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Ministry of Housing, Communities and Local Government Final Research Report

Fire Performance of Cladding Materials Research – Appendix F Analysis of experimental results

Prepared for:	**Technical Policy Division, MHCLG**
Date:	**20 March 2020**
MHCLG Contract:	**CCZZ17A36**
Report Number:	**P111324-1019 (M9D12V2)**

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F1 Introduction

The authors of this report are employed by BRE Global. The work reported herein was carried out under a Contract placed by the Ministry of Housing, Communities and Local Government. Any views expressed are not necessarily those of the Ministry of Housing, Communities and Local Government.

This Appendix is part of a Main report and Appendices and should be read in conjunction with these.

This Appendix contains a description of the analysis of the experimental results (Task 7).

F2 Methodology

The detailed results for each individual experiment were presented in Appendix E. The samples were sourced from different manufacturers or directly from MHCLG and represented a range of different material types based on a selection procedure informed by MHCLG and the input of the Project Steering Group.

The intention was always to refer to the samples as product typologies rather than specific products or materials and therefore no reference has been made to specific products or manufacturers. To this end, and to provide a comprehensible methodology for analysis, the samples have been grouped into five main typologies shown in Table F1. The details of the individual samples are set out in Appendix F1.

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**Table F1 – Samples classified by product typology**

Group	Sample reference	Generic description
C1	Calibration	PE Aluminium composite material (ACM)
C2	Calibration	FR ACM
C3	Calibration	A2 ACM
1	S1/S2/S4/S6	Aluminium honeycomb
2	S3/S5/S7/S8/S9/S10/S11/S12	High pressure laminate (HPL)
3	S13/S14/S17/S18	FR zinc composite material (ZCM)
4	S15/S16	FR copper composite material (CCM)
5	S19/S20/S21/S22	Reconstituted stone/brick slip system

The results, in terms of the measured values of heat release rate (HRR), total heat release (THR), heat flux and external and cavity temperatures and the observed behaviour, support the generic groupings proposed above. The experimental results show different behaviour in relation to both contribution to fire growth and conditions within the cavity for all of these different groupings.

The detailed results for each sample were provided in Appendix E. There are differences between the results from individual samples within each group. For Group 1, the aluminium honeycomb thickness for S1, S2 and S4 was 4 mm, whilst the thickness for S6 was 25 mm and the method of fixing was different, which needs to be taken account of in the analysis. For details of installation see Appendix E. Many of the differences, particularly for the HPL panels, appear to be related to the different thicknesses considered.

Details of the experimental rig and the instrumentation locations were presented in Appendix C. For clarity, the location of the heat flux gauges (for both the calibration exercise and the main experimental programme) and thermocouple locations relative to the fire source are shown in Figure F1.

The analysis of performance of the individual cladding panels or the groups as defined above is complex and depends on a combination of the results from a series of quantifiable measurements and the observed behaviour during the fire experiments.
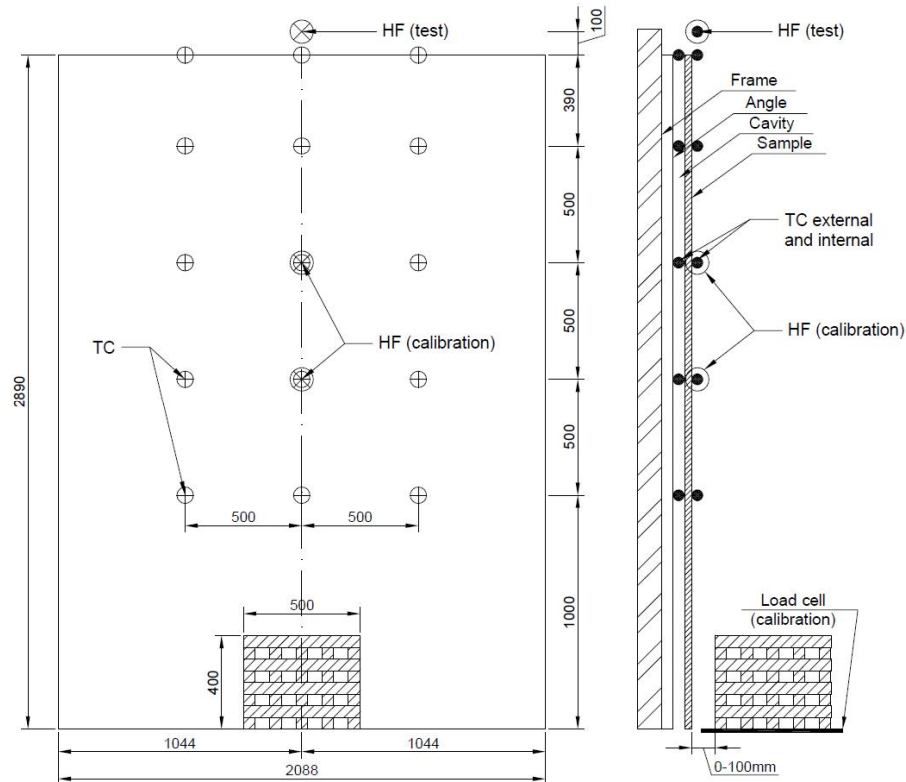
Key

HF = water cooled heat flux sensor (measures radiative and convective heat transfer)

TC = thermocouple

Figure F1 – Layout of the crib ignition source and location of instrumentation for calibration and main experiments (front elevation-left hand side; side elevation-right hand side)

The following measurements were obtained in order to provide quantitative data for the analysis:

- Heat release rate (HRR) is the rate at which a fire releases energy measured in Joules per second or Watts. The output from the experiments can be assessed in relation to the measured rate at which the material releases heat (HRR) as a function of time, the peak measured value at a specific time or the total energy released over the duration of the fire exposure (total heat release (THR)) measured in Joules. In this project, the heat release was measured by analysis of the products of combustion using the large calorimeter in the BRE Burn Hall Laboratory. The samples were located beneath a large extract hood within the facility. The energy released is derived from analysis of the depletion in oxygen (oxygen consumption calorimetry) and an increase in carbon dioxide from samples collected from the extract duct connected to the large hood. This is a standard method of calculating the energy released from burning materials during a fire scenario.

