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Fire performance and test methods for ACP external wall cladding

Technical Report

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Executive summary

DELWP has engaged CSIRO to provide a Technical Report on fire performance and test methods for Aluminium Composite Panel (ACP) external wall cladding, intended to provide suitable background information on this topic and be used and referred to by state or federal governments.

The report focuses primarily on Class 2-9 building external walls for Type A and B construction as defined by the National Construction Code Series, Building Code of Australia (NCC BCA) Vol 1 2019**.**

The report has been based on current, mostly publicly available information (at the time of original drafting in January 2020) . It has not included undertaking any new testing of materials.

Key topics for this report have been:

- Types of ACP.
- National Construction Code (NCC) Building Code of Australia (BCA) requirements.
- Australian State-based bans, ministerial guidelines and the like applied to ACP.
- Reaction to fire tests applicable to ACP.
- Material Characterisation testing for ACP.
- Known Performance of ACP in fire tests.
- Past fire incidents involving ACP.

General conclusions form this review are:

1. The most common type of ACP previously used in Australia has an organic polymer core of polyethylene or ethylene vinyl acetate. In some cases, mineral filler is mixed with the polymer to improve reaction to fire behaviour.
2. ACP can be grouped based on polymer mass% content or gross heat of combustion (MJ/kg). The groupings in order from highest polymer content (worst performance) to lowest polymer content are defined by the Insurance Council of Australia (ICA) risk ranking and are commonly named
    a. Category A – 30-100% polymer (ACP-PE),
    b. Category B - 8-29% polymer (ACP-FR),
    c. Category C – 1-7% polymer (ACP-A2) and
    d. Category D – 0% polymer (non-combustible).
3. The ICA risk ranking protocol was published to provide preliminary guidance for existing buildings with cladding of unknown origin.
4. NCC BCA Deemed to Satisfy (DTS – Prescriptive requirement) provisions have required that external walls for Class 2-9 Type A and B construction must be non-combustible. This has been a DTS requirement for more than the past two decades.
5. NCC BCA does permit performance solutions as an alternative to DtS compliance. Fire safety performance solutions would typically be designed and assessed by a fire safety engineer and documented in a Fire engineering report (FER).
6. Based on outcomes of the Victorian State-Wide Cladding Audit the use of combustible ACP for Class 2-9 Type A and B construction has proliferated over the past 2 decades, often without any DTS non-compliance being identified or performance solution being provided for approval of specific buildings.
7. Small-scale tests on individual materials do not directly predict real fire behavior of complete façade systems but can provide initial risk ranking of the individual material components.
8. Small scale tests are the least expensive tests and can be used to regulate fire performance of materials, but require conservative, strict acceptance criteria to account for the above limitations. An example of this is the AS 1530.1 combustibility test.
9. A review of published small, intermediate and full-scale fire tests on ACP external wall systems has concluded the following:

a. ACP-PE supports aggressive vertical fire spread, with significant flaming debris and formation of pool fires, regardless of the type of insulation behind. ACP-PE clearly has unacceptable façade fire performance.
b. ACP-FR combined with non-combustible insulation and cavity barriers can support some very limited fire spread and flaming debris but has passed BS8414 BR135 full scale façade test criteria (may not pass AS 5113 criteria relating to debris etc.). This indicates that, particularly where installed to existing buildings, fire behavior may be adequate on a performance solution or risk basis.
c. ACP-FR combined with combustible PIR or phenolic insulation and cavity barriers demonstrated some enhancement of fire growth (although still significantly less than ACP-PE). This failed BS8414 BR135 full scale façade test criteria. This indicates that such a system is unlikely to be suitable for new buildings and care should be taken when undertaking performance-based assessment of such systems on existing buildings, particularly where cavity barriers are not installed.
d. ACP-A2 passed the BRE135 criteria when tested with PIR insulation or with mineral wool insulation. It did not support any significant flame spread beyond the crib impingement area. This indicates that this material is likely to be acceptable on a performance basis for new or existing buildings.

10. Review of ACP external wall fire incidents around the would re-enforce the conclusion that ACP-PE has unacceptable façade fire performance, with fire incidents commonly characterised by aggressive vertical fire spread to the top of the building (where successful fire brigade intervention does not occur) combines with large amounts of falling molten flaming debris. No significant fire incidents involving ACP-FR, ACP-A2 or bonded laminated aluminium panels were identified.
11. The various types of testing that may be applied for regulation of ACP, can be prioritised based on direct prediction/correlation to real fire scenario performance in the following order (from most relevant to least):
    a. Full scale façade fire testing applied to complete system
    b. Intermediate scale façade fire testing applied to complete system
    c. Small scale reaction to fire tests (on each material component including bare exposed core)
    d. Material characterisation tests to determine core composition
12. ACP core material characterization testing (to quantify the core chemical composition) and the ICA risk ranking protocol were originally introduced in Australia as a means to quickly sample ACP from existing buildings and determine the type of ACP installed. It was not originally intended to be used for control or regulation of new ACP product.
13. There are a range of different materials characterization test methods than can be applied. Different laboratories in Australia currently apply different test methods. There is no Australian standard for sampling and material characterization testing of ACP for existing buildings which specifies which test methods are to be applied and what level of accuracy is to be achieved.
14. NSW, Queensland, Victoria and Western Australia have introduced bans, ministerial guidelines or other state-based regulation which act to limit the availability or use of combustible ACP with ~more than 30% PE content.
15. Existing state-based ACP bans, ministerial guidelines or other regulations essentially do either or both of the following:

    a. Re-in force/re-state NCC BCA 2019 Vol 1 DTS requirements which already prohibit the use of combustible cladding on external walls for Type A and B construction. An exception is the QLD ACP ban, which came into effect Oct 2019, which limits ACP use beyond NCC BCA DTS requirements as it bans more than 30% PE content ACP from external walls applicable to all classes and types of construction including Type C and Class 1;

       and/or

    b. Imposes restrictions on the types of materials that are permissible for performance-based solutions. For example, bans act to exclude more than 30 %PE content ACP use via performance-based solutions or (in the case of Western Australia) requires NCC BCA 2019 Vol 1 CV3 to be applied and no other form of performance-based assessment is accepted.

16. The following potential issues have been identified for the state-based ACP bans:
    a. The bans do not align with NCC BCA 2019 Vol 1 DTS requirements. ACP products not banned by the existing state-based bans may still fail to meet BCA DtS Non-combustibility requirements for Type A and B construction and are not compliant without an adequate performance-based solution
    b. There are some inconsistencies in detail between the different state bans.
    c. They state restrictions based on PE content (mass%). This does not capture all other combustible polymers that may potentially be used in ACP.
    d. They do not define the Material characterisation test methods or measurement accuracy that are to be applied. Methods (and possibly resulting accuracy) used between different labs currently varies.
    e. ACP bans do not directly address root causes of noncompliant product use and therefore may not prevent similar issues with other types of non-compliant product in future.
17. There is a significant proportion of ACP (from samples from existing buildings) that fall within the 30-45% polymer (55-70% mineral) content range. These are expected to have significantly improved reaction to fire performance compared to ~ 100% PE ACP, but these would still be ranked as ICA Cat A. Information reviewed in this report has not identified any testing or research which focuses specifically on understanding the fire performance of this range of ACP. Such understanding would be valuable for development of suitable performance solutions for rectification where such ACP is present on existing buildings.
18. A distinction should be made between performance solution assessment of ACP for new and existing buildings:
    a. For new buildings:
        i. Given the evidence presented above it would be most prudent to either comply with BCA DTS or apply combustible ACP as part of a complete external wall system as a performance solution for type A or B construction only where it is supported by an acceptable level of full-scale façade fire test performance, as is the case of ACP-A2 systems tested.
        ii. ACP-FR when combined with combustible insulation or other combustible materials can exhibit an enhancement of fire spread. Whilst this still performs significantly better than ACP-PE, it would be prudent to avoid use of this material for new buildings in cases where it is combined with combustible insulation or cavity barriers are not installed.
        iii. ACP-PE clearly has unacceptable external wall performance and should not be used on new buildings for this purpose.
    b. For existing buildings.
        i. A careful assessment of cost vs benefit/risk of cladding rectification performance solutions on a **'so far as is reasonably practical' (SFAIRP)** basis is recommended.
        ii. Where full scale façade tests are not available for the specific installed system, testing to identify core composition, cavity materials and fixing/construction details combined with comparison against limited available published full and intermediate scale façade fire test data for similar systems may provide a rough indication of expected performance.
        iii. However, based on holistic fire engineering assessment of the extent, location, orientation of cladding, ignition source hazards and other building fire safety systems, there may be cases where poorer performing existing external wall systems (such as ACP-PE or ACP-FR with combustible insulation) may be assessed as suitable for retention on a risk and cost basis. This would typically require limited continuity and extent of such wall systems.

A summary and conclusions for each section of this report is provided in Section 9.

1 Introduction

1.1 Project

Technical Report on Fire performance and test methods for ACP external wall cladding.

1.2 Client

Department of Environment, Land, Water and Planning

1.3 Scope of work

The scope of work as set out in CSIRO's proposal for this project is to provide a Technical Report on Fire performance and test methods for ACP external wall cladding, intended to provide suitable background information on this topic and be used and referred to by state or federal governments.

The report focuses primarily on Class 2-9 building external walls for Type A and B construction.

The report has been based on current, mostly publicly available information. It has not included undertaking any new testing of materials

The report does not directly refer to specific product brand names, manufacturers etc. but refer to product types in a generalized manner. An exception to this is where a list of ACP products currently certified by CodeMark has been summarized and reviewed.

The scope of the report covers:

1) Types of ACP available in Australia including 100% PE, different fire retarded grades of PE, bonded aluminium composites, other types of polymer ACP cores
2) Overview of current NCC BCA external wall fire safety requirements relating to ACP applied to external walls
3) Overview of current state-based ACP bans (e.g. NSW) or ministerial guidelines (e.g. VIC) in place in Australia.
4) Overview/summary of range of reaction to fire tests applied in Australia including:
   a) AS 1530.1 combustibility test
   b) Small scale reaction to fire test including AS 1530.3 and AS 3837
   c) Intermediate scale reaction to fire tests including AS ISO 9705
   d) Full scale tests including AS 5113 external wall and AS 5113 Building to building fire tests
5) Very brief summary of range of reaction to fire tests applied internationally (including combustibility, small scale, intermediate scale and full scale)
6) Overview/summary of Materials characterization tests applied to ACP. These are not reaction to fire tests but are tests used to characterize the composition of ACP core samples. A variety of tests are currently used in Australia
7) Review of published/known performance of different types of ACP in reaction to fire tests. Primary focus will be on Australian Tests.
8) Aggregated/generalized analysis of CSIRO material characterization tests conducted on ACP core samples to date. This would present the number of samples tested by CSIRO which fall within specific % combustible polymer composition ranges, and the details on the range of different types of polymers and fire-retardant filler materials tested. This only reflects the range of materials tested at CSIRO and may not fully reflect the range of ACP as installed in the community, however may assist to better

understand the typical range of ACP applied in the past (e.g. such as the amount of ACP which have cores slightly more than 30% PE vs slightly less than 30% PE etc.).

9) Overview/summary of past fire incidents involving ACP and the grade of ACP involved (where known).
10) Conclusions regarding:
    a) Any identified limitations of reaction to fire tests applied in Australia to ACP.
    b) Any identified limitations of material characterization tests applied in Australia to ACP.
    c) Ranking of reaction to fire performance of different grades of ACP (based on publicly available test results and fire incidents)
    d) Identification of grades/types of ACP that are generally demonstrated not to be suitable for Type A or B construction (when installed as extensive areas of cladding).
    e) Identification of any knowledge gaps or further research that could be undertaken to close any knowledge gaps related to ACP fire performance.

The reader's attention is drawn to the validity, limitations and assumptions for this assessment documented in Section 1.5 of in this report.

1.4 Sources of information

CSIRO has sourced literature addressing the above scope of work from sources including:

- The National Construction Code (NCC)[1], including Building Code of Australia (BCA) Volume 1 and Volume 2.
- The previous publicly CSIRO Report "*Fire Hazards of Exterior Wall Assemblies Containing Combustible Components"*[2].
- Scientific and industry journals and conference papers.
- Library searches, specifically on key fire engineering and materials flammability books such as the SFPE handbook, etc.
- Online searches.
- Searches of product accreditation schemes and specific product supplier information.
- Newspaper articles.
- CSIRO specifically acknowledges the University of Queensland (UQ) who have published a material library of cladding materials and a supporting protocol for sample preparation and testing methodologies[3-5], and have granted permission for CSIRO to reference, review and summarise the published work in this report.

From 2017-2019 CSIRO has acted as a fire safety engineering representative in various Advisory Reference Panels (ARP's) under the State-wide Cladding Audit on behalf of the Victorian Cladding Task Force, VBA and DELWP. This role has involved:

- Panel review of inspection reports by others of numerous buildings with combustible cladding in Victoria.
- Panel risk assessment of the buildings reviewed, and
- In several cases, in person inspection of buildings with combustible cladding has been carried out by panel members including CSIRO.

VBA, DELWP and the Victorian Cladding Task Force has not provided CSIRO with detailed statistical or summary data from this ARP process beyond that contained in The Victorian Cladding Taskforce interim[6] and final[7] reports. Other fire engineering consultants have also participated in the ARP process, so CSIRO has only been exposed to a significant portion (but not the whole) of the buildings inspected. CSIRO's observations from ARP's have helped to inform the understanding and knowledge of typical application of EIFS and ISP in Australia. However, due to confidentiality, CSIRO cannot include details of specific buildings reviewed via ARP's. Instead this knowledge is drawn upon as a generalised knowledge based on CSIRO ARP involvement and is used to supplement or fill gaps in information available from published literature.

CSIRO has extensive experience in application of a range of fire test methods to building products including EPS, EIFS and ISP. CSIRO testing is on behalf of clients and is client confidential, therefore CSIRO cannot include specific details sourced from this work, unless already publicly available.

1.5 Limitations

The reader's attention is drawn to the following limitations with respect to this Technical Report:

a. This report deals with the fire safety of ACP systems described in Section 2 only and does not directly provide detailed review of other non-fire related matters such as durability, weather performance, acoustic performance and thermal insulation performance, etc.
b. This report does not focus on other types of combustible external wall materials or systems including rendered EPS, Insulated sandwich panel, high pressure laminates, glass reinforced polymers etc.
c. This report focuses on application of ACP cladding for Class 2-9 building external walls for Type A and B construction. It does not focus on external wall application for Class 1 or Type C construction or other applications such as signage or internal building linings.
d. This report is based on publicly accessible publications and journals. Confidential test reports for specific products or systems have not been reviewed and cannot be included for reasons of confidentiality.
e. This report is limited in extent by the time and resources available to CSIRO. It is not exhaustive, and some relevant literature may not have been identified and included.
f. In reviewing the literature, CSIRO has attempted to identify cases where published literature appeared to be not based on peer reviewed scientific data and such literature has been excluded from this report except for cases of manufacturer product technical data etc.
g. The scope of this report has excluded communication with industry bodies to explore information they may be able to provide or related industry activity.
h. The scope of this report has also excluded detailed site inspections or audits.
i. Although this report does provide an overview of current state-based ACP bans or ministerial guidelines in place in Australia, this report does not:
    a. Make recommendations relating to state based or nationwide bans on ACP.
    b. Provide conclusions on the suitability of bans on ACP.
    c. Directly discuss what appropriate thresholds or other details for such a ban may be.

1.6 List of Abbreviations

Table 1. List of abbreviations

Abbreviation	Definition
A2	ACP-A2 is a common naming used to represent ACP core with ~1-7 mass% organic polymer
ABCB	Australian Building Codes Board
ACM	aluminium composite material (alternative name to ACP)
ACP	Aluminium Composite Panel. Also called aluminium composite material (ACM) or metal composite material (MCM)
ALARP	As low as reasonably practicable
ANSI	American National Standard Institute
ARP	Advisory Reference Panels conducted in Victoria on behalf of either VBA, DELWP or the Victorian Cladding Taskforce. Panel typically includes a fire engineering representative, a building surveyor representative and a fire brigade representative. The purpose of the panel is to review inspection reports and other information provided on specific building identified to have combustible cladding, risk assess the building and make recommendations to the municipal building surveyor.
AS	Australian Standards
ASTM	American Society for Testing Materials
ATH	Aluminium trihydroxide, mineral filler fire retardant
ATR-FTIR	Attenuated total reflection Fourier-transform infrared spectroscopy
BAB	Building Appeals Board (Victoria, Australia)
BAL	Bush fire attack level as defined by AS 3959.
BB	Building to Building classification as defined by AS 5113
BCA	Building Code of Australia
BMF	Building Ministers Forum, Australian Government Department of Industry, Innovation and Science. Oversees policy and regulatory issues affecting Australia's building and construction industries. The BMF is made up of Australian Government and state and territory government ministers with responsibility for building and construction.
BRAC	Building Regulations Advisory Committee
BRANZ	Building Research Association of New Zealand
BRE	Building Research Establishment Limited
BS	British Standard
CBD	Central Business District
CFA	Country Fire Authority, Victoria
CHF	Critical Heat Flux
CPD	Continuing Professional Development - involves maintaining and enhancing the knowledge, skills and experience related to professional activities following completion of formal training.
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCLG	Department for Communities and Local Government
Δh_c	Gross Heat of combustion (MJ/kg)
ΔH_{decomp}	Heat of decomposition of a material in an endothermic reaction (MJ/kg)
DELWP	Department of Environment, Land, Water and Planning, Victoria
DIN	Deutsches Institut für Normung (German Testing Standard)
DMIRS	Department of Mines, Industry Regulation and Safety, Western Australia

DSC	Differential scanning calorimetry
DTS	Deemed to Satisfy, prescriptive provision of Australian National Construction Code
EDS	Energy Dispersive X-Ray Spectroscopy
EIFS	Exterior Insulation Finishing Systems (typically rendered EPS)
EN	European Norm (standards)
EPS	Expanded Polystyrene
ETICS	Exterior Thermal Insulation Composite Systems (typically rendered EPS)
EVA	Ethylene vinyl acetate
EW	External Wa–l - specifically refers to AS 5113 External wall classification determined via full scale façade fire testing.
EWFA	Exova Warringtonfire Australia
FER	Fire Engineering Report
FIGRA	Fire growth rate index as defined by EN 13823
FM Global	American mutual insurance company with offices worldwide, that specializes in loss prevention services primarily to large corporations in the Highly Protected Risk (HPR) property insurance market secto“. "FM Glo”al" is the communicative name of the company, whereas the legal name “s "Factory Mutual Insurance Comp”ny". The company employs a non-traditional business model whereby risk and premiums are determined by engineering analysis as opposed to historically based actuarial calculations.
FR	ACP-FR is a common naming used to represent ACP core with ~ 30 mass% organic polymer
FRL	Fire Resistance Lev–l - means the grading periods in minutes determined in accordance with NCC BCA 2019 Vol 1 Specification A2.3, for the following criteria— (a) structural adequacy; and (b) integrity; and (c) insulation and expressed in that order. Note: A dash means that there is no requirement for that criterion. For example, 90/–/– means there is no requirement for an FRL for integrity and insulation, and –/–/– means there is no requirement for an FRL.
FRNSW	Fire & Rescue New South Wales
FSVM	Fire safety verification method as defined by NCC BCA 2019 Vol 1
FZ	Fire zone (Bushfire Attack Level)
GRP	Glass Reinforced Polymer
HDPE	High Density Polyethylene
HPL	High Pressure Laminate
HRR	Heat release rate. A measure of the rate of heat energy output in number of kilojoules per second, kJ.s-1 or kilowattS (kW)
HRRPUA	Heat release rate per unit area.
HS	Horizontal (fire) Spread
IBC	International Building Code (North American Model Building code)
ICA	Insurance Council of Australia
ICC	International Code Council
IR	Infra-red
ISO	International Standards Organisation
ISP	Insulated sandwich panel
JAS-ANZ	Joint accreditation system of Australia and New Zealand
LDPE	Low density polyethylene
LFS	Lateral Flame spread as defined by EN13823

LPCB	Loss Prevention Certification Board (UK)
LPS	Loss Prevention Standard
MCM	Metal composite material (alternative name to ACP)
MDH	Magnesium di-hydroxide, mineral filler fire retardant
MFB	Metropolitan Fire Brigade, Melbourne Victoria
MRF	Mineral Fibre Insulation
MW	Mineral wool fibre insulation (note – MW also denotes the units Mega Watts)
NCC	National Construction Code (NCC) Australia
NFPA	National Fire Protection Association
PBDR	Performance based design report (alternative name for Fire Engineering Report)
PE	Polyethylene
PE-VA	Polyethylene modified with vinyl acetate, also known as Ethylene vinyl acetate (EVA)
PIR	Polyisocyanurate foam
PP	Polypropylene
PU	Polyurethane
QBCC	Queensland Building and Construction Commission
QDC	Queensland Development Code
SBI	Single Burning Item (test) as defined by EN13823
SEM	Scanning electron microscope
SFAIRP	So far as is reasonably practical
SFPE	Society of fire protection engineers
SOG	Senior Officers' Group - comprises two senior building and construction policy officers from each jurisdiction and a senior representative from the Commonwealth. It supports the BMF by providing enhanced national policy development, collaboration and coordination amongst jurisdictions.
TGA	Thermal Gravimetric Analysis
THR	Total Heat Released
UBC	Uniform Building Code
UL	Underwriters laboratories
uPVC	Un-plasticized polyvinyl chloride: a hard form of PVC
UQ	University of Queensland
VA	vinyl acetate
VBA	Victorian Building Authority
VCAT	the Victorian Civil and Administrative Tribunal
VS	Vertical (fire) spread
WRB	Weather resistant barrier
XRD	X-ray diffraction crystallography
XRF	X-ray fluorescence

2 Types of Aluminium Composite Panel

2.1 Definition of ACP

Aluminium composite panel (ACP) was developed as an alternative to solid aluminium sheet (or other types of solid metal sheet) and consists of a thin aluminium sheet on the two external faces of the panel in composite with a lighter weight core material. ACP has typically been applied for external wall cladding and canopies, signage and internal linings for buildings. There are many different varieties and manufacturers of ACP. ACP has the following benefits compared to solid aluminium sheet.

1. Significantly less expensive than solid metal panels at a thickness required to achieve the same flexural stiffness.
2. Significantly less mass than solid metal panels at a thickness required to achieve the same flexural stiffness.
3. Easier to cut, fold, bend, drill and install than solid metal panels at a thickness required to achieve the same flexural stiffness.
4. Achieves a flat smooth surface finish.
5. A process called "coil coating" provides a high quality, corrosion resistant finish in a vast range of vibrant colours. This a continuous factory-automated roller process where coatings are applied to large rolls (coils) of thin metal sheet prior to fabrication into the end product. This process is not possible with solid metal panels at a thickness required to achieve the same flexural stiffness.
6. Enables easier design and installation for curved or segmented facades.

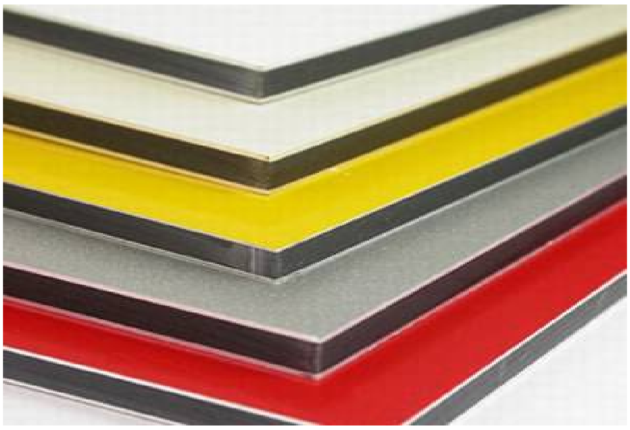


Figure 1.Typical ACP with 100% PE core[8]

ACP is defined by the following typical characteristics

- Total thickness ranging from 3-6 mm, with 4 mm being the most common thickness.
- Panel sizes typically available from 2-7.2 m in length and 0.6-2 m wide.
- Thin aluminium sheet external facing typically 0.5 mm thick (one sheet applied to both sides/faces)
- Lighter weight core material most typically polyethylene (PE) with or without varying quantities of mineral filler. Other polymer materials are less typical but can be used. The core can also be thin

aluminium formed into a “honeycomb” or “egg crate” bonded to the skins with a thin layer of adhesive.

- Very thin external face colour coating, typically coil coated Polyvinylidene fluoride or polyvinylidene difluoride (PVDF)

ACP is not to be confused with other types of combustible cladding which include:

- Insulated sandwich panels (ISP) which are thicker panels specifically designed to provide thermal insulation and most typically have thin steel sheet facings with an insulating core of either expanded polystyrene (EPS), Polyisocyanurate foam (PIR) or mineral wool fibre insulation (MW). ISP with other facing and insulation types also exist.
- Rendered expanded polystyrene (EPS) also known as Exterior Insulation Finishing Systems (EIFS) or Exterior Thermal Insulation Composite Systems (ETICS).
- High pressure laminates (HPL) panels which are typically layers of phenolic resin impregnated cellulose fibres / kraft paper (typically up to 70% cellulosic fibre content) with one or more decorative surface layers which are manufactured by pressing at high temperature and pressures.
- Glass reinforced polymer (GRP) panels which most typically consist of polyester resin with a glass fibre matrix and external gel coat surface.

ACP is typically installed to exterior walls on steel channels or battens/top hats. This can create an air gap (typically about 40 mm) between the next surface within the external wall cavity (typically sarking or other weather resistive barrier) and the cladding. The panels are typically fastened to the steel battens by either of the following two methods.

- Flat stick method – flat cut ACP panels adhered to steel battens using double sided adhesive tape.
- Cassette mount method – the edges of the panels are folded at right angles and are rivet or screw fixed to aluminium or steel channels or clips which are in turn screw fastened to the exterior wall.

Sealant is normally applied to the gaps between panels, this is called “face sealing”. The above type of installation typically forms a ventilated façade/rain screen with an air gap separating the ACP from the supporting wall behind. However, ACP can be incorporated into other forms of construction including pre-manufactured unitised curtain wall façade panels, etc.

Figure 2. ACP Flat Stick installation (photo by CSIRO)

Figure 3: Cassette mount installation onto column (Photo by CSIRO)

2.2 PE Core ACP with various amounts of mineral filler

2.2.1 POLYETHYLENE

ACP with close to 100% polyethylene (PE) core appears to have been developed in the 1960s[9]. It appears it may initially have been used for signage in Australia but began to be used for external wall cladding from the early 1990s onwards. ACP with 100% PE core or PE with varying amounts of mineral filler has been by far the most common type of ACP used in the building industry over the last 25 years. ACP with close to 100% PE core has also been involved in many of the most significant façade fire incidents both in Australia and internationally over the last decade or more.

In terms of tons of production per year, polyethylene is one of the most produced plastics globally accounting for 34% of global plastics production[10] and is used for a broad range of applications including plastic bags, bottes, containers, pipes, membranes and building sarking and 3D printing.

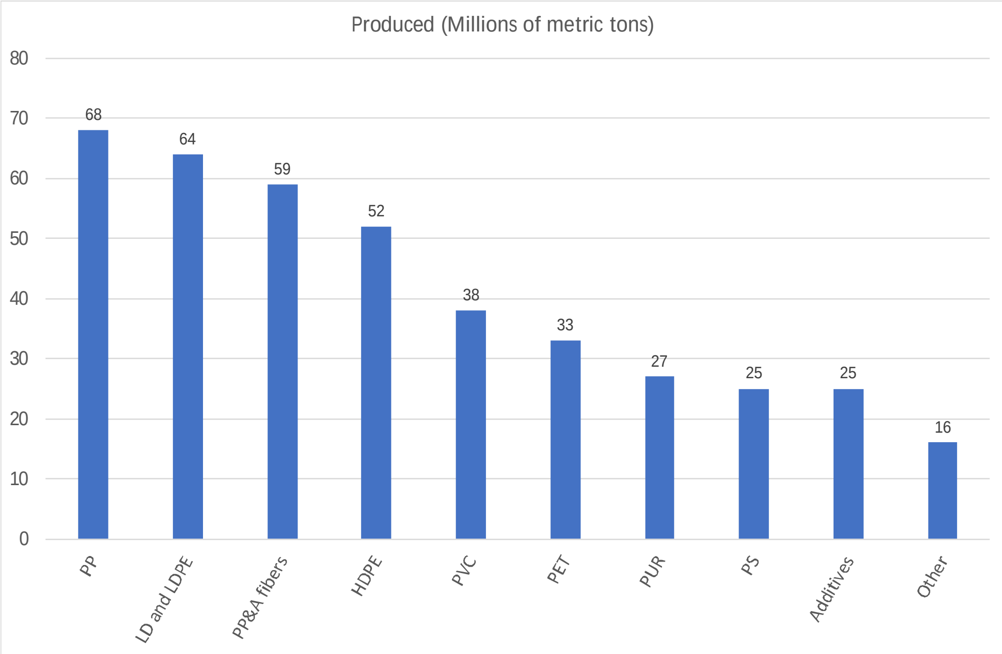


Figure 4. Total global production of various types of plastics in 2015 (PE represented by LDPE and HDPE) [10]

PE is manufactured by polymerisation of Ethylene molecules resulting in the polymer chemical formula $(C_2H_4)_n$. PE is usually a mixture of similar polymers of ethylene with various values of n and various amounts of polymer branching resulting in various grades of polyethylene which are classified by their density, polymer branching and crystalline structure. This affects the mechanical properties of the PE grade. The two most common grades of polyethylene are:

- High Density Polyethylene (HDPE)
  - Density = 930 to 970 kg/m^3
  - Melting point = 118-137°C
  - Increased hardness, tensile and flexural strength compared to LDPE
- Low Density Polyethylene (LDPE)
  - Density = 917 to 930 kg/m^3
  - Melting Point = 95-115 °C
  - Reduced hardness/stiffness, tensile and flexural strength compared to HDPE.

However, there are several other grades of polyethylene. Manufacturers information on ACPs generally do not clearly state the grade or details of the polyethylene used and it is likely that PE formulation may be specifically selected for ease of ACP manufacturing processing. Some product data sheets state LDPE.

The natural colour of PE is translucent/opaque, however it is commonly pigmented to produce a wide range of colours. Where increased photodegradation resistance to UV exposure is desired, Carbon black is typically added to the PE as a stabiliser to absorb or screen out UV rays and this results in a black coloured PE. ACP with close to 100% polyethylene (PE) core typically has a black coloured core.

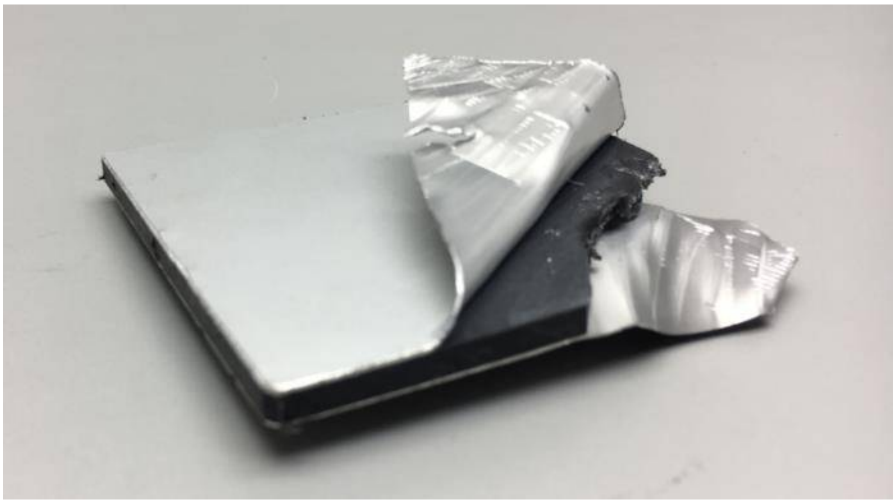


Figure 5. ACP with 100 % PE content (photo by CSIRO)

The SFPE Handbook[11] states a general range of net heat of combustion for Polyethylene to be 43.1-43.4 MJ/kg. Net Heat of combustion is the heat released per unit mass of fuel burnt assuming that all water vapour remains in the gaseous state. Polyethylene has an extremely high energy density compared to traditional combustible building materials such as timber (pine) and other foamed polymer insulation boards, as demonstrated in Table 2.

Table 2. Comparison of heat of combustion per unit volume of PE against gasoline and wood and other polymeric materials (values taken from SFPE Handbook[11]).

Material	Net Heat of combustion (MJ/kg)	Density (kg/m^3)	Heat of combustion per unit volume (MJ/m^3)
PE	43.3	950	41,135
Polypropylene	46.4	920	42,688
Polycarbonate	31	1210	37,510
Gasoline	46.7	750	35,025
Expanded Polystyrene (EPS) Foam insulation board	39.7	11-28	440-1,100
Polyisocyanurate (PIR) foam Insulation Board	26.3-28.1	32	840-900
Phenolic foam insulation board	21.6-27.4	38	820-1,040
Timber (pine)	18	500	9,000

Note regarding above table – Fire hazard should not be assessed based only on heat of combustion per unit volume. Other factors such as ease of ignition, melting and surface char formation influence hazard of fire spread. The extremely high heat of combustion per unit volume of PE combined with it melting behaviour and no intrinsic fire-retardant mechanisms such as charring result in a very high hazard of fire spread.

Whilst the reflective aluminium face of 100% PE ACP can result in this material not igniting when exposed to small scale fire tests where the exposure is predominantly radiant heat, it has poor fire performance when exposed to sufficient direct flame impingement as has been demonstrated by numerous fire incidents and full-scale façade fire tests. In such scenarios the 0.5 mm aluminium conducts heat to the PE core. The PE core softens, melts and ignites where it is exposed. The aluminium skin melts and falls away as debris exposing more surface area of PE. The PE supports rapid vertical flame spread both in an upwards direction and also downwards due to flaming molten PE dropping to horizontal surfaces below.

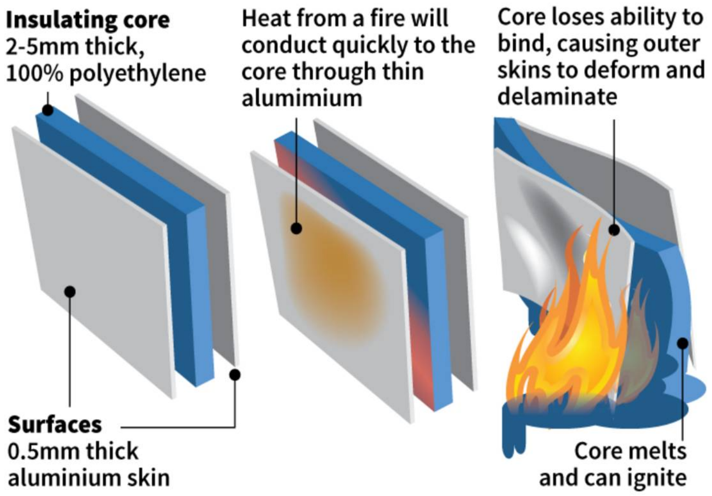


Figure 6. Degradation of ACP and ignition of PE (Image: Fairfax & Jamie Brown)

2.2.2 TYPES OF MINERAL FILLER

To improve the fire performance of 100% PE ACP (and ACP with other polymers), a variety of mineral fire-retardant based fillers can be added to the polymer core material.

Inert mineral additives reduce the total flammability of a polymer by:

- Reducing the total amount of fuel per unit volume.
- Increasing the heat capacity, thermal conductivity, reflectivity and emissivity of the material, therefore more heat is required to ignite and continue combustion of material.
- Reducing the rate of diffusion of oxygen into and fuel from the polymer bulk.
- In addition, some inert minerals have a significant synergistic effect when combined with active fire retardants though mechanisms such as increased char formation etc.

Active fire-retardant mineral additives, primarily Aluminium Hydroxide and Magnesium Hydroxide, react endothermically producing water vapour when heated. These have the following 3 active fire-retardant effects in addition to those of inert fillers described above:

- Endothermic reaction absorbs heat keeping the surrounding polymer cooler
- Production of water vapour acts as an inert diluent gas reducing the concentration of combustible volatiles at the material surface.
- Accumulation of an inert layer of metal oxides (char) at the surface of the material acting as a barrier against radiant heating and oxygen and pyrolysis product diffusion through the barrier

The most common minerals used in ACP are listed in Table 3.

Table 3. Mineral additives commonly added to PE for ACP applications[12-15].

