FE2568, 2004 Quincy, MA, USA.

[5] White, N., Delichatsios, M., Ahrens, M., Kimball, A., “Fire hazard of exterior wall assemblies containing combustible components”. Proceedings of 1st International Seminar for Fire Safety of Facade, 2013 Paris, pp. 77-88.

[6] UK Department for Communities and Local Government, “Interim report into the Review of Building Regulations and Fire Safety”, issued 18 December 2017 https://www.gov.uk/government/news/interim-report-into-the-review-of-building-regulations-and-fire-safety

[7] BS 8414-1:2015+A1:2017. “Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems applied to the masonry face of a building”.

[8] S. Colwell, T. Baker, “BR135”: Fire performance of external Thermal Insulation for Walls of Multistorey Buildings (3rd ed), IHS/BRE.

[9] UK Department for Communities and Local Government, “Collection: Grenfell Tower”, last update 22 November 2017 https://www.gov.uk/government/collections/grenfell-tower

[10] BRE. “Fire test report”, DCLG BS 8414 test no.1. 7 August 2017.

[11] BRE. “Fire test report”, DCLG BS 8414 test no.2. 3 August 2017.

[12] BRE. “Fire test report”, DCLG BS 8414 test no.3. 8 August 2017.

[13] BRE. “Fire test report”, DCLG BS 8414 test no.4. 11 August 2017.

[14] BRE. “Fire test report”, DCLG BS 8414 test no.5. 14 August 2017.

[15] BRE. “Fire test report”, DCLG BS 8414 test no.6. 25 August 2017.

[16] BRE. “Fire test report”, DCLG BS 8414 test no.7. 21 August 2017.

[17] Agarwal, G., “Research Technical Report”, Evaluation of the Fire Performance of Aluminum Composite Material (ACM) assemblies using ANSI/FM 4880. December 2017, FM Global, Norwood, MA02062, USA.

[18] NFPA 285. Standard Fire test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components, 2012.

[19] ISO 13785-1:2002. Reaction-to-fire tests for façades - Part 1: Intermediate-scale test.

[20] ISO 24473:2008. Fire tests - Open calorimetry - Measurement of the rate of production of heat and combustion products for fires of up to 40 MW.

[21] ISO 16405:2015. Room corner and open calorimeter - Guidance on sampling and measurement of effluent gas production using FTIR technique.

[22] ISO 19702:2015. Guidance for sampling and analysis of toxic gases and vapours in fire effluents using Fourier Transform Infrared (FTIR) spectroscopy.

[23] ISO 9705-1:2016. Reaction to fire tests - Room corner test for wall and ceiling lining products - Part 1: Test method for a small room configuration.