- The heat flux is a measure of the total heat flux (both the convective and radiative heat transfer) received by the instrument at the specific measurement point. In this case, a water-cooled heat flux sensor with a measurement range of 0-50 kW/m² was placed on the centre line of the experimental rig at a height of 3 m from ground level, as illustrated in Figure F1.

- Temperatures were measured using thermocouples placed in the locations specified in Figure F1 on both the outside of the panel (approximately 50 mm from the surface) and within the cavity (where a cavity was present – this depended on the specific material type).

In addition to the above measurements, the analysis of performance is based on visual observation in relation to observed flame spread and breakthrough of fire into the cavity behind the panels.

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F3 Analysis of experimental results

The approach to analysis of performance is related to the extent to which the panels of materials may contribute to fire growth in a realistic scenario.

When considering the performance of the products included in the experimental programme, their contribution needs to be viewed alongside:

- The base level of heat release provided by the ignition source

- The measured/observed performance for a product/material representing an unacceptable level of risk.

For the former, the base level provided by the crib ignition source against a non-combustible backing on the experimental rig was measured during the calibration process (see Appendix D) and is summarised in Table F2.

Table F2 – Base level results for the crib ignition source and non-combustible board

Parameter	Value
Peak heat release rate (kW)	300
Time to peak heat release (min)	6
Total heat release (MJ)	450
Peak measured heat flux on centre line 3 m from ground (kW/m²)	8

One of the primary objectives of this project identified by MHCLG was to establish if there were any other materials on the market that would provide a similar level of hazard to aluminium composite material (ACM) with a polyethylene (PE) core. As part of the calibration process undertaken for this project, a series of fire experiments were conducted on three types of ACM. The performance metrics adopted in this project are related to the measured and observed performance of the ACM panels with a PE core when subjected to the same thermal exposure and under the same conditions. The reference values, summarised in Table F3 are based on average values for the two PE ACM panels evaluated during the calibration process.

Table F3 – Summary of experimental results for ACM panels with PE core

Parameter	Value
Peak heat release rate (kW)	1459
Time to peak heat release (min)	21
Total heat release (MJ)	1061
Peak measured heat flux on centre line 3 m from ground (kW/m²)*	100**

*see Figure F6 and Figure F7 for time to peak heat flux and relation with cavity fire

**above range of instrument

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From the above, it can be seen that the peak HRR for the PE ACM samples are almost five times that of the base level provided by the crib ignition source, indicating a significant contribution to fire development from the material panel itself. This was supported by the visual evidence which showed both vertical and horizontal flame spread.

An increase in HRR over and above that provided by the ignition source indicates a contribution from the sample to the overall energy produced. This can be either a short-term increase which may represent, for example, the contribution from a surface coating which is ignited in the early stages and then consumed over a short period of time or may occur at a later time and be maintained for a longer duration which would be indicative of a contribution from the core or bulk of the material. The duration of the assessment for this programme was 30 minutes for every fire experiment corresponding to the time from ignition to almost complete combustion of the timber crib ignition source. Where there was an increase in the peak heat flux this would be indicative of a localised contribution from the sample in the region of the ignition source often accompanied by a breakthrough of fire into the cavity.

The clearest quantitative assessment of a breakthrough of the sample and/or a fire within the cavity is the peak measured heat flux at the top of the sample corroborated by a significant temperature rise within the cavity between the sample and the non-combustible substrate. All measured values need to be considered alongside the observed behaviour. In many cases, the breakthrough of the fire into the cavity space indicated by a rise in the temperature of the thermocouples within the cavity on the centre line and a subsequent rise in the peak measured heat flux can be confirmed from visual observation of flaming within the cavity.

The peak temperature measured in the cavity for the brick slip system (Group 5) was only 33 °C while the corresponding figure for the reconstituted stone panels was 266 °C. The reason for this difference is because the brick slip system with the PUR backing is mechanically fixed directly to a cement particle board which is itself fixed back to the aluminium T rails of the experimental rig, so there is no cavity present in this case and the measurement is made behind the cement particle board. The differences in method of fixing, installation procedure and location of any joints are detailed in Appendix E and Appendix F1.

There is a distinct difference between the behaviour of the zinc and copper composite panels, based largely on the differences in the relative melting temperatures of the two metals (420 °C for zinc and 1085 °C for copper). The lower melting temperature of the zinc panels results in an early breakthrough of the fire through the panel, exposing the core directly to the ignition source. Consequently, although the break through occurred early, the temperatures within the cavity at the top of the rig and the resulting peak heat flux in the same location were lower than for the copper panels. Once the fire entered the cavity for the copper panels, either from below or via the vertical joint as the fire did not melt through the panels, the flames and hot gases were confined and the measured temperatures, measured heat flux and observed behaviour all pointed to a very significant fire within the cavity with a significant contribution from the core of the panels. This highlights the difficulty in focusing on just one measurement such as fire growth based on HRR or THR as opposed to heat flux and temperatures in the cavity.

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F4 Discussion

Based on the methodology and analysis described above, the behaviour of each of the sample groups has been considered in relation to:

- Overall contribution to fire growth

- Potential for development of a cavity fire incident.

The performance will be related to the relative performance of the PE ACM panels investigated during the calibration process.