Common Name	Chemical Formula	Other Names	Active fire retardant or inert	Other information
Aluminium Hydroxide	$AL(OH)_3$	Gibbsite ATH (aluminium trihydroxide)	Active fire retardant	Endothermically decomposes at 180-200 °C producing water vapour, ΔH_{decomp} = 1300 kJ/g.
Magnesium Hydroxide	$Mg(OH)_2$	Brucite MDH (magnesium dihydroxide)	Active fire retardant	Endothermically decomposes at 300-320 °C producing water vapour, ΔH_{decomp} = 1450 kJ/g
Calcium Hydroxide	$Ca(OH)_2$	Portlandite	Active fire retardant	Endothermically decomposes at 430-450 °C ,ΔH_{decomp} = 1150 kJ/g. In practice not as effective as Aluminium Hydroxide or Magnesium Hydroxide due to high decomposition temperature and exothermic reaction to calcium carbonate which typically occurs in preference to endothermic reaction to calcium oxide.
Calcium carbonate	$CaCO_3$	Calcite, Aragonite, Limestone	Inert	
Calcium magnesium carbonate	$CaMg(CO_3)_2$	Dolomite	Inert	
Talc	$Mg_3Si_4O_{10}(OH)_2$	hydrated magnesium silicate	Inert / Synergist	Exhibits flame retardancy synergy when combined with Metal Hydroxides
Lizardite	$Mg_3(Si_2O_5)(OH)_4$.	Magnesium Silicate	Inert	
Magnesium Carbonate	$MgCO_3$	Magnesite	Inert	
Titanium Dioxide	TiO_2	Rutile, Anatase		Commonly used as a white pigment in paints and plastics
Silicon Dioxide	SiO_2	Silica, Quartz	Inert /Synergist	Exhibits flame retardancy synergy when combined with Magnesium Hydroxide.
Tricalcium Silicate	Ca_3SiO_5	Alite	inert	
Lime	CaO	Calcium Oxide	inert	Typically used in cement. Sometime used in production of Magnesium Hydroxide

Table 4. List of mineral filler active fire retardants and their most important properties

Name, Abbreviation	Chemical Formula	%mass-Loss on ignition (1000°C)	T_{decomp}. (°C)	Density g/cm^3	ΔH_{decomp} kJ/g
Aluminium hydroxide, ATH	$Al(OH)_3$	34.6	180-200	2.4	1300
Magnesium hydroxide, MDH	$Mg(OH)_2$	31	300-330	2.4	1450
Boehmite, AOH	AlOOH	17	340-350	3.0	560
Huntite, H	$Mg_3Ca(CO3)_4$	35	400-450	2.7	980
Hydromagnesite, HM	$Mg_5(CO_3)_4(OH)_2$ i $4H_2O$	45	220-240	2.2	1300

Notes:

- %-Loss on ignition (1000°C) = the total mass% loss of the material when heated at 1000°C. Materials lost usually consist of "combined water" (hydrated water and hydroxy-compounds) and carbon dioxide from carbonates.
- T_{decomp}. (°C) = temperature at which the material begins to decompose indicated by mass loss in TGA
- ΔH_{decomp}(kJ/g) = Endothermic heat uptake during decomposition

2.2.3 ICA AND BRE RANKING[16, 17]

The Insurance Council of Australia, Engineers Australia and Fire Protection Association (Australia) have published a protocol for the identification, categorisation and risk ranking of ACP and other combustible façade materials installed to existing buildings[16, 17]. Note this classification was first published in November 2017 and was updated on July 2, 2019 (ICA 2019). This groups ACP into four general categories as summarised in Table 5, which also compares other common naming or categories for similar ACP grades.

Table 5. ICA and other similar categories or groupings for ACP[16, 17]

ICA Risk Categories				Similar categories or groupings[Note 1]		
Category	**% organic polymer (mass%)**	**% inert material (mass%)**	**ICA Description**	**Common naming**	**BRE Category / Gross Calorific value**	**EN 13501 class**
A	30-100%	0-70%	*ACP's in this category typically have close to 100% organic polymer in their core and were identified by most manufacturers as PE (Polyethylene) core. Some core binders are polymers other than PE.[Note 2]*	PE	3 >35 MJ/kg	D
B	8-29%	71-92%	*Typically identified by ACP manufacturers as fr, FR, Plus or rated Class B per EN 13501 and typically have around 30% organic polymer in the core however some State Regulations limit the PE content to less than 30% for this category.*	FR	2 >3 MJ/kg and ≤ 35 MJ/kg	B
C	1-7%	93-99%	*Typically identified by ACP manufacturers as A2, rated as Class A2 per EN 13501. These are considered as having very limited combustibility. Testing to EN 13501 and obtaining class A2 is a valid alternative.*	A2	1 ≤ 3 MJ/kg	A2
D	0%	100%	*Typically, panels tested or deemed non-combustible by the building code (NCC BCA Vol 1). These could be aluminium skins with low adhesive aluminium honeycomb cores, compressed fibre cement core or even compressed fibre cement panel*. Steel panels with calcium silicate or similar core.* *ICA protocol description for Category D includes low adhesive honeycomb cores. It does not clarify if this would include all types of Bonded Laminates that comply with NCC Vol. 1 C1.9 e) vii) and that the adhesive layers are not to be included in categorisation by % organic polymer	Non-combustible	1 ≤ 3 MJ/kg	A1
Note 1	Calorific value provides a direct measurement of a key material fire property and therefore provides a more direct measure to categorise fire hazards of ACP cores compared to mass% composition Categorisation based on calorific value or EN 13501 class may not always align perfectly with ICA categories based on inert material mass% content. This may particularly be the case for materials close to the limiting values of each ICA category. Calorific value and material reaction to fire test performance can vary as a function of polymer type and mineral filler type (active fire-retardant vs inert) and is not simply a function of mass% of mineral filler. However, the ICA risk categories based on mass% of inert material do provide a practical and useful means of sampling, testing and identification of the expected risk presented by ACP, particularly on existing buildings					
Note 2	CSIRO material characterisation testing on ACP has revealed a distribution of ACP samples having mineral filler mass % around 70% with numerous samples being marginally below ICA Category B in the range of 65-69% and numerous samples being more significantly below ICA Category B in the range of 55-64%. Whilst these materials are ICA Category A, they are expected to have reduced heat of					

	combustion (based on mineral vs polymer content) and may have improved reaction to fire performance compared to ACPs with close to 100% organic polymer content. Further reaction to fire testing to characterise performance of ACP cores in this range may be useful.

2.2.4 VISUAL APPEARANCE OF TYPICAL ACP POLYMER CORES

The following figures demonstrate the typical range of ACP core visual appearance of samples received by CSIRO and quantified by laboratory materials characterisation tests. Note that core colour does not provide a definitive indication of mineral content. .

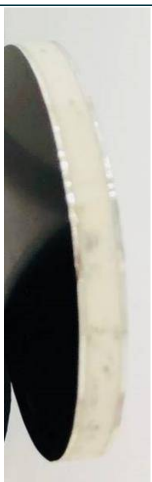
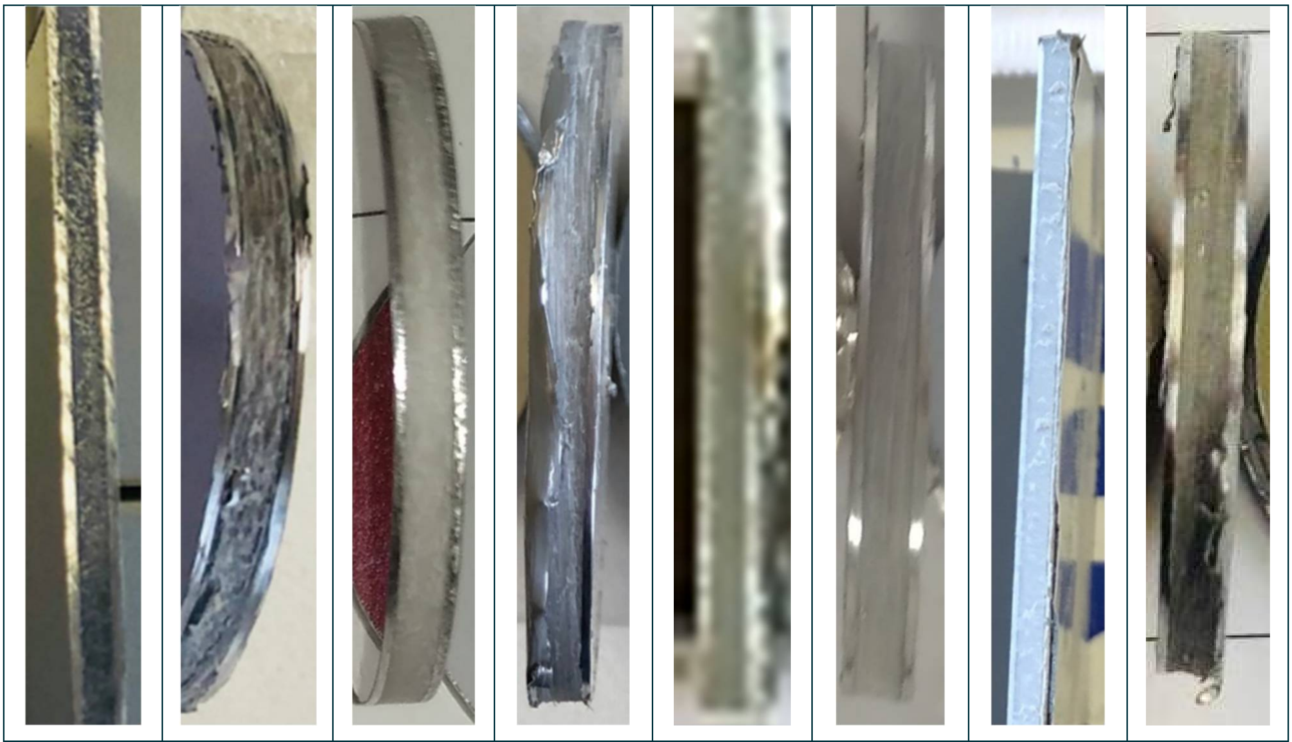
	
99%	95%
Mineral content mass%	

Figure 7. Examples of ICA Category C ACP cores with 93-99% mineral filler (Photos by CSIRO)

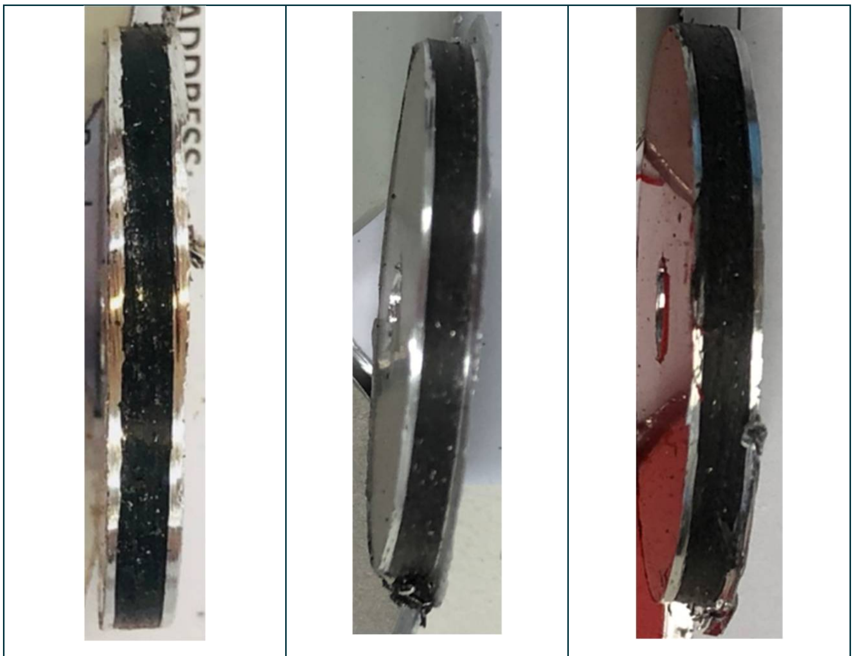
					
82%	75%	72%	72%	71%	71%
Mineral content mass%					

Figure 8. Examples of ICA Category B ACP cores with 71-92% mineral filler (Photos by CSIRO)



69%	68%	64%	64%	58%	57%	56%	55%
Mineral content mass%							

Figure 9. Examples of ICA Category C ACP cores with 50-70% mineral filler (Photos by CSIRO)



24%	23%	16%
Mineral content mass%		

Figure 10. Examples of ICA Category C ACP cores with <25% mineral filler (Photos by CSIRO)

CSIRO review of materials characterisation test samples concludes that:

- All samples confirmed to be ICA Category A having 93-99 mass% mineral content have had white coloured core.

- Samples confirmed to be ICA Category B having 71-92 mass% mineral content have had core colours ranging from white to light grey to dark grey independent of mineral content.
- Samples confirmed to be ICA Category C having 50-70 mass% mineral content have had core colours ranging from white to light grey to dark grey independent of mineral content.
- Samples confirmed to be ICA Category C having less than 25 mass% mineral content have had black core colours.

It is noted that ACP with high PE content may typically rely on the PE adhesion to bond the aluminium skins whilst ACP with high mineral content may typically apply a thin layer of adhesive (typically Ethylene-vinyl acetate (EVA) hot melt film adhesive) to bond the aluminium skins to the core.

2.3 ACP with other polymer core types

ACPs with other polymer core types have been used in Australia, although these are less prevalent that PE ACP (with or without mineral filler).

Some examples are:

2.3.1 CELLULOSE FIBRE WITH PHENOLIC RESIN

At least one type of ACP previously used in Australia has applied core made of cellulose (wood) fibre mixed with Phenolic resin. As testing by CSIRO has confirmed this core material to be close to 100% organic polymer (mostly wood fibre with some phenolic resin), however the exact concentration of phenolic resin has not been measured.

The core has an appearance similar to exterior grade Masonite (Hardboard/medium density fibreboard). Masonite it known to typically have a resin content in the range of 4-10 mass% phenolic resin[18, 19].

Phenol formaldehyde has a gross heat of combustion of 27.9-31.6 MJ/kg and has thermosetting/char forming behaviour. Cellulose (based on values for a range of wood types) has a gross heat of combustion of 19-21 MJ/kg and has char forming behaviour. University of Queensland testing of an ACP core of this type[4] measured a gross heat of combustion of ~23MJ/kg.

Although cellulose and phenolic resin have improved fire performance compared to PE in terms of thermosetting and charring rather than melting behaviour, ignitability, and heat of combustion, this type of ACP core is still combustible and considered to be ICA Category A

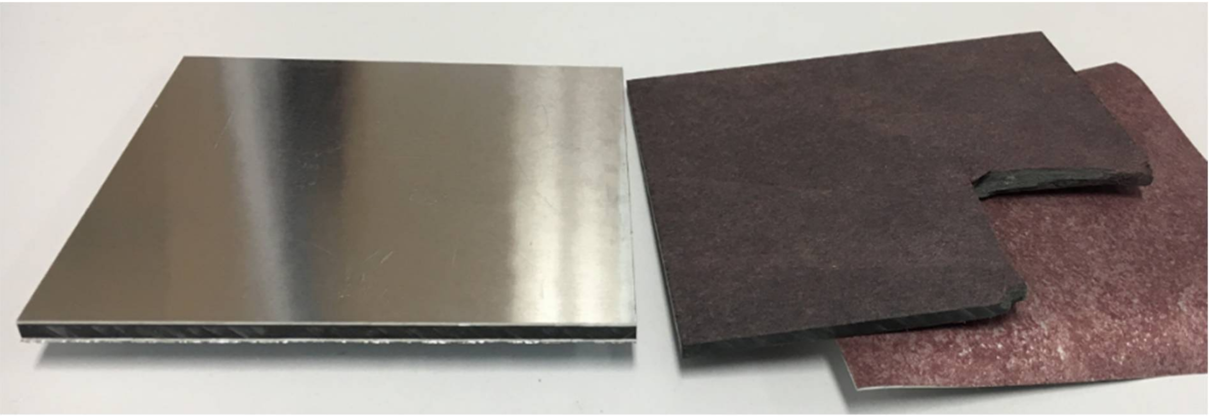


Figure 11. ACP with phenolic resin/cellulose fibre core (photo by CSIRO)

2.3.2 ETHYLENE-VINYL ACETATE (EVA)

The University of Queensland "*Material Library of Cladding Materials*"[4] includes numerous ACP samples with some having PE identified as the main polymer and others have Ethylene vinyl acetate (EVA) or Polyethylene modified with vinyl acetate (PE-VA) identified as the main polymer.

Ethylene vinyl acetate (EVA), also known as Polyethylene modified with vinyl acetate (PE-VA) is a co-polymer of ethylene and vinyl acetate (VA). It has the chemical formula $(C_2H_4)_n(C_4H_6O_2)_m$.

EVA with a low proportion of VA (~ up to 4%) may be referred to as polyethylene modified with vinyl acetate and is processed and used as the thermoplastic material with similar properties to low density polyethylene. This is the variety of EVA most likely used for ACP cores, it appears to have similar heat of combustion, thermal and physical properties to PE and may basically be considered equivalent to PE for the purposes of ACP fire performance.

EVA with a medium proportion of VA (~ 4-30%) is referred to as thermoplastic ethylene-vinyl acetate copolymer and is a thermoplastic elastomer material. EVA with approximately 11% VA are used as hot melt adhesives and may typically be applied as a thin film adhesive layer for ACP's with high mineral content cores and bonded laminates.

2.4 Aluminium Bonded Laminated Materials

Bonded laminated materials are defined by NCC BCA 2019 Vol 1 clause C1.9(e)(vii) as follows:

Bonded laminated materials where:

A. *each lamina, including any core, is non-combustible; and*

B. *each adhesive layer does not exceed 1 mm in thickness and the total thickness of the adhesive layers does not exceed 2 mm; and*

C. *the Spread-of-Flame Index and the Smoke-Developed Index of the bonded laminated material as a whole do not exceed 0 and 3 respectively (when tested to AS 1530.3).*

NCC BCA 2019 Vol 1 2019 permits bonded laminated materials complying with the above requirements to be used wherever a non-combustible material is required as DTS compliant

Industry and ACP suppliers often mis-state compliance of a product with the above requirements as being "*Deemed non-combustible".* However, this is incorrect as the adhesive layer is combustible and would likely not meet the AS 1530.1 test criteria for a material to be deemed not combustible if tested. Only materials tested to AS 1530.1 and which meet the AS 1530.1 test criteria for a material deemed not combustible should be stated to be non-combustible in accordance with the NCC BCA 2019 Vol 1.

There are several Aluminium bonded laminated material products available in Australia. These typically consist of:

- Thin aluminium sheet external facing typically 0.5 mm thick (one sheet applied to both sides/faces)
- A thin aluminium core with either a "honeycomb" profile or an "egg box" profile that creates a significant volume of air pockets within the core.
- A thin film of adhesive bonding each facing to the core. Most typically either an EVA hot melt adhesive or a polyurethane (PU) based adhesive may be used. Other adhesive types such as phenolic resins could possibly also be used for some products

The above construction has the following impacts:

- The core structure provides good weight vs flexural strength/stiffness properties

- The combustible material content per unit area is significantly reduced compared to high PE content core ACP.

Figure 12 shows an example of a bonded laminated panel with aluminium "egg box" profile core with EVA hot melt film adhesive. The adhesive appears to be added to the aluminium component surfaces as a thin film layer prior to assembly of the panel. During panel assembly it appears that the skins may be increased in temperature sufficiently to create a hot melt adhesion wherever the contact points between the skins and the core exist. Although this appears to apply an equivalent quantity of film adhesive to both sides of the core it results in a much stronger adhesion on the valley side of the core (which has a greater contact area) and a weaker adhesion on the apex side of the core (which has a lesser contact area).

Figure 13 shows an example of a bonded laminated panel with aluminium "honeycomb" profile core which appears to have a PU based adhesive layer

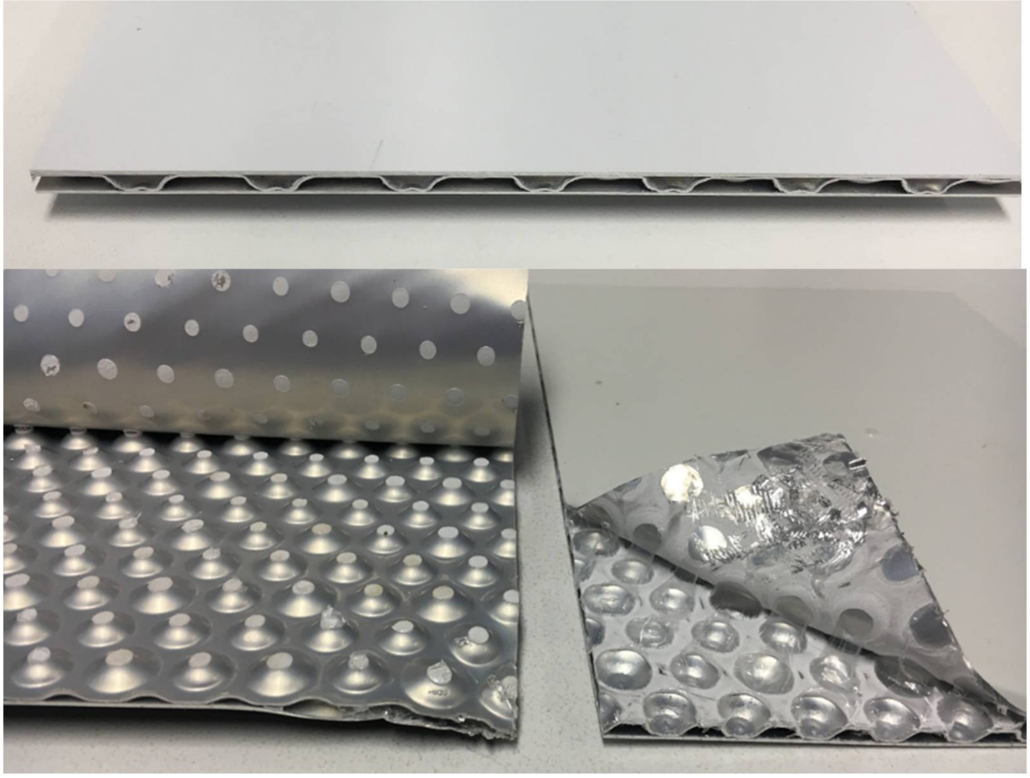


Figure 12. Bonded Laminated panel with aluminium "egg box" profile core with EVA hot melt film adhesive. Top = edge, left = skin delaminated showing apex side of core, right = skin delaminated showing valley side of core (photos by CSIRO).

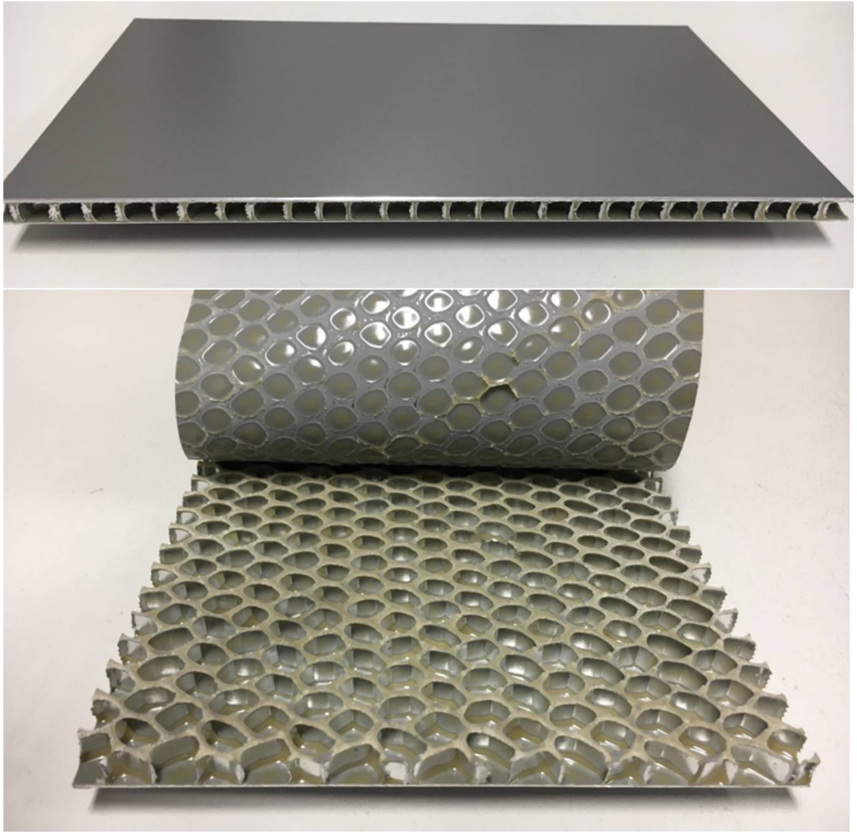


Figure 13. Bonded Laminated panel with aluminium "honeycomb" profile core. Appears to have a PU based adhesive layer. (photos by CSIRO)

Other types of panels containing a core with a very high mineral content that complies with AS 1530.1 as 'not deemed combustible', but which use a thin adhesive layer to bond the metal skins to the core, could be considered to be bonded laminated materials.

3 NCC BCA Requirements relating to fire safety of ACP applied to external walls

This section identifies and summarises the key Australian National Construction Code (NCC) requirements that relate to fire safety of ACP applied as external walls. The NCC has the following two main volumes which constitute the Building Code of Australia (BCA):

- BCA Volume One – which deals with Class 2 to Class 9 buildings.
- BCA Volume Two – which deals with Class 1 and 10 buildings.

The current edition of the NCC is NCC 2019, that was adopted from 1 May 2019. The current NCC edition defines external walls as;

a) for the purposes of Volume One'…an outer wall of a building which is not a common wall,' and
b) for the purposes of Volume Two '…an outer wall of a building which is not a separating wall.

The scope of this report focuses primarily on NCC BCA Volume 1 requirements for Class 2-9 type A and B construction.

A brief review of building code requirements relating to fire safety of external walls in other countries including New Zealand, UK, Germany and USA is provided in Appendix A.

The NCC BCA has been a performance-based code since its edition as the 1996 Building Code of Australia (BCA). The NCC BCA states a range of performance requirements. The Performance Requirements can only be satisfied by a—

a) Performance Solution (typically demonstrated via fire engineering analysis); or
b) Deemed-to-Satisfy (DTS) Solution (Prescriptive provisions of the NCC BCA deemed to comply with the performance requirements); or
c) Combination of (a) and (b).

The DTS requirements are summarised in detail in the following sections, however as an overview to facilitate understanding of sections on performance requirements and Performance Solutions, the key DTS requirements for reaction to fire of external walls are:

- External walls for Type A and B construction must be either non-combustible or constructed of a limited set of materials permitted by the NCC as DTS, were non-combustible materials are required,
- External walls for Type C construction and Class 1 buildings have significantly less stringent, to no reaction to fire requirements (depending on application including proximity to adjacent buildings and location within a bushfire prone area).

3.1 Current Class 2-9 requirements

The following flow diagram summarises the various NCC BCA 2019 Vol 1 DTS and performance-based compliance pathways possible for an external wall system relating to external wall reaction to fire for Type A and B construction. Other pathways to demonstrate compliance include a CodeMark Certificate of Conformity or a Certificate of Accreditation issued by a State or Territory accreditation authority. However, such certificates should ideally be based upon a similar process of testing and assessment as that depicted in the following diagram.

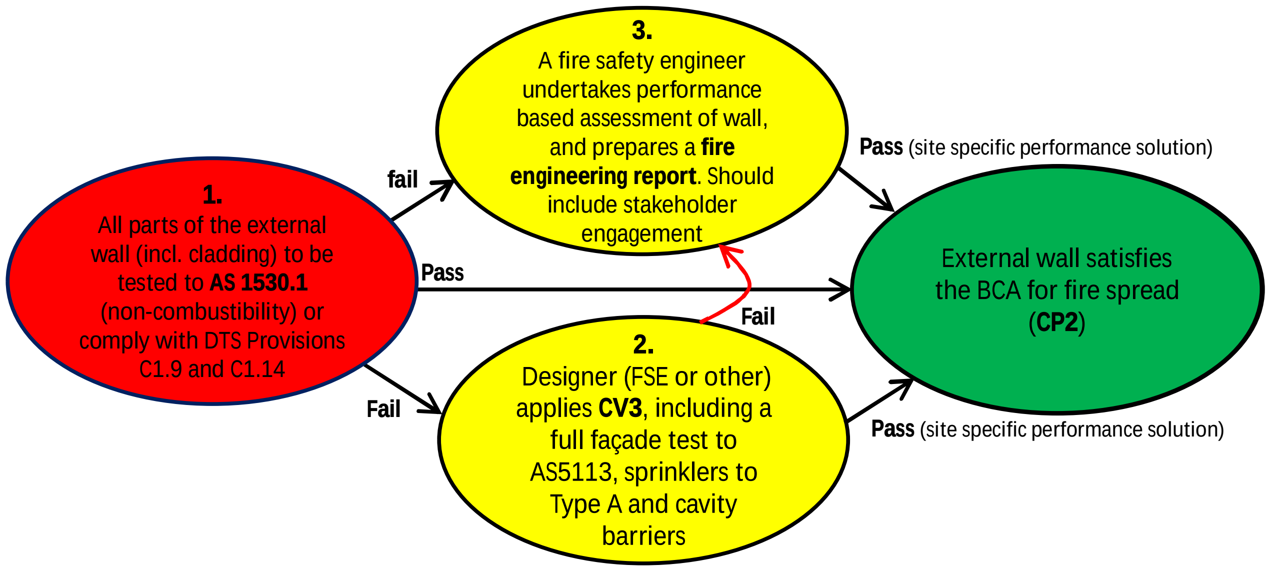


Figure 14. NCC BCA 2019 Vol 1 compliance pathways possible for an external wall system relating to external wall reaction to fire (does not cover fire resistance requirements) (Diagram originally by Stephen Kip and modified by CSIRO).

Note CV3 does require some additional sprinkler provisions for Type A construction to enhance performance and reliability, see Section 3.1.3 for further detail.

3.1.1 PERFORMANCE REQUIREMENTS

Performance Requirement means a mandatory NCC BCA requirement which states the level of performance which a Performance Solution or Deemed-to-Satisfy Solution must meet. NCC BCA Performance requirements are written in qualitative rather than quantitative terms.

The Engineers Australia "*Society of Fire Safety Practice Guide- Façade/External Wall Fire Safety Design*"[20] identifies that the following performance requirements may be relevant (but is not limited to these):

- CP1, CP2, CP4, CP9, EP1.4, EP2.2.

The NCC BCA 2019 Vol 1 Schedule 7 Fire Safety Verification method identifies that the following performance requirements may be relevant to horizontal fire spread (between buildings) or vertical fire spread involving external walls:

- CP2, CP4, CP7, CP8, EP2.2

CP2 and CP4 are the most relevant performance requirements which directly relate to the external wall reaction to fire behaviour and the impact this has on fire and smoke spread, occupant life safety, fire brigade intervention and other building safety systems. GP5.1 is also directly relevant for Class 2 and 3 building located in designated bushfire prone areas. CP2, CP4 and GP5.1 are presented below. The other performance requirements identified above are presented in Appendix B

CP2 – Spread of Fire

(a) A building must have elements which will, to the degree necessary, avoid the spread of fire—
(i) to *exits*; and
(ii) to *sole-occupancy units* and *public corridors*; and
Application: CP2(a)(ii) only applies to a Class2 or3buildingor Class4 part of a building.
(iii) between buildings; and
(iv) in a building.
(b) Avoidance of the spread of fire referred to in **(a)** must be appropriate to—
(i) the function or use of the building; and
(ii) the *fire load*; and

(iii) the potential *fire intensity*; and
(iv) the *fire hazard*; and
(v) the number of *storeys* in the building; and
(vi) its proximity to *other property*; and
(vii) any active *fire safety systems* installed in the building; and
(viii) the size of any *fire compartment*; and
(ix) *fire brigade* intervention; and
(x) other elements they support; and
(xi) the *evacuation time*.

CP4 – Safe conditions for Evacuation
To maintain tenable conditions during occupant evacuation, a material and an assembly must, to the degree necessary, resist the spread of fire and limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to—
(a) the *evacuation time*; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) any active *fire safety systems* installed in the building.
Application:
CP4 applies to linings, materials and assemblies in a Class 2 to 9 building.

GP5.1 – Bushfire Resistance

A building that is constructed in a *designated bushfire prone area* must, to the degree necessary, be designed and constructed to reduce the risk of ignition from a bushfire, appropriate to the—

(a) potential for ignition caused by burning embers, radiant heat or flame generated by a bushfire; and
(b) intensity of the bushfire attack on the building.

Application
GP5.1 only applies to—
(a) a Class2 or3building; or
(b) a Class 10a building or deck associated with a Class2 or3building, located in a *designated bushfire prone area*.

3.1.2 PERFORMANCE SOLUTIONS

A Performance Solution can be assessed using a number of Assessment Methods, which are defined in the NCC BCA 2019 Vol 1 and include:

(a) Evidence of suitability in accordance with Part A5 that shows the use of a material, product, form of construction or design meets the relevant Performance Requirements *(this includes a current CodeMark Certificate of Conformity, Certificate of Accreditation issued by a state or territory accreditation authority and other forms of evidence)*.
(b) A Verification Method including the following:
    (i) The Verification Methods provided in the NCC BCA 2019 Vol 1. *(This includes CV3, CV1, CV2 and NCC BCA 2019 Vol 1 Schedule 7 Fire Safety Verification Method)*
    (ii) Other Verification Methods, accepted by the appropriate authority that show compliance with the relevant Performance Requirements. *(This is typically other fire safety engineering analysis presented in a Fire Engineering Report (FER) or Performance-based design report (PBDR) and may be qualitative or quantitative, deterministic or risk based)*

(c) Expert Judgement.

(d) Comparison with the Deemed-to-Satisfy Provisions.

Development and assessment of performance solutions requires a high level of expertise and should only be carried out by a suitably qualified, competent and registered Fire Safety Engineer. However, it is important to note that the level of qualification, competence and requirement to be registered as Fire Safety Engineering professional in order to develop and assess performance solutions varies in different states and territory.

The Engineers Australia "*Society of Fire Safety Practice Guide- Façade/External Wall Fire Safety Design*"[20] provides a practice guide for identification, development and assessment of performance based solutions for combustible external walls. It primarily focuses on addressing existing buildings. It recommends assessment implementing the following approaches combined:

- Building Audit – this is applicable to existing buildings identified to have combustible external walls and should include an audit of not just the combustible external walls but the holistic building fire safety systems that have a bearing on risk.
- Risk assessment - Assessment of the risks to life safety, fire brigade intervention, adjacent property and any other stakeholder agreed objectives based on a holistic assessment of all of the buildings fire safety systems relevant to external wall fire scenarios. A risk assessment approach that eliminates or minimises risks so far as is reasonably practicable (SFAIRP) is recommended rather than an as low a reasonably practicable (ALARP) approach.
- Product and system testing – material characterisation/identification tests (for existing buildings) and relevant reaction to fire tests are required to determine the fire behaviour of the external wall.
- Deterministic assessment – In some cases, assessment of items such as access and egress may require deterministic modelling. This may not be necessary in all cases.

The NCC BCA 2019 Vol 1 Schedule 7 Fire Safety Verification method (FSVM) takes delayed effect from 1 May 2020. It provides a process for engineering design of fire safety performance solutions which is intended to promote increased consistency of fire engineering assessment methodologies. The FSVM includes the following:

- Tenability criteria for occupants and fire brigade are nominated.
- A range of specific design scenarios that must be considered are identified. This includes HS (horizontal spread between adjacent building external walls) and VS (Vertical fire spread involving cladding or arrangement of openings in walls)
- The relevant performance requirements that must be considered and addressed for each specific design scenario is identified
- The FSVM does not generally nominate specific methods of analysis or inputs other than requiring the proposed *Performance Solution* to be compared and be at least equivalent to a DTS compliant *reference building* that implicitly defines acceptable risk levels commensurate with public expectations.
- For design scenario VS compliance with CV3 is recommended
- For design scenario HS compliance with CV1 and CV2 is recommended.
- The ABCB "Handbook – Fire safety verification method" provides further guidance on the FSVM process and offers limited guidance on a range of fire engineering models but does not specifically nominate any particular model or inputs that must be used.

It is considered by CSIRO that performance solutions (particularly for existing buildings) relating to combustible external walls may typically be best addressed by product/system testing coupled with risk assessment.

