HALLIWELL
FIRE RESEARCH

Technical Report

PERLIFOC HP ECO + PROTECTED CONCRETE STRUCTURAL ELEMENTS

Halliwell Fire Research Report 35395-A V1.0 | 17 July 2024

Expiry date | 30 July 2029

Technical report on

PERLIFOC HP ECO + PROTECTED CONCRETE STRUCTURAL ELEMENTS

Halliwell Fire Research Report 35395-A V1.0 | 17 July 2024

Client:
Tremco CPG Australia Pty Ltd
12/4 Southridge Street
Eastern Creek
NSW 2766
Australia

Document Issue

Issue	Date		Author	Reviewer	Authoriser
V1.0	Issue date	17 July 2024	Imran Ahamed RPEQ 23210	Ryan Hilditch	Mario Lara Ledermann
	Expiry date	30 July 2029	Imran.		

Table of Contents

List of Figures

List of Tables

1 Executive Summary

Halliwell Fire Research has prepared this technical report to document the findings of an assessment undertaken to determine the contribution of non-reactive PERLIFOC HP Eco+ spray to the fire resistance of concrete structural elements.

AS 3600:2018 allows the use of insulation materials to increase the fire resistance periods (FRPs) for structural adequacy and insulation. While it is required to determine the necessary thickness of insulation material by testing in accordance with AS 1530.4:2014 to achieve a given fire resistance level (FRL), there is currently no recommended method for determining the contribution of such insulation material to fire resistance in either AS 1530.4:2014 or AS 3600:2018. Therefore, this report follows the methodology provided in EN 13381-3:2015, using test data obtained in accordance with EN 13381-3:2015, which is concluded to be more stringent than the requirements of AS 1530.4:2014.

Based on the analysis of the test data, this report determines the contribution of PERLIFOC HP Eco+ spray in enhancing fire resistance by calculating the equivalent concrete thickness for a given thickness of PERLIFOC HP Eco+ spray for a specified AS 1530.4:2014 fire exposure period. Table 1 summarises the outcomes for concrete floors and walls, whereas Table 2 summarises the outcomes for concrete beams and columns. These outcomes can be used as supporting evidence by structural or fire engineers to determine the FRL of PERLIFOC HP Eco+ spray protected concrete structural elements by conducting designs in accordance with AS 3600:2018 or to a recognised standard.

Table 1 Equivalent depth of concrete for concrete floors and walls

Time (minutes)	Equivalent depth of concrete (mm)	
	Minimum PERLIFOC HP Eco+ thickness (10.3 mm)	Minimum PERLIFOC HP Eco+ thickness (25.2 mm)
30	36.3	58.6
60	46.2	76.3
90	48.5	85.5
120	47.9	92.2
180	44.7	95.0
240	38.6	93.1

Table 2 Equivalent concrete thickness for concrete beams and columns

Time (minutes)	Equivalent depth of concrete (mm)	
	Minimum PERLIFOC HP Eco+ thickness (10.9 mm)	Minimum PERLIFOC HP Eco+ thickness (25.4 mm)
30	42.8	68.6
60	50.6	92.3
90	50.6	98.9
120	48.3	101.6
180	–	96.8
240	–	89.9

2 Introduction

2.1 General

Tremco CPG Australia Pty Ltd have engaged Halliwell Fire Research to prepare a technical report to determine the contribution provided by the non-reactive PERLIFOC HP Eco+ spray to the fire resistance of concrete structural elements.

AS 3600:2018 allows the use of insulation materials to increase the FRPs for structural adequacy and insulation. The required insulation thickness to achieve a given FRL must be determined by testing in accordance with AS 1530.4:2014. However, there is currently no recommended method for determining the contribution of such insulation material to fire resistance in either AS 1530.4:2014 or AS 3600:2018. Therefore, this report follows the methodology provided in EN 13381-3:2015, using test data obtained in accordance with EN 13381-3:2015.

2.2 The scope of this report

The scope of the engineering judgement report is limited to the below:

- Halliwell Fire Research has been engaged to provide a technical assessment on the contribution provided by the PERLIFOC HP Eco+ spray to the fire resistance of concrete structural elements. The report covers concrete floors, walls, beams and columns.
- This report discusses the response of PERLIFOC HP Eco+ spray protected concrete structural members exposed to AS 1530.4:2014 fire conditions. The response of the concrete structural members to any other fire scenarios is not part of the scope of this report.
- The findings of this report can be used as supporting evidence by structural or fire engineers to determine the FRL of concrete structural elements within a project. It is the responsibility of the engineer to use the outcomes (equivalent concrete thickness relating to the thickness of the applied PERLIFOC HP Eco+ spray) provided in this report to design the concrete structural elements in accordance with AS 3600:2018 or to a recognised standard to achieve the required periods for structural adequacy and insulation.
- The design of concrete members is not part of the scope of this report.
- The results are applicable to concrete beams and columns with a width equal or greater than that tested (150 mm) and with a height equal to or greater than that tested (450 mm). It is possible to decrease the height provided the section surface remains the same by increasing the width.
- The results are only applicable for thicknesses of PERLIFOC HP Eco+ between the minimum and maximum tested.

2.3 Limitations and requirements

- The ‘Guide to undertaking technical assessments of the fire performance of construction products based on fire test evidence’ prepared by the Passive Fire Protection Forum (PFPF) in the UK in 2021 defines a framework and competency standards for undertaking assessments based on fire test evidence. Given there is no specific framework, standard or methodology in New Zealand and Australia for preparing such assessments, Halliwell Fire Research has adopted this PFPF 2021 guideline to prepare this report.
- This report has been prepared based on information provided by the report sponsor including test reports, fire assessment reports and material properties. We have not independently verified the accuracy of this information and therefore cannot be held responsible for any errors or omissions that may be present in this report as a result.
- This report was prepared at the request of Tremco CPG Australia Pty Ltd for their specific purposes. Structural engineers, fire safety engineers, building certifiers, approval

authorities, and other third parties are responsible for determining the suitability of using the outcomes of this report for a given construction circumstance.