F4.1 Contribution to fire growth

Figure F2 shows the measured HRR for all the individual samples compared to the base value for the crib ignition source.
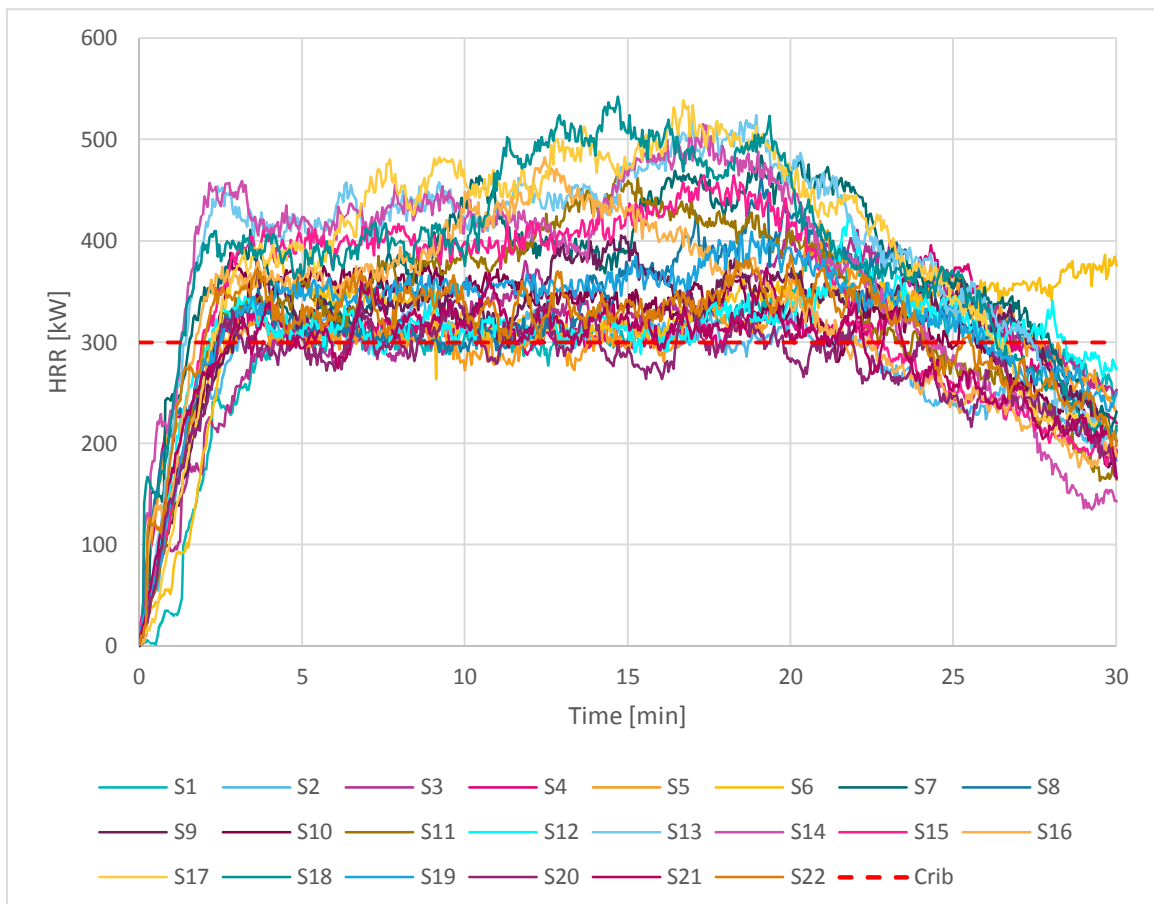
Figure F2 – Heat release rate for all samples showing base value of ignition source

It can be seen from the figure that there is some differentiation between the five groups identified above with Groups 1 and 5 clustered around the crib base level and Groups 2 and 3 showing a contribution up to approximately 200 kW above the base level. Figure F3 shows the values in Figure F2 alongside the results of the two PE ACM samples evaluated as part of the calibration process.
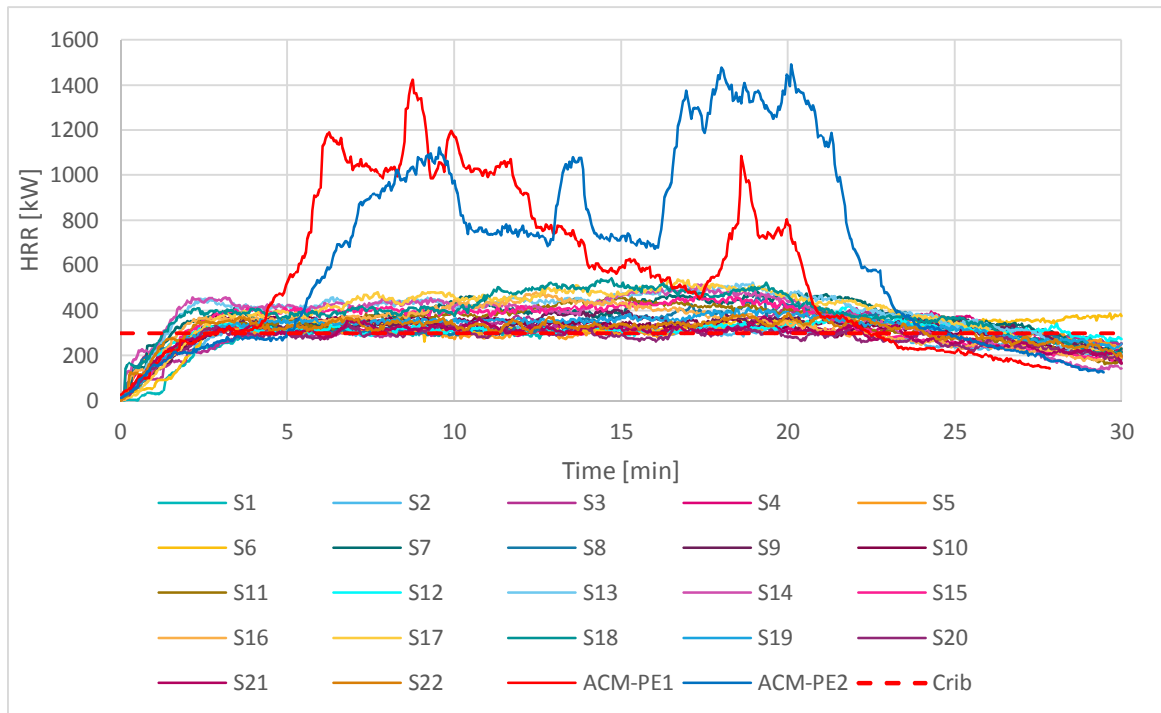
Figure F3 – Heat release rate for all samples showing base value of ignition source and comparison with PE ACM samples