For performance solutions relating to combustible external walls:

- The Society of Fire Safety Practice Guide provides a useful and practical approach for addressing existing buildings with combustible external walls. However, for new buildings seeking design approval, performance assessment focused on a rigorous deterministic fire test approach (applying CV3 or at least AS 5113) to demonstrate a level of fire safety at least equivalent to DtS may be more acceptable from the perspective of stakeholders and society.
- The FSVM is not particularly useful or practical for addressing existing buildings with combustible external walls. For existing buildings the FSVM would typically require either to:
    - Demonstrate equivalence to a comparable DTS Building with non-combustible external walls – this would be difficult and unlikely to be cost effective for existing buildings; or
    - Demonstrate compliance to CV3 including AS5113.1 EW compliance and other sprinkler and cavity barrier provisions. AS 5113.1 testing is applied to each unique wall system. Each existing building may have multiple unique wall systems and many of these are likely to fail AS 5113.1 EW tests on criteria such as falling debris (even if aggressive vertical fire spread does not occur). Considering the extent of existing building stock, cost and availability of test labs this may not be feasible. Existing buildings are unlikely to be fitted with additional measures required by CV3 including cavity fire barriers.
- However, for new buildings seeking design approval, the FSVM does re-enforce the reasonable expectation that a level of fire safety at least equivalent to DtS should be achieved.
- For new buildings it is prudent that either BCA DtS compliant external wall systems or attachments are used or a performance solution based on compliance with CV3 or other relevant full scale façade test data for the specific system which demonstrates acceptable fire performance.
- For existing buildings impacted by combustible external walls or attachments:
    - A careful assessment of cost vs benefit/risk of cladding rectification performance solutions on a SFAIRP basis is recommended.
    - Where full scale façade tests are not available for the specific installed system, testing to identify core composition, cavity materials and fixing/construction details combined with comparison against limited available published full and intermediate scale façade fire test data for similar systems may provide a rough indication of expected performance.
    - However, based on holistic fire engineering assessment of the extent, location, orientation of cladding, ignition source hazards and other building fire safety systems, there may be cases where poorer performing existing external wall systems (such as ACP-PE or ACP-FR with combustible insulation) may be assessed as suitable for retention on a risk and cost basis. This would typically require limited continuity and extent of such wall systems.

3.1.3 VERIFICATION METHOD

An NCC BCA Verification Method is a test, inspection, calculation or other method that determines whether a Performance Solution complies with the relevant Performance Requirements. It is not intended to be a DTS provision. NCC BCA Verification methods are non-mandatory.

Verification Method CV3 states that compliance with **CP2** to avoid the spread of fire via the *external wall* of a building is verified when the requirements summarised in the following flow diagram are satisfied.

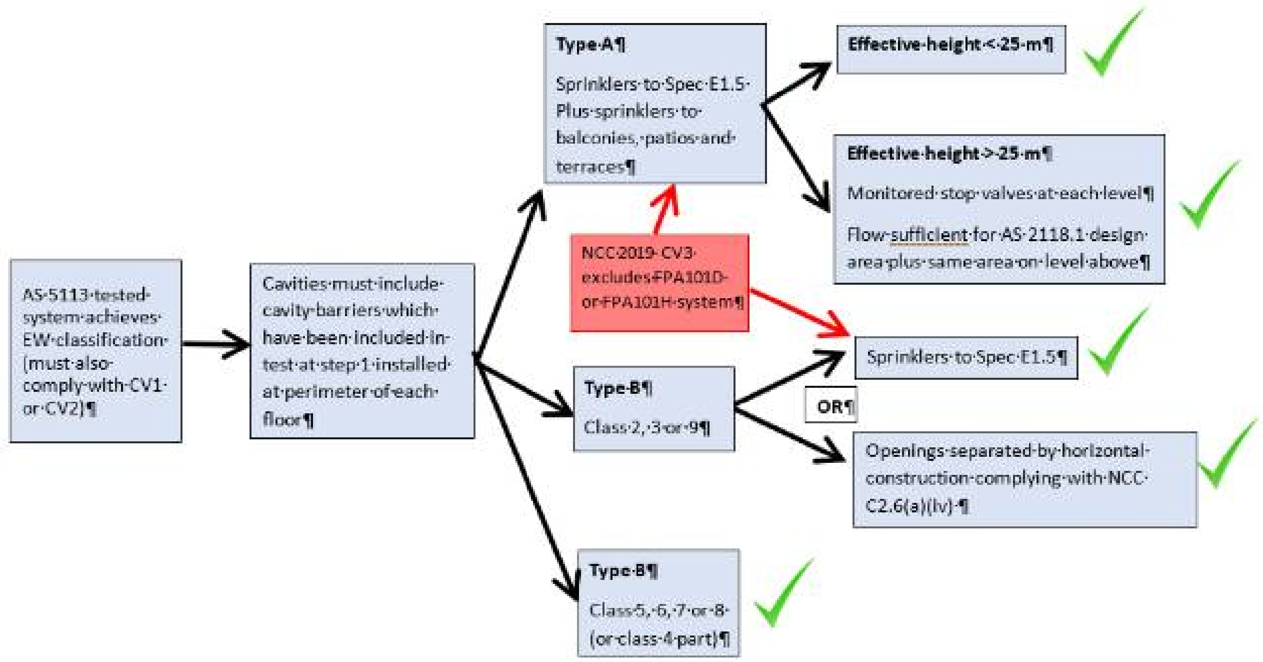


Figure 15. Summary of NCC BCA 2019 Vol 1 CV3 Requirements (diagram by CSIRO).

It is noted that CV3 sets a high level of stringency as it requires the additional measures of cavity fire barriers and (in many cases) sprinklers with additional requirements to be applied to façade systems which have achieved AS 5113 EW classification.

Compliance with CP2(a)(iii) is verified by CV1 and CV2. CV1 and CV2 simply state a range of limiting heat fluxes either emitted by or received by a building exterior which must not be exceeded, and which vary with distance either from the allotment boundary or between buildings. CV1 and CV2 do not specify a calculation method or inputs that are to be applied. The outcome of this verification method is sensitive to inputs adopted such as the fire/heat source configuration factor (size and shape), temperature and emissivity assumed.

Application of CV1, CV2 or CV3 is not mandatory and these are not DTS provisions of the NCC BCA. Other forms of assessment method or evidence (as detailed in NCC BCA 2019 Vol 1 clauses A2.2and A5.2) may be used to demonstrate compliance of a performance solution.

3.1.4 DTS PROVISIONS

The following key aspects of regulation have been identified to have significant impact on performance and fire risk of external wall assemblies and therefore the review DTS requirements has focussed primarily on these aspects:

1. Reaction to fire requirements for external wall assemblies and materials.
2. Fire stopping/cavity barrier requirements both within and behind external walls.
3. Separation of buildings, in terms of minimum separation of unprotected openings from a relevant boundary (or fire source feature).
4. Separation of openings between storeys.
5. Requirements for sprinkler protection – which influences the risk of an initiating compartment fire and fire spread into compartments.

The minimum type of fire resisting construction required is grouped into 3 different Types dependant on building class and rise in storeys as summarised in the table below. DTS requirements vary with Type of construction.

Table 6. Type of fire resisting construction (from NCC BCA 2019 Vol 1 Table C1.1)

Rise in storeys	Class of Building	
	2, 3, 9	**5, 6, 7, 8**
4 or more	Type A	Type A
3	Type A	Type B
2	Type B	Type C
1	Type C	Type C

NCC BCA 2019 Vol 1, Clause C1.5 for two storey Class 2, 3, or 9c buildings permits a building having a rise in storeys of 2 may be of Type C construction if—

(a) it is a Class 2 or 3 building, or a mixture of these classes and each sole-occupancy unit has—

(i) access to at least 2 exits; or

(ii) its own direct access to a road or open space; or

(b) it is a Class 9c building protected throughout with a sprinkler system (other than a FPAA101D or FPAA101H system) complying with Specification E1.5 and complies with the maximum compartment size specified in Table C2.2 for Type C construction.

It is noted that if a two-story Class 2, 3, or 9c is determined to be Type C then there may be no requirements relating to external wall combustibility or reaction to fire.

3.1.4.1 External wall reaction to fire

NCC BCA 2019 Vol 1, Clause C1.9 Non-combustible building elements:

See Table 7. for a detailed summary of this DTS Clause.

A building required to be of Type A or B construction is required to have external walls which are non-combustible, including all components incorporated in them including the facade covering, framing and insulation.

NCC BCA 2019 Vol 1 Clause C1.9(e) lists materials that may be used wherever a non-combustible material is required such as plasterboard, cement sheet, pre-finished metal sheeting and bonded laminated materials (with limitations).

ACP with a combustible core would not comply with this DTS requirement for Type A or B Buildings.

Aluminium Bonded laminated materials with a non-combustible core can comply with this DTS requirement for Type A or B Buildings.

NCC BCA 2019 Vol 1, Clause C1.10 fire hazard properties

BCA Vol 1 2019 (and 2016 Amendment 1) Clause C1.10 was revised from previous editions to clarify that it applies to "internal linings, materials and assemblies”. Previous editions did not include the text “Internal” in the Clause C1.10 requirement.

Clause C1.10 controls internal wall and ceiling lining fire hazard properties based on Group Number which is determined based on time to flashover in the AS/ISO 9705 room corner test (or prediction of this result based on AS 3837 cone calorimeter tests with limitations). Flashover broadly is defined as when a fire transitions rapidly from a localised area of burning to flaming over the majority surfaces within an enclosure or extended area. The BCA, via AS 5637.1 defines flashover in an AS ISO 9705 test as a measure heat release rate (HRR) of 1 MW inclusive of burner output.

The current BCA could still possibly be interpreted to include external walls as “Other Areas” and therefore require Group Number 3 for external walls, particularly for Type C construction, where other non-combustible requirements do not apply. However, interpretation of this is likely to vary.

Other test methods specified in NCC BCA 2019 Vol 1 Clause C1.10 and Specification C1.10 including AS 1530.2 and AS 1530.3 for "Other Materials" are not relevant to external walls and attachments except for "sarking type materials" and "insulation" (where not already controlled by other DtS requirements such as non-combustibility).

NCC BCA 2019 Vol 1 Clause C1.13 - provides a concession for fire protected timber to be acceptable for Type A or B construction where non-combustible elements are required. This:

- is limited to buildings with effective height not more than 25 m
- requires the building to be sprinkler protected in accordance with NCC Spec C1.5 (excluding FPAA101D or FPAA101H system)
- requires cavity insulation to be non-combustible
- requires cavity fire barriers to be provided
- DTS Clause C1.9 requirement for non-combustible materials would apply to all other parts of the external wall system including the external cladding

Therefore, Combustible ACP would not be permitted with fire protected timber construction.

NCC BCA 2019 Vol 1 Clause C1.14 Ancillary elements -

See Table 8 for a detailed summary of this DTS Clause.

This clause lists ancillary elements which are permitted to be combustible and be attached to internal parts or external face of an external wall that is required to be non-combustible. NCC defines an ancillary element as "*an element that is secondary to and not an integral part of another element to which it is attached".*

This permits combustible ACP used for signs, awnings and canopies attached as ancillary elements to non-combustible external walls, but places restrictions on the reaction to fire performance, extent and location.

NCC BCA 2019 Vol 1 Specification C1.1 Clause 3.10 and Clause 4.3 –

This provides concessions applicable to Class 2 or 3 buildings having a rise in storeys of not more than 3 (or 4 storeys if the lowest storey is car parking or ancillary use of masonry or concrete construction having the required FRL separation from the stories above) to permit external walls to be timber frame construction combined with other non-combustible materials, provided that any insulation installed in the cavity of a wall required to have an FRL is non-combustible; and the building is fitted with an automatic smoke alarm system complying with Specification E2.2a.

This does not permit combustible ACP to be applied to timber framed Type A or B construction.

NCC BCA 2019 Vol 1 Clause G5.2 Construction in bushfire prone areas:

In a *designated bushfire prone area*, the following construction must comply with AS 3959—
(a) A Class 2 or 3 building; or

(b) A Class 10a building or deck associated with a Class 2 or 3 building,
Note there are several state based NCC BCA 2019 Vol 1 Appendices which vary the application of NCC BCA 2019 Vol 1 Clause G5.2.

Given that Clause C1.9 requires external walls for type A and B construction to be non-combustible, Bushfire requirements are only relevant to combustible ACP for Type C construction.

AS3959 specifies construction requirements for each Bushfire Attack Level (BAL).

- For BAL-12.5 to BAL-19:
  - exposed elements of external walls that are less than 400 mm from the ground or other near horizontal external surfaces must be non-combustible or a limited set of materials that does not include ACP. Combustible ACP is not permitted in these areas.

- there are no requirements for external walls 400 mm or more above ground or other near horizontal external surfaces. Combustible ACP would be permitted in these areas.

- For BAL-29 to BAL-40, exposed components of external walls at all locations. must be non-combustible or a limited set of materials that does not include ACP. Combustible ACP is not permitted.
- For BAL-FZ external walls must be either:
    - Non-combustible minimum 90 mm thickness masonry, concrete or earth walls.
    - Have an FRL of 30/30/30 or -/30/30 when tested from the outside.

Alternative to these prescriptive construction requirements, elements of construction must be tested to and comply with:

- AS 1530.8.1 for BAL-12.5 to BAL-40 (applying crib class AA); or
- AS 1530.8.2 for BAL-FZ

CSIRO is not aware of AS 1530.8.1 or AS 1530.8.2 testing applied to combustible ACP wall systems.

Table 7. NCC BCA 2019 Vol 1 DTS Clause C1.9 applicability to ACP

BCA Vol 1 Clause	Requirement	Comment / Applicability to ACP external walls
C1.9(a)	*In a building required to be of Type A or B construction, the following building elements and their components must be non-combustible:* *(i) External walls and common walls, including all components incorporated in them including the facade covering, framing and insulation.* *(ii) The flooring and floor framing of lift pits.* (iii) *Non-loadbearing internal walls where they are required to be fire-resisting.*	ACP with combustible core materials is not permitted for external walls of Type A and B construction
C1.9(b)	*A shaft, being a lift, ventilating, pipe, garbage, or similar shaft that is not for the discharge of hot products of combustion, that is non-loadbearing, must be of non-combustible construction in—* *(i) a building required to be of Type A construction; and* *(ii) a building required to be of Type B construction, subject to C2.10, in—* *(A) a Class2,3 or9building; and* *(B) a Class5,6,7 or8buildingifthe shaft connects more than2 storeys.*	Not relevant to external walls
C1.9(c)	*A loadbearing internal wall and a loadbearing fire wall, including those that are part of a loadbearing shaft, must comply with Specification C1.1.*	Not relevant to external walls
C1.9(d)	*The requirements of (a) and (b) do not apply to the following:* *(i) Gaskets.* *(ii) Caulking.* *(iii) Sealants.* *(iv) Termite management systems.* *(v) Glass, including laminated glass.* *(vi) Thermal breaks associated with glazing systems.* *(vii) Damp-proof courses*	Combustible gaskets, caulking and sealant are permitted. Although the NCC does not set any limits for reaction to fire properties or the extent of application for these materials it is considered that this clause is intended for application to limited extents of these materials such as: • Face sealing joints between non-combustible external walls • Sealing windows, flashings and other penetrations within non-combustible external walls

BCA Vol 1 Clause	Requirement	Comment / Applicability to ACP external walls
C1.9(e)	*The following materials may be used wherever a non-combustible material is required:* *(i) Plasterboard.* *(ii) Perforated gypsum lath with a normal paper finish.* *(iii) Fibrous-plaster sheet.* *(iv) Fibre-reinforced cement sheeting.* *(v) Pre-finished metal sheeting having a combustible surface finish not exceeding 1 mm thickness and where the Spread-of-Flame Index of the product is not greater than 0.* *(vi) Sarking-type materials that do not exceed 1 mm in thickness and have a Flammability Index not greater than 5.* *(vii) Bonded laminated materials where—* *(A) each lamina, including any core, is non-combustible; and* *(B) each adhesive layer does not exceed 1 mm in thickness and the total thickness of the adhesive layers does not exceed2mm; and* *(C) the Spread-of-Flame Index and the Smoke-Developed Index of the bonded laminated material as a whole do not exceed 0 and 3 respectively.*	• Paper faced plasterboard and fibre-reinforced cement sheet present a low fuel load and are therefore permitted wherever non-combustible materials are required in the NCC regardless if they comply with AS 1530.1 test criteria or not. These materials could potentially be used in place of non-combustible cores for bonded laminated materials. • Solid aluminium or other metal sheeting with surface coatings complying with C1.9(e)(v) are permitted • Sarking comply with C1.9(e)(vi) would typically be installed as part of the moisture barrier within the external wall cavity • C1.9(e)(vii) permits bonded laminated ACP with non-combustible Lamina (typically with aluminium honeycomb or egg box profile). This does not permit ACP with a PE core of typical thickness. It would permit materials which use PE (or similar other polymers which could be considered adhesives) which comply with thickness limitations.

Table 8. NCC BCA 2019 Vol 1 Clause C1.14 applicability to ACP

BCA Vol 1 Clause	Requirement	Comment / Applicability to ACP external walls
C1.14	*An ancillary element must not be fixed, installed or attached to the internal parts or external face of an external wall that is required to be non-combustible unless it is one of the following:* *(a) An ancillary element that is non-combustible.* *(b) A gutter, downpipe or other plumbing fixture or fitting.* *(c) A flashing.* *(d) A grate or grille not more than 2m² in area associated with a building servicl(e) An electrical switch, socket-outlet, cover plate or the like.* *(f) A light fitting.* *(g) A required sign.* *(h) A sign other than one provided under (a) or (g) that—* *(i) achieves a group number of 1 or2; and* *(ii) does not extend beyond one storey* *(iii) does not extend beyond one fire compartment; and* *(iv) is separated vertically from other signs permitted under (h) by at least2 storeys.* *(i) An awning, sunshade, canopy, blind or shading hood other than one provided under (a) that—* *(i) meets the requirements of Table 4 of Specification C1.10 as for an internal element; and* *(ii) serves a storey—* *(A) at ground level; or* *(B) immediately above a storey at ground level; and* *(iii) does not serve an exit, where it would render the exit unusable in a fire.* *(j) Apart of a security, intercom or announcement system.* *(k) Wiring.* *(l) A paint, lacquer or a similar finish.* *(m) A gasket, caulking, sealant or adhesive directly associated with (a) to (k).*	• PE ACP has been used as signage in the past • C1.14(h) permits combustible ACP signage but limits the extent and requires a group number 1 or 2 material as defined by NCC Specification C1.10. PE ACP typically achieves Group 3 and would not be permitted. FR or A2 ACP would be required • C1.14(i) permits combustible awnings and canopies at ground level or immediately above a story at ground level provided they meet the requirements for NCC Spec C1.10 Table 4 which only requires testing to AS 1530.2 and AS 1530.3 as for an internal element. • C1.14(i) does not clarify if this is intended only for flexible (fabric/elastomer/sarking type) awning materials or if it also applies to solid awnings which protrude from external walls and may typically be clad with ACP. Given that AS 1530.2 and AS 1530.3 do not suitably determine the fire spread risk of ACP, CSIRO recommends that solid ACP clad awnings/Canopies should be considered an integral part of the external wall (not an ancillary element) and that External wall DtS requirements be applied. • C1.14(i) also requires that the awning does not serve an exit where it would render the exit unusable in a fire. Conservatively interpreting this requirement would conclude that combustible awnings and canopies are not permitted directly above exit discharge locations. • C1.14(m) permits gasket, caulking, sealant or adhesive directly associated with the permitted ancillary items. In the case of ACP could reasonably include face sealing gaps between panels etc. However there is likely to be uncertainty by stakeholders on whether other combustible elements commonly used in facades such as backing rods, packers and the like are exempted as acceptable combustible ancillary elements.

In summary

- NCC BCA 2019 does not specifically identify or define ACP and does not state any requirements that are intended exclusively for these products, however the general DTS requirements of Clause C1.9 require external walls for Type A and B construction to be non-combustible.
- Therefore, NCC BCA 2019 Vol 1 DTS does not permit ACP with combustible core as DTS for Type A or B construction.
- NCC BCA 2019 Vol 1 DTS is silent on combustibility and fire spread/reaction to fire requirements for external walls in Type C construction, except that FRL and construction in bushfire prone area DTS requirements may apply in specific circumstances. Therefore, ACP with combustible cores are permitted as DTS for Type C construction but may be impacted by FRL and bushfire requirements in circumstances where these additional requirements apply.

3.1.4.2 Fire stop barriers

NCC BCA 2019 Vol 1 Clause C2.6 states that buildings of Type A construction which are not sprinkler protected require any gaps behind curtain or panel walls at each floor level to be packed with a non-combustible material which is resistant to thermal or structural movement to act as a seal against fire or smoke.

NCC BCA 2019 Vol 1 Specification C1.13 details cavity barrier requirements applicable to fire protected timber.

NCC does not clearly state a requirement (except for CV3) for fire stop barriers to be installed within the external wall system cavity between the external cladding and any other internal elements (as opposed to gaps behind a curtain wall or panel wall system)

3.1.4.3 Separation between buildings

NCC BCA 2019 Vol 1 Specification C1.1 states that non loadbearing external walls separated by 3 m or more from a fire source feature (far side of a road, a side or rear boundary of an allotment or an external wall of another building on the same allotment) do not require an FRL. Non-loadbearing external walls with less than 3 m separation distance from a fire source feature are required to have an FRL.

NCC BCA 2019 Vol 1 Clause C3.2 states the requirements for separation or protection of openings in external walls where the external wall is required to have an FRL. Such openings are generally required to be separated from other buildings or fire source features by the following horizontal distances.

- 3 m from a side or rear boundary of an allotment.
- 6 m from the far boundary of road, river, lake or the like adjoining the allotment.
- 6 m from another building on the same allotment.

If openings in are not separated by the above distances, then buildings must be separated by walls having prescribed FRLs and all openings are to be protected by either external sprinkler protection or self-closing barriers having prescribed FRL's.

NCC BCA 2019 Vol 1 Clause C3.3 states required separation distances between external walls and associated openings in different fire compartments (within the same building). Required separation distance reduces with angle between the walls from 6 m separation required for 0° (opposite walls) to no separation distance required for walls with 180° angle or more. If required separation distances are not provided the external walls must have an FRL not less than 60/60/60 and all openings are to be protected by either external sprinkler protection or self-closing barriers having prescribed FRL's

3.1.4.4 Separation of vertical openings

NCC BCA 2019 Vol 1 Clause C2.6 states for Buildings of Type A construction, openings (windows) in external walls that are above openings in the storey below must be separated by either:

- A non-combustible spandrel having an FRL of 60/60/60 that is at least 900 mm in height and extends at least 600 mm above the intervening floor, or;

- A non-combustible horizontal projection having an FRL of 60/60/60 which projects 1100 mm horizontally from the external face of the wall and extends along the wall at least 450 mm beyond the openings.

The above separation is not required if the building is internally sprinkler protected.

3.1.4.5 Sprinkler protection

NCC BCA 2019 Vol 1 Clause E1.5 states that sprinkler protection is required for the following buildings:

- All classes with an effective height greater than 25 m.
- Class 2 or 3 building (excluding residential care) with a rise in storeys of 4 or more and an effective height not more than 25 m.
- Class 3 building used as residential care (regardless of height).
- Class 9a building used for residential aged care or class 9c buildings.
- Class 7a non-open deck carparks accommodating more than 40 vehicles (protection of car park fire compartment).
- Building containing Atrium where required by **NCC BCA 2019 Vol 1 Part G3** (sprinkler protection throughout).
- Theatre, public hall or the like where required by **NCC BCA 2019 Vol 1 Part H1** (sprinkler protection throughout).
- Or for buildings where maximum fire compartment size limits (which are dependent on the class of building) are exceeded.

NCC BCA 2019 Vol 1 Clause D1.3 states that sprinkler protection is required for:

- Class 2 building where an open stair is connecting 4 consecutive storeys (sprinkler protection is required throughout).
- Class 3, 5, 6, 7, 8 or 9 (excluding 9c and 9a) building open stair connecting 3 consecutive storeys requires sprinkler protection throughout.

Required fire sprinkler systems must generally comply with NCC BCA 2019 Vol 1 Specification E1.5 which references AS 2118.1, AS 2118.6 and AS2118.4.

AS 2118.1-2017 clause 5.9.10 has increased stringency on the dimensional criteria for the sprinkler protection of covered balconies (required for covered balconies more than 6 m^2 OR more than2 m deep).

An exception is provided for Class 2 or 3 building (excluding residential care) with a rise in storeys of 4 or more and an effective height not more than 25 m which may have a sprinkler system which complies with NCC BCA 2019 Vol 1 Specification E1.5a. This references FPAA101D (sprinkler system with drinking water supply) and FPAA101H (sprinkler system with hydrant water supply). Note that FPAA101D and FPAA101H are excluded (regardless of height) from use in several cases for example where CV3 (for combustible external walls) or C1.13 fire protected timber concession is applied.

FPAA101D and FPAA101H both require sprinkler protection of covered balconies as defined by the dimensional criteria in AS 2118.1-2017.

NCC BCA 2019 Vol 1 Specification E1.5a permits concessions related to fire compartmentation, exit travel distance and hydrant requirements where class 2 and 3 buildings with a rise in storeys of 4 or more and an effective height not more than 25 m are sprinkler protected.

NCC BCA 2019 Vol 1 Schedule 1 Victoria Appendix Vic H103.1 permits concessions related to fire compartmentation, exit travel distance and hydrant requirements where class 2 and 3 buildings with a rise in storeys of not more than 3 and an effective height not more than 25 m are sprinkler protected (excluding FPAA101D and FPAA101H).

NCC BCA 2019 Vol 1 Schedule 1 Victoria Appendix states that for class 2 and 3, AS 2118.1-2017 clause 5.9.10 does not apply and is replaced with “Covered balconies shall be sprinkler protected”. This means that for sprinkler protected residential buildings in Victoria, Sprinkler protection must extend to all covered balconies regardless of dimensions.

4 Australian State-based bans, ministerial guidelines and the like applied to ACP

The Victorian Cladding Taskforce final report[7] provides a useful timeline account of regulatory review and action (focused on Victoria but includes Federal Building Ministers Forum (BMF), Senate enquiry and ABCB actions). It commences from:

- the Lacrosse fire in 25 November 2014 which was followed by the VBA desktop audit,
- the Grenfell Tower Fire on 14 June 2017 which was followed by much more significant state based and federal government review and action,
- and the Neo200 fire on 4 February 2019, which was followed by the BMF agreeing in principle to a national ban on unsafe use of combustible ACP in new construction, subject to further analysis and which has not yet been implemented.

Table 9, below, provides a summary review of the current (as of 1/11/2019) Australian Federal and State based bans, ministerial guidelines and the like acting to limit the use of combustible ACP. It also provides a review of the cladding audits and other inquiries.

The following discussion is provided based on this review:

- NSW, Queensland, Victoria and Western Australia have already introduced bans, ministerial guidelines or other state-based regulation which act to limit the availability or use of combustible ACP. There are some inconsistencies with the details of these state-based bans/guidelines including:
    - PE content criteria of more than or equal to 30%
    - Application to just Class 2-9 Type A and B construction, or other classes and types of construction.
- Existing state-based ACP bans, ministerial guidelines or other regulations essentially do either or both of the following:
    - Re-in force/re-state NCC BCA 2019 Vol 1 DTS requirements which already prohibit the use of combustible cladding on external walls for Type A and B construction. An exception is the QLD ACP ban, which came into effect Oct 2019, which limits ACP use beyond NCC BCA 2019 Vol 1 DTS requirements as it bans more than 30% PE from external walls applicable to all classes and types of construction including Type C and Class 1;

      and/or
    - Imposes restrictions on the types of materials that are permissible for performance-based solutions. For example, bans act to exclude more than30 %PE ACP use via performance-based solutions or (in the case of Western Australia) requires NCC BCA 2019 Vol 1 CV3 to be applied and no other form of performance-based assessment is accepted.
- ACP bans, In-practice, primarily act to prevent use of banned materials on new construction or refurbishments. They do not generally automatically require removal/replacement of banned materials from existing buildings. In some cases the bans may legislate or facilitate identification of existing buildings with ACP and determination of any remedial action required. For example in the case of NSW, existing buildings identified to have banned ACP are issued an “affected building notice” and relevant Authorities then determine if any further remedial action is required.
- ACP bans act to prohibit or limit use for combustible ACP types which are already non-compliant under DTS requirements for Type A and B construction.

- Based on the Victorian statewide cladding audit it is evident that where ACP-PE has been applied to existing Type A and B construction, often no DTS non-compliance has been identified or performance solutions provided in building approval documentation. The Shergold-Weir report (2018) identifies the root causes which have led to non-compliant ACP use proliferation. ACP bans do not act to rectify these root causes which could potentially lead to future similar problems with non-compliant use of other products.
- While the 2017 Interim Senate report on non-conforming building products "Aluminium composite cladding", recommended a ban on PE ACP, subsequent reports such subsequent reports such as the Shergold-Weir report (2018) and the final Senate report on non-conforming building products (2018) have not directly recommended a ban on ACP but have made numerous recommendations focused on rectification or elimination of root causes which have led to proliferation of non-compliant building product use. These focus on:
    - Registration and training of practitioners.
    - Integrity of private building surveyors.
    - Role and responsibilities of regulators and fire authorities.
    - Adequacy, collection, sharing and post construction information management of building design, construction and approval documents.
    - Inspection regimes.
    - Addressing product safety via establishment of a compulsory product certification system for high risk building products.
    - National uniformity of approach to the above items administered by different states and jurisdictions
- The BMF is considering recommendations relating to establishment of a compulsory product certification system for high risk building products. However, such a system has not been enacted and no detailed framework for such a system has been released at this time.
- ACP bans, guidelines or regulations generally focus on restrictions based on PE content (mass%). This does not capture all other combustible polymers that may potentially be used in ACP. In order to capture all types of potentially combustible core, it may be more sensible to state such restrictions based on filler content (mass %) or on Gross heat of combustion (kJ/m^3).
- However, stating restrictions based on filler content (mass %) does not capture the difference between "inert" fillers such as talc and "active fire retardant" fillers such as Magnesium hydroxide or Aluminium hydroxide and the impact that the ratio of these components may have on overall reaction to fire.
- ACP bans, guidelines and the like recently introduced to Australia apply core PE content (mass%) as the criteria for restriction of new ACP use. However, they do not clarify the test methods or measurement accuracy to be applied to determine PE content. A range of material characterisation methods typically applied to ACP cores are reviewed in Section 6. These methods are not defined by specific test standards to the same degree as existing small-scale and full-scale reaction to fire test. Currently different laboratories apply different material characterisation test methods which may result in some variation of accuracy.
- Material characterisation tests to determine composition of ACP cores were introduced in Australia as a means of cost-effectively determining the type of ACP core installed to existing buildings (due to poor or unavailable construction records). For existing buildings this provides a practical way to roughly indicate the intrinsic fire risk of installed ACP via the ICA risk protocol. The ICA ACP PE content categories are very roughly (but not directly) aligned with EN13501 classifications.
- Assessment of core composition should be considered as only an approximate indicator of likely small-scale reaction to fire tests. Small-scale reaction to fire test should only be considered as

rough indicators (with significant limitations) of full-scale façade system performance. Testing of core composition could be considered further removed from indication of full-scale fire performance compare to small scale reaction to fire tests.

- CSIRO does not recommend any reduction of the existing NCC BCA DTS external wall requirements for Type A and B construction from the current non-combustibility requirements, as these are suitably conservative. CSIRO also does not suggest or recommend that new NCC BCA DTS small scale reaction to fire test methods are required to regulate combustible ACP. However based on the above, If ACP bans are to be introduced, then it may be more sensible to either align the ban criteria with existing NCC BCA DTS requirements, or at minimum, apply the established small-scale reaction to fire tests (such as AS1530.1, EN13501 classifications or others) to impose any bans or revised regulations for new ACP cores in preference to measurement of core composition.
- Bans which do not align directly with NCC BCA DTS requirements has potential to result in some level of confusion for industry practitioners and broader society. Banning a group of products also implies acceptance of products not falling within the ban scope. ACP products not banned by the existing state based bans may still fail to meet BCA DtS Non-combustibility requirements for Type A and B construction and are not compliant without an adequate performance based solution. Any such confusion may impact on section of ACP products for new buildings and rectification of existing buildings where combustible cladding is being replaced.

Table 9. Review of Bans, ministerial guidelines and the like acting to limit the use of combustible ACP and Cladding audits or inquiries around Australia as of 1/11/2019

Jurisdiction	Bans, ministerial guidelines and the like acting to limit the use of combustible ACP	Cladding Audits or other inquiries
Federal	In summary: • There have been federal government reports which make recommendations ranging from bans on PE ACP to compulsory certification • The BMF has agreed (in principle) to a ban on unsafe use of combustible ACP in new construction and a national framework to address the issues identified in the Shergold-Weir report. • No national ban or compulsory national certification is currently in place. • The NCC BCA Vol 1 has been revised to clarify and address reaction to fire requirements relating to external walls. • A Standards Australia technical specification for permanent labelling of new ACP products has been published 12 March 2018 – NCC BCA Vol 1 2016 Amendment 1 adopted out of cycle. Changes included adoption of CV3 referencing AS 5113, clarification of requirements relating to external wall cladding and attachments (Particularly Clause C1.9, C1.14 and Spec 1.1 Clause 2.4), revised NCC BCA evidence of suitability provisions and increased stringency for sprinkler protection of balconies through referencing revised AS 2118. 8 February 2019 – BMF met agreed support "*in principle to a national ban on the unsafe use of combustible ACPs in new construction, subject to a cost/benefit analysis being undertaken on the proposed ban, including impacts on the supply chain, potential impacts on the building industry, any unintended consequences, and a proposed timeline for implementation*".[21] No National Ban has been implemented at this time. 1 May 2019 – NCC BCA 2019 adopted which provides some further minor revisions relating to reaction to fire performance of external walls including permitting combustible sarking (with thickness <1 mm and flammability index of 5 or less) where combustible external walls are required. 18 July 2019 – BMF met and agreed "*All jurisdictions support a national framework to address the issues identified in the Shergold Weir Building*	6 September 2017 – Interim Senate report on non-conforming building products "Aluminium composite cladding"[23] put forward eight recommendations ((see Appendix D) including "*The committee recommends the Australian government implement a total ban on the importation, sale and use of Polyethylene core aluminium composite panels as a matter of urgency*" 22 February 2018 – Shergold-Weir report[24] delivered to BMF contained 24 recommendations for building system improvements in Australian states and territories (see Appendix D). 4 December 2018 - – Final Senate report on non-conforming building products[25] includes thirteen recommendations (see Appendix D) around national consistency and regulation, better consultative and reporting mechanisms and broader protection. Many of the recommendation re-enforce the recommendations of the Shergold-weir report.