- It is to be noted that due to the complexity inherent in fire testing and the consequent challenges in accurately quantifying measurement uncertainties, it is not feasible to provide a specified level of accuracy. Variability in test procedures, materials, construction methods, and installation may result in performance differences among elements of similar construction.
- The client must withdraw this report from circulation if the component or element of structure is the subject of a fire test by a test authority in accordance with the standard against which this assessment is being made and the results are not in agreement with this report. They must also withdraw this report if they get to know any information that could adversely affect the conclusions of this report.

3 Background Information

3.1 General

This technical report was prepared based on the test evidence listed in Table 3.

Table 3 Test evidence

Report	Issuing authority	Test date
19/20234-1430 M2	Applus Laboratories	29 August 2019
21/25361-1128 M1	Applus Laboratories	26 May 2021
Nr 9804-19	LICOF Centre for Fire Testing and Research	17 October 2019
Nr 9836-19	LICOF Centre for Fire Testing and Research	19 February 2020

3.2 Fire test evidence

3.2.1 Fire test report 19/20234-1430 M2

The fire test report 19/20234-1430 M2 details the fire test conducted on a 4600 mm (length) × 3000 mm (width) × 150 mm (thick) concrete floor slab protected with 10.3 mm thick (average) PERLIFOC HP (equivalent to PERLIFOC HP Eco+) spray. This tested concrete floor specimen is referred to as “Slab minimum” throughout this report.

Thermocouples were embedded at various depths, as required by EN 13381-3:2015, within the floor specimen to measure temperature progression with time and to quantify the protection provided by the PERLIFOC HP Eco+ spray. A total load of 60.7 kN was applied on the test specimen to produce tensile stress of 300 MPa in the reinforcement bars as required by the EN 13381-3:2015. The test was performed on 29 August 2019. Upon testing in accordance EN 13381-3:2015, the test specimen maintained structural adequacy and, integrity and insulation up to 246 minutes. Further details of the test specimen are provided in Table 4.

3.2.2 Fire test report 21/25361-1128 M1

The fire test report 21/25361-1128 M1 details the fire test conducted on a 4600 mm (length) × 3000 mm (width) × 150 mm (thick) concrete floor slab protected with 25.2 mm thick (average) PERLIFOC HP (equivalent to PERLIFOC HP Eco+) spray. This tested concrete floor specimen is referred to as “Slab maximum” throughout this report.

Thermocouples were embedded at various depths, as required by EN 13381-3:2015, within the floor specimen to measure the temperature progression with time and to quantify the protection provided by the PERLIFOC HP Eco+ spray. A total load of 55.7 kN was applied on the test specimen to produce tensile stress of 300 MPa in the reinforcement bars as required by the EN 13381-3:2015. The test was performed on 26 May 2021. Upon testing in accordance EN 13381-3:2015, the test specimen maintained structural adequacy and, integrity and insulation up to 249 minutes. Further details of the test specimen are provided in Table 4.

3.2.3 Fire test report Nr 9804-19

The fire test report Nr 9804-19 details the fire test conducted on a 4480 mm (length) × 450 mm (height) × 150 mm (width) concrete beam protected with 10.9 mm thick (average) PERLIFOC HP (equivalent to PERLIFOC HP Eco+) spray. This tested concrete beam specimen is referred to as “Beam minimum” throughout this report.

Thermocouples were embedded at various depths, as required by EN 13381-3:2015, within the beam to measure the temperature progression with time and to quantify the protection provided by the PERLIFOC HP Eco+ spray. A total load of 46.1 kN was applied on the test specimen to produce a maximum bending moment of 29.46 kNm on the beam. The test was performed on 17 October 2019. Upon testing in accordance EN 13381-3:2015, the test specimen maintained structural adequacy up to 155 minutes. Further details of the test specimen are provided in Table 4.

3.2.4 Fire test report Nr 9836-19

The fire test report Nr 9836-19 details the fire test conducted on a 4480 mm (length) × 450 mm (height) × 150 mm (width) concrete beam protected with 25.4 mm thick (average) PERLIFOC HP (equivalent to PERLIFOC HP Eco+) spray. This tested concrete beam specimen is referred to as “Beam maximum” throughout this report.

Thermocouples were embedded at various depths, as required by EN 13381-3:2015, within the beam to measure the temperature progression with time and to quantify the protection provided by the PERLIFOC HP Eco+ spray. A total load of 46.1 kN was applied on the test specimen to produce a maximum bending moment of 29.46 kNm on the beam. The test was performed on 19 February 2020. Upon testing in accordance EN 13381-3:2015, the test specimen maintained structural adequacy up to 243 minutes. Further details of the test specimen are provided in Table 4.

Table 4 Details of the fire test specimens

Specimen	Depth (mm)	Concrete cover (mm)	Concrete strength		Spray thickness (mm)
			At 28 days (MPa)	At the test (MPa)	
Slab minimum	150	20	29.2	31.5	10.3
Slab maximum	150	20	31.7	36.3	25.2
Beam minimum	452	25	25.6	30.2	10.9
Beam maximum	452	25	44.4	49.1	25.4

4 Overview of the Construction

4.1 Description

Based on the results of fire tests summarised in section 3.2, this technical report addresses following aspects.

Assessment 1 – The tests were conducted in accordance with EN 13381-3:2015. This report compares the requirements between EN 13381-3:2015 and AS 1530.4:2014, and establishes the response of PERLIFOC HP Eco+ protected concrete structural members subjected to the fire conditions stipulated in AS 1530.4:2014.

Assessment 2 – This report examines the fire resistance performance of concrete floors and walls protected by PERLIFOC HP Eco+, and establishes the contribution that PERLIFOC HP Eco+ provides towards enhancing the fire resistance of these concrete elements.

Assessment 3 – This report examines the fire resistance performance of concrete beams and columns protected by PERLIFOC HP Eco+ and establishes the contribution that PERLIFOC HP Eco+ provides towards enhancing the fire resistance of these concrete elements.

4.2 Materials

Table 5 outlines the materials and its requirements relevant for this report.

Table 5 Materials

Material	Description	Value
Concrete	Density	2200 kg/m^3 to 2500 kg/m^3
	Strength	30 MPa
PERLIFOC HP Eco+ spray	Density	Nominally 600 kg/m^3
	Application	Application process must be similar to that of the fire tests

5 Technical discussion 1 – Comparison Between Fire Test Standards

5.1 General

Referenced test reports in Table 3 were conducted in accordance with EN 13381:3:2015. Table 6 provides a detailed comparison between EN 13381-3:2015 and AS 1530.4:2014 test standards.