Based on a consideration of Figure F3 and a review of the video evidence, it can be concluded that none of the samples included in the experimental programme exhibit fire performance which is comparable to the fire growth and fire spread of the PE ACM samples when subjected to the same fire exposure and experimental methodology which underpins this project.

F4.2 Cavity fire performance

For real cavity systems, it is necessary to consider not only the potential impact of fire growth from the external panel but also the potential impact of a breakthrough of fire.

Figure F4 shows the measured value of heat flux on the centre line at a height of 3 m from the ground for all samples. The baseline contribution of the ignition source is indicated on the figure as a constant value of 4 kW/m².
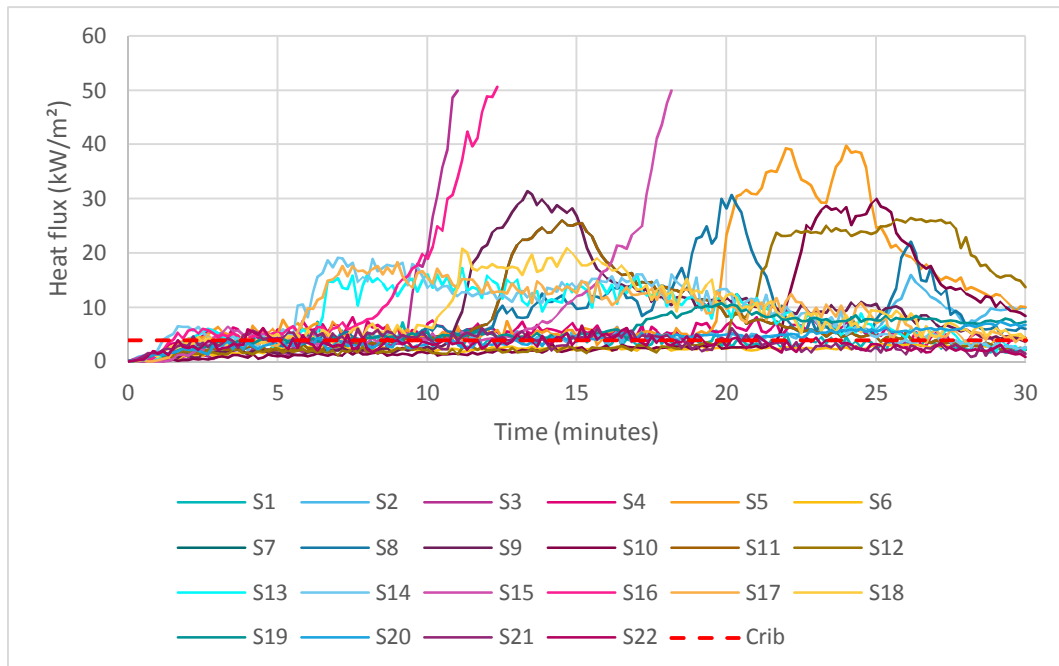
Figure F4 – Measured heat flux for all samples at 3 m from the ground on the centre line

The figure shows a significant difference in behaviour between the various samples. The values of 50 kW/m² and a termination of the readings for S3, S15 and S16 are where the maximum capacity of the heat flux meter was exceeded. The assessment needs to consider the issue of break through both in terms of time to breach the cavity and the intensity of the cavity fire once a breach has occurred and the potential impact on any combustible materials contained within the space behind the front panel. The time to break through can be assessed in relation to the measured values and the observed behaviour. The severity of any subsequent fire within the cavity can be related to the temperature measured within the cavity and the peak heat flux measured at the top of the sample. As with the assessment of the contribution to fire development it is important to consider the results relative to the results from a material with a known level of performance. Figure F5 shows the measured values alongside the results from the two PE ACM samples considered as part of the calibration process. The values of 100 kW/m² and the termination of the readings for the two PE ACM calibration samples are where the maximum capacity of the heat flux meter was exceeded.