	Confidence Report To achieve this an implementation team will be established, for a period of time, as part of the Australian Building Codes Board. The implementation team will be tasked with developing and publicly reporting on a national framework for the consistent implementation of recommendations of the Shergold Weir Building Confidence report, as well as the design, construction and certification of complex buildings. Industry are invited to contribute to the development of the framework through in-kind secondments to the implementation team. The national framework will be responsive to the most efficient mechanism to achieve the desired outcome and will result in amendments to the National Construction Code (NCC) and/or the development of other guidance as required. Adoption of the framework and ultimate implementation of the Building Confidence report recommendations will remain the responsibility of the state and territory governments."[22] On 10 August 2019 the BMF met and agreed that an Australian standard for the labelling of ACP should be developed. In February 2019 the BMF agreed upon development of a lower consensus technical specification in place of an Australian Standard to provide a more rapid response. On 23 September 2019 Standards Australia published SA TS 5344:2019 Technical Specification for permanent labelling of ACP. This only affects new ACP products.	
Victoria	Ministers Guideline MG-14[26] came into effect from 22 March 2018. MG-14 identifies the following as prescribed combustible products: • ACP having a core or lamina that is comprised of ≥ 30% PE by mass • EPS used in an external insulation and finish (rendered) system MG-14 prohibits a relevant building surveyor from issuing a building permit in relation to a building of Type A or B Construction which includes the installation of a Prescribed Combustible Product as part of an External Wall (including as an attachment), unless the application for the building permit includes a determination of the Building Appeals Board that the installation of the Prescribed Combustible Product in relation to that application complies with the Act and Regulations	April 2015 – VBA commenced a limited investigation of non-compliant use of ACP in Melbourne CBD and inner urban municipalities 3 July2017 – Victorian cladding task force established August 2017 – 30 June 2018 – Victorian cladding taskforce pilot audit undertaken November 2017 – Victorian Cladding taskforce interim report[6] released December 2017- December 2018 – Government building audit completed, assessment and rectification ongoing. December 2017 – VBA led Victorian State-wide Cladding Audit commenced. Phase 1 priority list completed 30 June 2018. Phase 2 Audit is ongoing. Victorian State-wide cladding audit included detailed building inspections and risk assessment via expert Advisory Reference Panel (ARP) reviews for buildings identified to have combustible cladding. July 2019 – Victorian cladding task force final report[7] released stating combined results of above audits to date. Summary audit results as of July2019: <u>Private Buildings</u> • Audit limited to Class 2, 3 and 9 Type A and B construction built after March 1997 • Total buildings inspected = 2227

		• Total buildings assessed by ARP = 1198 • Total buildings (of buildings inspected) found to have combustible cladding = 1068 • Number of Buildings determined by ARP by risk category • Extreme = 72 (7%) • High = 409 (38%) • Moderate = 388 (36%) • Low = 200 (19%) Government Buildings • Desktop review of ~4700 buildings to identify those likely to have combustible cladding, of these 384 buildings were inspected and 294 were assessed by expert panel • Number of buildings determined by expert panel by risk category: • Extreme =0 (0%) • High = 89 (30%) • Moderate = 107 (37%) • Low = 98 (33%) 2018-19 - Victorian Government provided $20.5 million for the rectification of 16 school buildings and 7 hospitals (work ongoing). 2019-20 Budget provides $150.3 million for the rectification of State-owned buildings. DELWP is leading this process which is ongoing 16 July 2019 Vic government announced $600 Million funding to rectify private buildings over 5 years. A new state gov agency, Cladding Safety Victoria was established to prioritise and oversee rectification development, approval, funding and completion of cladding rectification works
New South Wales	Commissioner building product use ban relating to ACP came into effect from 15 August 2018[27]. ACP with a core comprised of > 30% PE by mass has been banned for use in any external cladding, external wall, external insulation or rendered finish in buildings of Type A or B construction. Non-compliance can result in fines of up to $1.1 million for a corporation and $220,000 for an individual. There are two exceptions to this ban:	From July 2017 desktop review/data analysis audits of 185,00 building records was undertaken to identify buildings across NSW that may have combustible cladding installed. From July 2017 Fire & Rescue NSW (FRNSW) has conducted inspections of buildings identified likely to have combustible cladding with further review/assessment provided by NSW cladding task force. 22 October 2018 – new regulations commenced which require owners of Class 2, 3 and 9 buildings of 2 or more stories which have combustible cladding to register the building with NSW government via a cladding registration portal and provide details of the building and the

	• The product is tested in accordance with AS 1530.1 and is not deemed combustible • The product is tested in accordance with AS 5113 and successfully meets the requirements for both EW and BB classifications AS 1530.1 or AS 5113 test results relied upon to accept a building product that is otherwise from the ban must: • be dated on or after 1 July 2017; • be produced by an Accredited Testing Laboratory; and • describe the methods and conditions of the test; • describe the form of construction of the tested building product or prototype wall assembly or facade. The above ban primarily applies to new construction and rectification of existing buildings via removal of combustible cladding. Existing buildings identified to have banned ACP are issued an “affected building notice” and relevant Authorities then determine if any further remedial action is required.	cladding. For buildings occupied before 22 October 2018, the deadline for registration is 22 February 2019. Owners of new buildings will be required to register their building within four months of the building first being occupied. Penalties apply for failure to comply. NSW Cladding taskforce update as of 24 July 2019[28] • 4019 private buildings identified requiring assessment for potential combustible cladding. FRNSW has inspected all. • 3471 of these have been assessed as “not a risk form cladding” or “having cladding that does not pose significant fire safety risk” • 629 buildings initially assessed as requiring further assessment due to cladding quantity/location/arrangement. 76 of these have now been cleared. 553 remaining buildings still undergoing assessment or rectification. 154 of these are residential high rise. • All government buildings reviewed. Out of “thousands”, 34 had cladding requiring investigation and remediation. Half of these have been rectified and remaining 17 are undergoing works or planning.
Queensland	22 September 2017 the Queensland Government introduced a ban on the use of any polyethylene (PE) core cladding on government constructions. 1 November 2017 - legislation commenced addressing non-conforming building products through the Building and Construction Legislation (Non-conforming Building Products – Chain of Responsibility and Other Matters) Amendment Act 2017. This establishes duties for building products supply chain participants and give the QBCC expanded powers to investigate and rectify non-conforming building products. Queensland Development Code Part 2.5 – Use of external cladding (QDC MP2.5) came into effect from 18 October 2019. This imposes the following bans: • ACP > 30 % PE core by mass are not permitted to be used on any building in any external cladding, external insulation or façade. (Note that this includes all building classes and all Types of construction) • Expanded polystyrene product is not permitted to be used on a Class 2-9 building of Type A or B construction in any external wall insulation and finish (rendered) system – including as an attachment. The above ban applies to new construction and does not apply to rectification of existing buildings involving performance solutions for retaining cladding	On 30 June 2017, the Queensland Government established an Audit Taskforce to conduct a targeted investigation into buildings using ACP cladding and other possible combustible products. The Taskforce includes representatives from the Department of Housing and Public Works, Queensland Fire and Emergency Services and the Queensland Building and Construction Commission. The buildings built between 1 January 1994 – 1 October 2018 that are registered by buildings are being used as part of the Audit. This process is ongoing, with all registered buildings required to complete the process on the Safer Buildings website by the 3 May 2021[29]. On 17 May 2018, the Audit taskforce status report[30] was released. As of this date: • 879 government buildings were referred to taskforce for detailed investigation and of these 71 building have been identified with potential non-compliant combustible ACP. This included the Princess Alexandra Hospital. • No details were provided for private buildings other than around 12,000 buildings have been identified to require review and it is expected that ~ 10% of these will require detailed assessment. No more recent audit results appear to be published on Queensland government websites at this time. On 1 October 2018 the Queensland government introduced regulation (QLD Building Regulation 2006 Part 4A) requiring owners of buildings of Class 2-9, and Type A or B construction, that were built or had cladding altered between 1 January 1994- 1 October 2018

		to register their building and complete a combustible cladding checklist via the "Safer Buildings" website. This requires owners (and their consultants) to review exiting combustible external wall materials and determine any rectification needed. It is noted that QLD Building Regulation 2006 Part 4A defines combustible cladding as cladding that is deemed to be combustible when tested to AS 1530.1 or cladding that is not mentioned in BCA Clause C1.9(e)(i), (ii), (iii), (iv) or (v). It is noted that this definition would consider bonded laminated materials (complying with C1.9(e)(vi)) to be combustible cladding requiring further assessment.
South Australia	Currently no Bans or similar appear to be in place for ACP are in place within South Australia	Department of Planning Transport and Infrastructure is leading a building audit aimed at identifying aluminium composite panel cladding in collaboration with councils, Metropolitan Fire Service and Country Fire Service. A cladding audit Interim report was released on 10/10/2019[31] which states the following results • Public buildings – 17,000 public assets considered, of these 126 buildings were identified requiring further investigation. Of these 52 were found to incorporate ACP. Of these 2 buildings were assessed High risk, 39 buildings were assessed Moderate risk and 11 buildings were assessed low risk. • Private buildings – through council review 172 residential and assembly buildings were identified requiring further review. Of these 124 buildings were confirmed to have ACP with 96 (77%) assessed to be low or moderate risk, 21 (17%) assessed as high risk and 7 (6%) assessed as extreme risk. At present there is no specific legislation which clarifies an assessment or rectification process for buildings identified to be impacted by combustible external walls or attachments. "problem" buildings from the above audit are understood to be "handed over" to a fire safety committee for the relevant region and dealt with on an Ad-hoc basis.
Western Australia	Western Australian *Building Regulations 2012* were amended to include new regulation 31HA "Applicable building standards for non-combustible external walls" which came into effect on 5 October 2018. This prevents performance solutions for combustible external walls other than those verified in accordance with CV3. This only applies to new construction and not remedial work to existing buildings. This permits that the AS 5113 debris criteria do not need to be complied with if it can be shown that, in the event of a fire in the external walls, the debris — (a) will not prevent the safe evacuation of the building's occupants; and (b) will not pose a risk to an officer or member of a permanent fire brigade as defined in the Fire Brigades Act 1942 section 4(1).	The Department of Mines, Industry Regulation and Safety (DMIRS) is co-ordinating Western Australia State-wide cladding Audit and issues fortnightly status update reports[32]. As of 17 October 2019: • Public building audit (limited to buildings constructed or refurbished after 2000, 3 stories or taller and classes 2, 3, 4 and 9). Number of buildings reviewed = 1914, number of buildings requiring detailed risk assessment = 130. Number of buildings concluded to require remedial action = 22 • Private buildings (limited to buildings constructed or refurbished between 1 January 2001 and 30 June 2017, 3 stories or taller and classes 2, 3, 4 and 9). Number of buildings reviewed = 1795, Number of buildings found to have cladding and preliminary risk assessment completed = 475, Number of buildings which required further detailed risk assessment = 258. Number of buildings where risk assessed to be > Low and referred to permit authorities for further action = 52.

Tasmania	Currently no Bans or similar appear to be in place for ACP are in place within Tasmania. The Tasmanian Aluminium Composite panel audit summary report was completed in January 2018. An outcome stated in this report is that the Director of Building Control (Tasmania) intends to "Restrict the use of ACP with a PE core in Tasmania via the Product Accreditation processes in the *Building Act 2016*". However, the current Tasmanian *Building Act 2016* (accessed 31 October 2019) does not include any restrictions specific to the use of ACP with PE core.	The Tasmanian Aluminium Composite panel audit summary report was release on 19 January 2018[33]. 43 buildings were identified where ACP was used. Of these, 42 buildings were assessed to be low risk. One building, Launceston General Hospital, was assessed to be high risk.
Australian Capital Territory	Currently no Bans or similar appear to be in place for ACP	The ACT Government is carrying out a building cladding review to identify, risk assess and advise on remediation or risk reduction it is summarised at the following website https://www.planning.act.gov.au/build-buy-renovate/reviews-and-reforms/building-cladding-review It is understood that there is cladding audit task force and ACT Fire & Rescue identify problem buildings to the task force. However as of 1/11/2019 no results or findings appear to have been released. At present there is no specific legislation which clarifies an assessment or rectification process for buildings identified to be impacted by combustible external walls or attachments.
Northern Territory	Currently no Bans or similar appear to be in place for ACP	As of 1/11/2019 no details of a building cladding audit for NT were found.

5 Reaction to fire tests applicable to ACP

A detailed summary of reaction to fire tests applicable to ACP is provided in Appendix C of this report.

Reaction to fire tests can broadly be grouped into the following categories defined as:

- **Small-scale tests** – fire tests on small test specimens which typically consist of single materials or assemblies of materials which do not directly represent products or systems in actual end use configurations. Small scale tests typically only measure limited (and not all) aspects of a specimen's reaction to fire behaviour under a specific set of test exposure conditions. Test exposure conditions often have a reduced severity (such as radiant heat exposure only without direct flame immersion) and do not directly represent or correlate to possible real fire scenarios. Reduced severity, limited testing parameters and exposure conditions which do not fully reflect possible end-use conditions makes it very difficult to extrapolate small-scale test results to predict real/large scale outcomes. Small scale tests are the least expensive tests and are typically used in conjunction with acceptance criteria to regulate or benchmark acceptable fire performance of materials without directly predicting real fire scenario performance.
- **Room corner fire tests** – these are intermediate/large scale tests typically applied to assess internal wall and ceiling lining performance and typically not directly applicable to external walls. An example is the AS/ISO 9705 test. Depending on interpretation of the BCA Group Number 3 might be considered to apply to external walls, particularly for Type C construction, where other non-combustible requirements do not apply.
- **Intermediate scale tests** - end-use assembly type fire test that is of a reduced height and width, offering a limited area to evaluate extent of fire spread. Due to its reduced size, intermediate-scale tests generally apply a smaller ignition source than their full-scale counterparts. They often provide a measure of reaction to fire limited to localised fire growth/fire spread for end use assemblies/configurations of materials in response to small to medium fire exposure scenarios that typically involve a limited area of flame immersion. Intermediate scale tests are more expensive than small scale tests but significantly less expensive than full scale tests. They are less typically used for regulation of materials but are used for experimental investigations. For the purposes of external wall vertical fire spread testing, intermediate scale tests could be defined as having at least one of the following characteristics:
    - Ignition source of between 5kW-350kW
    - Specimen exposure surface to be ≤ 4m in height and ≤ 2 in width.
- **Full scale (or Large scale) tests** –fire tests on complete systems of products/assemblies in sizes and configurations representing end-use. The extent of the tested system must be large enough to enable measurement or observation of fire spread beyond the area of application of the ignition source. The ignition source applied is typically large representing a large area of flame immersion upon the tested system (or other type of large scale fire source such as radiant heat over a significant surface area) and may range from large localised fires of the order of 300 kW up to post flashover compartment fires. A strength of full-scale tests is that they directly indicate whole system performance and interaction between various building products and the arrangement when exposed to a large ignition source. Full scale tests are typically used to regulate systems where there is a lack of confidence in the ability of small-scale testing to be adequate for this task. Full-scale tests are also used for experimental research. Full-scale tests are expensive, and results apply to the system tested. Extrapolation of results to predict performance of significant variations to tested systems is difficult and challenging.

It is noted that the fire research and testing community does not appear to have one universally accepted set of definitions for small, intermediate and full or large-scale tests.

For readers not familiar with these tests, a detailed description of most reaction to fire tests applicable to ACP both in Australis and Internationally is provided in Appendix C.

5.1 Australia

Appendix C, Table 42 provides a detailed summary of all the reaction to fire tests applicable to ACP that are referenced in the NCC BCA 2019, including their test conditions and any known limitations. The following is a brief summary.

Table 10. Summary of reaction to fire tests applicable to ACP referenced in the NCC BCA 2019

Test method/standard	Scale	Test exposure	Application
AS 1530.1 Combustibility test for materials	Small	small specimens (45 mm diameter, 50 mm high cylindrical) exposed to 750 °C within conical tube furnace	Used to determine if a material is non-combustible as defined by the BCA
AS 5113 – external wall classification (Australian labs apply BS 8414 with AS5113 requirements and criteria)	Full	Façade specimen minimum 9 m high with 2.6 m wide main wall and 1.5 m wide wing wall. Timber crib located in combustion chamber at base. Timber crib is 1.5 m wide x 1 m deep x 1 m high having a nominal heat output of 4500 MJ over 30 minutes and a peak HRR of 3±0.5 MW	Referenced by BCA CV3 as part of verification method for external wall fire spread performance. Applies BS 8414 full scale façade test with test criteria that are different/more stringent than BR135
AS 5113 – Building to Building fire spread classification	Full	Façade specimen 3 m x 3 m exposed to radian heat flux levels ranging from 10-80 kW/m² with a small pilot ignition flame applied	Not referenced by BCA DTS or CV1, CV2 or CV3. Predominantly radiant heat exposure test to determine fire spread between buildings in response to various exposure heat fluxes.
AS 1530.2 – Test for flammability of materials	Small	Small specimens 535 mm long by 75 mm wide. Small flame from 0.1 mL absolute alcohol applied to base of specimen	Not applicable directly to ACP. Applied to Sarking which may be used in conjunction with ACP
AS 1530.3 - Simultaneous determination of ignitability, flame propagation, heat release and smoke release	Small	450 × 600 mm specimen mounted vertically. Exposed to radiant heat flux incrementally increased from ~2.5 kW/m² up to a maximum of 25 kW/m² with small pilot ignition flame applied	Applied by BCA DTS 2019 Vol 1 Clause C1.9 (e) for prefinished metal sheeting and Bonded Laminated materials (in conjunction with AS 1530.1 Applied by BCA DTS 2019 Vol 1 Clause C1.10 for other internal materials such as insulation (which may be used in conjunction with ACP)
AS 3837 ISO 5660.1– using oxygen consumption calorimeter (cone calorimeter)	Small	small 100 x 100 mm specimen typically mounted horizontally. Exposed to radiant heat (adjustable from 0-100 kW/m2) in presence of spark igniter. A heat flux of 50 kW/m² is used for material group number predictions	Applied by BCA DTS 2019 Vol 1 Clause C1.10 and AS 5637.1 for to predict material group number and smoke production related measurements for wall and ceiling linings. AS 5637.1 requires a correlation to AS ISO 9705 to be demonstrated, and requires the combination of all layers of a material and also each separate layer tested individually, with the worst result being applied. AS 5637.1 identifies that materials with a reflective surface (aluminium) or which melt or shrink away from a heat source (PE) are not suitable for group number determination based on cone calorimeter. There fore Cone calorimeter should not be used for determination of material group number for ACP and AS ISO 9705 test should be used instead.

			Also applied for non DTS testing/research to determine ignition and heat release rate per unit areas properties for exposed core layers.
AS ISO 9705	Full/ Intermediate	Wall and ceiling materials installed to interior of a test room 2.4 m high x 2.4 m wide x 3.6 m deep. A propane gas burner is applied to one internal corner of the room at 100 kW/m2 for 10 minute and then 300 kW/m2 for another 10 minute period	Primary test used in conjunction with AS 5637.1 to determine the group number for internal wall and ceiling linings.

5.2 International

5.2.1 EN 13501 EUROPEAN CLASSIFICATION TESTS

EN 13501-1[34] is used to classify reaction to fire of construction products throughout Europe based on a range of small scale tests. Although it was originally developed for internal materials/linings it is also applied by UK and Europe to regulate external wall materials. Materials are classified as A1, A2, B,C, D, E and F with A1 being the highest performance and F being the lowest performance

Table 11. EN 13501-1 reaction to fire classification summary.

Class	Definition	Comment
A1	Non- Combustible Requires testing to both EN ISO 1182 combustibility test and EN ISO 1716 bomb calorimeter (PCS ≤ 1.4-2.0 MJ/kg)	EN ISO 1182 is similar to AS 1530.1 combustibility test but EN ISO 1182 is slightly more stringent due to temperature increase limit of 30 °C and mass loss criteria. A1 classification also requires bomb calorimeter testing which is not required in NCC BCA or AS 1530.1 for a materials to be deemed not combustible
A2	Low combustibility: Requires either: • EN ISO 1182 combustibility test with temperature limit increased to 50°C and sustained flaming time increased to 20 s OR • EN ISO 1716 bomb calorimeter (PCS ≤ 3.0-4.0 MJ/kg); and • EN13823 SBI Test - FIGRA ≤ 120 W/s, and LFS < edge of specimen, and THR_{600s} ≤ 7.5 MJ	Some A2 materials tested to EN ISO 1182 may comply with AS 1530.1 non-combustible criteria, and A2 Materials tested to EN ISO 1716 and EN13823 alone may not comply with AS 1530.1 non-combustible criteria as bomb calorimeter plus SBI test criteria is likely to be less stringent.
B	EN13823 SBI Test - FIGRA ≤ 120 W/s, and LFS < edge of specimen, and THR_{600s} ≤ 7.5 MJ; and prEN ISO 11925-2 small flame test Fs ≤ 150 mm within 60 s	Standard states "*Class B products are combustible, will not lead to a flashover situation but will contribute to a fully developed fire*". Whilst this is typically true for most Class B materials, Class B relies upon small scale tests and does not require ISO 9705 room corner fire testing. Therefore, flashover may be possible for some Class B materials.
C-E	EN13823 SBI Test plus prEN ISO 11925-2 small flame test with reducing criteria for C-E	Standard states "*Class C-E products may lead to flashover*" with time to flashover reducing with each classification
F	No testing	No performance determined

5.2.2 BS8414, ISO 13785 PART 2 AND NFPA 285 FULL SCALE FAÇADE TESTS

See Appendix C for full descriptions of these test methods.

The UK and some of Europe apply the BS8414 test in conjunction with BR135 test criteria. This is the same test method that is applied in Australia for AS 5113 however AS 5113 applies different and more stringent test criteria compared to BR135, and which requires some additional rear face thermocouples and debris measurements compared to BS8414 test in conjunction with BR135 test criteria. The UK based Loss Prevention Certification Board (LPCB) has also published LPS 1581 and LPS 1582 standards for certification of cladding for industry and insurers. These standards apply BS 8414 part 1 and part 2 test methods but specify additional test criteria including criteria for visual flaming, mechanical performance, burning debris and pool fires and glowing combustion which are more stringent than BR135 but different to AS 5113.

ISO 13785 Part 2 is not significantly used in practice around the world for regulatory testing. This is due in part to the impractically large fire enclosure and gas burner arrangement specified as the fire source. Despite this large enclosure and gas burner arrangement, a lower intensity/extent of fire exposure is presented to the external façade compared to BS 8414 due to the ventilation and flame immersion conditions at the opening at the base of the façade test rig.

NFPA 285 is applied for regulatory testing of external wall systems in the USA. However, it has limitations such as no inclusion of a wing wall with re-entrant corner and a lower severity of fire exposure presented to the external façade compared to BS8414.

A detailed summary and comparison table of international full-scale façade fire spread tests is provided in Appendix C.5.

5.2.3 USA BUILDING CODE TESTS.

USA has specific building code fire testing requirements for ACP (referred to as metal composite materials or MCM). See Appendix B for detailed summary of USA Building code requirements and see Appendix C for summary of USA Building code reference fire tests.

6 Material Characterisation testing for ACP

There is currently no Australian Standard for material characterisation testing of ACP. Different laboratories providing this service in Australia may apply a variety of different sampling, sample preparation, and laboratory test methods. The ICA website currently lists six Laboratories who have participated in ICA round robin testing and been identified to provide material characterisation testing (with various methods) with the level of confidence required by ICA (acceptance criteria and required accuracy are not published). Testing from these laboratories is typically client confidential.

The University of Queensland has published a material library of cladding materials and a supporting protocol for sample preparation and testing methodologies[3-5]. UQ are to be commended for publicly releasing a framework for characterisation testing of cladding materials. There have been limited other papers published on this topic[35, 36].

6.1 The purpose of Materials Characterisation testing for ACP

The purpose of material characterisation testing for ACP is either to:

- Determine the material composition of the core material; or
- Apply other small-scale reaction to fire tests such as the Bomb-Calorimeter that may be used to characterise the core material.

It is extremely important to note that the above testing does not directly characterise the fire risk associated with a cladding material.

Protocols or rankings such as the ICA protocol and the BRE ACP categories have been published which provide a rough ranking of fire risk based on the above testing, however these are simplistic categories based on a limited set of full-scale façade tests. Other fire safety factors and combinations of materials can influence the holistic fire risk related to a building’s façade.

These rankings/categories should be applied with caution by competent fire engineers or other suitable professionals with consideration of the above limitations.

6.2 Sampling of ACP for Materials characterisation tests

Samples will typically be taken from existing buildings.

The materials characterisation tests described below require relatively small samples (sample size varies with test method). To ensure that sufficient material is collected it is recommended by CSIRO that two 40-50mm diameter hole saw samples be collected from each location to be sampled. Samples must be clearly identified and chain of custody verified.

It is important to photograph and document the following at each sample location:

- Unique sample ID
- Sample location (large photos which give context of surrounding building features/location are best)
- Sample photos showing colours of both faces and core.

- Wall cavity materials including sarking, insulation and other materials at sample location
- ACP fixing method at sample location (taking samples close to supporting sub frame assists if possible)

The resulting holes in the cladding should be capped or filled with a suitable material to protect against water ingress.

Buildings may have a number of different ACP products installed in different areas. Whilst this will typically be indicated by different coloured facings, there have been examples of ACP products with the same coloured facing but different core materials being used on the same building.

Figure 16. ACP with same colour external facing but different cores used on same building (Photo by CSIRO)

The number of sample locations required to confirm the composition of cladding materials for an entire building requires careful consideration based on preliminary inspection by an expert. The Queensland Government has published a guideline for assessing buildings with combustible cladding[37] which states the following minimum requirements for cladding material sample collection.

Table 12. Queensland Government minimum requirements for cladding material sample collection[37]

Building Grouping	Sample Collection Requirement	Suggested Samples	Sample Range
Height 1-2 levels Floor area <2000m²	Lowest and highest points (low sample to be diagonally opposed to high sample point)	2 (minimum requirement)	2 to 6 samples
	Colour variations (are more than 20 panels of the same colour used?)	1 - 2 per colour variation	
	Cladding volume (is the use of cladding product/s extensive?)	1 extra if extensive	
	Staged construction work (if yes, collect samples from lowest and highest points)	2 per stage (minimum requirement)	
Height 3-9 levels Floor area >2000m² and <10,000m²	Lowest, mid and highest points (low sample to be diagonally opposed to high sample point)	3 (taken from 1-2 sides of building)	6 to 10 samples
	Colour variations (are more than 20 panels of the same colour used?)	1 - 2 per colour variation	
	Cladding volume (is the use of cladding product/s extensive?)	3 additional samples if extensive product use	
	Staged construction work (if yes, collect samples from lowest and highest points)	2 per stage (minimum requirement)	
Height 10 or more levels Floor area >10,000m²	Lowest, mid and highest points (low sample to be diagonally opposed to high sample point)	3 (taken from 2 sides of building)	10 to 15 samples
	Colour variations (are more than 20 panels of the same colour used?)	1 - 2 per colour variation	
	Cladding volume (is the use of cladding product/s extensive?)	3 additional samples if extensive product use	
	Staged construction work (if yes, collect samples from lowest and highest points)	2 per stage (minimum requirement)	

6.3 Types of Material Characterisation testing

6.3.1 ONSITE SCREENING

The following rudimentary onsite screening checks can be used to identify if an ACP core is likely to be close to 100 % ACP. If one or more of these screening checks identifies ACP to be highly likely to be 100 % ACP then it is reasonable to conservatively assume the material to be 100% PE core as this has the worst fire performance. However, in some cases stakeholders or Authorities may request further laboratory testing as confirmation.

For ACP cores with a significant mineral filler or other polymer content the following screening tests do not provide any reliable measure of the amount and type of mineral fillers or other polymers and Laboratory tests are definitively required to confirm and quantify mineral filler content.

Visual Inspection

ACP with close to 100% polyethylene (PE) core typically has a black coloured core, However, it is technically possible for PE to be produced pigmented in a wide range of colours including white and grey.

ACP with more than 50% mineral filler typically may have a core colour ranging from chalky grey to white (based on CSIRO materials characterisation test experience).

Density

LDPE has a density of 917 to 930 kg/m^3. HDPE has a density of 930 to 970 kg/m^3.

Aluminium Hydroxide and Magnesium Hydroxide both have densities of ~ 2400 kg/m^3. Calcium Carbonate has a density of 2710 kg/m^3. Talc has a density of 2760 kg/m^3.

Therefore, the density of ACP cores increases with mineral filler content. The relationship for core density and core mineral filler content is given in Equation 1 and Equation 2 below. This relationship is based on the following simplifying assumptions:

- The mineral filler and polymer types are pure and their densities are known (typically this is not the case as a variety of mineral types may be blended together and polymer formulation used can vary)
- The total volume of the mixed core is equal to the sum of the volumes of the unmixed components (where molecular bonding or reactions occur this is not always the case, for example when mixing most miscible liquids a volume compression occurs resulting in a final volume that is less than the sum of the volumes of the two unmixed liquids)

Equation 1. Core Density

$$\rho_{core} = \frac{100}{\left(\frac{C_{filler}}{\rho_{filler}}\right) + \left(\frac{100 - C_{filler}}{\rho_{PE}}\right)}$$

Equation 2. Core filler content (concentration) mass %

$$C_{filler} = 100 \times \frac{\rho_{filler}(\rho_{core} - \rho_{PE})}{\rho_{core}(\rho_{filler} - \rho_{PE})}$$

Where

C_{filler}= Core filler content (concentration) mass % (w/w%)

ρ_{core} = total core density (kg/m^3 or g/cm^3)

ρ_{filler} = mineral filler density (kg/m^3 or g/cm^3)

ρ_{PE} = density of PE (kg/m^3 or g/cm^3)

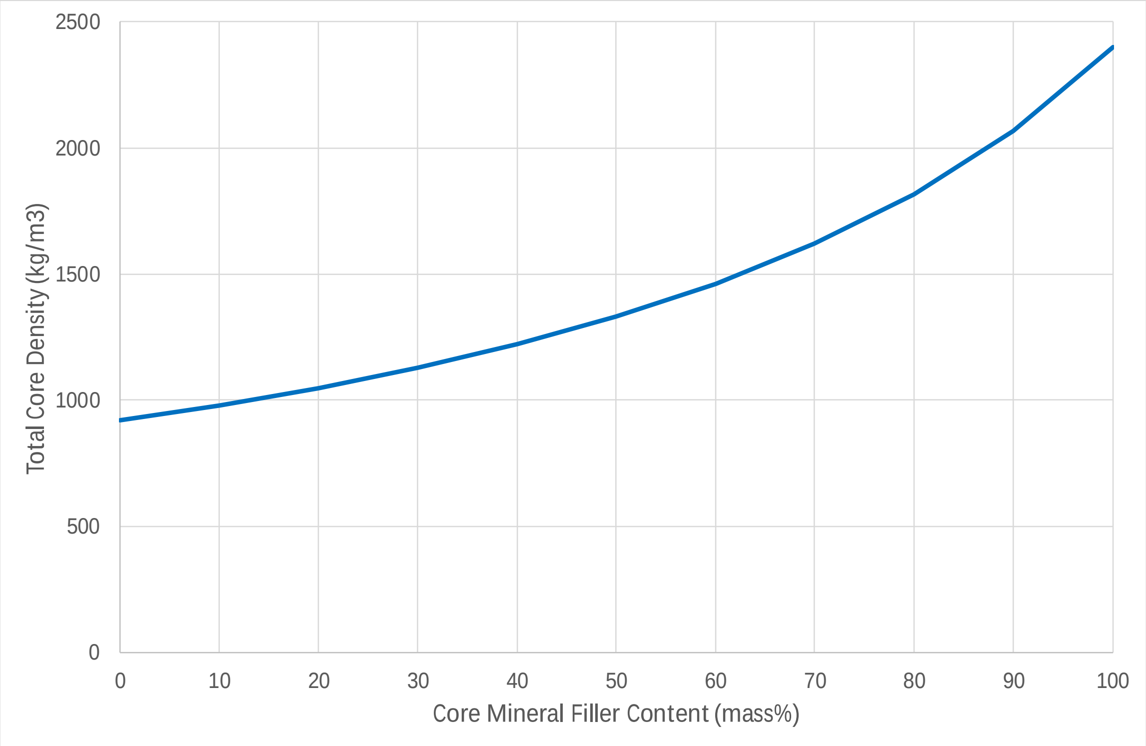


Figure 17. Increase in density of ACP core with increasing mineral content applying Equation 1 and assuming ρ_{PE} = 920 kg/m^3 and ρ_{filler} = 2400 kg/m^3.

Whilst density of core samples can be measured by weighing the sample mass and determining sample volume by liquid volume displacement or use of a pycnometer, this should not be relied upon for accurate determination of mineral filler content due to inaccuracies of density measurement for small samples and expected variability of filler and polymer types and densities

As the density of water is 1000 kg/m^3, close to 100% PE will typically float in water and cores with ~ 30% mineral filler or greater will typically sink in water and this could be used as a simple onsite preliminary screening test to determine if core could reasonably be assumed to be 100% PE (worst case).

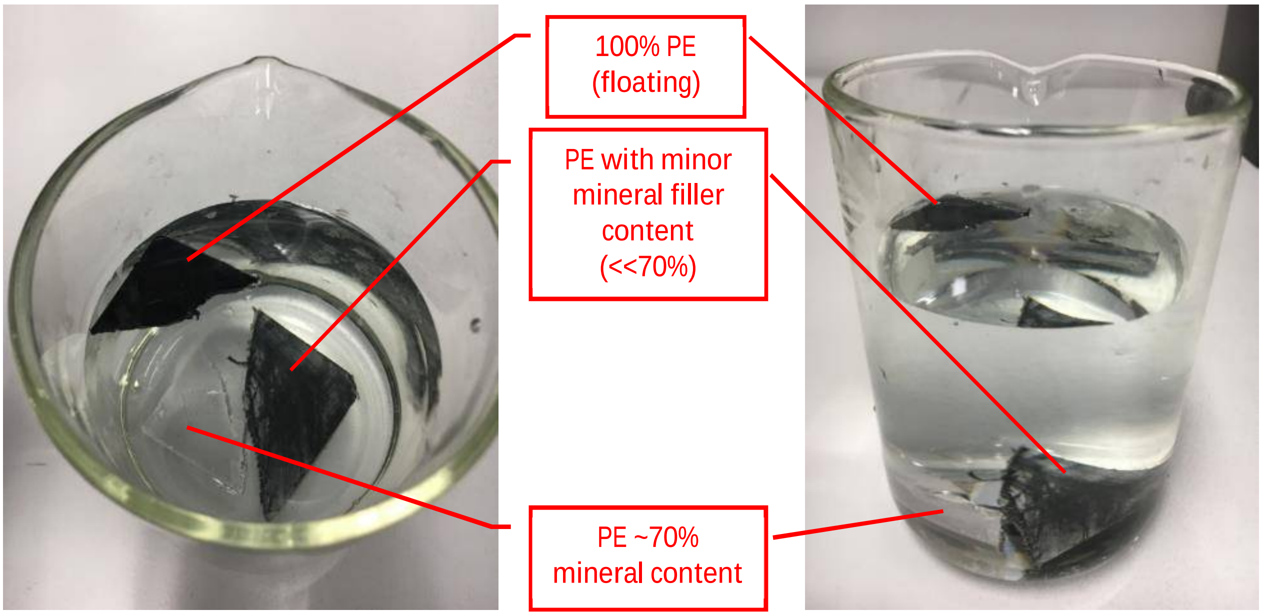


Figure 18. Buoyancy of three different types of ACP core in water (photos by CSIRO)

Small Flame

Application of a blowtorch or butane lighter flame to ACP core provides a rudimentary screening test.

- Close to 100% PE will ignite readily, melts and continues to burn with flaming droplets when the flame is removed. The heat effected area will be very molten/fluid when poked. Upon cooling the damaged area will form a smooth black PE surface with no sign of charring.
- PE with minor mineral filler content (significantly less than 70% mineral) will ignite and may continue to burn after flame is removed but does not form droplets. The heat effected area will be molten/tacky when poked. Upon cooling the damaged area forms a rough slightly charred surface
- FR ACP core with ~ 70% or more mineral filler does not sustain ignition when the flame is removed and forms a visible char layer. When the heat effected area is poked the char layer disintegrates and the core beneath may be slightly molten/soft.

The example small flame tests in the following photos were conducted on the same three ACP samples shown in the Buoyancy test in Figure 18.