5.2 Application of test data

As outlined in Table 6, it is established that most of the standard requirements between EN 13381-3:2015 and AS 1530.4:2014 test standards are similar. Moreover, variations in furnace thermocouples, test specimen size, structural adequacy and integrity failure criteria are expected to be more stringent in EN 13381-3:2015. Therefore, it is reasonable to anticipate that if the fire resistance tests referenced in Table 3 were conducted in accordance with AS 1530.4:2014, the specimen would have achieved similar or possibly better fire resistance performance.

For these reasons, it is our opinion that the referenced test data can be used as a basis to determine the contribution of PERLIFOC HP Eco+ when protecting concrete structural members subjected to the fire conditions stipulated in AS 1530.4:2014.

Table 6 Comparison between EN 13381-3:2015 and AS 1530.4:2014

Item	EN 13381-3:2015	AS 1530.4:2014
Furnace thermocouples	EN 13381-3:2015 refers to EN 1363-1:1999 for furnace thermocouple requirements. The furnace thermocouples specified in EN 1363-1:1999 are plate thermometers comprising an assembly of a folded nickel alloy plate, a thermocouple fixed to it, and insulation material. The folded metal plate must be constructed from a nickel-based superalloy, measuring 150 ± 1 mm in length, 100 ± 1 mm in width, and 0.7 ± 0.1 mm in thickness. The measuring junction must consist of nickel chromium/nickel aluminium (Type K) wire as defined in IEC 60584-1, contained within mineral insulation in a heat-resisting steel alloy sheath with a nominal diameter 1 - 3 mm. The hot junctions must be electrically insulated from the sheath. The thermocouple hot junction must be fixed to the geometric centre of the plate using a small steel strip made from the same material as the plate. The steel strip can either be welded to the plate or screwed to it to facilitate replacement of the thermocouple. If spot-welded to the plate, the strip should be approximately 18 mm by 6 mm, while if screwed to the plate, it should be nominally 25 mm by 6 mm. The screw that are used, should have a diameter of 2 mm. The assembly of plate and thermocouple must be fitted with a pad of inorganic insulation material measuring 97 ± 1 mm in length and width, and 10 ± 1 mm in thickness with a density of 280 ± 30 kg/m^3. The location of the furnace thermocouples must be 100 mm ± 50 mm from the exposed face of the specimen.	The furnace thermocouples specified in AS 1530.4:2014 are mineral-insulated metal-sheathed (MIMS) type K thermocouples. They consist of a stainless-steel sheath with a wire diameter of less than 1 mm and an overall diameter of 3 mm, with the measuring junction insulated from the sheath. The MIMS thermocouple must be supported by a heat-resistant tube, with or without additional insulation, ensuring that the measuring junction protrudes at least 25 mm from the supporting heat-resistant tube. The location of the furnace thermocouples is to be 100 mm ± 10 mm from the exposed face of the specimen.
	Furnace thermocouples required by EN 1363-1:1999 are generally less responsive than those specified in the AS 1530.4:2014. The difference in sensitivity can result in a potentially more onerous heating condition for specimens tested to EN 1363-1:1999. Therefore, a test conducted in accordance with EN 13381-3:2015 can be considered more onerous than a specimen tested AS 1530.4:2014.	

Heating curve	As per both EN 1363-1:1999 (which is referred by EN 13381-3:2015) and AS 1530.4:2014, the average temperature of the furnace must be controlled to follow the below relationship. $$T = 345log_{10}(8t + 1)$$ Where, T is the average furnace temperature, and the t is the time minutes. In addition to this similarity, both standards stipulate similar parameters to determine the accuracy of furnace temperature control. It is therefore established that the heating conditions of both standards are equivalent.
Furnace pressure	As per both EN 1363-1:1999 (which is referred by EN 13381-3:2015) and AS 1530.4:2014, a furnace pressure of approximately 20 Pa to be established at a position 100 mm below the floor and beam test specimens. In addition to this similarity, both standards stipulate similar parameters to determine the accuracy of furnace pressure control. It is therefore established that the pressure conditions of both standards are equivalent.
Specimen size	Both standards require floor specimens to be minimum 4000 mm in length and 3000 mm in width. For beam specimens, EN 13381-3:2015 requires a minimum length of 4000 mm, whereas AS 1530.4:2014 requires a minimum length of 3000 mm. Therefore, the requirements of the EN 13381-3:2015 is considered to be similar for floor specimens and more onerous for beam specimens.
Criteria of failure – Structural adequacy	EN 13381-3:2015 specifies that the load must be applied at a constant magnitude throughout the test period until either a deformation of $L_{sup}/30$ is reached or the rate of deflection exceeds the limit set by EN 1363-1:1999, at which point the load should be removed. On the other hand, AS 1530.4:2014 standard stipulate following structural adequacy criteria for floors and beams: Limiting deflection = $L^2/400d$ mm Limiting rate of deflection = $L^2/9000d$ mm/min, where L is the clear span and d is the distance from the extreme fibre of the compression zone to the tension zone. This means that if a test was conducted in accordance with AS 1530.4:2014, it could achieve a higher structural adequacy rating than what is achieved in an EN 13381-3:2015 test. Therefore, the requirements of the EN 13381-3:2015 are considered to be more onerous for floors and beams.

Criteria of failure – insulation	As per both EN 1363-1:1999 (which is referred by EN 13381-3:2015) and AS 1530.4:2014 test standards, insulation failure is deemed to have occurred when: The average temperature of the unexposed side exceeds the initial temperature by 140 K, or The maximum temperature of the unexposed side exceeds the initial temperature by 180 K. In addition, the requirements regarding the locations of the thermocouples on the unexposed side in both standards are not different. Therefore, it is established that the criteria for insulation failure in both standards are identical.
Criteria of failure – Integrity	EN 13381-3:2015 does not specify criteria for integrity failure. As per both EN 1363-1:1999 and AS 1530.4:2014 test standards, integrity failure is deemed to have occurred upon: • Ignition of a cotton pad • Penetration of a gap gauge • Sustained flaming While the failure criteria in relation to the ignition of cotton pads and penetration of gap gauges between the two standards are similar, the failure criteria in relation to sustained flaming slightly differs. AS 1530.4:2014 deems failure under sustained flaming if flaming occurs on the unexposed face for 10 seconds or longer, whereas EN 1363-1:1999 deems failure if flaming is observed without mentioning sustained flaming in terms of time. As such, failure criteria of sustained flaming under EN 1363-1:1999 can be considered to be onerous. Therefore, while generally integrity criteria of AS 1530.4:2014 and EN 1363-1:1999 are similar, some specific requirements of EN 1363-1:1999 can be considered to be more onerous.