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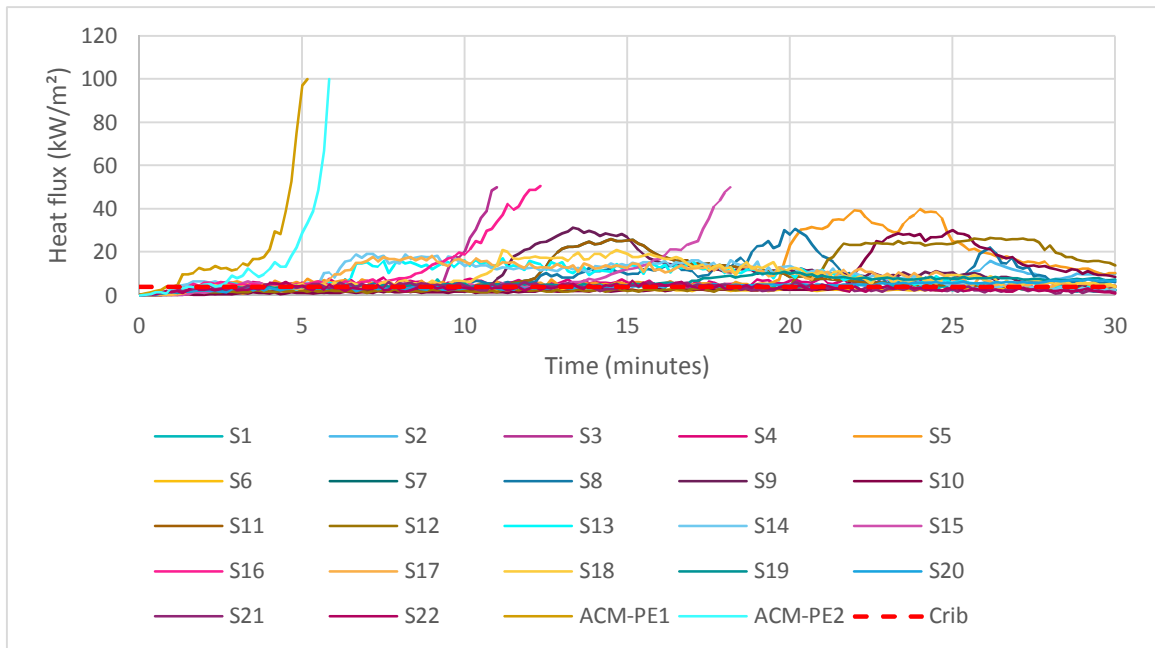
Figure F5 – Measured heat flux for all samples at 3 m from the ground on the centre line

The relative contribution of each group in relation to both fire growth (peak HRR) and break through into the cavity (peak heat flux) is illustrated in Figure F6 which also illustrates the variation within the selected groups. Figure F7 shows the measured heat flux alongside the time to develop a significant fire in the cavity.
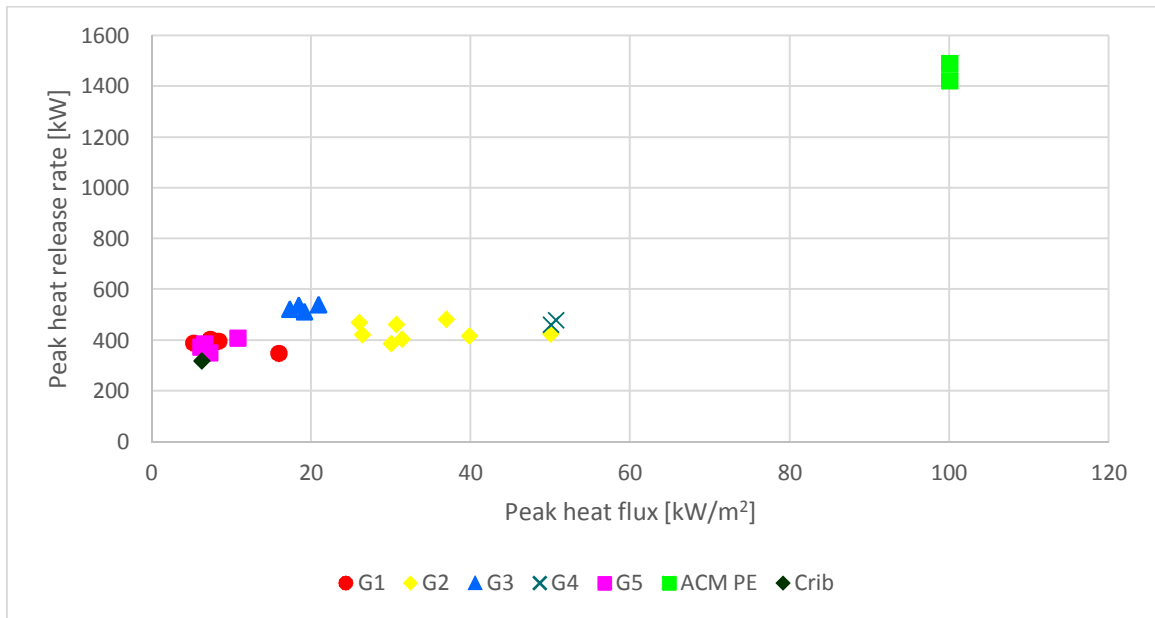

Figure F6 – Group results related to measured peak heat release rate and measured peak heat flux including PE ACM panels used for calibration
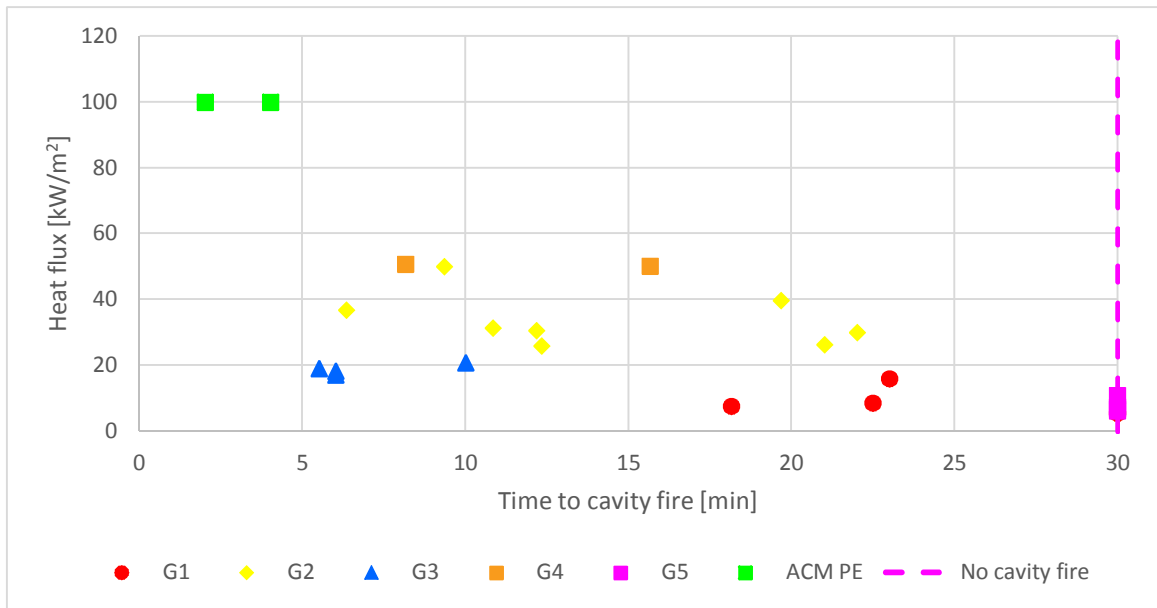
Figure F7 – Group results related to measured peak heat flux and time to initiation of a fire within the cavity