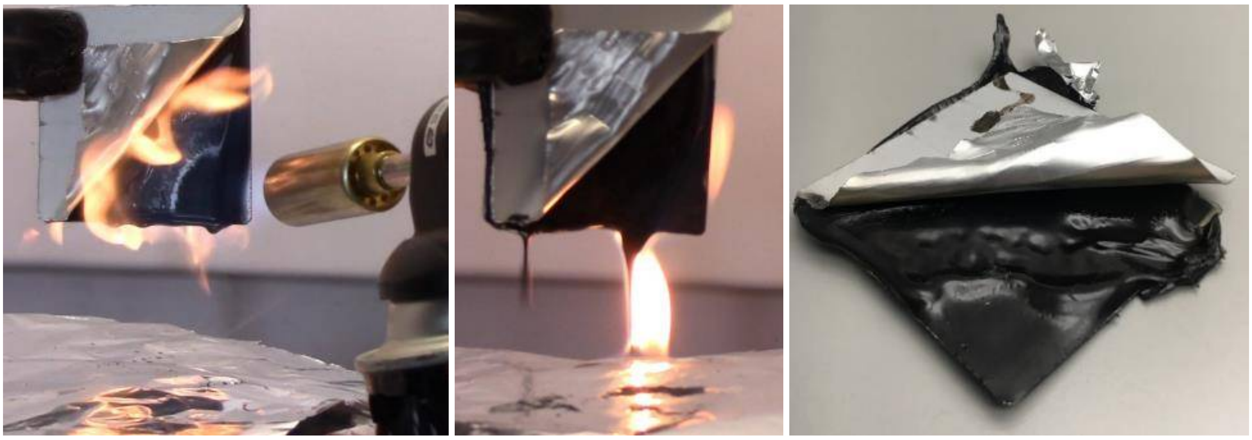


Figure 19. 100% PE ACP, Left -butane flame applied for 30 s, Centre – 20 s after butane flame removed, Right-damage (all photos by CSIRO)

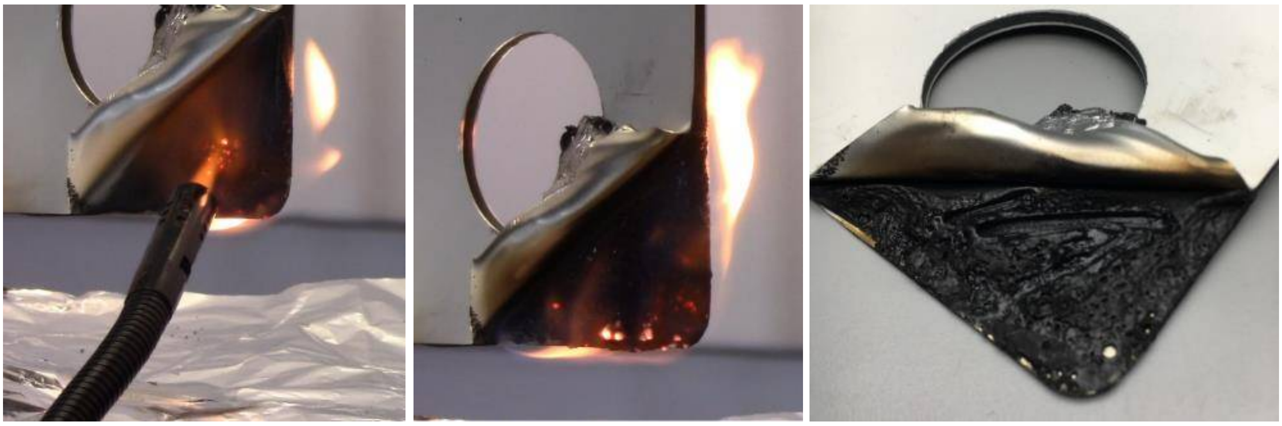


Figure 20 PE ACP with minor mineral filler content (not quantified but significantly < 70% mineral filler, Left -butane flame applied for 30 s, Centre – 20 s after butane flame removed, Right-damage – note core was probed post test to observe viscosity (all photos by CSIRO)

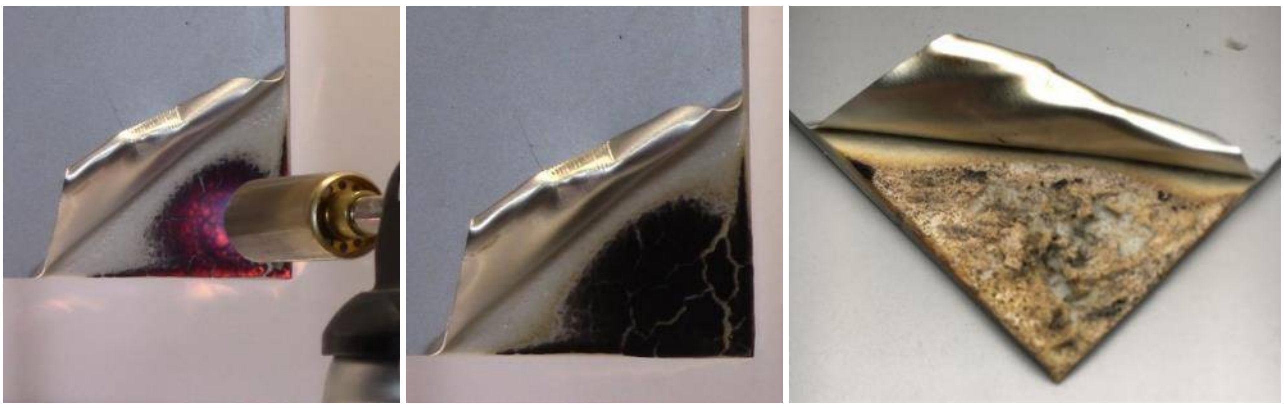


Figure 21 FR ACP with 70 mass% mineral content, Left -butane flame applied for 30 s, Centre – 20 s after butane flame removed, Right-damage – note core was probed post test to observe viscosity (all photos by CSIRO)

6.3.2 ASH CONTENT IN PLASTICS TESTING (GRAVIMETRY)

Ash content testing (ASTM D5630-13) is applied to conservatively indicate the mass content of mineral fillers in ACP cores. CSIRO also combines this with XRD analysis to more accurately calculate the polymer mass%. The basic principle is to burn/decompose the material at high temperature in a furnace and measure the ratio of the residual ash mass to the original sample mass. However as common mineral fillers used in ACP also partially decompose to produce water or CO_2 when heated this method conservatively underpredicts the filler mass content and should only be applied as a laboratory screening test to confirm if a material is close to 0% mineral filler or be applied in conjunction with another method such as XRD.

Small samples of ACP core (typically 2 g) and inert crucibles are pre dried, with samples being dried in an oven at 40-50 °C for a period of at least 2 hours. The dried sample and crucible are weighed prior to ashing. The sample is placed on a crucible and ignited and ashed by placing within a muffle furnace at 800-900 °C for a pre-defined period of 20 minutes (which may be increased to 2 hours to ensure compete ashing if needed). The crucible and ash sample are cooled to room temperature in a desiccator and the resulting ash and crucible mass is weighed. The ash mass % is calculated by the following equation.

$$Ash\ mass\% = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

Where

W_1 = mass of sample crucible (g)

W_2= mass of sample crucible plus mass of sample prior to ashing (g)

W_3= mass of sample crucible plus ashed mass of sample (g)

The Ash mass% is taken to indicate the mineral filler content (mass%).

ASTM D5630-13 states that this test method is limited to filler materials that are stable at 900 °C. It does not provide absolute filler content for aluminium hydroxide and magnesium hydroxide which decompose to release water vapour or other minerals such as calcium carbonate which decomposes to release carbon dioxide at temperatures less than 900 °C. CSIRO testing indicates that ACP cores with ~ 70% mineral filler result in an ash mass% of around 45% (variable dependant on mix of fillers used).

This method is suitable for a laboratory screening test to determine if the sample is close to 0% mineral filler. If a low ash mass% is measured (say less than 20 mass%) then the materials can conservatively be concluded to be ICA Category A (inert material 0-70 mass%).

If a significant ash mass% is measured (say more than20 mass%) then further testing is required to measure to more accurately measure and characterise mineral content. CSIRO combines this test with XRD analysis (which identifies and measures the amount of crystalline minerals in the material). Based on the XRD results CSIRO carries out calculations to compensate for the amount of mass that would be lost due to water vapour and CO_2 released by the identified minerals in the ashing test and therefore provide a more accurate measure of polymer mass% of the ACP sample.

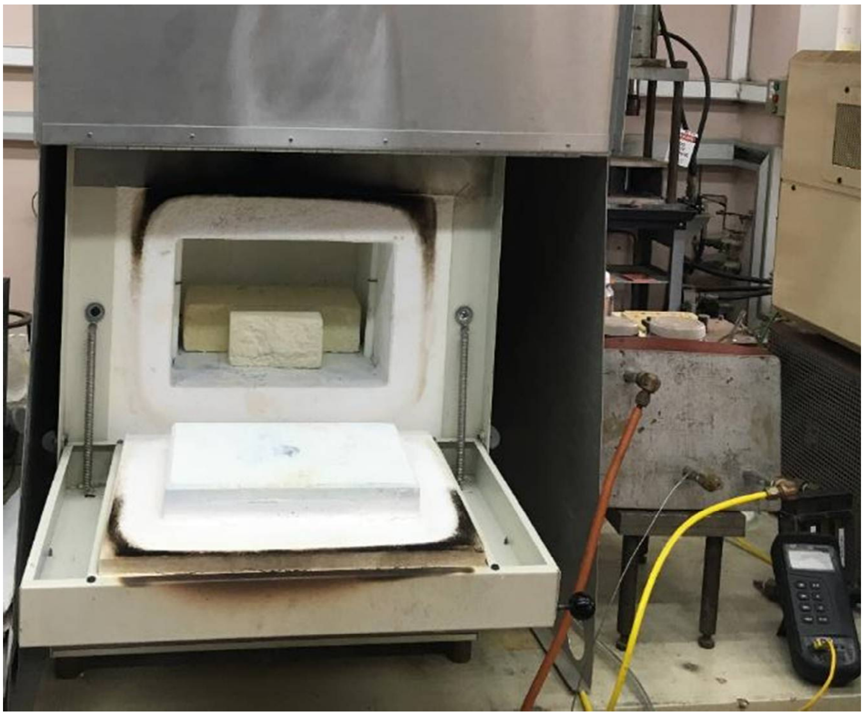


Figure 22. CSIRO's muffle furnace used for ash testing of ACP.

Advantages of this method are:

- Fast and low cost laboratory screening test to determine if samples very low filler content ICA Category A
- Minimal sample preparation
- Conservatively under predicts actual mineral content for ACP cores.
- Can be combined with XRD to provide more accurate prediction of polymer mass%.
- A 2gram sample is significantly (factor of 10) more than TGA method. A larger sample provides better averaging of the sample where there may be non-homogeneous variation and therefore reduces uncertainty.

Limitations of this method are:

- Not suitable for accurate measurement of mineral content which is required for cores which are close to ICA category B and higher unless combined with other methods such as XRD or XRF with FTIR
- Does not identify chemical components (polymer or mineral types) in a sample.

6.3.3 THERMOGRAVIMETRIC ANALYSIS (TGA) AND DIFFERENTIAL SCANNING CALORIMETRY (DSC)[38]

TGA (ISO 11358) measures mass change vs temperature. This is used to analyse the thermal decomposition of a material as a function of a steadily increasing temperature. Reactions where mass is lost such as pyrolysis and oxidation can be identified and may occur at different temperature ranges for different materials. The key measurements are mass, temperature and time.

Differential scanning calorimetry (ISO 11357) measures heat flow vs temperature. The basic principle is that the difference in the amount of heat required to increase the temperature of a specimen and a reference material (with a well-known heat capacity over the range of temperatures to be measured) is measured as a function of temperature. Both the specimen and reference material are maintained at approximately equal temperatures and the temperature is typically slowly increased over time at a typically linear rate (same as for TGA). This enables the identification of phase transitions such as glass transition temperature, crystallisation temperature and melting temperature. It enables identification of the temperature at which bonded water is released for mineral fire retardants and measurement of the amount of heat endothermically absorbed by the material in this process. It also enables the measurement of other fundamental properties such as heat of pyrolysis and specific heat capacity over a range of temperatures.

TGA and DSC are typically conducted simultaneously on the same specimen using a single instrument (simultaneous thermal analysis). This enables both measurements to be compared using the same specimen and temperature vs time profile.

TGA and DSC may be conducted under normal air atmosphere or inert nitrogen atmosphere and this will influence reactions such as oxidisation.

TGA results are plotted as mass vs temperature referred to as a TGA curve. DSC results are plotted as Heat flow vs Temperature referred to as a DSC curve.

Specimens tested in this method are very small and are typically in the range of 1-10 mg.

A typical temperature vs time profile is to heat specimen from close to ambient temperature to 800-1000°C at a rate of 10-20 °C/minute.

Advantages of TGA and DSC are

- Measurement of fundamental thermal properties and thermal degradation behaviour such as specific heat capacity, glass transition temperature, melting temperature, pyrolysis temperature range and heat of pyrolysis, oxidisation temperature ranges etc

Limitations:

- Although different materials can have different TGA and DSC curves there can be significant overlaps and similarities between corves for different materials. These curves should not be relied on for identification of chemical composition.
- Similar as for the ash content test, the TGA will measure the mass of residual ash and this could be used to roughly indicate mineral content or be combined with other methods such as XRD or XRF & FTIR to calculate a more accurate miner content. However, the specimen size is very small (milligrams). This small specimen size means that if minerals are not very homogenous within the material then the specimen will not be as representative a sample as for the ashing test.

Figure 23. CSIRO's TGA-DSC which has been used in past ACP analysis (but we now use mostly ashing test with XRD). Photo by CSIRO

6.3.4 ATTENUATED TOTAL REFLECTANCE FOURIER TRANSFORM INFRARED (ATR-FTIR) SPECTROMETRY[38, 39]

FTIR Spectrometry is applied to identify chemical components, both polymer or mineral types, in a sample. It does not quantify the amounts of each component. The basic principle relies on the fact that unique molecular vibrations for different molecules will absorb infrared light energy at different (often unique) parts of the infrared wavelength spectrum. By passing infrared light though a material and measuring the intensity of received infrared light at specific wavelengths over a wide spectral range, an infrared spectrum of absorption is measured, with peaks at specific wavelengths acting like a fingerprint to identify the molecules contained in a material.

Traditional FTIR spectrometry by passing and IR light beam directly through a sample requires problematic sample preparation for solid materials which must be not more than a few tens of microns thick (or else the light is too strongly absorbed).

ATR-FTIR enables easier sample preparation for solid samples. In this case the IR beam is passed through an optical crystal with a relatively thick solid sample in contact with one surface of the crystal. As the beam passes through the crystal it is reflected off the surface of the sample either single or multiple times before passing to the detector. This results in measurement of the IR spectrum of absorption over a depth of 0.5-5µ into the sample surface.

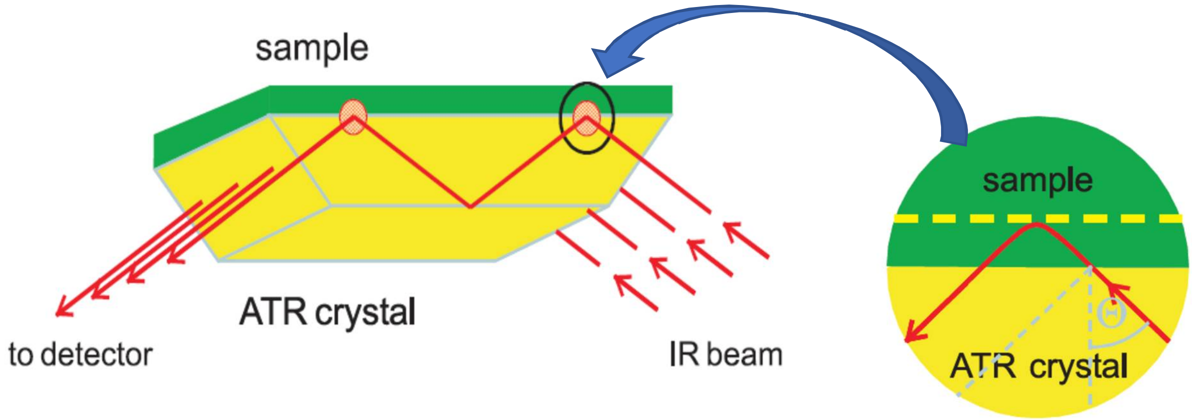


Figure 24. ATR-FTIR Principle[40]

ACP samples for this test are prepared by cutting them into thin layers and testing the internal cut side to avoid any contamination (such as adhesives etc) at the outer surface of the specimen. The ATR crystal used is typically a small ~2 mm diamond and the sample is mechanically clamped/pressed onto the crystal to ensure good optical contact.

Figure 25. CSIRO FTIR with Diamond ATR accessory which has been used in past ACP analysis (but we now use mostly ashing test with XRD). We continue to use ATR-FTIR for analysis of other insulation and cladding materials. (Photo by CSIRO)

Advantages of this method are:

- Identifies chemical components
- Relatively easy sample preparation
- Relatively fast test time.
- Highly effective for samples of simple composition (e.g. pure single materials or a limited mix of materials).
- Can provide a more detailed/confident identification of the polymer type compared to compared to XRD (for example identifying difference between PE and EVA).

Limitations of this method are:

- Does not measure quantities of components. Whilst FTIR can technically be used for quantitative analysis of concentrations of some samples (for example combustion gas analysis) based on magnitude of characteristic spectra peaks, it does not provide reliable quantitative analysis for ACP cores.
- Assumes material is a homogenous mixture as measurement is at surface of material. ATR FTIR measurement does not penetrate deep beyond the surface. This can be addressed by scanning multiple slices of material.
- For complex materials with multiple components identification can become difficult as some components may absorb in the same wavelength regions. In this case cross referencing with other test methods may be required.
- Sensitive to sample surface contamination.
- Method relies on analysis against a library of IR spectra for reference materials. Analysis can be affected by the quality of the library used. The reference spectra are influence by the configuration under which they were tested. For example, spectra recorded by reflection will often differ from spectra recorded by transmission.
- The method requires a high level of laboratory expertise.

6.3.5 X-RAY DIFFRACTION (XRD)[41]

XRD is applied to identify the types of crystalline materials in a sample and, once the types are known, the amount (in mass%) of each crystalline material can be quantified. The basic principle relies on unique X-ray diffraction patterns given by crystalline structures. Crystals are regular, unique arrays of atoms, and X-rays are waves of electromagnetic radiation. The array of atoms scatters incoming monochromatic X-rays waves. These scattered waves predominantly cancel each other out in most directions through destructive interference but add constructively in a few specific directions unique to the crystalline material. This process is called diffraction. X-rays are used as they have a wavelength that is the same order of magnitude as the spacing between atomic planes in crystalline materials.

X-ray diffraction instrumentation consists of three basic elements

1. X-Tube – which is a stationary source of monochromatic X-rays which are focused onto the sample.
2. A sample holder which is rotated during the test.
3. An X-ray detector which rotates with the sample.

Figure 26 CSIRO's XRD instrument used for ACP analysis (photo by CSIRO)

As the sample and detector are rotated, the angle of the sample and the corresponding intensity of the reflected X-rays is recorded. The resulting plot of these two quantities is called an X-ray Diffractogram.

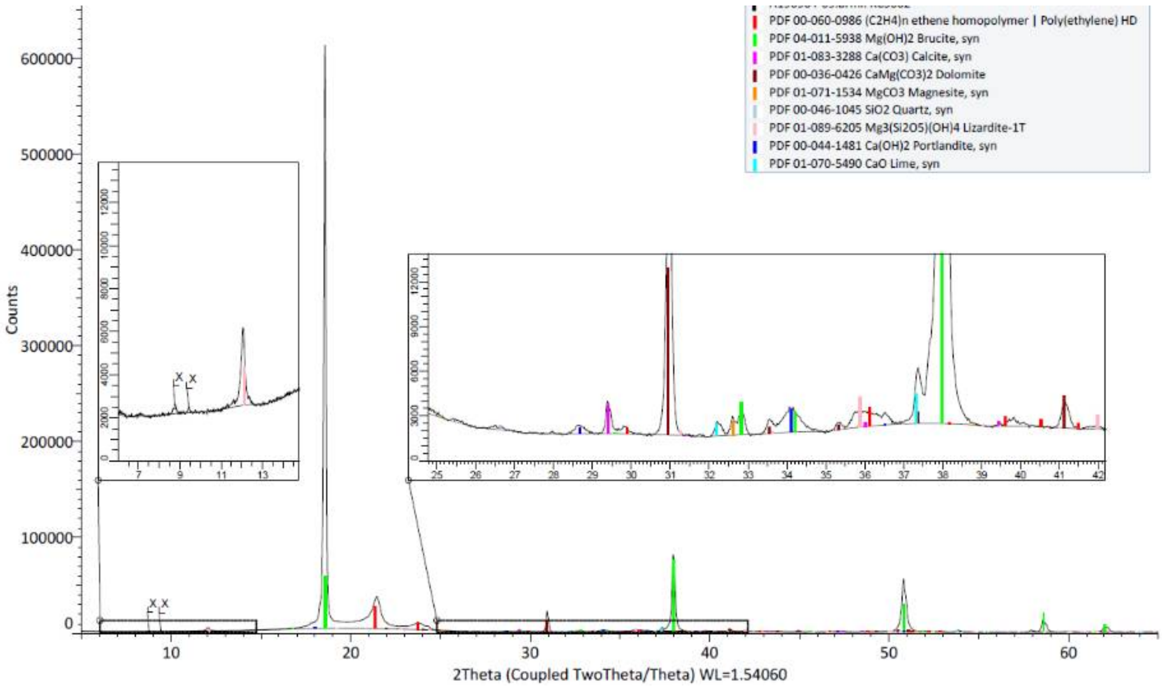


Figure 27. Example X-ray diffractogram for ACP core with magnesium hydroxide and other fillers

Characteristic peaks in X-ray intensity at specific angles are matched against a reference library to identify the types of crystalline materials present. Once the types of crystalline materials are determined the quantities of these materials in mass% can be determined based on the magnitude of X-ray intensity peaks at characteristic angles. The accuracy of this quantification is typically <± 1.0 mass%.

XRD is typically performed on the solid ACP core sample, cut to the required specimen size, with aluminium skin removed from one face and the exposed face of the specimen ground flat using 240 grit SiC paper. However, XRD can also be performed on ACP samples ground into a power form and placed in a powder sample holder.

Advantages of this method are:

- Identifies and quantifies crystalline materials which include most typical ACP fillers.
- Measurement penetrates deeper within the sample surface compared to FTIR so provides a more representative sample measurement compared to FTIR.
- XRD is typically more sensitive compared to FTIR to detecting (and quantifying) minor mass% crystalline mineral components (which are typically present in addition to fillers such a magnesium hydroxide, possibly due to impurities of the magnesium hydroxide used).
- Quantifies crystalline filler mass% to a reasonably acceptable accuracy.

Limitations of this method are:

- Amorphous (non-crystalline) materials are not detected. Many polymers can be amorphous and some minerals and other materials (such as glass) are amorphous. These are not typically present in any significant quantity in ACP but if present would be missed by XRD and may not even be detected by comparison back to aching test (with compensation calculations for H_2O and CO_2).
- LDPE and HDPE are considered semi-crystalline. This means they are tightly packed molecular chains characterised by areas of crystallinity with amorphous areas between the crystalline areas. As a result, PE type (or similar) polymers can be detected by XRD but cannot be quantified. Several other similar polymer types have characteristic peaks at similar angles so it is difficult to confidently identify the polymer as PE. CSIRO would report such a result as “Tentatively PE”.
- XRD is typically not good for identifying organic materials which are often amorphous or have very similar signatures.

- Assumes material is a homogenous mixture as measurement is at surface of material. This can be addressed by scanning multiple slices of material
- The method requires a high level of laboratory expertise

6.3.6 ENERGY DISPERSIVE X-RAY FLUORESCENCE (XRF)[42]

XRF (ASTM D6247 – 10) is applied to directly determine the types and quantities of elements in a material sample. It does not directly determine the types and quantities of compounds present (which are made up by these elements). However, when used in combination with FTIR or other methods capable of identifying compounds then it can be used to quantify the specific compounds present via an interactive analysis.

The basic principle of XRF is that a sample is bombarded with a primary high energy X-ray (or Gamma Ray) The electrons in each of the elements present in the sample become excited and emit secondary fluorescent X-rays at specific wave lengths and energy levels unique for each specific element. Energy dispersive XRF plots and XRF spectrum for a material in terms of number of photons emitted (count) against photon energy level (keV).

The types of elements contained are determined by matching the peak locations on the XRF spectrum against the characteristic signature peak locations for each element from a reference library

The quantity of each element in mass% is determined based on the intensity (photon count) at the characteristic peak location for each element.

ACP core samples can be tested via energy dispersive XRF as solid polymer samples (simply with the aluminium facing removed), but care must be taken to prepare the surface of the sample to be smooth and clean of contaminants (typically by fine sanding). However, as the fluorescent X-ray intensity is also related to the thickness of the material, samples are sometimes ground to powder and then hot pressed to a thin film (1 mm thick), as the controlled known thickness and the ability to use standard reference samples of the same thickness as a calibration curve increases the reliability of quantitative XRF analysis. Care must be taken if hot pressing samples to apply temperatures and exposure times that avoid degradation of common inert or fire retardant fillers. XRF can also be applied to the ash residue from ACP ashing tests.

Advantages of this method are:

- Identifies and quantifies element components only
- If used in conjunction with FTIR and iterative analysis can quantify filler mass% to a reasonably acceptable accuracy
- XRF typically scans a larger area of the sample compared to SEM-EDS (which may only be ~ 1mm^2) and therefore provides a more representative sample measurement.

Limitations of this method are:

- Does not directly identify or quantify molecular compounds (for this reason CSIRO uses XRD in preference to XRF).
- Where there is a complex mixture of components and fillers with similar elements the quantification of compounds based on analysis of XRF determined element quantities can become difficult. For example, a core sample containing both Al_2O_3 and $Al(OH)_3$
- Can require complex sample preparation.
- Where there is a mixture of elements in a sample emission of photons from atoms can cause secondary interactions with other atoms. Also heavier (high atomic number) elements can cause shielding effects. Both effects must be compensated for by analytical methods.
- XRF does not detect elements with very low atomic numbers. Typically, Carbon (atomic number 6) and heavier are detectable.
- Oxygen (atomic number 8) emits a very low fluorescent energy which means that oxygen is typically not directly able to be quantified by XRF.
- The method requires a high level of laboratory expertise

6.3.7 SCANNING ELECTRON MICROSCOPY (SEM) COMBINED WITH ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDS)[38, 43]

SEM is applied to ACP cores to produce a high resolution (down to 1 nm or less) image of the core surface which can show particles of fillers distributed within the polymer. EDS is typically applied as part of the same scanning electron instrument. EDS is applied to directly determine the types and quantities of elements in a material sample (like XRF). It does not directly determine the types and quantities of compounds present (which are made up by these elements).

The basic principle of SEM is production of high-resolution images by controlled scanning of the sample surface with a focused beam of electrons. The electrons interact with atoms at various depths within the sample to produce various signal types including secondary (emitted) electrons, reflected (back-scattered) electrons, characteristic X-rays and light. These signal types are received, measured and mapped against scan location across the specimen to build high resolution images.

The basic principle of EDS is similar to XRF except that the sample is bombarded with a high energy beam of electrons (instead of X-rays as for XRF) to excite the atomic structure of elements within the sample resulting them in emitting characteristic X-rays at specific wave lengths and energy levels unique for each specific element. The measured X-rays are plotted as an EDS spectrum for a material in terms of number of photons emitted (count) against photon energy level (keV).

The types of elements contained are determined by matching the peak locations on the EDS spectrum against the characteristic signature peak locations for each element from a reference library.

The quantity of each element in mass% is determined based on the intensity (photon count) at the characteristic peak location for each element

SEM can be conducted on solid ACP core samples with the aluminium facing removed and typically the exposed surface polished/sanded to remove any contaminants. SEM requires the sample to be electrically conductive to and grounded to prevent excess electrons building up on the sample surface which would act to distort the SEM image. For non-conductive samples such as polymers it is necessary to coat the sample surface with a very thin layer of carbon, gold or other conductive materials. This requires special sample preparation equipment to ensure the conductive film is ~ 10 nm so it does not interfere with the SEM and EDS. For a correct quantitative EDS analysis, the sample surface needs to be polished to a flat very smooth surface (where the specimen itself cannot be polished it is typically embedded in a resin block which is polished and the coated with conductive film)

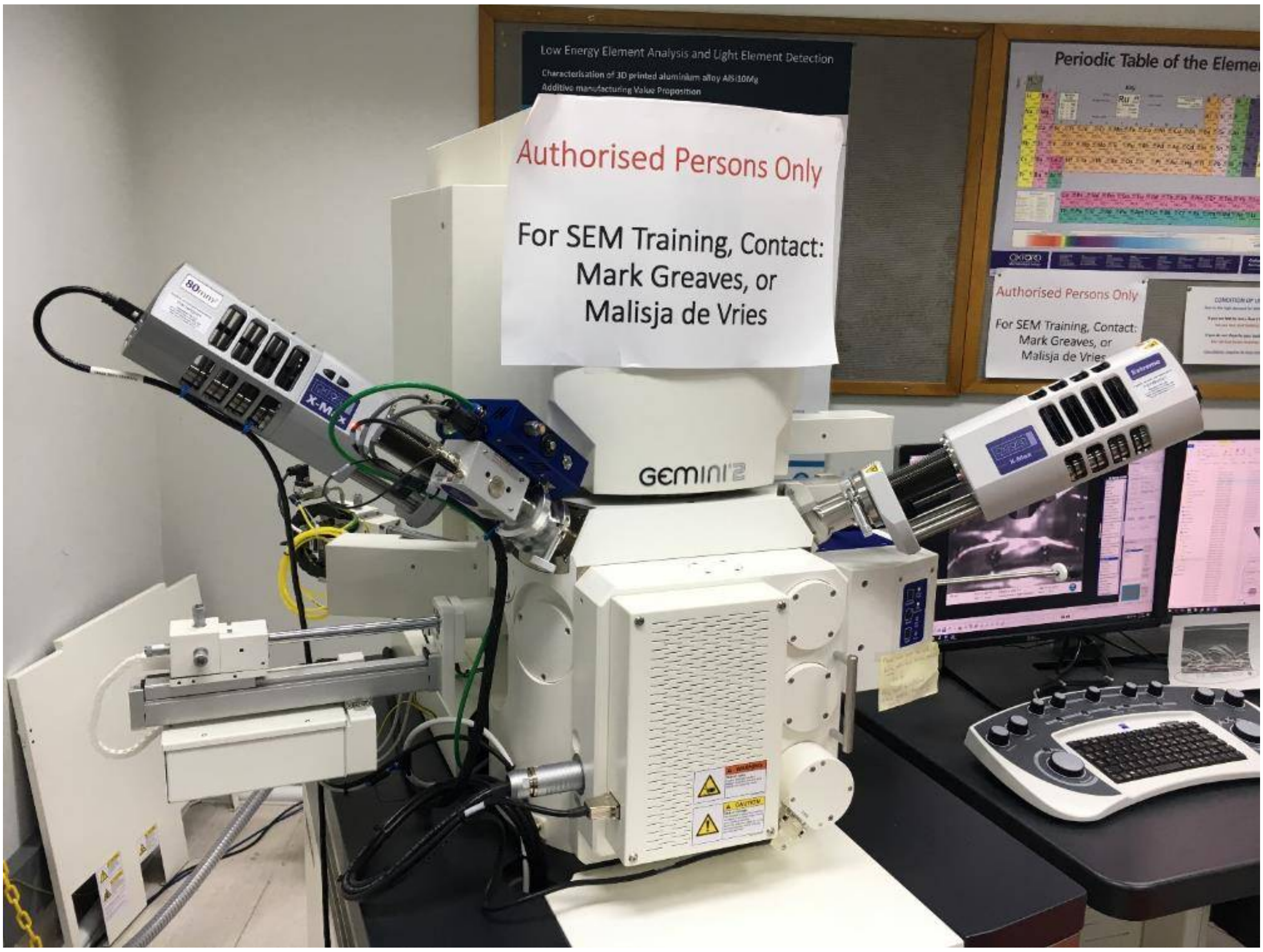


Figure 28. CSIRO's SEM-EDS. We do not typically use this for ACP analysis. Photo by CSIRO

Advantages of SEM-EDS are:

- SEM provides a high resolution image of the core surface where the presence of fillers can be seam but types not identified
- EDS Identifies and quantifies element components only.
- If EDS is used in conjunction with FTIR and iterative analysis it can quantify filler compounds and mass%

Limitations of SEM-EDS are:

- SEM could be used as a screening test to identify if any fillers are present or not, but sample preparation and lab costs are higher than for other simpler screening tests.
- SEM combined with image analysis can be used to measure the ratio of filler surface area to polymer surface area. Assuming that particle sizes are uniform having equal dimensions in different axis then the filler volume% concentration can be predicted. If the densities of the polymer and filler (assuming it is one pure filler material) are known or assumed, then this can be converted to filler mass%. However, the large number of assumptions make this method highly inaccurate.
- The limitations of EDS are similar to those of XRF.
- XRF typically scans a larger area of the sample compared to SEM-EDS (which may only be ~ $1mm^2$) and therefore provides a more representative sample measurement.
- Sample preparation is complex.
- The method requires a high level of laboratory expertise

6.3.8 BOMB CALORIMETER

A bomb calorimeter (EN ISO 1716) measures the Gross Heat of combustion of a material. Whilst this could be considered a reaction to fire tests rather than a test which characterises the chemical composition of a material it is included here as BRE have used Gross Heat of Combustion for ranking of ACP cores which has been loosely compared (by ICA's ACP core ranking protocol and others) to filler mass%.

The basic principle of a bomb calorimeter is that a specified small mass of material (typically ~ 1 g) is burnt under standardised conditions within a confined volume combustion chamber with high oxygen concentration to promote complete combustion. A fuse wire is used to ignite the specimen. The sealed combustion chamber is surrounded by an insulated water jacket. The temperature increase of the water jacket is accurately measured up until the time that the combustion chamber returns to 25 °C so that any water vapour within the combustion chamber has condensed. The water jacket temperature increases in conjunction with a bomb factor (calibration factor dependant on heat capacity of metal parts of calorimeter) determines the gross heat of combustion.

Samples are small (~1 g), must be free of contaminants, are typically dry and will typically be broken into several pieces to increase the surface area. For specimens which are difficult to ignite a compound of known gross heat of combustion (typically a benzoic acid pill) are added to promote ignition and combustion of the sample.

It is important to understand the difference between the following three measures of heat of combustion:

- Gross Heat of combustion - is the total energy released as heat when a unit mass of substance undergoes complete combustion with oxygen under standard conditions using an oxygen bomb calorimeter. This includes the heat of vaporisation of any water produced as the vapour is condensed back to liquid.
- Net Heat of combustion – is the heat released per unit mass of fuel burnt assuming that all water vapour remains in the gaseous state (gross heat of combustion minus the heat of vaporisation of any water produced). It is equal to the gross heat of combustion measured in an oxygen bomb calorimeter minus the heat of vaporization of the water in the products of combustion which is a function of the moisture and hydrogen content of the fuel. Net heat of combustion is also measured using a bomb calorimeter however the water jacket temperature rise is measured at the time when the combustion chamber has cooled to 150 °C (prior to water vapour condensing back to liquid)
- Effective heat of combustion – is the heat released per mass of material consumed taking into account real fire combustion effects such as moisture contained in the materials (heat of vaporisation is not included as water vapour leaves the combustion system via the fire plume), and incomplete combustion of pyrolysis products (which leave the combustion system as unburnt mass via the fire plume as products such as soot and gaseous products of incomplete combustion). Effective combustion can be measured via test methods such as the cone calorimeter and is defined as

Equation 3. Effective heat of combustion

$$Effective\ Heat\ of\ Combustion = \frac{measured\ HRR}{Measured\ mass\ loss\ rate}$$

Effective heat of combustion of a material will typically change as burning behaviour changes from ignition time to cessation of combustion. Average effective heat of combustion can be defined as follows.

Equation 4. Average effective heat of combustion

$$Average\ Effective\ Heat\ of\ Combustion = \frac{Total\ heat\ released\ (over\ set\ period)}{Total\ mass\ loss\ (over\ set\ period)}$$

Whilst effective heat of combustion is more relevant to actual fire behaviour, it is less suitable for categorising materials such as ACP cores as the measured effective heat of combustion for the same material can be highly variable depending upon factors such as the test method used, the calculation method (and averaging period) used and combustion conditions such as ventilation and imposed heat flux.

The SFPE Handbook[11] states the following for polyethylene:

- Gross heat of combustion = 46.2-46.5 MJ/kg
- Net heat of combustion = 43.1-43.4 MJ/kg.

Based on the simplifying assumption that the mineral fillers do not contribute any endothermic or exothermic reactions except for production of water vapour, the Heat of combustion of a PE mineral filled ACP core can be roughly related to the PE Mass% by the following equation.