6 Technical Discussion 2 – Contribution of PERLIFOC HP Eco+ Towards Fire Resistance of Concrete Floors and Walls

6.1 General

In this section of the report, the relationship between concrete temperature at various depths over time and for a given thickness of PERLIFOC HP Eco+ is established to determine the contribution of PERLIFOC HP Eco+ towards the fire resistance of concrete floors and walls. Since there is no recommended method of assessment for fire protection applied to concrete members in Australian Standards (AS 3600:2018 and AS 1530.4:2014), the methodology provided in EN 13381-3:2015 is adopted in this report.

6.2 Characteristic temperature of concrete at various depths

The characteristic temperature at different depths of the tested slabs, for each applied thickness of fire protection, is plotted at 30-minute intervals. These measurements are taken at the unexposed surface and various depths within the concrete including at the interface between the fire protection product and concrete. The characteristic temperature is calculated as the average between the mean temperature and the highest individual temperature for each thermocouple group. The temperatures recorded at each location, along with the corresponding graphs for the slab specimens (Slab minimum and Slab maximum), are presented in Table 7 and Table 8, and subsequently in Figure 1 to Figure 3.

Table 7 Characteristic temperatures of Slab minimum at various depths

Time (minutes)	Characteristic temperature (°C) at specified depth							
	0 mm	15 mm	30 mm	45 mm	60 mm	75 mm	150 mm	R/f
0	24	24	24	24	24	24	24	24
30	195	103	74	56	43	36	27	91
60	297	168	120	98	77	63	34	142
90	379	237	159	128	105	97	49	196
120	451	304	212	153	121	111	66	255
150	520	365	264	197	146	123	81	310
180	588	422	314	241	182	143	88	363
210	662	484	367	286	219	174	91	422
240	742	543	420	332	259	206	93	479

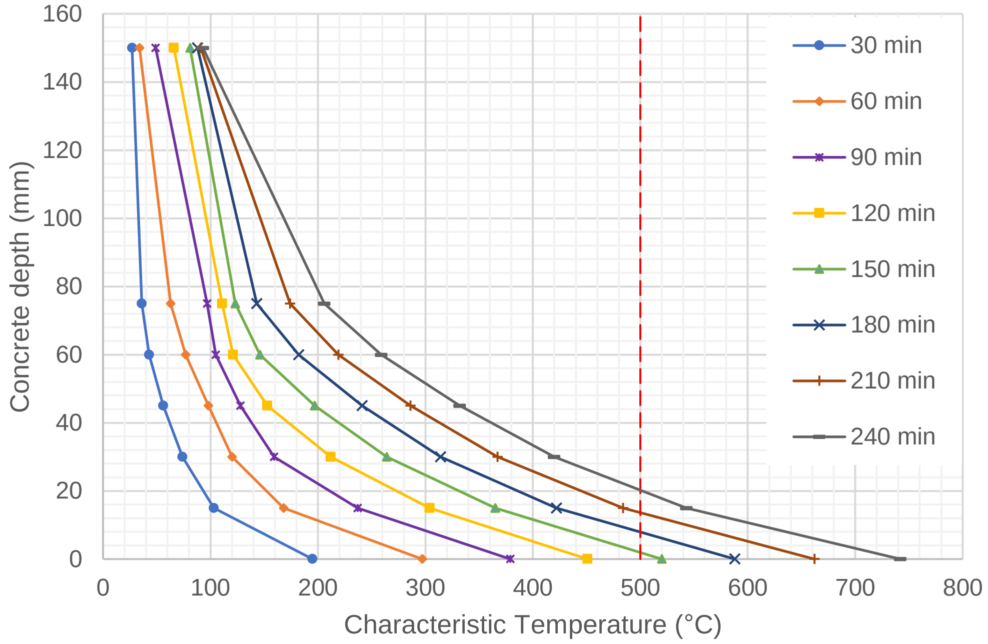

Figure 1 Characteristic temperatures of Slab minimum at various depths

Table 8 Characteristic temperatures of Slab maximum at various depths

Time (minutes)	Characteristic temperature (°C) at specified depth							
	0 mm	15 mm	30 mm	45 mm	60 mm	75 mm	150 mm	R/f
0	17	17	17	17	17	17	17	17
30	70	51	40	31	25	22	18	42
60	117	78	63	50	42	34	22	65
90	166	104	88	71	60	49	28	86
120	214	128	105	91	79	66	36	106
150	251	158	124	104	95	83	45	127
180	291	190	151	118	107	96	55	154
210	334	223	179	137	116	106	65	183
240	376	256	210	160	132	114	75	212