The figures support the idea of generic groups while showing the variability within individual groups and the relative performance in relation to PE ACM panels. Some of the variability, particularly for the HPL panels, can be explained in relation to the different thicknesses considered. Figure F8 provides a comparison between the different HPL panels in relation to measured peak HRR and heat flux. Figure F9 is a comparison of the same samples in relation to peak heat flux and time to burn through of the panels. Although the joint locations were different between individual samples (see Appendix F1) there were no significant differences in the location of the joints between panels within the individual groups.
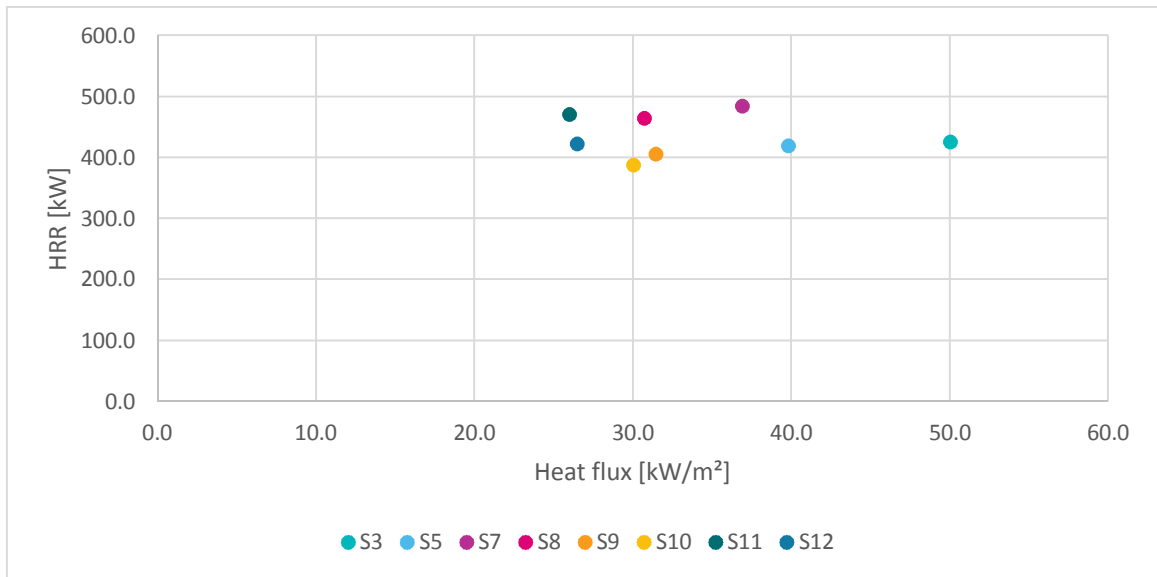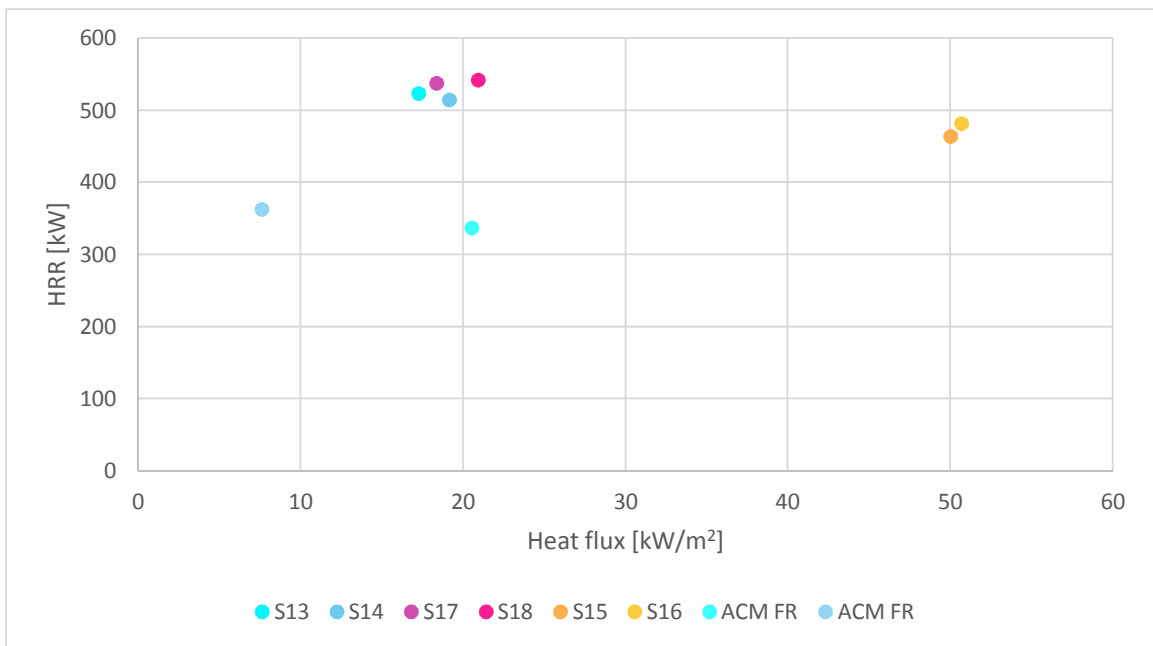