Equation 5. Variation of core gross heat of combustion with PE mass % content

$$\Delta h_{c\ CORE} = \frac{C_{PE}}{100} \times \Delta h_{c\ PE}$$

Where

$\Delta h_{c\ CORE}$ = Total gross heat of combustion of core (MJ/kg)

$\Delta h_{c\ PE}$ = Gross heat of combustion of PE (46.5 MJ/kg)

C_{PE} = mass content of PE in core (mass%)

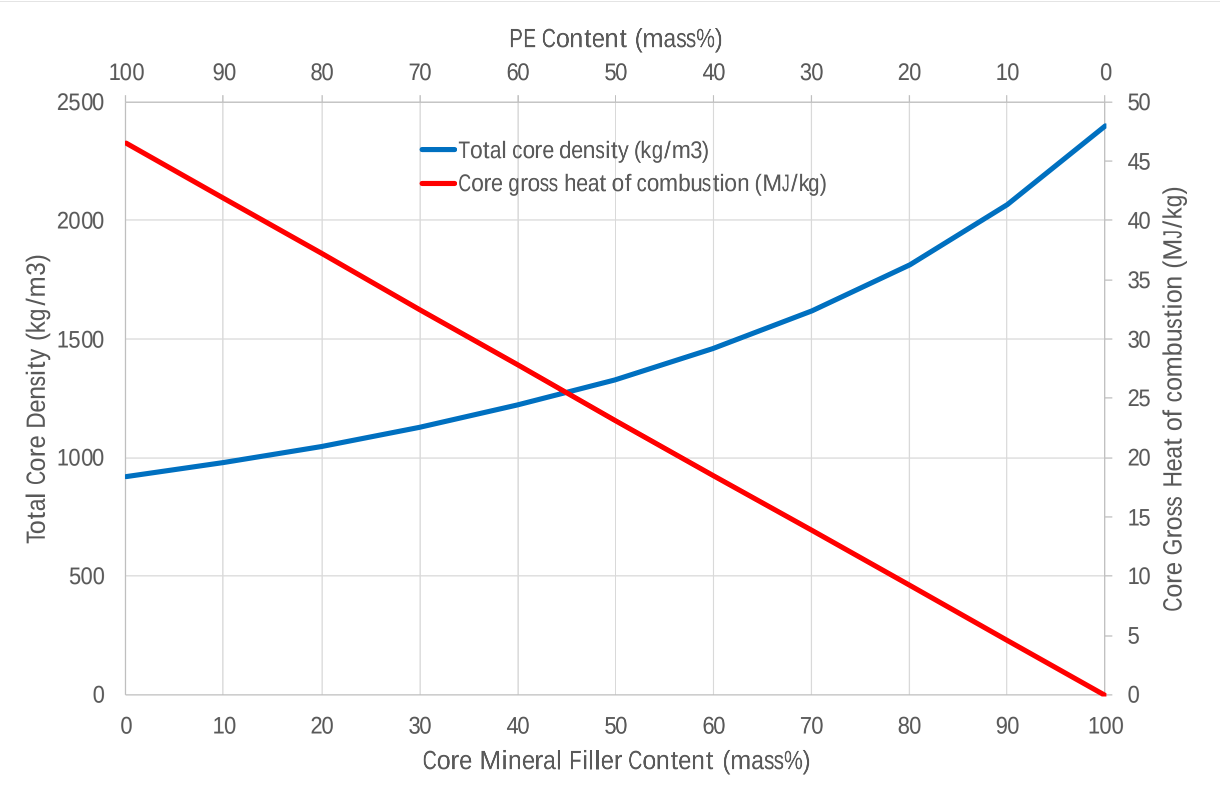


Figure 29. Variation in density and gross heat of combustion of ACP core with increasing mineral content applying Equation 1 assuming ρ_{PE} = 920 kg/m^3 and ρ_{filler} = 2400 kg/m^3, and Equation 5 .

The accuracy of the above relationship will be impacted by presence of any other polymer types or materials (incuding some minerals) which produce any endothermic or exothermic reactions except for production of water vapour

Advantages of bomb calorimetry are:

- Heat of combustion more directly measures reaction to fire behaviour than characterisation of chemical composition.
- Gross heat of combustion is used by BRE ranking and EN 13501-1 classification systems to rank ACP materials
- Sample preparation is simple, and testing is relatively quick and simple.
- Gross heat of combustion can roughly indicate combustible polymer content (mass%).

Limitations of SEM-EDS are:

- Gross heat of combustion does not distinguish between cores filled with active fire retardants minerals (which produce water vapour) and cores filled with inert mineral. Net Heat of combustion is possibly a more relevant measure for ranking materials with these different types of filler but does not appear to be currently in common use.
- Gross, Net and effective heat of combustion based on small core samples does not directly predict the full-scale fire behaviour of complete systems.

6.4 What Material Characterisation tests are Australian Laboratories currently applying.

Whilst there are broad standards for many of the laboratory test methods described above, there does not appear to be a specific standard addressing sampling and material characterisation testing and accuracy for ACP cores.

Whilst some Australian test laboratories hold Nata Accreditation for other unrelated test methods (such as reaction to fire tests or environmental testing), most do not hold Nata accreditation for the full range of materials characterisation test methods specific to ACP testing.

Different Australian laboratories are currently applying a range of different methods as follows

- CSIRO has capability to do all the above listed methods. After trialling several different options we have settled upon the following as providing a balance of accuracy and ease of sample preparation and testing.
    - Ashing test as screening test – specimens that visually match ACP-PE and achieve ~less than 20% ash content are concluded to be ICA Category A and no further testing is required.
    - For more than20% ash content materials XRD is performed on complete polymer core sample. This identifies and quantifies all crystalline materials (which captures the commonly occurring mineral filler types) and identifies semi-crystalline PE like polymers. To increase accuracy a back calculation is applied to the ash content test result accounting for the known mineral types and the expected mass loss due to water and CO_2 production.
    - For non-PE based ACP (such as cellulose/phenolic resin cores) or other materials such as insulation a range of additional test methods are employed dependant on the material type but often including ATR-FTIR
    - CSIRO typically requires two-three 40-50 mm diameter hole saw samples for each sample location.
- UQ has published a protocol for sample preparation and testing methodologies[3-5] which include characterisation of core composition and small scale reaction to fire tests. They specify two different testing protocols:
    - Screening protocol (requires 40 mm hole saw samples).
        - ATR-FTIR – to identify chemical components.
        - XRF on cryo-milled powdered core sample – to quantify elemental composition.
        - TGA – to quantify fraction of ash mass residue.

        - Quantities of chemical/mineral components back calculated based on the above measurements.
    - Detailed testing protocol (requires larger specimens and more of them)
        - Screening protocol tests to quantify chemical composition, plus the following additional tests.
        - Bomb calorimeter (to measure gross heat of combustion).
        - Cone calorimeter at 35, 50 and 60 kW/m^2 (to measure ignition time and HRRPUA and calculate ignition temperature, critical heat flux for ignition and effective heat of combustion).
        - Lateral ignition and flame spread test ISO 5658.
- Various other Australian test labs apply the following different combinations:
    - Combination 1:
        - ATR-FTIR – to identify chemical components
        - Ash content (at 650 Deg C instead of 800-900 deg C)
        - XRF on Ash residue sample - to quantify elemental composition
        - Quantities of chemical/mineral components back calculated based on the above measurements.
    - Combination 2:
        - ATR-FTIR – to identify chemical components
        - Ash content (at 650 Deg C instead of 800-900 deg C)
        - Quantities of chemical/mineral components back calculated based on the above measurements.
    - Combination 3:
        - Thermal stability – Intact ACP heated in heat bath up to 400 deg C, temperature measured and visual observation of events such as melting, discolouration, smoking, swelling, delamination of aluminium skin etc recorded with temperature. This does not quantify chemical composition and should be regarded as a preliminary screening test.
        - Small flame test – (should be regarded as preliminary screening test
        - ATR-FTIR – to identify chemical components
        - Ash content
        - Quantities of chemical/mineral components back calculated based ATR-FTIR and ash content measurements
        - Reports state that XRD and TGA-DSC may be used if above methods are inconclusive, but these do not appear to be often applied.

6.5 Permanent Labelling for ACP

It is a common practise in industry for manufacturers of ACP to label their products with some form of printing typically on the rear face. Such labels in practice can often be difficult to access and read on existing buildings without destructive access to wall cavities. Due to the absence of a mandatory labelling standards and certification (or other forms of verification), there is no way of ensuring this information is correct.

Standards Australia released SA TS 5344:2019, Technical Specification for permanent labelling of ACP in 2019. This standard applies to new ACP product (not existing ACP already installed to buildings.

It requires that ACP be:

- Marked with labels providing
    - Name/trademark of manufacturer
    - Model number/name or designation
    - Date of manufacture
    - Batch identifier or other traceability information
- Marking can be on either face and need not be on exposed face

- Marking must be human readable with minimal character size of 5 mm.
- Be placed in recurring pattern so that the label is visible on any 1m x 1 m piece cut from a sheet.

The standard does not require details of core chemical composition or reaction to fire test results to be included on the label.

The standard does not preclude other non-visible markings which require a scanning device from being used on the more accessible external face so long as this is in conjunction with human readable labelling on the rear.

If this specification is adopted by industry this would reduce the need for ACP sampling and materials characterisation testing on future new buildings, except if it is required to verify the authenticity of the labelling.

6.6 Generalised analysis of CSIRO material characterisation testing conducted on ACP

CSIRO provides material characterisation testing of ACP cores. This is predominantly carried out for samples taken from existing buildings. In most cases CSIRO has not been responsible for sampling from buildings, and CSIRO has simply been sent labeled samples with specimen description forms provided by clients for testing. In limited cases where CSIRO has been responsible for sampling, we take full photographic records of the sampling locations and processes. Whilst specific details of this testing are client confidential, CSIRO can present a generic statistical summary of this testing.

After a preliminary period of CSIRO trialling many of the types of material characterisation tests summarised above, we have settled on Ash testing combined with XRD as being the most practical and reliable approach for CSIRO to characterise ACP cores. CSIRO also provides characterisation tests on other cladding and insulation material types (using other methods such as ATR-FTIR) however these materials have been extracted/excluded from the summary below.

ACP materials characterisation test data up to August 2019 was extracted which included results on 244 ACP samples and is summarised below.

It should be noted that this test data is unlikely to be truly representative of the total ACP installed to existing buildings in Australia for the following reasons:

- A 244 sample set represents a very small proportion of the total ACP installed to existing buildings.
- The 244 samples include some cases where multiple samples of ACP have been sourced from the same building, The total number of buildings in the 244 sample set has not been extracted and included in the aggregated data.
- It is expected that in many cases 100% PE ACP will have been visually identified and assumed to be the worst performing (ICA Category A) for the purposes of risk assessment and rectification without further testing. Therefore, the proportion of close to 100% ACP installed in Australia is likely to be higher than indicated by the CSIRO test data.
- Around 2017 onwards, industry awareness of the hazards of 100% PE ACP in Australia increased (post Grenfell and during Australian cladding audits) and it becomes more likely that cladding installed after this point would be either DTS compliant or have a heavily mineral filled core. It is also more likely that records and traceability of Installed ACP for buildings built after this time improved reducing the need for testing of cladding installed in the last 2-3 years. Therefore, CSIRO test data is less likely to include a significant portion of cladding installed in the last 2-3 years.

The following plots the number of ACP samples tested grouped by mineral content (in 5 mass% increments).

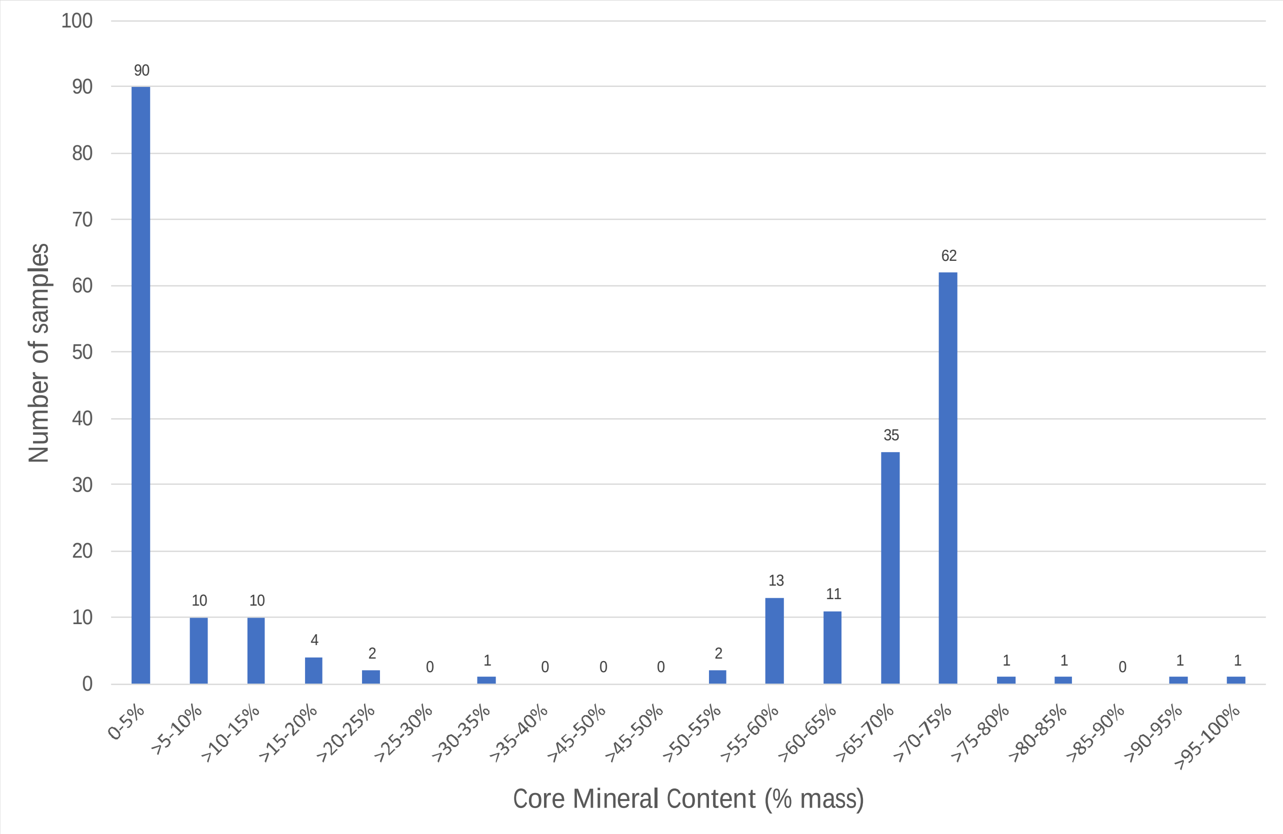


Figure 30. Number of ACP samples tested grouped by mineral content (in 5 mass% increments)

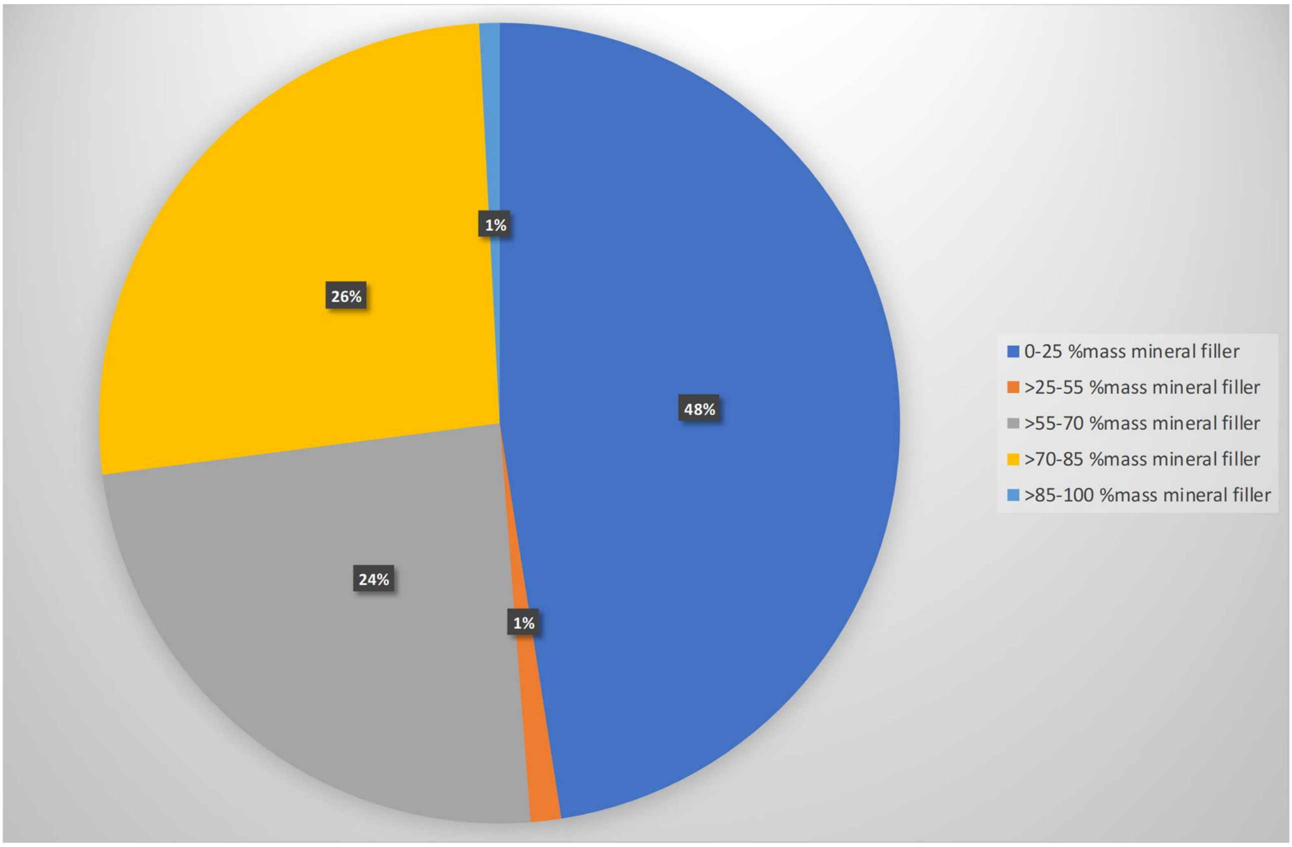


Figure 31. Number of ACP samples tested grouped by mineral content

Table 13. Number of ACP samples categorised by major mineral filler type grouped by mineral content.

Major Mineral filler type	Mineral Filler % mass grouping				
	0-25%	>25-55%	>55-70%	>70-85%	>85-100%
All Samples	116	3	59	64	2
NA or not recorded	102	0	0	2	0
Brucite	0	2	30	7	0
Gibbsite	0	0	29	55	2
Talc, Calcite	1	0	0	0	0
Calcite	11	1	0	0	0

7 Known performance of ACP in fire tests

7.1 Small scale tests

7.1.1 AS 1530.1 COMBUSTABILITY TEST

Based on CSIRO testing experience:

- ≥ 30 mass% PE core ACP is deemed combustible when tested to AS 1530.1
- ACP described as EN13501 Class B are deemed combustible when tested to AS 1530.1.
- ACP described as FR or ICA Category B are deemed combustible when tested to AS 1530.1.
- ACP described as A2 are typically deemed combustible when tested to AS 1530.1

Note that:

- EN13501 criteria for Class A2 permits “low combustibility” materials which can exhibit limited sustained flaming in a combustibility test, or alternatively can achieve class A2 via combination of bomb calorimeter and SBI test without combustibility testing.

7.1.2 BOMB CALORIMETER TEST

The following table presents the range of Gross heat of combustion for

- BRE screening categories,
- ACP tested in BRE DCLG post Grenfell fire BS 8414 tests
- Alpolics range of ACP’s as stated in Alpolic product literature and ICA “BRE_NOTES_ANEXURE”

Table 14. Range of gross heat of combustion for different types of ACP core

BRE Screening Category Ranges	ACP tested in BRE DCLG post Grenfell fire BS 8414 tests	Alpolic range of ACP
Category 1 ≤ 3 MJ/kg	Category 1 = 2.3 MJ/kg	ALPOLIC A2 < 3 MJ/kg
Category 2 > 3 MJ/kg and ≤ 35 MJ/kg	Category 2 = 13.6 MJ/kg	ALPOLIC-fr < 13 MJ/kg
Category 3 > 35 MJ/kg	Category 3 = 46.4 MJ/kg	ALPOLIC PE > 45 MJ/kg.

ALPOLIC-fr product states it is < 30% PE. A gross heat of combustion of approximately 13 MJ/kg may be typical for ACP in the ~ 30 mass% PE content range. However, there is a wide range in the calorific value within BRE Category 2 and this may possibly reflect a wide range within the EN13501 Class B which does not apply the bomb calorimeter as a criterion but applies SBI and small flame test as acceptance criteria.

The following bomb calorimeter results from UQ[4] tests are extracted and plotted bellow. This shows a cluster of ACP with polymer content varying from 24-33 mass% and gross heat of combustion varying from 13.1-19.8 MJ/kg

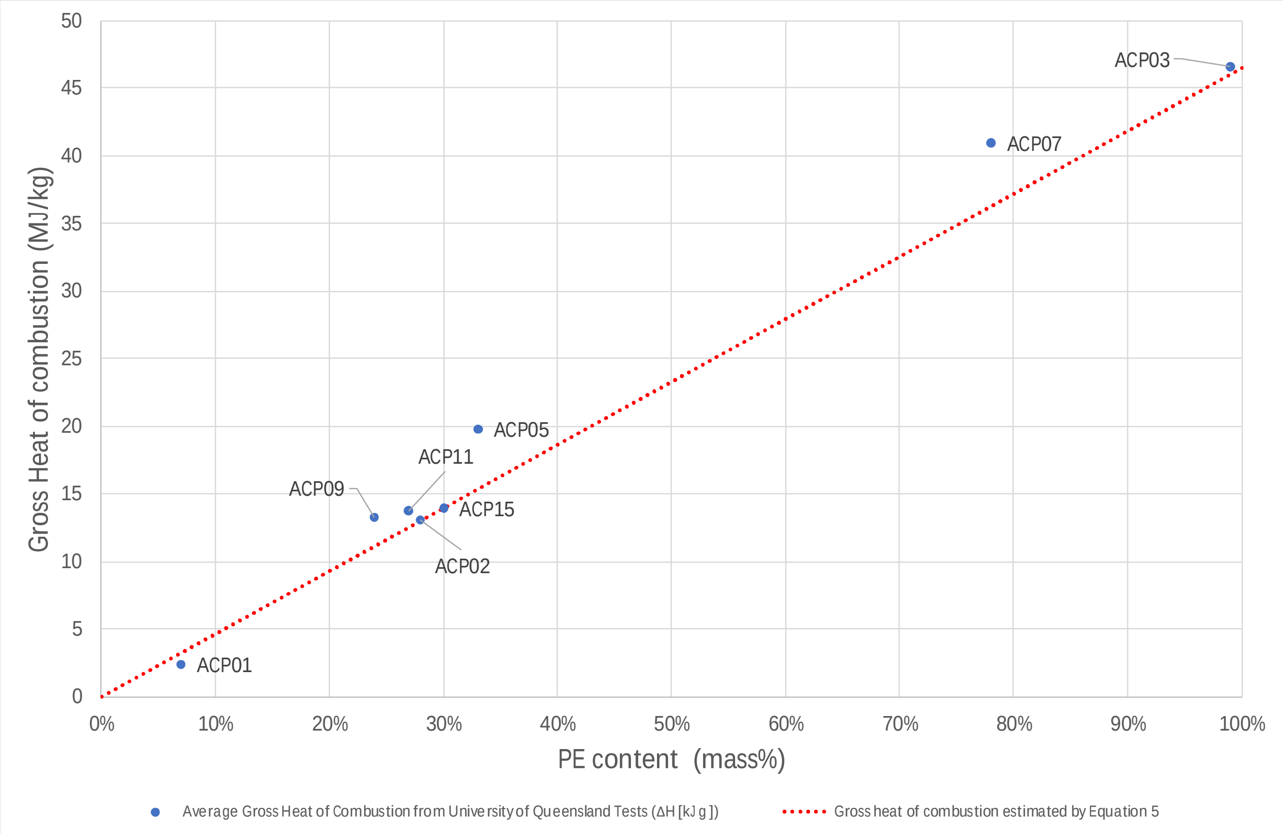


Figure 32. Variation of gross heat of combustion with core composition for PE based ACP cores from UQ tests[4]

Table 15. Variation of gross heat of combustion with core composition for PE based ACP cores from UQ tests[4]

ID number	Material Type	Polymer %	Average Gross Heat of Combustion [kJ g])	Polymer type	Major Mineral type	$CaCO_3$ (wt%)	$Al(OH)_3$ (wt%)	$Mg(OH)_2$ (wt%)
ACP01	Aluminium composite panel with a predominantly inorganic core	7%	2.37	EVA	Calcium Carbonate	51%	20%	13%
ACP02	Aluminium composite panel with a core consisting of ethylene-vinyl acetate (EVA) and a fire retardant.	28%	13.07	EVA	Alumina Trihydrate	-	72.0%	-
ACP03	Aluminium composite panel with a core consisting of polyethylene (PE).	99%	46.62	PE	Calcium	-	-	-
ACP05	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant	33%	19.78	PE-VA	Magnesium Hydroxide	7.0%	-	58.0%
ACP07	Aluminium composite panel with a core consisting of polyethylene (PE) and an inorganic filler	78%	40.96	PE	Calcium Carbonate	19.0%	-	-
ACP09	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant	24%	13.24	PE-VA	Magnesium Hydroxide	4.0%	-	71.0%
ACP11	Aluminium composite panel with a core consisting of polyethylene (PE) and a fire retardant	27%	13.77	PE	Alumina Trihydrate	-	73.0%	-
ACP15	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant and an inorganic filler	30%	13.91	PE-VA	Magnesium Hydroxide	13.0%	-	55.0%

Note:

- EVA = ethylene-vinyl acetate
- PE = Polyethylene
- PE-VA = polyethylene modified with vinyl acetate

Table 16. Gross heat of combustion for other ACP cores and bonded laminate adhesives from UQ tests[4]

ID number	Material Type	Average Gross Heat of Combustion [kJ g]	Polymer type	Polymer %
ACP04	Predominantly organic composition rich in aromatics, such as cellulose-based and/or phenolic polymers.	22.79	Cellulose and phenolic binder	100%
ACP06-S1	Aluminium composite panel consisting of an aluminium egg-box core with polymer adhesive on both sides - S1 - profiled side	45.83	EVA	Thickness of thin adhesive film not recorded
ACP10	Aluminium composite panel with a core consisting of an aluminium foil honeycomb structure connected with a polyurethane-based adhesive containing an inorganic filler	19.55	Polyurethane	Thickness of thin adhesive film not recorded

McKenna et al[44] present results of material characterisation, thermal analysis, bomb calorimetry, microscale combustion calorimetry and cone calorimeter on a range of façade materials after the Grenfell fire. They resent the following bomb calorimeter results

Code	Filling	Density (kg m^{-3})	Thickness (mm)
ACM_PE1	PE	1400 (950*)	4
ACM_PE2	PE	1375 (925*)	4
ACM_FR1	PE with FR	1900 (1625*)	4
ACM_FR2	PE with FR	1900 (1650*)	4
ACM_FR3	PE with FR	1900 (1600*)	4
ACM_NC1	Mineral filled	1900 (1625*)	4
ACM_NC2	Corrugated aluminium	1100	4
HPL_PF	High pressure laminate (phenol formaldehyde)	1350	10
HPL_FR	High pressure laminate (phenol formaldehyde FR)	1350	8
MWB_1	Mineral wool board	1200	8
MWB_2	Mineral wool board	1250	9

* Measured density of filler material excluding aluminium.

Code	Filling/Composition
ACM_PE1	LDPE (100%)
ACM_PE2	LDPE (100%)
ACM_FR1	LDPE with 65-70% $Mg(OH)_2$
ACM_FR2	LDPE with 64-69% $Al(OH)_3$
ACM_FR3	LDPE with 65-71% $Mg(OH)_2$
ACM_NC1	LDPE (5%), $Al(OH)_3$ (15%), $Mg(OH)_2$ (33%), $CaCO_3$ (45%)
ACM_NC2	Aluminium (86%), epoxy resin (14%)
HPL_PF	Wood fibre bound with phenol-formaldehyde resin
HPL_FR	Fire retarded version of HPL_PF
MWB_1	Mineral fibre and organic binder (16%)
MWB_2	Mineral fibre and organic binder (9%)

Sample	Heat of Combustion: Bomb calorimetry /kJ g^{-1}
ACM_PE1	46.2
ACM_PE2	46.5
ACM_FR1	13.8
ACM_FR2	14.2
ACM_FR3	13.9
ACM_NC1	3.4
ACM_NC2	*
HPL_PF	21.3
HPL_FR	19.8
MWB_1	4.2
MWB_2	2.8

Figure 33 Bomb calorimeter results by McKenna et al[44]

7.1.3 CONE CALORIMETER

BCA DtS Group number assessment applying AS 5637.1 and cone calorimeter requires testing to be done at 50 kW/m^2 heat flux exposure. AS 5637.1 requires a correlation to AS ISO 9705 to be demonstrated, and requires the combination of all layers of a material and also each separate layer tested individually, with the worst result being applied. AS 5637.1 identifies that materials with a reflective surface (aluminium) or which melt or shrink away from a heat source (PE) are not suitable for group number determination based on cone calorimeter. Therefore, Cone calorimeter should not be used for determination of material group number for ACP and AS ISO 9705 test should be used instead.

The cone calorimeter test does not directly predict full scale fire behaviour of ACP, however, cone calorimeter testing of exposed ACP cores at various heat flux's can be applied, not for BCA DtS compliance, but to provide a measure and comparison of reaction to fire properties for this test including time to ignition and Heat release rate per unit area (HRRPUA). HRRPUA is the amount of heat released per unit surface area of tested material (kW/m^2). HRRPUA will vary with time over a given test and also with heat flux exposure. Fire engineers sometimes use HRRPUA data as an input to fire modelling or to estimate the size of a fire that has spread to involve a given surface area of fuel. However, Cone calorimeter test data does not directly correlate to real scale fire behaviour due to a number of factors including differing heat flux and flame impingement exposure conditions, differing oxygen and fire plume conditions, impact of aluminium encapsulation etc.

As the test applies a radiant heat exposure, if the reflective aluminium skin is not removed to expose the core the radiant heat exposure is typically not sufficient to melt the protective aluminium skin and the sample typically will not ignite.

For cone calorimeter tests on most material, the following test factors have the following effect on test results

- Exposure heat flux – As heat flux increases, time to ignition decreases and Peak HRRPUA increases

- Specimen thickness – As specimens increase in thickness the time to ignition increases as the sample has more mass and takes longer to heat up to ignition temperature. Beyond a certain thickness, materials behave as thermally thick and further increase in thickness has reduced impact on ignition time. As specimens increase in thickness there is more material available to burn, so they burn for longer and produce more total energy over time.

Cone calorimeter results from UQ tests on a range of ACP core types (aluminium facing removed) tested at heat fluxes of 35 kW/m^2, 50 kW/m^2 and 60 kW/m^2 are extracted and plotted on the following pages. The following is concluded from these results.

- Please note that lines of best fit have been applied to the plotted summary results to indicate general trends but there is significant variation in results between different ACP samples. Time to ignition and Peak HRRPUA cannot be accurately predicted based on organic polymer content as the types of mineral fillers present can influence behaviour.
- Time to ignition generally decreases with increasing organic polymer content (the material becomes easier to ignite).
- Peak HRRPUA generally increases with increasing organic polymer content. At 50 kW/m^2 exposure:
    - 99% Polymer ACP had a Peak HRRPUA of 725 kW.
    - ACP in the range of 24-33% Polymer content had Peak HRRPUA in the range of 145-255 kW/m^2.
    - ACP with 7% polymer content had Peak HRRPUA of 99 kW/m^2
- The 99% PE core HRR had a sharp peak rather than a period of steady peak burning indicating that the peak HRRPUA was limited by the 3 mm thick sample burning out and a thicker sample of 99% PE would have achieved a significantly higher Peak HRRPUA.
- The Peak HRRPUA for the 99% PE core was strongly influenced by heat flux exposure level.

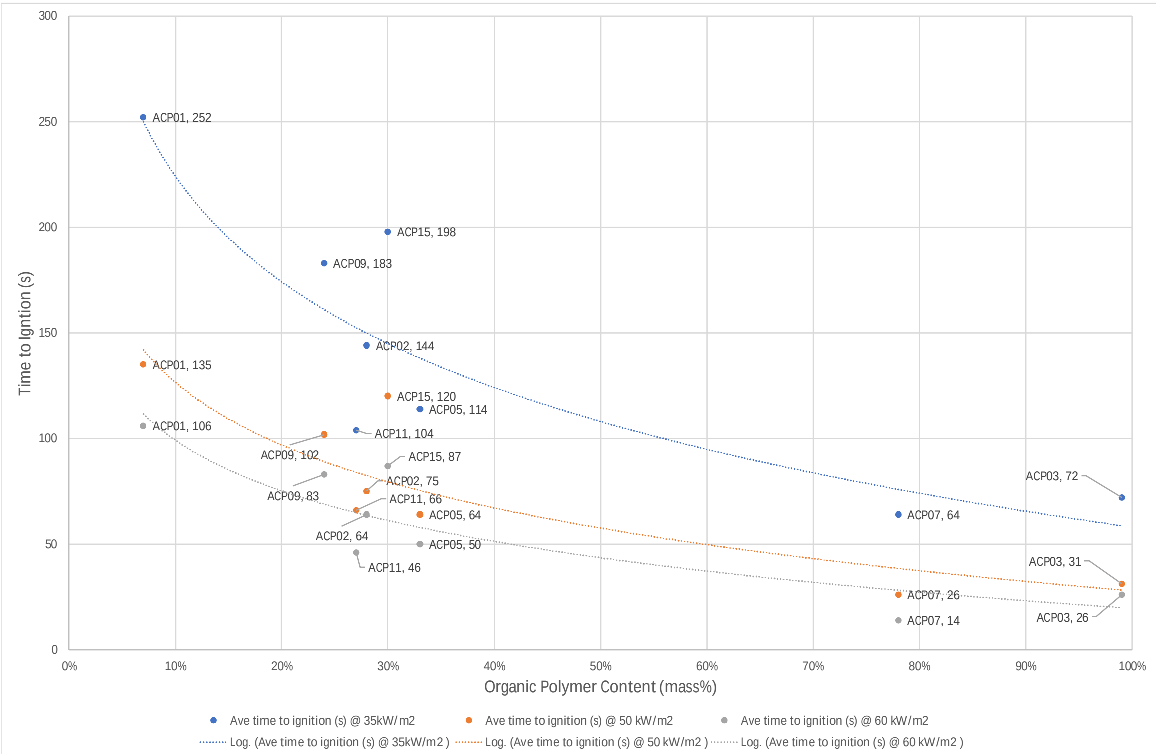


Figure 34. Cone calorimeter test at 35, 50 and 60 kW/m^2. Time to ignition variation with core composition for PE based ACP cores from UQ tests[4]

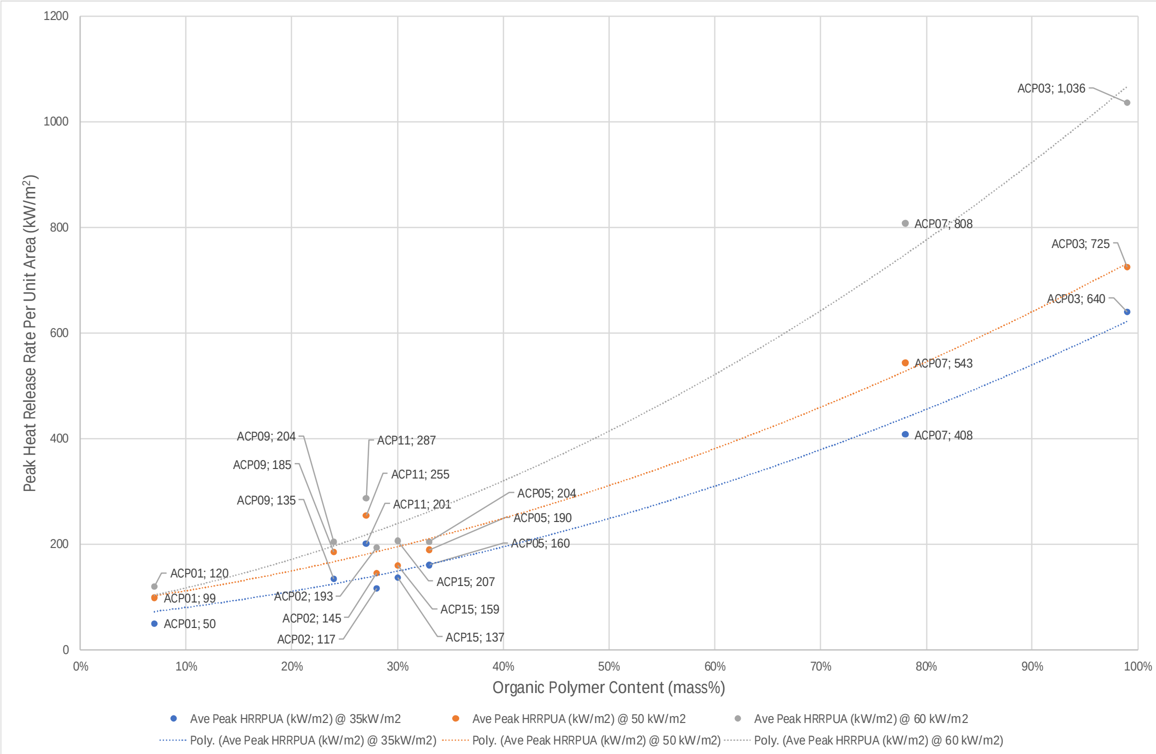


Figure 35. Cone calorimeter test at 35, 50 and 60 kW/m^2. Peak HRRPUA variation with core composition for PE based ACP cores from UQ tests[4]

Table 17. Cone calorimeter test at 35, 50 and 60 kW/m^2 from UQ tests[4].