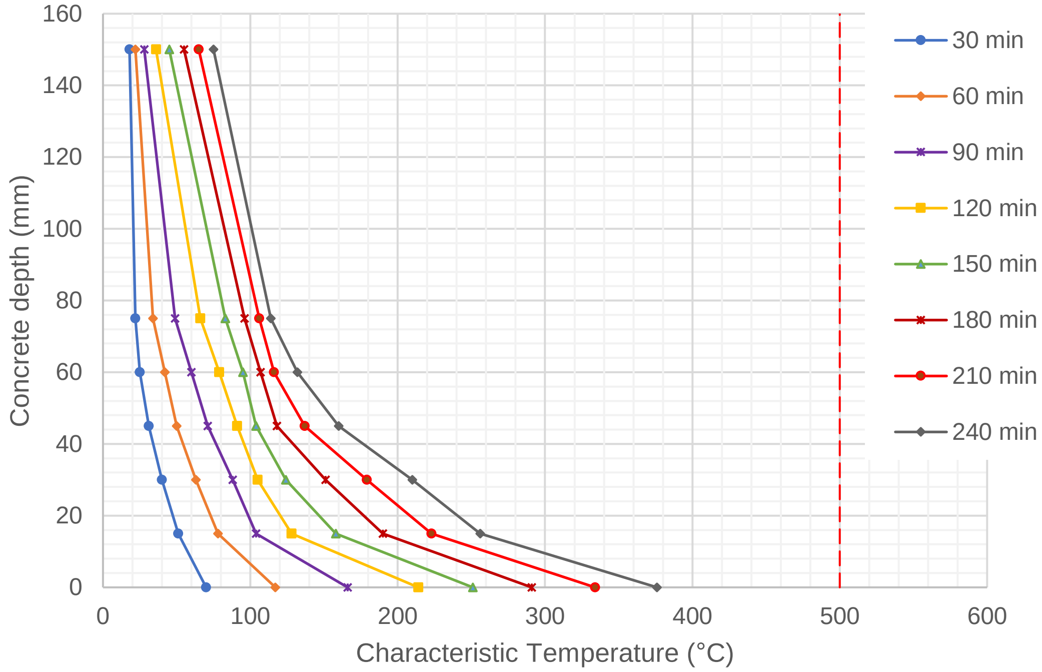

Figure 2 Characteristic temperatures of Slab maximum at various depths

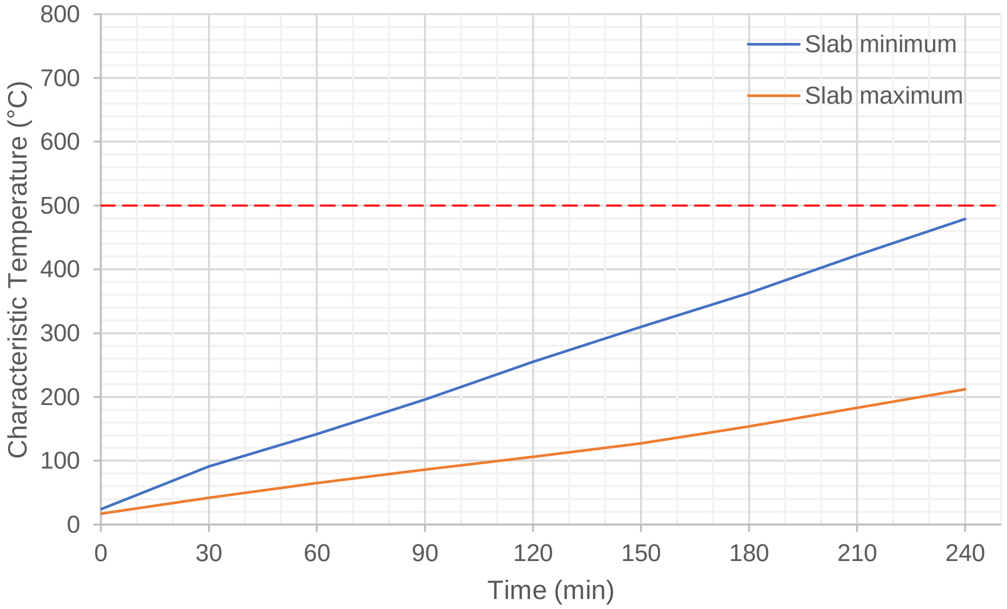

Figure 3 Characteristic temperatures on main reinforcement (cover – 20 mm)

6.3 Concrete depths at various critical temperatures

The depth along the concrete cross-sections for the slabs at which a series of critical limiting temperatures (in steps of 50°C) is reached is shown in Table 9 and Table 10.

Table 9 Concrete depths of Slab minimum at various critical temperatures

Time (minutes)	Concrete depths (in mm) at various critical temperature (°C)							
	300	350	400	450	500	550	600	650
60	–	–	–	–	–	–	–	–
90	8.3	3.1	–	–	–	–	–	–
120	15.7	10.3	5.2	–	–	–	–	–
150	24.7	17.2	11.6	6.8	1.9	–	–	–
180	32.9	25.0	18.1	12.5	8.0	3.4	–	–
210	42.4	33.1	25.8	19.4	13.7	9.4	5.2	1.0
240	48.4	41.9	33.4	26.3	20.2	14.5	10.7	6.9
'–' denotes that the critical temperature has not experienced at the given time period								

Table 10 Concrete depths of Slab maximum at various critical temperatures

Time (minutes)	Concrete depths (in mm) at various critical temperature (°C)							
	300	350	400	450	500	550	600	650
180	–	–	–	–	–	–	–	–
210	4.6	–	–	–	–	–	–	–
240	9.5	3.3	–	–	–	–	–	–
'–' denotes that the critical temperature has not experienced at the given time period								

6.4 Equivalent concrete thickness

With reference to EN 13381-3:2015, a thermocouple placed within a protected concrete slab will show a characteristic temperature of θ (d_{cp}, t) at a depth of d_{cp} from at a specified time t. This same characteristic temperature can be found in an unprotected concrete specimen at a depth called d_{cc}, which can be determined from Figure C.5 and Table C.1 in EN 13381-3:2015. This data can be used to calculate the equivalent thickness of an unprotected concrete slab that provides the same fire resistance as a specific layer of applied fire protection material. This concept is used to determine the equivalent concrete thickness for a given thickness of PERLIFOC HP Eco+.

The thermocouples placed at 15 mm from the interface between the concrete and fire protection material is used to provide data for the calculation of the equivalent concrete thickness. This data is shown in Table 11. Based on the temperature readings of Table 11, the equivalent depth of unprotected concrete slab is determined and shown in Table 12.

Table 11 Characteristic temperature at 15 mm from the exposed surface

Time (minutes)	Temperature (°C)	
	Minimum PERLIFOC HP Eco+ thickness (10.3 mm)	Minimum PERLIFOC HP Eco+ thickness (25.2 mm)
30	103	51
60	168	78
90	237	104
120	304	128
180	422	190
240	543	256

Table 12 Equivalent depth of unprotected concrete as per EN 13381-3:2015

Time (minutes)	Equivalent depth of unprotected concrete (mm)	
	Minimum PERLIFOC HP Eco+ thickness (10.3 mm)	Minimum PERLIFOC HP Eco+ thickness (25.2 mm)
30	51.3	73.6
60	61.2	91.3
90	63.5	100.5
120	62.9	107.2
180	59.7	110.0
240	53.6	108.1

Equivalent unprotected concrete depths derived in Table 12, were then used to determine the equivalent concrete thickness of PERLIFOC HP Eco+. They are summarised in Table 13 and illustrated in Figure 4.