Figure F8 – Comparison of measured performance of HPL panels in relation to peak heat release rate and peak heat flux
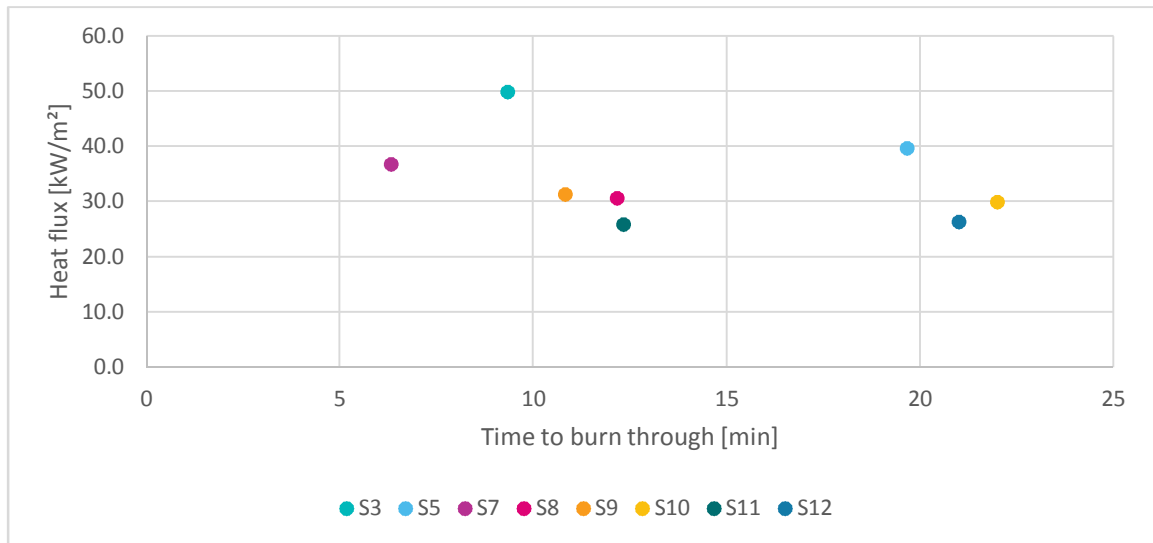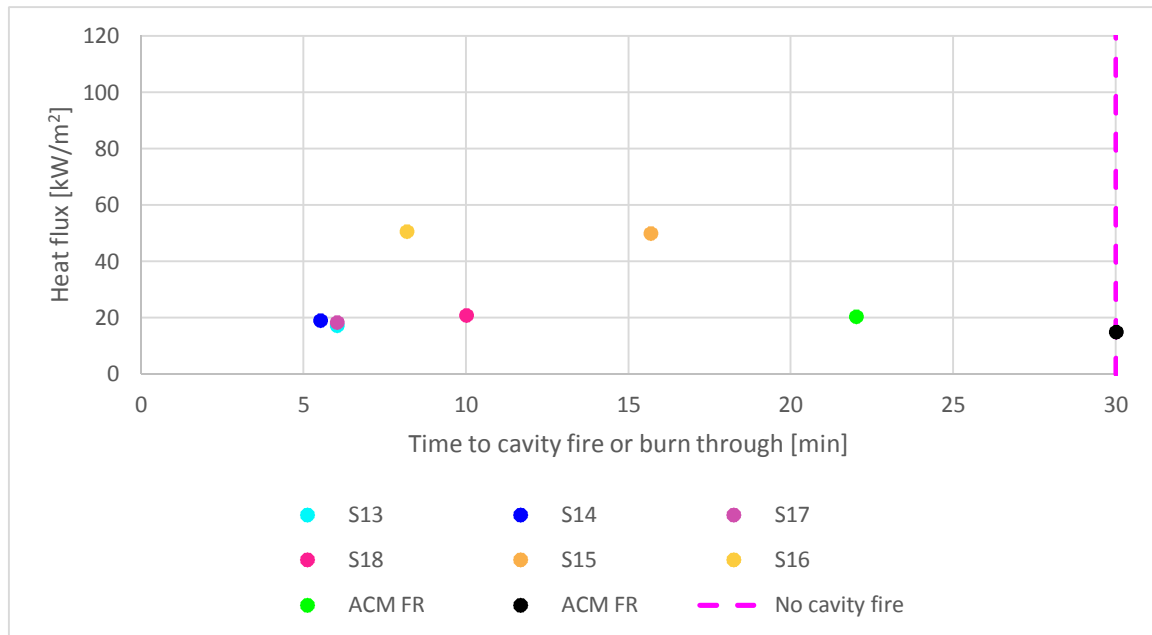
Figure F9 – Comparison of measured performance of HPL panels in relation to peak heat flux and time to burn through of the panels

The metal composite materials (MCM) included in the experimental programme were incorporated to ascertain if the behaviour would be similar to the ACM material included in the calibration phase. It was only possible to procure FR core versions of the zinc and copper composite materials as no PE or A2 core panels were available for purchase in the UK market. Therefore, it is not possible to provide a direct comparison between the PE or A2 versions of these products.

Figure F10 provides a comparison between the FR versions of the MCM including zinc (samples S13/S14/S17/S8), copper (S15/S16) and aluminium from the calibration programme in relation to measured peak HRR and heat flux. Figure F11 is a comparison of the same samples in relation to peak heat flux and time to initiation of a cavity fire or burn through of the panel.