ID number	Material Type	Specimen core thickness	Polymer type	Polymer %	Major Mineral type	35 kW/m^2 Heat Flux exposure			50 kW/m^2 Heat Flux exposure			60 kW/m^2 Heat Flux exposure		
						Ave time to ignition (s) @ 35kW/m2	Ave Peak HRRPUA (kW/m2) @ 35kW/m2	Total energy released (MJ/m2) @ 35kW/m2	Ave time to ignition (s) @ 50 kW/m2	Ave Peak HRRPUA (kW/m2) @ 50 kW/m2	Total energy released (MJ/m2) @ 50 kW/m2	Ave time to ignition (s) @ 60 kW/m2	Ave Peak HRRPUA (kW/m2) @ 60 kW/m2	Total energy released (MJ/m2) @ 60 kW/m2
ACP01	Aluminium composite panel with a predominantly inorganic core	2.81	EVA	7%	Calcium Carbonate	252	50.15	12.84	135	98.96	10.85	106	119.97	11.14
ACP02	Aluminium composite panel with a core consisting of ethylene-vinyl acetate (EVA) and a fire retardant.	2.9	EVA	28%	Alumina Trihydrate	144	116.75	34.68	75	145.3	56.9	64	193.48	60.63
ACP03	Aluminium composite panel with a core consisting of polyethylene (PE).	2.86	PE	99%	Calcium	72	639.72	93.07	31	724.65	93.3	26	1036.47	87.76
ACP05	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant	3.12	PE-VA	33%	Magnesium Hydroxide	114	160.48	75.93	64	189.66	87.58	50	204.13	74.33
ACP07	Aluminium composite panel with a core consisting of polyethylene (PE) and an inorganic filler	3.18	PE	78%	Calcium Carbonate	64	407.64	91.94	26	543.06	104.65	14	807.57	127.06
ACP09	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant	3.11	PE-VA	24%	Magnesium Hydroxide	183	134.72	73.17	102	185.15	74.94	83	203.88	73.84
ACP11	Aluminium composite panel with a core consisting of polyethylene (PE) and a fire retardant	3.38	PE	27%	Alumina Trihydrate	104	201.37	64.05	66	254.57	73.41	46	286.67	72.59
ACP15	Aluminium composite panel with a core consisting of polyethylene modified with vinyl acetate (PE-VA) and a fire retardant and an inorganic filler	5.3	PE-VA	30%	Magnesium Hydroxide	198	136.75	119.98	120	159.2	129.61	87	206.5	126.9

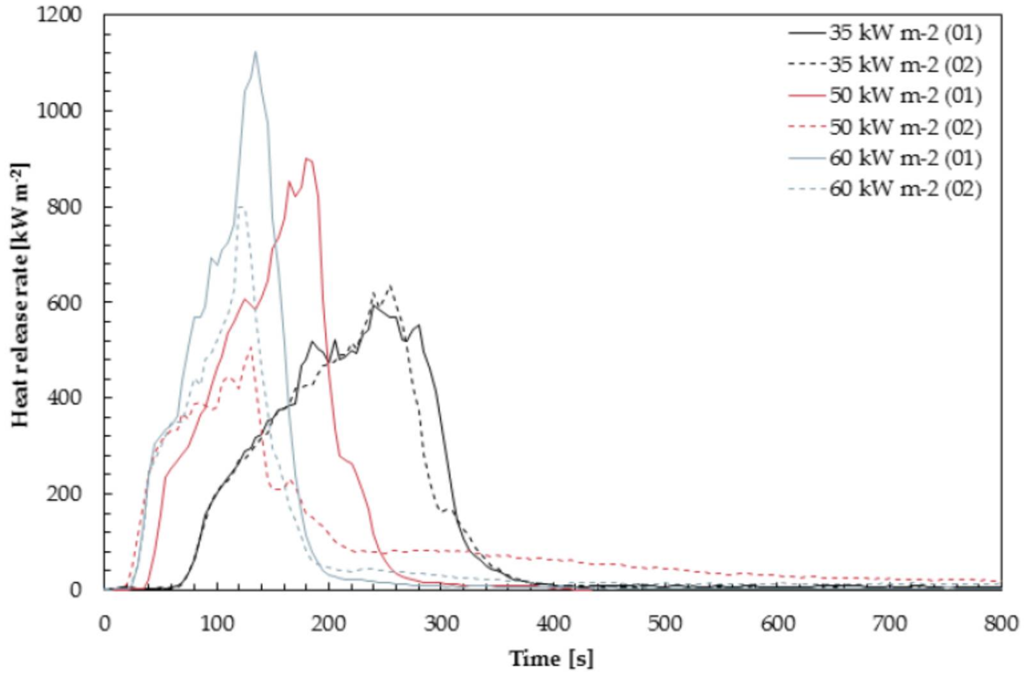


Figure 36. Cone calorimeter test on ACP03 (99% PE) from UQ tests[4], sharp peak in HRR shows that HRR was continuing to increase until 3 mm core material was mostly burnt away.

CSIRO has not undertaken our own detailed cone calorimeter test investigation of a range of ACP core types but based on client confidential testing of a limited number of core types we consider the UQ test results to be reasonable.

Other cone calorimeter test results published in literature do vary from the above results, but this is likely to be due to variation in sample thickness, core composition or other test parameters. Some of these results are summarised below

A 2005 BRANZ Study report[45] presented cone calorimeter results for a range of FR grade and non-FR (PE) grade 6 mm thick ACP from different manufacturers (not disclosed). The samples were tested with aluminium skin removed.

Table 18. ACP core cone calorimeter test results by BRANZ[45]

Sample	Grade	Peak HRRPUA (kW/m^2)	Total Heat Released (MJ/m^2
ACM Type A (6 mm)	FR	225	59
ACM Type B (6 mm)	FR	132	35
ACM Type C (6 mm)	FR	168	61
ACM Type D (6 mm)	FR	193	50
ACM Type E (6 mm)	Non-FR	382	36
ACM Type F (6 mm)	Non-FR	507	48

The exact composition and polymer mass% content is not provided for the BRANZ test results. The following is noted:

- The Peak HRRPUA for non-FR seems unreasonably low for ~ 100% PE but may be resendable for ~60-80% PE.
- The total heat released measures for all samples seems unreasonably low considering the 6 mm thickness, the typical gross heat of combustion (or gross heat per unit area) and UQ results. This is concerning as NZ use this parameter to regulate/control ACP for external walls.

One paper presents results for Granulated (1 mm granules) PE laid in a tray to a thickness of 6 mm and tested in the cone calorimeter[46]. At 50 kW/m^2 the average time to ignition was 48 s and the peak HRRPUA was 710 kW/m^2. This appears to match well with UQ 99% PE results.

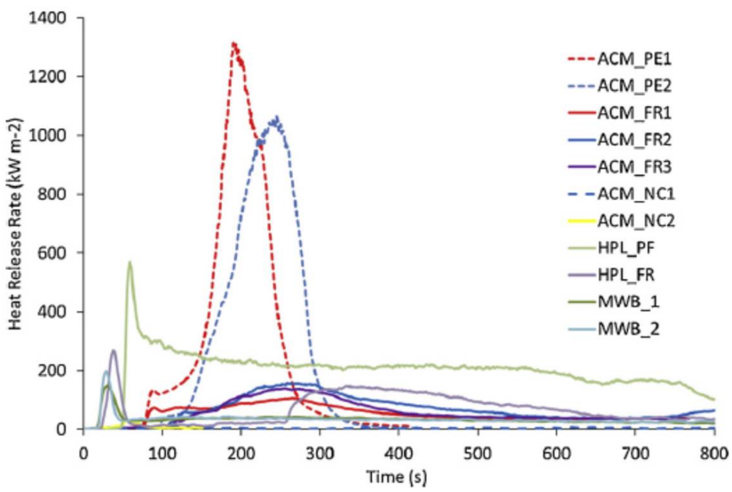
Other papers[47, 48] focused on developing PE fire retardant formulations (not specifically for cladding) present cone calorimeter results on pure PE and PE mixed with 50-60% ATH or MDH. The cone calorimeter specimen thickness is not stated. The pure PE achieved a peak of ~1200 kW/m^2 (possibly indicating a specimen more than 3-6 mm thick). The mineral filled PE samples achieved Peak HRR in the range 200 -500 kW/m^2.

McKenna et al[44] conducted cone calorimeter tests on ACP samples at a reduced sample size of 70 mm x 70 mm placed in the 100 mm x 100 mm sample holder with the aluminium skins still in place but so that the core material was exposed around the cut edges. They state that the results have been “re-scaled so they are presented in kW/m^2” but they do not clarify what sample surface area was used in this re-scaling calculation (e.g. was 70 x 70 mm or the exposed surface area of the core at the perimeter of the sample used to represent the sample exposed surface area in the HRRPUA calculation). The results are summarised below.

Code	Filling	Density (kg m^{-3})	Thickness (mm)
ACM_PE1	PE	1400 (950*)	4
ACM_PE2	PE	1375 (925*)	4
ACM_FR1	PE with FR	1900 (1625*)	4
ACM_FR2	PE with FR	1900 (1650*)	4
ACM_FR3	PE with FR	1900 (1600*)	4
ACM_NC1	Mineral filled	1900 (1625*)	4
ACM_NC2	Corrugated aluminium	1100	4
HPL_PF	High pressure laminate (phenol formaldehyde)	1350	10
HPL_FR	High pressure laminate (phenol formaldehyde FR)	1350	8
MWB_1	Mineral wool board	1200	8
MWB_2	Mineral wool board	1250	9

* Measured density of filler material excluding aluminium.

Code	Filling/Composition
ACM_PE1	LDPE (100%)
ACM_PE2	LDPE (100%)
ACM_FR1	LDPE with 65-70% $Mg(OH)_2$
ACM_FR2	LDPE with 64-69% $Al(OH)_3$
ACM_FR3	LDPE with 65-71% $Mg(OH)_2$
ACM_NC1	LDPE (5%), $Al(OH)_3$ (15%), $Mg(OH)_2$ (33%), $CaCO_3$ (45%)
ACM_NC2	Aluminium (86%), epoxy resin (14%)
HPL_PF	Wood fibre bound with phenol-formaldehyde resin
HPL_FR	Fire retarded version of HPL_PF
MWB_1	Mineral fibre and organic binder (16%)
MWB_2	Mineral fibre and organic binder (9%)



Sample	Cone calorimeter data	
	Peak HRR /kW m^{-2}	Total heat release /MJ m^{-2}
ACM_PE1	1364	105.4
ACM_PE2	1123	106.6
ACM_FR1	123	59.6
ACM_FR2	195	70.9
ACM_FR3	144	65.07
ACM_NC1	13.8	2.57
ACM_NC2	30.2	0.87
HPL_PF	530	172.71
HPL_FR	263	67.49
MWB_1	150	37.03
MWB_2	194	27.75

Figure 37. McKenna et al[44] summary cone calorimeter test results for ACP (70 mm x 70 mm samples with aluminium skin not removed but edges exposed.

7.1.4 AS 1530.3 TEST

Based on CSIRO test experience and review of results published in various ACP product data sheets, ACP with PE or other organic polymer core, with or without mineral fillers (including all ranges from 0% mineral filler to more than 93% mineral filler) generally all get the same result as follows:

- Ignitability Index = 0
- Spread of Flame Index = 0
- Heat Evolved Index = 0
- Smoke Developed Index = 1-2

This is close to the best possible result achievable for this test and occurs because the ACP core does not ignite and only a small amount of smoke is produced from the surface coating of the aluminium. This is because the maximum exposure heat flux in the test (~25 kW/m^2) combined with the small pilot flame (generally applies to the centre of the aluminium skin rather than exposed core at cut edges) is not enough to degrade the aluminium and expose the core.

It is noted that NCC BCA 2019 Vol 1 Schedule 6 states the following for determination of fire hazard properties via AS 1530.3:

"Test specimens must incorporate—

a) all types of joints; and
b) all types of perforations, recesses or the like for pipes, light switches or other fittings, which are proposed to be used for the member or assembly of members in the building."

However, in practice ACP has generally been tested as flat sheet specimens, without any joints, perforations or penetrations and without the aluminium skin removed to expose the core material.

Past application of the AS 1530.3 test has clearly failed to predict the real fire behaviour of this material when exposed to larger flame immersion scenarios and has failed to discriminate performance between the different fire-retardant filler content types of ACP.

7.2 Room corner tests

AS ISO 9705 is used by NCC BCA 2019 Vol 1 Clause C1.10 in combination with AS 5637.1 to control the fire hazard of internal wall and ceiling linings.

Group 1	Material that does not reach flashover when exposed to 100 kW for 600 s followed by exposure to 300 kW for 600 s.
Group 2	Material that reaches flashover following exposure to 300 kW within 600 s after not reaching flashover when exposed to 100 kW for 600 s.
Group 3	Material that reaches flashover in more than 120 s but within 600 s when exposed to 100 kW.
Group 4	Material that reaches flashover within 120 s when exposed to 100 kW

Flashover broadly is defined as when a fire transitions rapidly from a localised area of burning to flaming over the majority surfaces within an enclosure or extended area. The BCA, via AS 5637.1 defines flashover in an AS ISO 9705 test as a measure heat release rate (HRR) of 1 MW inclusive of burner output.

Group 1 is the best performing result, and Group 4 is the worst performing result.

The following table summarises the range of AS ISO 9705 room corner fire test results achieved by ACP based on CSIRO testing experience, review of results stated in ACP product data sheets, CodeMark certificates and in some cases review of confidential test reports by other test laboratories. Specific product names are only stated where results have been published in product data sheets:

Table 19. ISO 9705 test result summary for different grades of ACP.

ACP type	Typical ISO 9705 Group Number Result	Comment
PE (close to 100% organic polymer)	Group 3	Alucobond PE data sheet states AS ISO 9705 Group 3. AS ISO 9705 test by CSIRO on a different PE ACP product has Group 3 result.
FR (~ 30% organic polymer)	Group 2 or Group 1	Results for different FR ACP products vary between Group 2 and Group 1. This could possibly be due to variation in core composition between different products or possibly fixing and jointing details applied in different tests. CSIRO has conduct ISO 9705 tests on three different FR ACP products. All achieved Group 2 result. All tests were done prior to 2014 and exact details of mass% core composition were not provided by test sponsors or determined by CSIRO. Product data sheets and CodeMark certificates state that Alucobond Plus, Alpolic-fr and Larson FR achieved Group 1 based on ISO 9705 tests. Review of a confidential ISO 9705 test report by another laboratory on an FR ACP product which achieved Group 1 shows that during the 300 kW gas burner phase of the test the total peak HRR was 784 kW with significant combustion of ACP core in burner impingement area and some fire spread extending across ceiling. This indicates that whilst FR ACP may achieve a group 1 result, it is likely to contribute significantly to total peak HRR during the test
A2 (≤ 7 % organic polymer)	Group 1	All A2 ACP products reviewed achieved Group 1

Room corner tests not intended (and should not be applied) to assess fire performance of external walls and facades as the specimen installation, arrangement and fire exposure scenario are typically not representative of an external wall arrangement.

However, the ISO9705 test does discriminate performance between the different fire-retardant filler content types of ACP. Whilst FR ACP does achieve Group 1 (no flashover) in some cases, it appears that these tests may typically show an elevated peak HRR during the 300 kW burner exposure phase of the test compared to A2 ACP products.

7.3 Intermediate scale tests

7.3.1 ISO 13785 PART 1

The purpose of the ISO 13785-part 1 test was designed as a screening tool for poor performing external wall systems before ISO 13785-2 full scale application. It has no specified performance criteria. However it can reasonably be assumed that a system which demonstrates significant fire spread in ISO 13785-part 1 would not pass the AS 5113 EW test (applying either BS 8414 or ISO 13785-2). Further details on this test method is provided under Appendix C.4.

Guillaume et al have published a detailed series of intermediate scale façade fire tests on a range of ACP and cavity insulation material types, applying the ISO 13785-1[49].

The tested materials included are summarised in Table 20.

Table 20. Materials tested by Guillaume et al[49]

Material type	Name	Description
Cladding	ACM-A2	Alpolic A2 limited - combustibility cladding
	ACM-FR	Alpolic/fr - RF Reduced - combustibility cladding
	ACM-PE	Reynobond PE standard cladding with polyethylene core
Insulation	K15	Kingspan K15 phenolic foam, Thickness of the insulant was 50 mm
	PIR	Celotex RS5000 PIR hereafter designed as " PIR ". Thickness of the insulant was 50 mm
	MW	Mineral wool Rockwool Duoslab. Thickness = 100 mm

The materials were tested in a series of nine tests in the combinations summarised in

Table 21. Tested material combinations by Guillaume et al[49]

Tested Composition	Cladding	Insulant
Composition 1	ACM-FR	PIR
Composition 2		K15
Composition 3		MW
Composition 4	ACM-A2	PIR
Composition 5		K15
Composition 6		MW
Composition 7	ACM-PE	PIR
Composition 8		K15
Composition 9		MW

The test materials were installed in the ISO 13785-1 standard arrangement with a back wall and side wall.

- Cladding was installed as 779 x 508 mm panels with open (not face sealed) 20 mm wide gaps between panels
- Insulation was installed behind with a 50 mm air cavity between insulation and cladding.
- Cladding was supported on a vertical frame of aluminium profiles
- An intumescent cavity barrier was installed at ~ 1.5 m above the lower edge of the test specimen. Prior to intumescing there was a 24 mm gap between the cavity barrier and the cladding.
- The lower edge of the installed specimen was capped with a 2 mm thick aluminium "L" profile, with a 20 mm air-gap between the bottom of the cladding panel and the capping. The cavity at the top edge of the specimen was not capped.

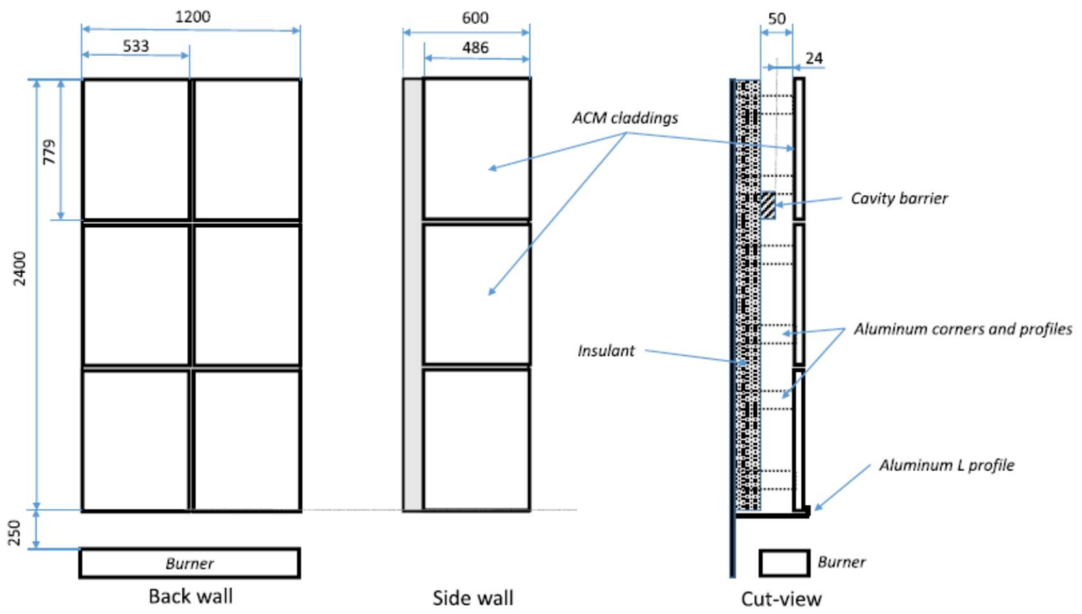


Figure 38. Installed test specimens by Guillaume et al[49]

Each test was instrumented with numerous thermocouples and a heat flux meter at the top of the specimen. Tests were conducted within an oxygen consumption calorimetry hood with additional measurement of smoke production rate and some toxic gas species. Uncertainty on the HRR measurement is stated to be ±10%. For each test a 100 kW gas burner was applied to the base of the back wall specimen for a period of 30 minutes.

The results are summarised in Table 22, Figure 39 and Figure 40.

Table 22. Heat release test results by Guillaume et al[49]

Cladding	ACM-FR			ACM-A2			ACM-PE		
Insulant	PIR	K15	MW	PIR	K15	MW	PIR	K15	MW
HRR max (kW)	397	280	298	306	244	194	5100	5159	4883
(without burner)	297	180	198	206	144	94	5000	5059	4783
THR (MJ)	438	412	360	421	387	318	848	821	636
(without burner)	258	232	180	241	207	138	668	641	456

Key conclusions from this are:

- The ACP PE was by far the most significant contributor to fire growth and was the only material to support flame spread to the top of the specimen, reaching a peak HRR of ~ 5MW, more than 16 times higher than for all other tests. Significant fire growth occurred early at 4 minutes and by 8 minutes the majority of the ACP had burnt away.
- The test did discriminate between ACP FR and ACP A2 based on HRR (300 KW Peak HRR for ACP-FR with MW compared to 200 kW Peak HRR for ACP A2 with MW) however the difference between these two ACP materials was marginal compared to the ACP PE. Based on photo's only it is difficult to discern a difference in terms of extend of flame spread for the ACP FR and ACP A2 tests.
- For ACP-FR and ACP-A2 the tests showed some limited contribution from PIR and K15 insulation with PIR contributing more to peak HRR and THR than K15 (PIR contributed an additional 100 kW Peak HRR compared to MW)
- For ACP-FR and ACP A2 tests the cavity barrier was effective and prevented involvement of insulation in cavity (and flame spread on cladding) above cavity barrier location.

- For ACP PE tests the cavity barrier was not effective as fire spread to cladding and cavity insulation above.
- For all tests the PIR and K15 was only burnt/charred to a depth of ~ 10 mm in areas of fire spread. Therefore, the majority of the combustible insulation material was not consumed.

Guillaume et al are to be commended for this detailed investigation, however the following should be noted:

- The tests did not investigate performance of the ACP-FR and ACP-A2 systems without a cavity barrier. If tested without a cavity barrier it is possible that fire may have spread to the entire surface of installed combustible insulation within the cavity and increased the area of cavity fire interaction with the cladding. This could possibly have resulted in a greater degree of discrimination between ACP-FR and ACP-A2, and between PIR, K15 and MW.
- Increasing the installed specimen height to 3-4 m and testing without cavity barriers may have increased propensity for cavity fire spread produced even greater discrimination between ACP-FR and ACP-A2, and between PIR, K15 and MW. However, it is understood that increasing test heights moves the test further away from an "Intermediate-scale test" can may introduce problems with test hood height.
- The burner ignition source of 100 kW is relatively small but may credibly represent a localised balcony fire scenario. Increasing the burner HRR may have increased discrimination between ACP-FR and ACP-A2, and between PIR, K15 and MW.

Figure 39.Test Photographs comparing ACM FR and ACM A2 tests by Guillaume et al[49]

Figure 40. Test Photographs for ACM PE tests by Guillaume et al[49]

7.3.2 FM 4880 16 FT (4.9 M) PARALLEL PANEL TESTS[50].

FM global has undertaken a series of seven tests investigating the ability of the 16 ft parallel panel test (PPT) to suitably classify the difference in fire performance for different grades of ACP, with and without combustible insulation[50].

FM Global has identified a possible weakness with the NFPA 285 full scale façade test (used in USA building codes to approve combustible external wall systems for unlimited height) possibly passing some external wall systems that would not pass other international test method such as BS8414/BR135.

FM global provides the following comparison of external wall fire test methods and concludes that the heat flux exposure for the NFPA 285 test is too low to suitably represent heat flux exposure to external walls for the scenario of flames emerging from openings in post flashover compartment fires. FM concludes that in such scenarios heat flux to the external wall can range from ~20kW/m^2-200kW/m^2 and that heat fluxes of the order of 100 kW/m^2 would therefore be more suitable for external wall system fire tests.

Table 23. Comparison of external wall fire test methods

External wall fire test	Ignition source	Peak heat flux to external wall	Wall specimen height above window/burner	Primary criteria for acceptance
16-ft PPT	Propane burner: HRR = 360 kW Duration = 15 min	~100 kW/m^2 Measured at 1 m above combustion chamber	4.9 m	50 ft (15.2 m) approval – 830 kW < Peak HRR ≤ 1100 kW Unlimited height approval – ≤ 830 kW
BS 8414/ BR135	Wood crib: HRR = 3 ± 0.5 MW Duration = 30 min	~75 kW/m^2 Measured at 1 m above combustion chamber	6.0 m	Level 2 (5 m) temperature < 600°C above ambient
NFPA 285	2 Propane burners: HRR gradually increased from 0.85 MW -1.3 MW over 30 min duration	Following peak only occurs for last 5 min of 30 min test. ~40 kW/m^2 at 0.6 m and 0.9 m above the opening and 34 kW/m^2 at 1.2 m	4.0 m	Temperature at exterior 3.05 m above opening < 538 °C. Flames must not extend > 3.05 m above opening.

FM identified that in the US, ACP-FR systems both with and without combustible insulation typically pass NFPA-285 so that there is no requirement to use better performing materials such as ACP-A2 and that these better performing ACP materials less commonly used in the US (due to higher price and no requirement for use).

The materials included in the seven FM global 16ft PPT tests are summarised in tables below.

Table 24. Materials used in FM Global 16-ft PPT tests[50].

Aluminium composite panel

Product	Total thickness (mm)	Outer aluminium face thickness (mm)	Inner aluminium face thickness (mm)	Core type	Gross heat of combustion of core (MJ/kg)
ACP-PP	6	0.8	0.4	Polypropylene (~100%)	~45
ACP-PE	4	0.5	0.5	Polyethylene (~100%)	~45
ACP-FR	4	0.5	0.5	Polyethylene with mineral filler (~ 30% PE)	~13

Insulation

Product	Description	Total thickness (mm)	Outer aluminium foil face thickness (mm)	inner aluminium foil face thickness (mm)	Total R value ($h.ft^2.°F/BTU$)	Fire test standard results	
						ASTM E84	ASTM E2058-13a FPA Note 1
PIR1	Glass fibre reinforced PIR with Al Foil facing	51	0.0254	0.0254	13.0	Class A	Worse than PIR2
PIR2	Glass fibre reinforced PIR with Al Foil facing	51	0.0317	0.0229	13.0	Class A	Better than PIR1

Weather resistant Barrier (WRB)

Type of (WRB)	Coverage per unit area (l/m^2)	Wet film thickness (mm)	Dry film thickness (mm)	ASTM E84 result
Fluid coating	1.7	1.8	0.9	Class A

Note 1 – FM global stated that PIR2 had performed better than PIR1 in the fire propagation apparatus (FPA) test but did not provide details of results

Note – ASTME84 Class A is a minimum requirement for any insulation or WRB to be compliant with NFPA 285

The range of ACP, insulation and WRB materials were selected based on most of these being used in wall systems previously assessed to pass NFPA 285 either via actual tests or via desktop assessments (based on assessment of variations to tested systems).

The 16ft PPT test specimens were assembled as follows (listed in order from the non-exposed internal side to the exposed external side):

- Test rig (4.9 m high x 1.1 m wide) metal frames lined with 13 mm thick fire-retardant plywood and 25 mm thick non-combustible calcium silicate board.
- Exterior sheathing board (16 mm thick gypsum board with fibreglass facing) screw fixed to calcium silicate board.
- WRB (if installed) was painted over exterior sheathing board.
- Metal stud frame installed to support perimeter of ACP sheets
- Insulation (if installed) was installed to cover area between metal stud frames.
- ACP installed as four sheets each 533 mm wide x 2,438 mm high installed to metal stud frame with air cavity behind.
- The exposed edges of the wall assembly were capped with 16-ga steel channel profiles. The steel capping appears to be applied both around the perimeter of the entire test wall and at the edges of each ACP panel.
- The ACP appears to have been mechanically fixed to the supporting metal stud frame.

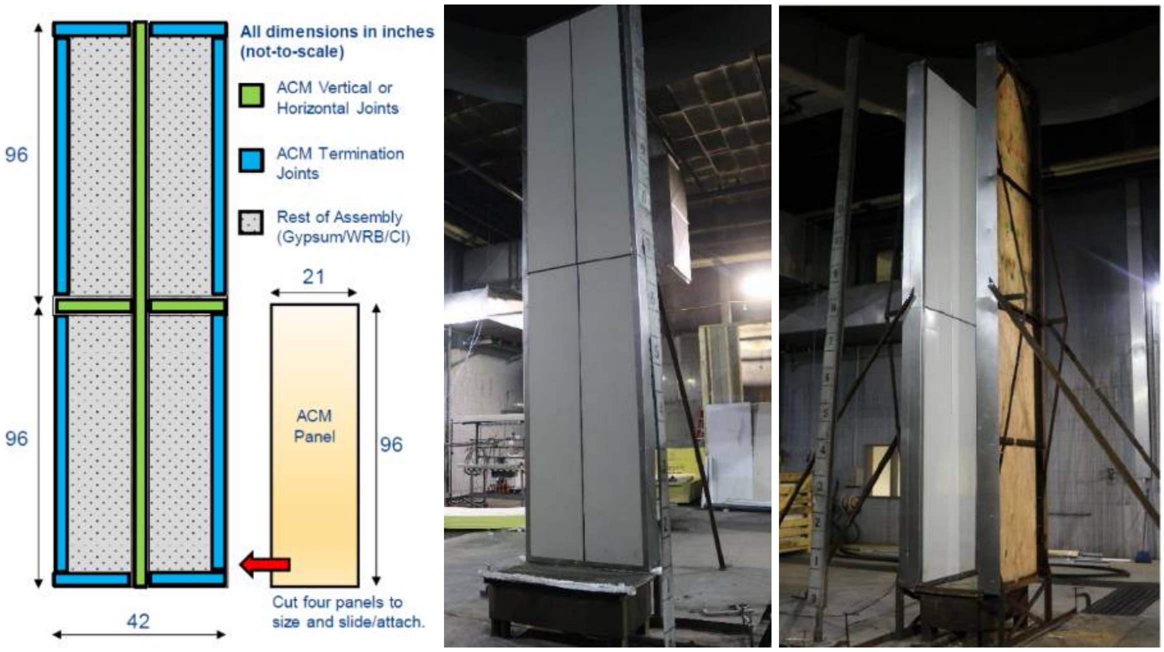


Figure 41. FM Global 16ft PPT test set up (all images taken from FM Global report[50])

All 16ft PPT tests were conducted to the same test procedure with the 360 kW Propane burner applied for a period of 15 minutes and HRR being measured via a 5MW oxygen consumption calorimeter test hood.

Table 25. Summary FM Global 16 ft PPT test results on ACP wall systems[50]

Test			1	2	3	4	5	6	7
Tested assembly		ACP	ACP-PP	ACP-PP	ACP-PE	ACP FR	ACP FR	ACP FR	ACP FR
		Air cavity	6 mm	31 mm	51 mm	51 mm	51 mm	51 mm	51 mm
		Insulation	None	PIR1	None	None	None	PIR1	PIR2
		WRB	Yes	Yes	None	None	Yes	Yes	Yes
16ft PPT results	Peak HRR (kW)		6600 Note 1	8270 Note 1	9200 Note 1	510	760	990	990
	Peak Burn height (m)	ACP (m)	4.9	4.9	4.9	1.8	2.1	4.3	3.0
		Insulation (m)	-	4.9	-	-	-	4.6	3.7
		WRB (m)	4.9	4.9	-	-	5.5	0.9	0.9
Comparison of External wall classification system results		FM 4880	Fail	Fail	Fail	Pass – unlimited ht.	Pass – unlimited ht.	Fail – unlimited ht. Pass – 50ft (15m) ht.	Fail – unlimited ht. Pass – 50ft (15m) ht.
		BS 8414 BR135 Note 2	Unknown	Unknown	Fail	Pass	Pass	Fail Note 3	Fail Note 3
		NFPA 285	Pass Note 4	Pass Note 5	Fail	Pass Note 4	Pass Note 4	Pass Note 5	Pass Note 5

- Note 1 – Tests 1, 2 and 3 were supressed with water while measured HRR was still increasing to prevent overwhelming the exhaust capacity of the test hood. Measured peak HRR are HRR at time of suppression.
- Note 2 – BS8414/BR135 external wall system results have been indicated by BRE/DCLG post Grenfell tests summarised in Section 7.4. Whilst similar product types were tested, the exact products and insulation thickness may differ.
- Note 3 – ACP-FR with PIR insulation failed BS8414/BR135 criteria due to flame extending above top of test rig between 15 and 30 min. However, the Level 2 temperature criteria were not exceeded within 15 minutes and the fire growth was not as rapid or large as for the ACP-PE tests. PIR used in the BS8414/BR135 was 100 mm thick and flammability properties of foam were not published.
- Note 4 – passed NFPA 285 actual test.
- Note 5 – passed NFPA 285via desktop assessment for unlimited height.

FM Global note although ACP-PE and ACP-PP have thermoplastic cores with very similar heat of combustion and burning characteristics, the reason ACP-PE had failed NFPA 285 but ACP-PP had passed NFPA 285 was because ACP-PP had a 0.8 mm thick aluminium facing which was 60% thicker than for ACP-PE.