Table 13 Equivalent depth of concrete

Time (minutes)	Equivalent depth of concrete (mm)	
	Minimum PERLIFOC HP Eco+ thickness (10.3 mm)	Minimum PERLIFOC HP Eco+ thickness (25.2 mm)
30	36.3	58.6
60	46.2	76.3
90	48.5	85.5
120	47.9	92.2
180	44.7	95.0
240	38.6	93.1

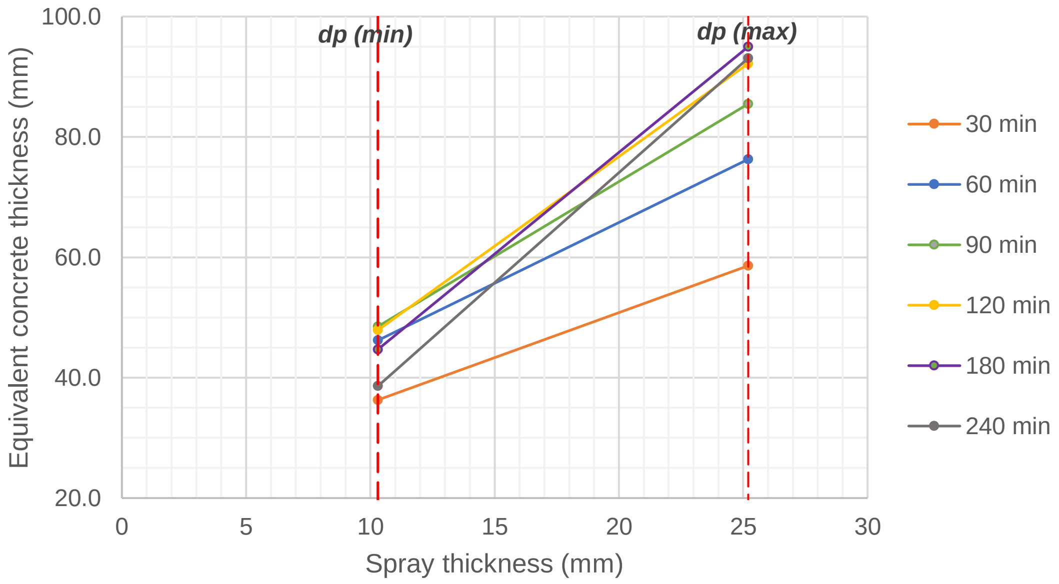

Figure 4 Equivalent concrete thickness vs sprayed thickness of PERLIFOC HP Eco+

Based on the findings of this section, the contribution of PERLIFOC HP Eco+ to the fire resistance of concrete slabs can be determined by considering the equivalent concrete thickness corresponding to a specific thickness of PERLIFOC HP Eco+. For instance, 10.3 mm of PERLIFOC HP Eco+ spray is equivalent to 38.6 mm of concrete when protecting a concrete slab exposed to 240 minutes of AS 1530.4:2014 fire exposure. Similarly, equivalent concrete thickness of PERLIFOC HP Eco+ spray for other time periods for a given spray thickness can be determined using Table 13 and Figure 4.

6.5 Stickability performance of PERLIFOC HP Eco+ spray

With reference to EN 13381-3:2015, stickability failure is deemed when the maximum temperature recorded on the exposed concrete surface (the temperature at the interface between the concrete and fire protection material) exceeds 50% above the mean value of all surface temperatures. It also requires observing any noticeable detachments of the fire protection material (area > 0.25 m²). In the tests conducted on the slab, there was no failure of stickability in the applied fire protection system.

6.6 Conclusion

This section of the report determined the equivalent concrete thickness of PERLIFOC HP Eco+ spray when protecting concrete slabs up to 240 minutes of AS 1530.4:2014 fire exposure from below. These results are summarized in Table 13 and Figure 4.

The results are only applicable between the minimum and maximum tested spray thicknesses (10.3 mm to 25.2 mm). For intermediate thicknesses, it is permitted to interpolate between the minimum and maximum values for a given time period.

The results are also applicable for concrete walls exposed to standard fire from one side.

7 Technical discussion 3 – Contribution of PERLIFOC HP Eco+ Towards Fire Resistance of Concrete Beams and Columns

7.1 General

In this section of the report, the relationship between concrete temperature at various depths over time and for a given thickness of PERLIFOC HP Eco+ is established to determine the contribution of PERLIFOC HP Eco+ towards the fire resistance of concrete beams and columns. The methodology provided in EN 13381-3:2015 is adopted in this report.

7.2 Characteristic temperature of concrete at various depths

The characteristic temperature at different depths of the tested slabs, for each applied thickness of fire protection, is plotted at 30-minute intervals. These measurements are taken at the unexposed surface and various depths within the concrete along the diagonal axis from the bottom corner of the cross-section as required in EN 13381:2015. The temperatures recorded at each location, along with the corresponding graphs for the beam specimens (Beam minimum and Beam maximum), are presented in Table 14 and Table 15, and subsequently in Figure 5 and Figure 6.

Table 14 Characteristic temperatures of Beam minimum at various depths – along diagonal axis

Time (minutes)	Characteristic temperature (°C)		
	35 mm	77 mm	106 mm
30	112	70	57
60	216	135	121
90	329	198	159
120	442	300	255
150	546	398	353