Figure F10 – Comparison of measured performance of FR metal composite panels in relation to peak heat release rate and peak heat flux

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Figure F11 – Comparison of FR metal composite materials in relation to peak heat flux and time to burn through of the panels

The results summarised in Figure F10 and Figure F11 show that both the FR zinc composite and copper composite panels provide a larger contribution to fire growth than the corresponding FR ACM panels and that this contribution is more pronounced for the zinc composite panels. The results also indicate that the zinc composite panels will burn through quicker than the corresponding ACM panels due to the lower melting temperature of zinc. It is therefore reasonable to conclude that the zinc composite panels will provide a similar or worse performance than the corresponding PE (or A2) ACM panels. The copper panels do not behave in the same manner due to the higher melting temperature of copper and therefore should be treated separately.

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F5 Conclusions

The following conclusions are based on the results and observations of the experimental programme in accordance with the methodology described in previous Appendices. The project only considered the external cladding panels in isolation from other components of the cladding system. Based on the measured and observed behaviour of the samples, a comparison with the measured and observed behaviour of the PE ACM panels when subject to the same experimental procedure as part of the calibration process and a consideration of the potential risk based on contribution to fire growth and the potential risk associated with a cavity fire, the following conclusions can be drawn:

- None of the samples investigated shows the same or a similar type of fire performance to that of PE ACM panels, whether in relation to contribution to fire growth, fire spread or potential issues with breakthrough and initiation of cavity fires. All the samples included in this study to date had an indicative (based on information from the manufacturers' websites) reaction to fire performance of at least Class B (European classification) or Class 0 (national classification).

- Although not included in the current experimental programme due to the unavailability of zinc composite panels with PE core, the results and the comparison between the FR ZCM and the FR ACM suggest that zinc composite panels with a polyethylene core may give a similar fire performance to PE cored ACM panels.

- The copper composite panels did not behave in a similar way to the aluminium or zinc panels and should therefore be considered separately.

- There is no evidence for any of the samples investigated to indicate that the products represent a similar hazard to the PE ACM panels.

- In terms of relative performance, the zinc composite material exhibited the highest contribution to fire growth and shortest time to burn through. However, it should be borne in mind that the most significant cavity fire and the largest measured heat flux at the top of the specimen was recorded for the copper composite panels where no breakthrough of the panels took place.

- Group 1 (aluminium honeycomb) and Group 5 products (reconstituted stone and brick slip systems) exhibited a relatively low contribution to fire development and fire spread. For the brick slip system, the solid PUR carrier plate is bonded and mechanically fixed back to a cement particle board which forms the substrate for the cladding system so there is no cavity directly behind the brick slip/PUR panels.

Based on the results from the experiments carried out to date, it is recommended that further work is conducted to establish the relationship between (FR) zinc and copper composite panels in conjunction with different types of insulation in the cavity. If this were to be carried out at intermediate level, a programme of work would be necessary to determine the level of correlation with large-scale fire performance of a cladding system which incorporates cavity barriers. The programme should also be extended to consider the performance of a range of HPL panels (standard and FR) under similar conditions.

The location of the joints between panels also requires further study to determine its impact on the fire performance characteristics of the materials. In most cases, the vertical joint between panels was offset from the centre to correspond with the width of the panels supplied. For the PE ACM panels used in the calibration and for the FR metal composite panels included in the project, the panel widths were 1 m and the central joint was located on the centre of the ignition source.

Appendix F1   Details of experimental samples

Sample ref.	Description	Manufacturer's stated RTF performance
S1	Aluminium honeycomb panels 4 mm thick with 0.7 mm aluminium face	A2-s1, d0
S2	Aluminium honeycomb panels 4 mm thick with 0.7 mm aluminium face	A2-s1, d0
S3	High pressure laminate (HPL) panels 6 mm thick	B-s2, d0
S4	Aluminium honeycomb panels 4 mm thick with 0.7 mm aluminium face	A2-s1, d0
S5	High pressure laminate (HPL) panels 10 mm thick	B-s2, d0
S6	Aluminium honeycomb panels 25 mm thick	A2-s1, d0
S7	Wood composite HPL panels 6 mm thick	B-s2, d0
S8	Wood composite HPL panels 10 mm thick	B-s2, d0
S9	HPL PUR resin panels 6 mm thick	B-s2, d0
S10	HPL PUR resin panels 10 mm thick	B-s2, d1
S11	HPL phenolic panels 6 mm thick	B-s1, d0
S12	HPL phenolic panels 10 mm thick	B-s1, d1
S13	Zinc composite panels 4 mm thick	B-s1, d0
S14	Zinc composite panels 4 mm thick	B-s1, d0
S15	Copper composite panels 4 mm thick	B-s1, d0
S16	Copper composite panels 4 mm thick	B-s1, d0
S17	Zinc composite panels 4 mm thick	B-s1, d0
S18	Zinc composite panels 4 mm thick	B-s1, d0
S19	Reconstituted stone panels 6mm thick	Class 0
S20	Reconstituted stone panels 10mm thick	Class 1
S21	Brick slip system bonded to PUR insulation	B-s2, d0
S22	Brick slip system bonded to PUR insulation	B-s2, d0

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Sample ref.	Thickness (mm)	Vertical joint (measured from centre line) (m)	Horizontal joint measured from ground level (m)	Cavity (mm)	Fixing spacing (mm)
S1	4				
S2	4				
S3	6	0.5	2	50	300 (vertical) 400 (horizontal)
S4	4				
S5	10				
S6	25	0.5	2	140	M6x30 in the corners
S7	6	0.2	2	50	300 (vertical) 400 (horizontal)
S8	10				
S9	6	0.5	2	50	300 (vertical) 400 (horizontal)
S10	10				
S11	6	0.25	2	50	300 (vertical) 400 (horizontal)
S12	10				
S13	4				
S14	4				
S15	4	0	2	50	300 (vertical) 400 (horizontal)
S16	4				
S17	4				
S18	4				
S19	6	0.2	2	50	300 (vertical) 400 (horizontal)
S20	10				
S21	55-65	N/A	N/A	N/A	Mechanical fixings and cement-based adhesive

Report Ends