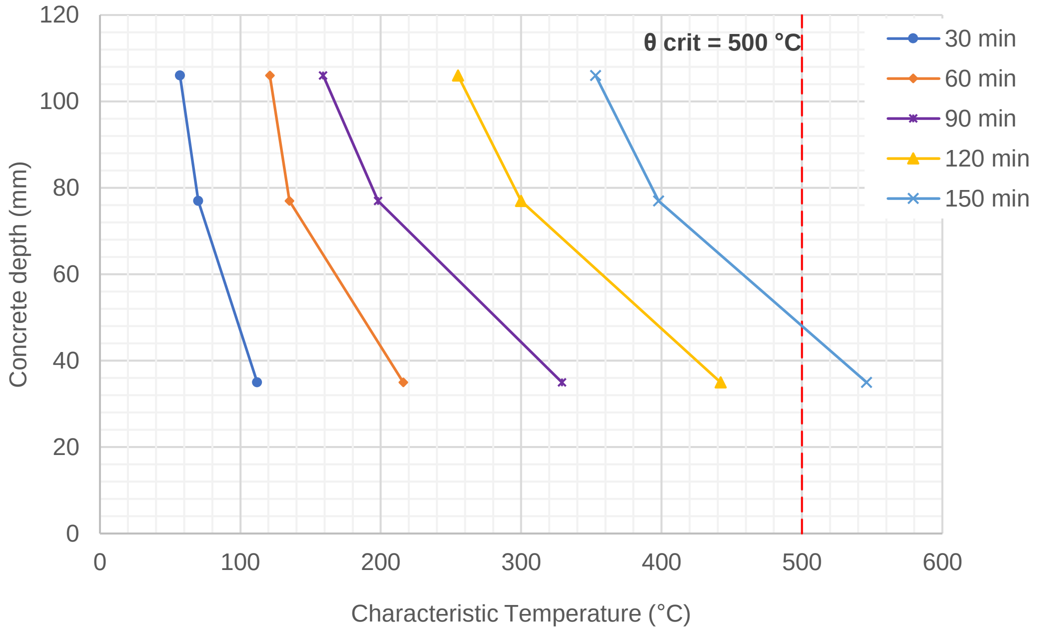

Figure 5 Characteristic temperatures of Beam minimum at various depths

Table 15 Characteristic temperatures of Beam maximum at various depths - along diagonal axis

Time (minutes)	Characteristic temperature (°C)		
	35 mm	77 mm	106 mm
30	51	36	26
60	83	69	57
90	126	102	88
120	173	129	114
150	233	166	132
180	301	219	161
210	369	282	209
240	437	347	268

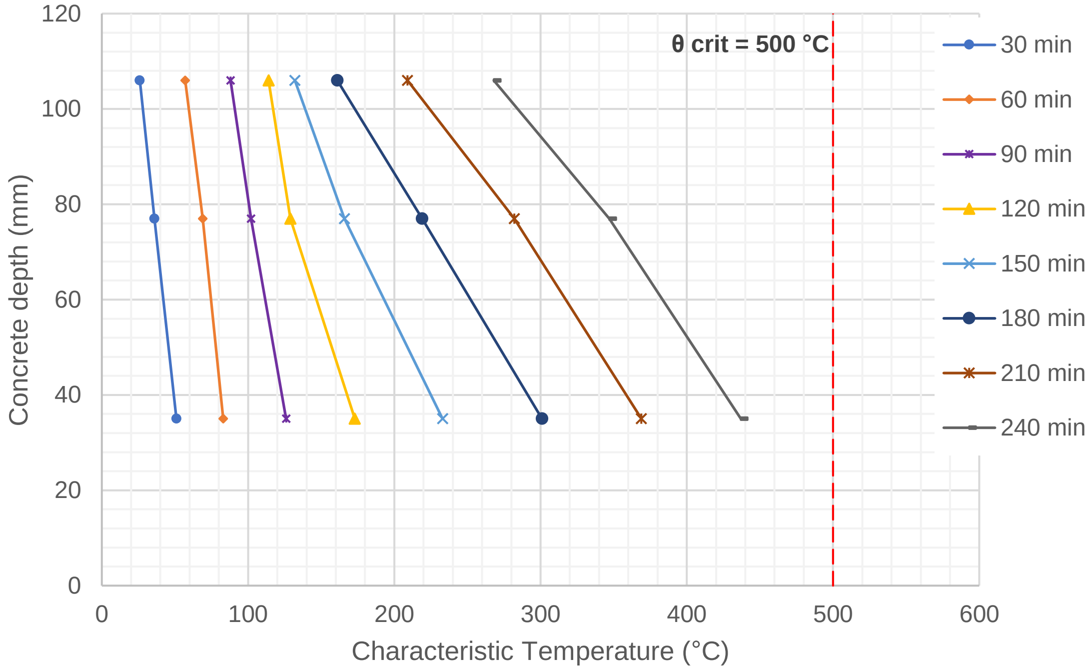

Figure 6 Characteristic temperatures of Beam maximum at various depths

7.3 Concrete depths at various critical temperatures

The depth along the concrete cross-sections for the slabs at which a series of critical limiting temperatures (in steps of 50°C) is reached is shown in Table 16 and Table 17.

Table 16 Concrete depths of Beam minimum at various critical temperatures

Time (minutes)	Concrete depths (in mm) for various critical temperature (°C)							
	300	350	400	450	500	550	600	650
60	–	–	–	–	–	–	–	–
90	44.3	–	–	–	–	–	–	–
120	77.0	62.2	47.4	–	–	–	–	–
150	–	17.2	76.4	62.2	48.1	–	–	–
‘–‘ denotes that the critical temperature has not experienced at the given time period								

Table 17 **Concrete depths of Beam maximum at various critical temperatures**

Time (minutes)	Concrete depths (in mm) for various critical temperature (°C)							
	300	350	400	450	500	550	600	650
180	35.5	–	–	–	–	–	–	–
210	68.3	44.2	–	–	–	–	–	–
240	94.3	75.6	52.3	–	–	–	–	–
'–' denotes that the critical temperature has not experienced at the given time period								

7.4 Equivalent concrete thickness

With reference to EN 13381-3:2015, a thermocouple placed within a protected concrete beam will show a characteristic temperature of θ (d_{cp}, t) at a depth of d_{cp} from at a specified time t. This same characteristic temperature can be found in an unprotected concrete beam at a depth called d_{cc}, which can be determined from Figure C.7 and Table C.2 in EN 13381-3:2015. This data can be used to calculate the equivalent thickness of an unprotected concrete beam that provides the same fire resistance as a specific layer of applied fire protection material. This concept is used to determine the equivalent concrete thickness for a given thickness of PERLIFOC HP Eco+.

The thermocouples placed at the lower steel reinforcement is used to provide data for the calculation of the equivalent concrete thickness. This data is shown in Table 18. Based on the temperature readings of Table 18, equivalent concrete thickness for concrete beams is determined and shown in Table 19.

Table 18 **Characteristic temperature at the lower steel reinforcement**

Time (minutes)	Temperature (°C)	
	Minimum PERLIFOC HP Eco+ thickness (10.9 mm)	Minimum PERLIFOC HP Eco+ thickness (25.4 mm)
30	112	51
60	216	83
90	329	126
120	442	173
180	–	301
240	–	437

Table 19 Equivalent concrete thickness for concrete beams

Time (minutes)	Equivalent concrete thickness (mm)	
	Minimum PERLIFOC HP Eco+ thickness (10.9 mm)	Minimum PERLIFOC HP Eco+ thickness (25.4 mm)
30	42.8	68.6
60	50.6	92.3
90	50.6	98.9
120	48.3	101.6
180	–	96.8
240	–	89.9

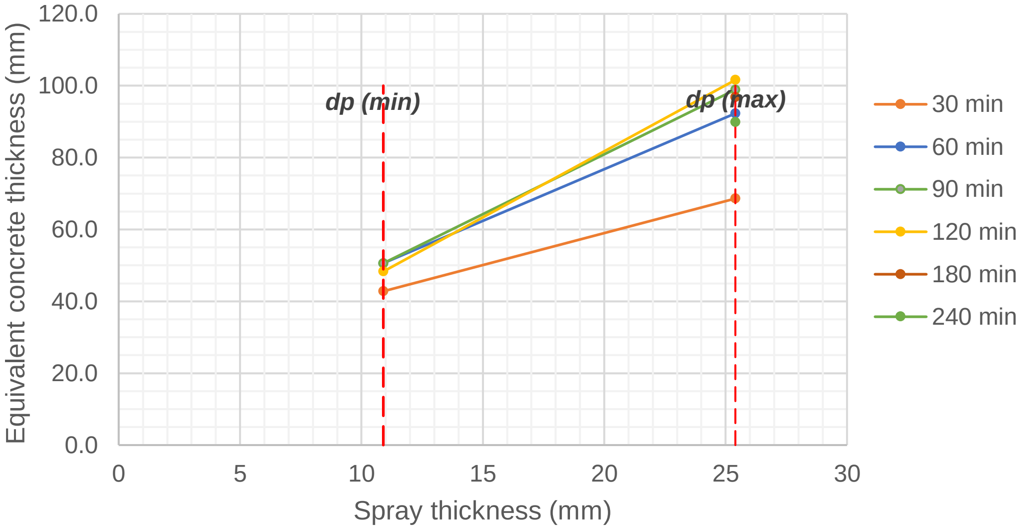

Figure 7 Equivalent concrete thickness vs sprayed thickness of PERLIFOC HP Eco+

Based on the findings of this section, the contribution of PERLIFOC HP Eco+ to the fire resistance of concrete beams and columns can be determined by considering the equivalent concrete thickness corresponding to a specific thickness of PERLIFOC HP Eco+. For instance, 10.9 mm of PERLIFOC HP Eco+ spray is equivalent to 48.3 mm of concrete when protecting a concrete beam exposed to 120 minutes of AS 1530.4:2014 fire exposure. Similarly, equivalent concrete thickness of PERLIFOC HP Eco+ spray for other time periods for a given spray thickness can be determined using Table 19 and Figure 7.

7.5 Stickability performance of PERLIFOC HP Eco+ spray

With reference to EN 13381-3:2015, stickability failure is deemed when the maximum temperature recorded on the exposed concrete surface (the temperature at the interface between the concrete and fire protection material) exceeds 50% above the mean value of all surface temperatures. It also requires observing any noticeable detachments of the fire protection material (area > 0.25 m^2). In the tests conducted on the beams, there was no failure of stickability in the applied fire protection system.

7.6 Conclusion

This section of the report determined the equivalent concrete thickness of PERLIFOC HP Eco+ spray when protecting concrete beams up to 240 minutes of AS 1530.4:2014 fire exposure. These results are summarized in Table 19 and Figure 7.

The results are only applicable between the minimum and maximum tested spray thicknesses (10.9 mm to 25.4 mm). For intermediate thicknesses, it is permitted to interpolate between the minimum and maximum values for a given time period.

The results are also applicable for concrete columns exposed to standard fire.

8 References

[1]. Applus Laboratories, 2019, Fire test report - 19/20234-1430 M2, LGAI Technological Center, S.A., Barcelona, Spain.

[2]. Applus Laboratories, 2021, Fire test report - 21/25361-1128 M1, LGAI Technological Center, S.A., Barcelona, Spain.

[3]. European Committee for Standardization 2015, Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members, EN 13381-3:2015, European Committee for Standardization, Brussels, Belgium.

[4]. LICOF Centre for Fire Testing and Research, 2020, Test report - Nr 9804-19, Madrid, Spain.

[5]. LICOF Centre for Fire Testing and Research, 2019, Test report - Nr 9836-19, Madrid, Spain.

[6]. Standards Australia 2018, Concrete structures, AS 3600:2018, Standards Australia, NSW.

[7]. Standards Australia, 2014, Australian Standard Methods for fire tests on building materials, components and structures – Part 4: Fire-resistance tests for elements of construction, AS 1530.4:2014, Standards Australia, NSW, Australia.

[8]. Passive Fire Protection Forum (PFPF). 2019, Guide to undertaking technical assessments of the fire performance of construction products based on fire test evidence, Passive Fire Protection Forum (PFPF), UK.

Appendix A Experience and Qualifications of Halliwell Fire Research

Halliwell Fire Research are a group of highly qualified international experts in fire safety science and engineering with extensive experience in passive fire product/system development, fire testing and fire assessments. Our team is well-versed in providing research-based expert services related to fire testing and fire assessments conforming to Australian, New Zealand and European test standards.

Table 20 Tabular summary of contributors to this report

Role	Personnel	Qualifications and relevant experience
Author	Dr. Imran Ahamed	BSc (Civil Engineering) PhD (Structural Fire Engineering) CPEng (Structural and Fire Safety) MIEAust NER, RPEQ, RPEV IFE Level 3 Certificate in passive fire protection 8+ years of experience in fire testing and assessments
Reviewer	Dr. Ryan Hilditch	BSc (Fire Safety Engineering) PhD (Fire Safety Engineering) CPEng (Fire Safety) MIEAust NER, RPEQ, APEC Eng, IntPE(Aus) 12+ years of experience in fire safety strategy and assessments
Authoriser	Mario Lara Ledermann	BSc (Industrial) MFireSafeEng AIFireE 8+ years of experience in fire testing and assessments