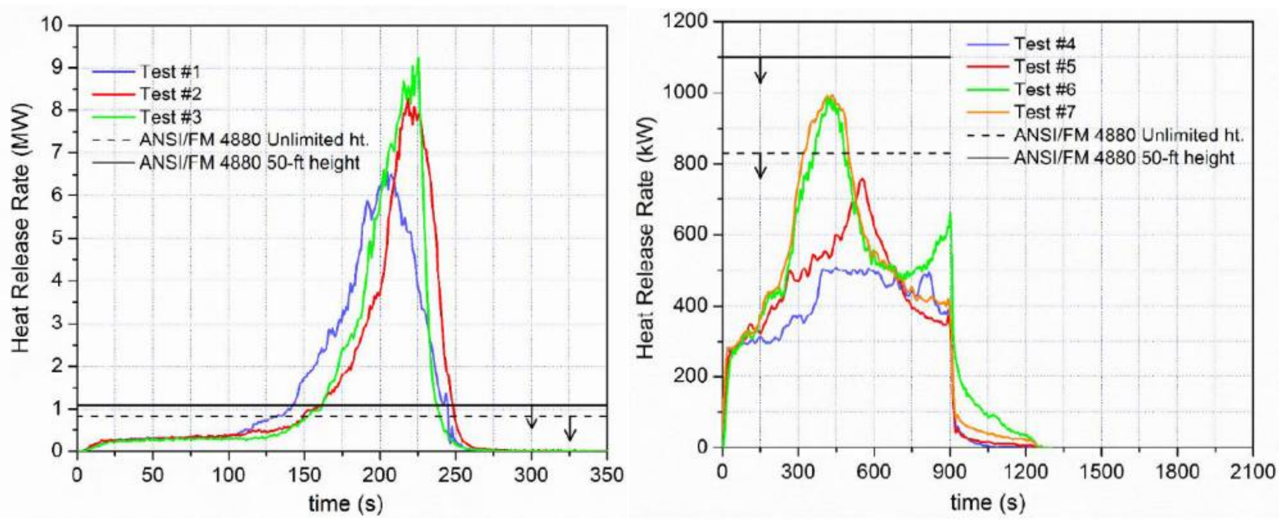
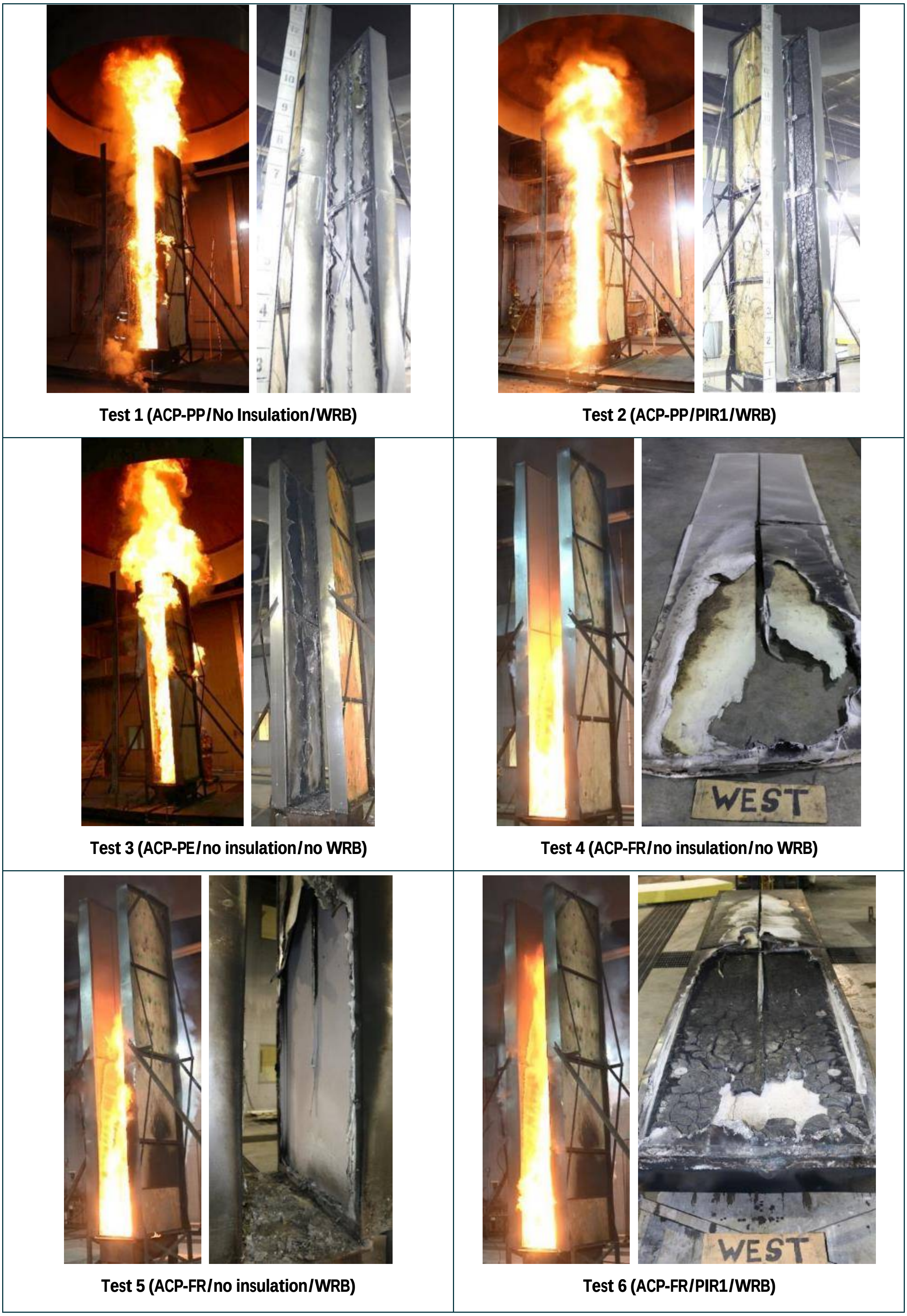


Figure 42. FM Global 16ft PPT HRR, Left – Tests 1-3, Right -Tests 4-7. (Taken from FM Global report[50])



Test 1 (ACP-PP/No Insulation/WRB)

Test 2 (ACP-PP/PIR1/WRB)

Test 3 (ACP-PE/no insulation/no WRB)

Test 4 (ACP-FR/no insulation/no WRB)

Test 5 (ACP-FR/no insulation/WRB)

Test 6 (ACP-FR/PIR1/WRB)

Figure 43. FM Global 16 ft PPT tests 1-6, left-peak fire size, right-damage (all photos taken from FM global report[50])

Figure 44. FM Global 16 ft PPT Tests 7 (ACP-FR/PIR2/WRB), left-peak fire size, right-damage (all photos taken from FM global report[50])

The following is concluded from this work:

- FM Global have identified a potential weakness of NFPA 285 test method where the low heat flux exposure to the tested wall (peaking at 40 kW/m^2) only in the last 5 minutes of the test) results in passing systems for unlimited height use that may perform unacceptably in real building fires (ACP -PP with slightly thicker skin) or that have failed other international tests (ACP—FR combined with PIR insulation).
- The 16 ft PPT presents a heat flux exposure to the wall system of ~ 100 kW/m^2 which is considered to better represent fire scenarios in re-entrant corners or post-flashover fires from the building interior.
- The ACP-PP systems had passed NFPA 285 for unrestricted height. However, the 16 ft PPT resulted in a complete failure with rapid aggressive fire growth similar to ACP-PE.
- The ACP-FR with PIR insulation systems had passed NFPA 285 for unrestricted height. However similar systems when tested to BS 8414 failed the BR135 criteria but showed significantly less aggressive fire growth compared to ACP-PE. The 16ft PPT capable of discerning a difference between these systems and passed them for limited height (15 m) use only.
- FM concluded that the 16 ft PPT provides a suitable, cost-effective means of testing ACP wall systems which suitably discerns between different levels of fire performance. They recommend it for use evaluating fire performance of external wall systems such as ACP.
- Whilst FM global are commended for this research the following limitations are identified
  - ACP-PE and ACP-PP tests were suppressed while fire size was still growing so do not show the fully developed fuel-controlled fire size that would be supported by these materials in this arrangement and is likely to be significantly greater.
  - The FM global test did not include cavity barriers and it is unclear if the 16 ft PPT test is suitable for assessing the performance of cavity barriers. It possibly may be suitable but would need some experimental investigation to verify this.
  - The test does not include a simulated window opening. The failure of cavity sealing around such openings can be a weak point for fire spread into the cavity.
  - The perimeter of the tested wall system specimen was capped with steel channel which may significantly reduce ventilation which can enhance cavity fire spread. As the section of wall is relatively small this may not be suitably representative of the ventilation and fire spread that can occur within large wall cavity areas not fitted with suitably performing cavity barriers.

7.4 Full scale tests

7.4.1 AS 5113 EW FULL SCALE FAÇADE TESTS

This report has omitted including reference to specific ACP test results for AS 5113 EW. Whilst CSIRO has knowledge of such tests, they are individual tests for individual sponsors and are subject to test sponsor confidentiality. There has not been a focused series of AS 5113 EW tests done in Australia for the purpose of publicly available research to demonstrate fire behaviour of various types of ACP wall systems. However a similar tests series in UK (BRE DCLG POST GRENFELL BS8414 TESTS) van be used to infer likely AS 5113 EW test behaviour.

It is known that ACP wall systems typically have difficulty passing AS 5113 EW falling debris criteria and that this is the case even for ACP wall systems which pass BR135 criteria (which does not include a falling debris criteria). This can present difficulty in A2 or FR ACP wall systems achieving full compliance with AS 5113 EW and NCC BCA Vol 1 CV3. However such tests may still form important supporting information for performance based solutions.

7.4.2 BRE DCLG POST GRENFELL BS8414 TESTS[51-57]

In response to the Grenfell Tower fire an independent expert panel on fire safety recommended that a series of full scale faced fire tests be undertaken to establish how different types of ACP in combination with different types of insulation behave in fire. The UK Department for Communities and Local Government (DCLG) sponsored BRE Global to undertake a total of seven BS 8414 Façade Tests on three different categories of ACP's with three different Insulation types. The installations included vertical and horizontal cavity barriers. The following summarizes the key parameters and the results.

Ref: https://www.gov.uk/government/news/expert-panel-recommends-further-tests-on-cladding-and-insulation

The range of ACP and Insulation materials tested are summarised in Table 26

Table 26. Material types tested in BRE DGLC BS8414 tests

Material Type	Material Name	Description
ACP	ACP-PE	ACP with Gross heat of combustion of ~46.4 MJ/kg, total thickness = 4 mm, core thickness = 3 mm. (BRE CAT3 – No flame-retardant properties - > 35 MJ/kg)
	ACP-FR	ACP with Gross heat of combustion of ~ 13.6 MJ/kg, total thickness = 4 mm, core thickness = 3 mm. (BRE CAT2 – Limited flame retardant - > 3 MJ/kg and ≤ 35 MJ/kg)
	ACP A2	ACP with Gross heat of combustion of ~ 2.3 MJ/kg, total thickness = 4 mm, core thickness = 3 mm. (BRE CAT1 Limited combustibility - ≤ 3 MJ/kg)
Insulation	PIR	100 mm, foil faced, density 31.2 kg/m3, moisture content from 2.4% to 3.9%
	MW	180 mm, density 47.7 kg/m3, moisture content from 0.5% to 0.6%
	Phenolic	100 mm, foil faced, density 32 kg/m3, moisture content 8.5%

The installation details are summarised in Table 27, Figure 45 and Figure 46 below.

Figure 45 Left – Horizontal and vertical cavity barrier installed through entire depth and aluminium cladding support brackets bolted to masonry wall (MW insulation being installed to wing wall), Centre – cavity barriers and MW insulation installed, Right – Aluminium railing sub structure installed (all photos taken from BRE test report[51])

Table 27. Installation details for BRE DGLC BS8414 tests

Installation Detail	Description
Framing and fixings	Cladding brackets and framing were generally aluminium profiles with steel screws and fixings
Vertical cavity barriers	75 mm wide stone wool with stated integrity/insulation performance of 90/30 minutes, compressed 10 mm. Depth of cavity barriers was varied between tests with different insulation thickness to maintain 55 mm air gap cavity for all tests. Two vertical cavity barriers on were installed on main wall 1980 mm apart with the combustion chamber opening centred between them. The wing wall had the vertical barrier at the outside edge about 1250 mm from the main wall
Horizontal cavity barriers	75 mm wide stone wool with intumescent. Stated integrity/insulation performance of 90/30 minutes. The intumescent looks like a 15mm thick foam attached to the edge of the stone wool horizontal barrier. Depth of cavity barriers was varied between tests with different insulation thickness to maintain a 25mm gap between the horizontal cavity barrier and the ACP to allow ventilation vertically. The horizontal cavity barriers were installed at the following locations: • Directly above the combustion chamber opening • 2395 mm above the first cavity barrier • 2330 mm above the second cavity barrier • Close to the top of the rig, 1635 mm above the third cavity barrier and 6360 mm above the combustion chamber opening
Air gap cavity	The air cavity between the insulation and the rear surface of the ACP was 50-55 mm.
ACP fixing and jointing	ACP panels were mechanically fixed as flat sheets (edges were not folded). They were installed with 20 mm gaps between all edges of ACP panels. The core was exposed at the panel edges and the gaps between panels were left open (not filled with sealant)
Window pod	A pre-fabricated welded window pod constructed of 5 mm thick aluminium was fixed to the combustion chamber opening with steel screws. The window pod extended perpendicular from the masonry wall so that it extended ~ 30 mm beyond the front face of the finished cladding system.
Total installation dimensions	• Height above combustion chamber = 6492 mm (requirement ≥ 6000 mm). • Width across main wall = 2615 mm (requirement ≥ 2400 mm). • Width across wing wall = 1340 mm (requirement ≥ 1200 mm) • Wing wall to combustion chamber opening = 222 mm (requirement = 260 ±100 mm • Combustion chamber opening = 2000 mm x 1940 mm (requirement = 2000 mm x 2000 mm ±100 mm)

Figure 46. Left – Aluminium window pod, combustion chamber and ACP joints and fixing detail. Right – complete façade system prior to test (all photos taken from BRE Test report[51])

The test results are summarised in Table 28 and Figure 47 below.

Table 28. Comparison of results for BRE DGLC BS8414 tests[51-57])

Test		1	2	3	4	5	6	7
ACP		ACP-PE	ACP-PE	ACP-FR	ACP-FR	ACP-A2	ACP-A2	ACP-FR
Insulation		PIR	MW	PIR	MW	PIR	MW	Phenolic
BR135 classification criteria	BR135 result	Fail	Fail	Fail	Pass	Pass	Pass	Fail
	Flame spread above top of test rig and test terminated early (> 30 min) after ignition	Yes	Yes	Yes	No Note 8	No	No	Yes
	Level 2 external temperature > 600 °C above ambient for a period of at least 30 s, within 15 minutes of t_s	Yes	Yes	No	No	No	No	No
	Level 2 cavity temperature > 600 °C above ambient for a period of at least 30 s, within 15 minutes of t_s	N/A Note 7	N/A Note 7	No	No	No	No	No
	Level 2 insulation temperature > 600 °C above ambient for a period of at least 30 s, within 15 minutes of t_s	N/A Note 7	N/A Note 7	No	No	No	No	No
Start time, t_s (seconds after crib ignition) Note 1		130 s	118 s	110 s	85 s	105 s	105 s	115 s
Time Level 2 external temperature > 600 °C above ambient for a period of at least 30 s		360 s	305 s	1190 s	Not clearly reported ~ 1270-1340 s	Did not occur	Did not occur	1500 s
Peak temperature / time at Level 2, external		814 °C 390 s	675 °C 310 s	877 °C 1395 s	810 °C 1290 s	565 °C 1380 s	508 °C 1325 s	939 °C 1570 s
Peak temperature / time at Level 2, cavity		410 °C 380 s	334 °C 310 s	225 °C 1395 s	269 °C 1725 s	215 °C 1055 s	370 °C 1530 s	319 °C 995 s
Peak temperature / time at Level 2, insulation		218 °C 380 s	46 °C 225 s	102 °C 590 s	88 °C 775 s	141 °C 890 s	298 °C 1605 s	142 °C 1300 s
Time of frequent flaming above level 2		300 s	275 s	475 s	Not clearly reported ~ 1000 s	945 s Note 3	998 s Note 4	Not clearly reported
Time of frequent flaming above top of test rig		370 s	305 s	1390 s	Did not occur	Did not occur	Did not occur	1566
Test Termination (crib ext.) time		395 s (early)	314 s (early)	1402 s (early)	1775 s (30 min after ign)	1695 s (30 min after ign)	1695 s (30 min after ign)	1579 s (early)
Time of flaming debris burning > 20 s (s)		170 s	195 s	375 s	335 s	435 s	Not reported	390 s Note 5
Time of pool fire starting at base (s)		200 s	Not reported	430 s	485 s	505 s	Not reported	611 s Note 6

- Note 1 - Start time, t_s is measured from crib ignition time is defined as the time when the temperature measured by any external thermocouple at level 1 exceeds 200 °C above ambient.
- Note 2 – All other times in above table are measured from Start time, ts.
- Note 3 – report states *"Flickering flames observed in the horizontal joint above panels 2C&2D"* at level 2
- Note 4 - report states *"Flame tips to Level 2 thermocouples"*
- Note 5 – report states "*Steady stream of flaming debris from the system"*
- Note 6 – report states *"Flaming material in front of hearth"*
- Note 7 – temperature criteria cannot be applied as test was terminated early prior to 15 minutes of t_s. Failure may possibly have occurred if test had not been terminated early.
- Note 8 – Test 4 ACP-FR with MW test report states at 1340 s *"Frequent flaming along main-wing wall junction to top of the cladding system"*. Based on this it is assumed flames reached the top of the test rig but did not extend above the test rig and therefore the test was not terminated early. It is noted that Test 3 ACP-FR with PIR test report states that flame tips extended > 1m above test rig prior to early test termination.
- 15 minutes = 900 s, 30 minutes = 1,800 s

	PIR	MW	Phenolic
ACP-PE	**Test 1** 	**Test 2** 	No Test
ACP-FR	**Test 3** 	**Test 4** 	**Test 7** 
ACP-A2	**Test 5** 	**Test 6** 	No Test

Figure 47. Post-test damage photos (all photos taken from BRE test reports[51-57])

The following can be concluded from these tests:

- ACP-PE supports aggressive vertical fire spread, with significant flaming debris and formation of pool fires, regardless of the type of insulation behind. Flames extended several meters above the test rig at the time of early test termination
- ACP-FR supported significantly less aggressive fire spread compared to ACP-PE but did still support some flame spread beyond the crib impingement area and flaming debris, even with mineral wool insulation behind. It appears that ACP-FR / MW resulted in flames extending along main-wing wall junction to just reach the top of the test rig but not extend above the test rig. On this basis it narrowly met the BR135 classification criteria
- ACP-FR combined with combustible PIR or Phenolic insulation showed some enhancement of fire spread and resulting fire size, compared to ACP-FR/MW, due to burning of the insulation within the cavity and this possibly enhancing the burning of the ACP-FR. Both tests failed BR135 classification criteria due to flames extending above the top of the test rig. Fire spread was significantly less aggressive and was delayed compared to ACP-PE tests.
- ACP-A2 did not support significant fire spread beyond the crib impingement area even when combined with PIR insulation. All ACP-A2 tests met the BR135 classification criteria
- Due to the charring behaviour of PIR and Phenolic these insulation materials were not completely consumed in the tests. No tests were conducted with other combustible insulation types. It is expected that thermoplastic insulation such as EPS or woven polyester may be likely to enhance fire spread and molten flaming debris beyond that indicated in the above tests.
- The above tests included horizontal and vertical cavity barriers. These cavity barriers performed well for the ACP-FR and ACP-A2 tests where fire did not spread on PIR or Phenolic above level 2 cavity barriers. For the ACP-PE/PIR test the fire did not spread on the PIR above the level 2 cavity barriers, however this was due to the early termination of the test. If the test had continued it is expected that fire spread on the ACP-PE cladding external to the cavity would have eventually led to PIR insulation burning above level 2
- Before introduction of BCC BCA Vol 1 CV3, Cavity barriers have not typically been specified for ACP external walls in Australia. The expectation is that such systems with no cavity barriers installed would have considerably worse fire spread performance. This is a significant concern for ACP-FR with any combustible insulation installed within cavity.
- The above tests had open 20 mm gaps between ACP panels with non-folded, cut edge cores exposed and no sealant filling gaps. This may have had some effect on fire spread and temperatures within the cavity.
- The test reports do not provide any photos during tests visually showing the area of flames and extent of flaming molten debris and pool fires. Based on written observations and measurements these appear to have been significantly reduced for ACP-FR compared to ACP-PE.
- Tests which are terminated early do not show the fully developed fire intensity, fire spread and fire duration. It is likely that the ACP-PE tests would have grown to a significantly larger fire size if not terminated.
- Post-test damage photos are can be misleading. For example, ACP-PE tests show less damage than ACP-FR and ACP-A2 tests because the ACP-PE test was terminated at a significantly earlier stage, even though the flame extension from the involved PE at the time of termination was significantly greater than for ACP-FR and ACP-A2.

8 Past Fire incidents involving ACP

A Review of past fire incidents involving ACP is presented in Appendix E.

The following provides a more detailed review of three ACP façade fire incidents involving ACP which have had a critical impact on Australian awareness and regulatory authority actions on ACP in Australia.

8.1 Three ACP fire incidents that had an important impact on Australia

8.1.1 LACROSSE DOCKLANDS, MELBOURNE, 2014 NOVEMBER 25

An MFB post incident analysis report[58] provides a very detailed account of this fire incident (much of the below summary is paraphrased from this report). A Municipal Building Surveyors (MBS) report[59] also documents the MBS post fire incident inspection and review. The VCAT report on the Lacrosse Fire Civil decision[60] was released in February 2019

The Lacrosse building (Eastern tower) located at 673-675 La Trobe St, Docklands is a residential apartment building with some restaurant/retail and car-parking areas. It has a rise in storeys of 21 (contains 23 storeys total) and an effective height of 56.7 m. The building is concrete slab and loadbearing wall construction with light weight infill walls.

The building was installed with:

- Combined sprinkler and internal hydrant system (no sprinklers on balconies)
- Fire extinguishers in residential levels in lieu of fire hose reels
- 2 fire isolated stairs with stair pressurisation systems
- AS 1670.1 fire detection system throughout common areas. AS 3786 smoke alarms within each apartment
- Emergency Warning and Intercommunication System (EWIS) with speakers throughout all common areas and additional speakers installed within every apartment bedroom.

The fire effected wall construction is described as follows

- Level by level balconies constructed of concrete slabs with glass balustrades
- External wall at south end of balconies extend out 450 mm from external face of balcony slab and was described as:
  - o Light weight steel stud construction
  - o Internal face of walls lined with 2 x layers 13 mm standard grade gypsum plasterboard
  - o Insulation (staed in MFB report to be fibreglass)
  - o Sarking
  - o Cavity included PVC drain pipe, cables and apartment exhaust penetrations
  - o PE ACP, 4 mm thick stated to be “alucobest”
- The ACP clad wall was vertically continuous between balcony levels due to the ACP clad section of the wall extending 450 mm past balcony slab edge and returning into each balcony level.

On 25 November 2014 sometime between 1.30 am and 2:24 am (when MFB received notification) a fire started on the level 8 balcony of Apartment 805. The side walls of the balconies were a lightweight wall construction clad with “Alucobest” PE ACP. The ACP was vertically continuous between balcony levels.

MFB investigation concluded that the fire was started by a cigarette but disposed of in a plastic container on the Apartment 805 balcony which spread to a significant fuel load on the balcony including outdoor furniture, clothing on cloths drying racks, clothing in plastic garbage bags and an A/C unit with cardboard box on top directly adjacent to the ACP.

The first MFB crew arrived at 2.29 am, at which time the fire had spread rapidly on the ACP involving ~ 6 levels. By 2:35 am the fire had spread to level 21 (top of building).

Luckily an MFB aerial appliance was able to be set up on the La Trobe Street overpass (which extended its height above street level) and at approximately 02:46 hours, was operational and had water onto the fire. The water stream from the water monitor on this appliance was able to reach all levels on the building, making extinguishment of the burning façade more efficient.

Fire damage was essentially restricted to the façade and external balcony area adjacent to Apartment 605 and Apartments 805 to 2105. Fire had spread downwards to level 6 balcony by falling burning debris starting secondary fire on this level.

All occupants (~ 400 people) had to be evacuated from the building, presenting a challenge for their care and management.

After the fire, it was observed that many apartments contained bedding arrangements indicating a higher occupancy level than what would normally be expected. This resulted in increased combustible fuel loads due to the greater amount of personal belongings.

The fire caused 26 sprinkler heads to activate. Two fire hydrants were also used; however, it was undetermined whether both fire hydrants were used simultaneously.

Despite the demand on the system running well over its designed capabilities, all witness reports and subsequent investigations, suggest the sprinkler system performed exceptionally well. Of the sixteen levels that were affected by the fire, there were only two instances where fire-fighters had to use hose lines from the internal fire hydrants. This was to combat a larger fire inside Apartments 1005 and 1905. Fire-fighters identified that in these two instances the sprinklers were containing the fire from spreading deeper into the apartment.

The installed combined fire hydrant/fire sprinkler system, compliant with AS2118.6, was designed to facilitate simultaneous operation of four sprinkler heads and two fire hydrants. The sprinkler system appeared to perform well beyond the above design number of simultaneous operating heads. Reasons for this may be:

- Combined sprinkler /hydrant systems enable more water supply to be available for sprinklers during times when hydrants are not is full use.
- If water supply was greater than minimum requirements (not confirmed in MFB report)

In 2018, affected property owners sued the builder for damages in the Victorian Civil and Administrative Tribunal (VCAT) along with the architect, the building surveyor, and the fire engineer. The VCAT decision was released in February 2019. This ruled the following parties as significantly liable:

- The builder: LU Simon Pty Ltd
- The architect: Elenberg Fraser Pty Ltd
- The building surveyor: Gardner Group Pty Ltd
- The fire engineer: Tanah Merah Pty Ltd, trading as Thomas Nicolas

Architectural drawings proposed façade cladding as ‘composite wall cladding – silver aluminium composite sheet’. The Architectural specification described the material as ‘indicative to Alucobond’. The Fire engineering report and building surveyor approval documents did not identify or address the presence of this non-compliant combustible cladding.

Although the builder was found liable to pay damages, VCAT determined that these damages were to be paid by other respondents as they were expert consultants engaged by the builder to identify and address fire safety matters such as non-compliant combustible cladding. Damages were to be paid in the following proportions:

- Gardner Group: 33 percent
- Elenberg Fraser: 25 percent
- Thomas Nicolas: 39 percent
- Mr Gubitta (tenant who started the fire): three percent

The Owners claimed at least $12,765,812.94 in damages. VCAT awarded damages in the sum of $5,748,233, finding that damages in the sum of $194,414.01 were not proven by the Owners and were disallowed. The remainder of at least $6,823,165 are to be the subject of further submissions and remain unresolved.

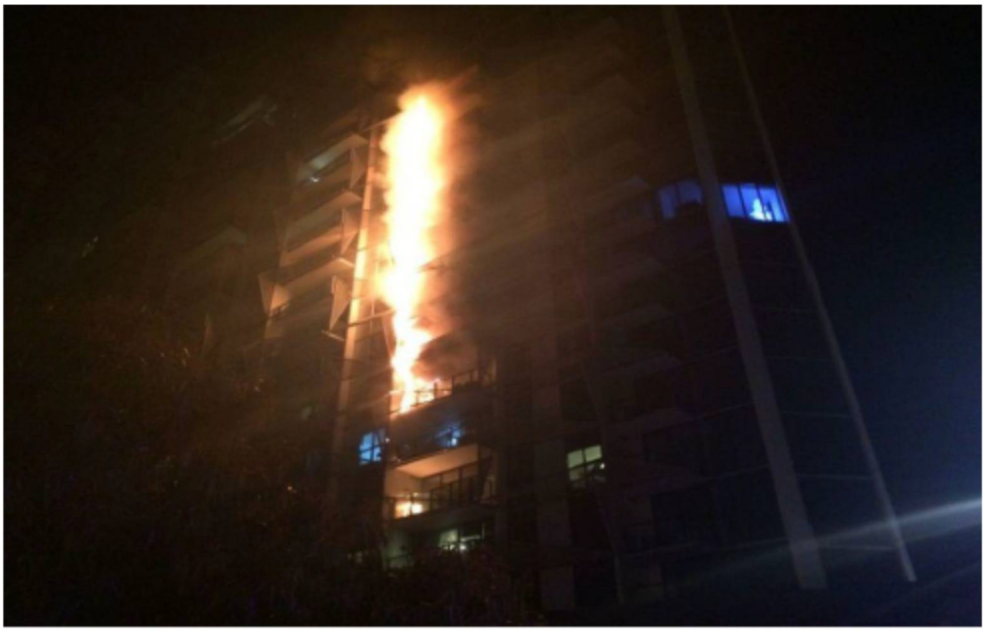


Figure 48. Lacrosse fire on level 6 and on level 8-14 at 2:29 (Photo by MFB)

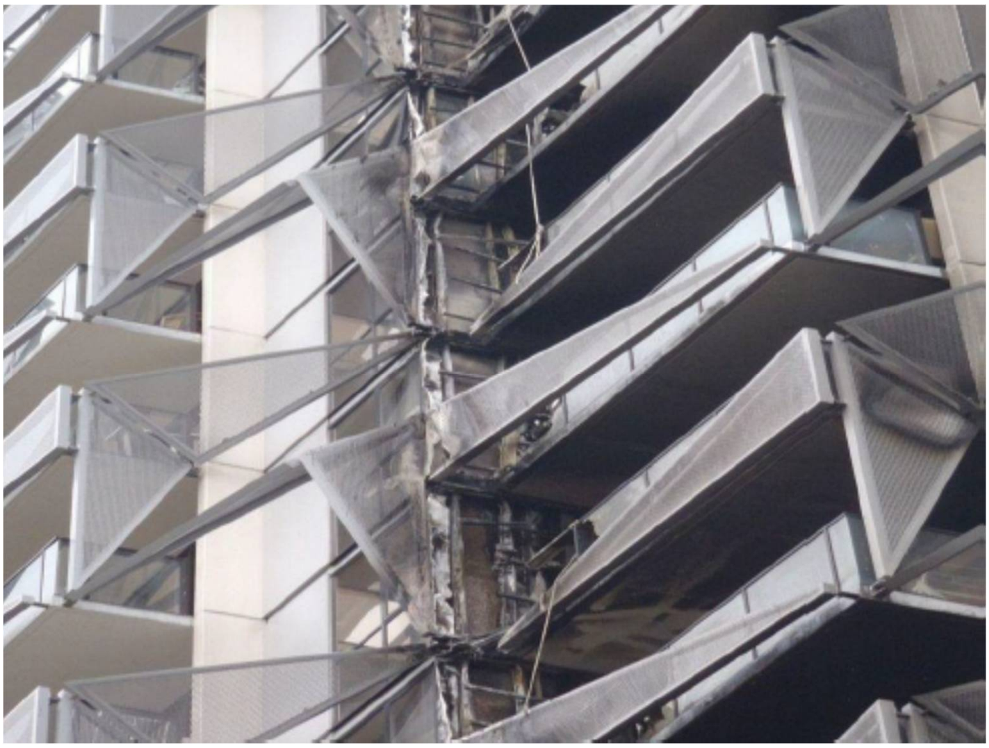


Figure 49. Lacrosse post fire damage (photo by MFB)

Figure 50. Lacrosse Inside kitchen of Apartment 805 (photo by MFB)

8.1.2 GRENFELL TOWER, LONDON, 2017, JUNE 14

The Grenfell Tower fire[61] is subject to ongoing investigations and inquiries. The Grenfell Tower Inquiry Phase 1 report[62] provides a detailed account of the fire and the issues that contributed to it. In the wake of this fire the UK has undertaken a review of building regulations and fire safety[63] which has led to some significant changes in regulation relating to combustible cladding

Grenfell Tower, part of Lancaster West Estate, was a council housing complex in north Kensington. It was a 24-storey, 67.3 m tall building comprising 20-storeys of residential SOU's and 4-storeys of community/office space at podium level. Later two of the lower levels were converted to residential. The total number of SOU's was 129. It was originally constructed in 1972-74 as a concrete construction.

Grenfell Tower underwent a major refurbishment completed in 2016 which included

- Hydronic heating system
- New windows with uPVC surrounds to floors 4-23 – these were moved outward so they no longer flush with concrete but flush with new cladding system and in many locations were smaller than original windows. This created gaps between the window frames which were sealed with uPVC (9.5 mm thick) and in some cases with expanding polyurethane foam, EPDM membrane (1 mm thick) or nothing (open gap) filling wall cavity to window frame gap behind.
- Spandrel and column insulation and cladding to floors 4-23 – PIR Insulation boards were directly fixed to the concrete exterior with two 80 mm layers of Celotex RS5000 PIR on spandrels and one 100 mm layer of Celotex RS5000 PIR on columns. Kingspan K15 PIR was also used in some limited areas. An ACP rainscreen cladding system manufactured from "Arconic Reynobond 55 PE" PE core ACP was installed to the columns and spandrels with a cavity between the ACP and the insulation which varied from 139 mm on the columns to 156 mm on spandrels.
- Cavity Barriers – Intumescent cavity barriers were installed but were not continuous as cladding support rails broke through them and in many cases were poorly installed with gaps between them
- Architectural crown – concrete beams and columns at the top of the building were wrapped in a band of tall, narrow Reynobond 55 PE ACM cassettes or "fins" which extended around the perimeter of the building above level 23. These were purely aesthetic.

- Smoke ventilation system – Due to heat build-up in lift lobbies, in normal mode fresh air ventilation was provided to lift lobbies on all floors via south shafts and warm air was expelled form lift lobbies on all floors via north shafts. In the event of smoke detected in a lift lobby dampers closed and fans operated so that smoke is exhausted from the lift lobby of first fire detection via north shafts with fresh air being drawn from the stairs. It was designed to operate in this mode on only one floor at a time.

On June 14 2017 the fire started at 12:54 am. It is considered to have started by an electrical fault in a Fridge-freezer in the kitchen of Flat 16 on the fourth floor. The fire is likely to have initially spread to the cladding/insulation cavity via the uPVC window jamb. The fire had spread to the cladding before fire fighters reached the room of fire origin at 1:14 am. Fire fighters initially suppressed the fire within the room of origin. The fire rapidly spread up the east face of the building, then spread around the top crown of the building in both directions and down the sides until flame fronts converged on the west face near the south-west corner, enveloping the entire building in under three hours. The vertical fire spread was enhanced within the cavity between the ACP and PIR (columns being the principle route of vertical fire spread) and via falling of molten flaming material to lower levels. The horizontal flame spread was enhanced by the crown feature and the wind conditions. Fire and smoke spread back into the building via broken windows, uPVC window surrounds and plastic based kitchen extractor fans. By 2:00 am the lobbies on a significant number of levels were heavily smoke logged and by 2:20 am smoke in the stair posed a significant risk to life. The fire brigade initially enacted a "stay put" strategy for occupants (which was standard practice at the time) and continued with this strategy until well after the fire and smoke compartmentation was breached on multiple levels.

There were 71 direct deaths and one additional death 7 months later (seriously effected by smoke inhalation but death not directly caused by fire), more than 70 injuries and 223 people escaped. The building was destroyed and will be demolished after inquiries have concluded.

The inquiry has identified that there were many layers of the fire safety strategy/system for this building which were deficient with no redundancy provided and contributed to the catastrophic outcome. These include:

- Fire sprinklers – Grenfell tower did not have fire sprinklers. This is not unusual in the UK as the vast majority of older high rise residential buildings do not have fire sprinklers, however they are required by the building code for new high rise residential buildings. Fire sprinklers when installed are highly effective at controlling or suppressing the fire to the room of fire origin and may have prevented spread to the cladding. However, sprinklers are not typically solutions to prevent fire spread back into the building in response to exterior fire spread on multiple levels.
- Combustible cladding and insulation – These were the main cause of rapid external fire spread.
- Cavity fire barriers – were poorly installed and failed.
- Fire and smoke compartmentation – the fire initially spread directly to the cladding cavity due to poor sealing/compartmentation around the windows. Fire and smoke then spread back in at multiple levels via windows and kitchen extraction fan units. Smoke spread to lobbies and eventually the fire stairs via doors that failed to self-close due to faulty closing devices, being broken down by fire fighters or wedged open by fire fighter equipment and evacuating occupants.
- Evacuation and fire brigade access provisions – The building had a single fire isolated stair.
- Fire brigade intervention –
    - The fire brigade enacted a "stay put" strategy and persisted with this strategy beyond the point where the fire and smoke compartmentation for the building had failed on multiple levels.
    - The inquiry identifies significant problems encountered with fire brigade communication.
    - The inquiry identifies some delays in arrival of a high ladder appliance and problems with mains water supply pressure.
    - Fire brigade access around the perimeter of the building was limited by surrounding buildings
- Gas supply shut-off – There were problems cutting off the supply of gas to the building. Gas was not cut off until 23:40

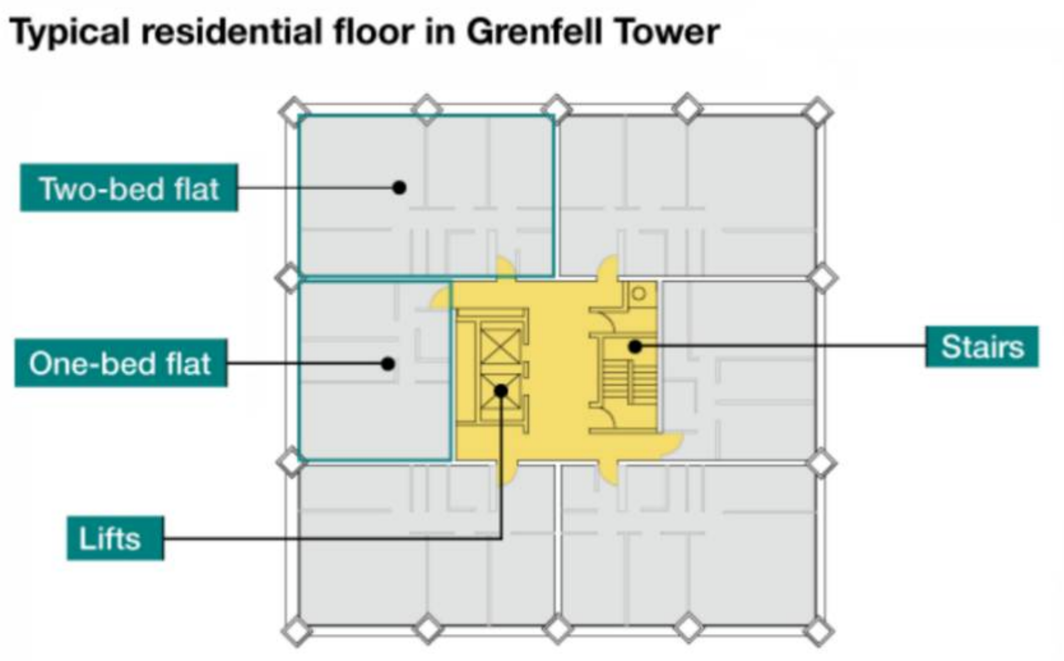


Figure 51. Grenfell tower typical residential floor layout (image from BBC News[64])

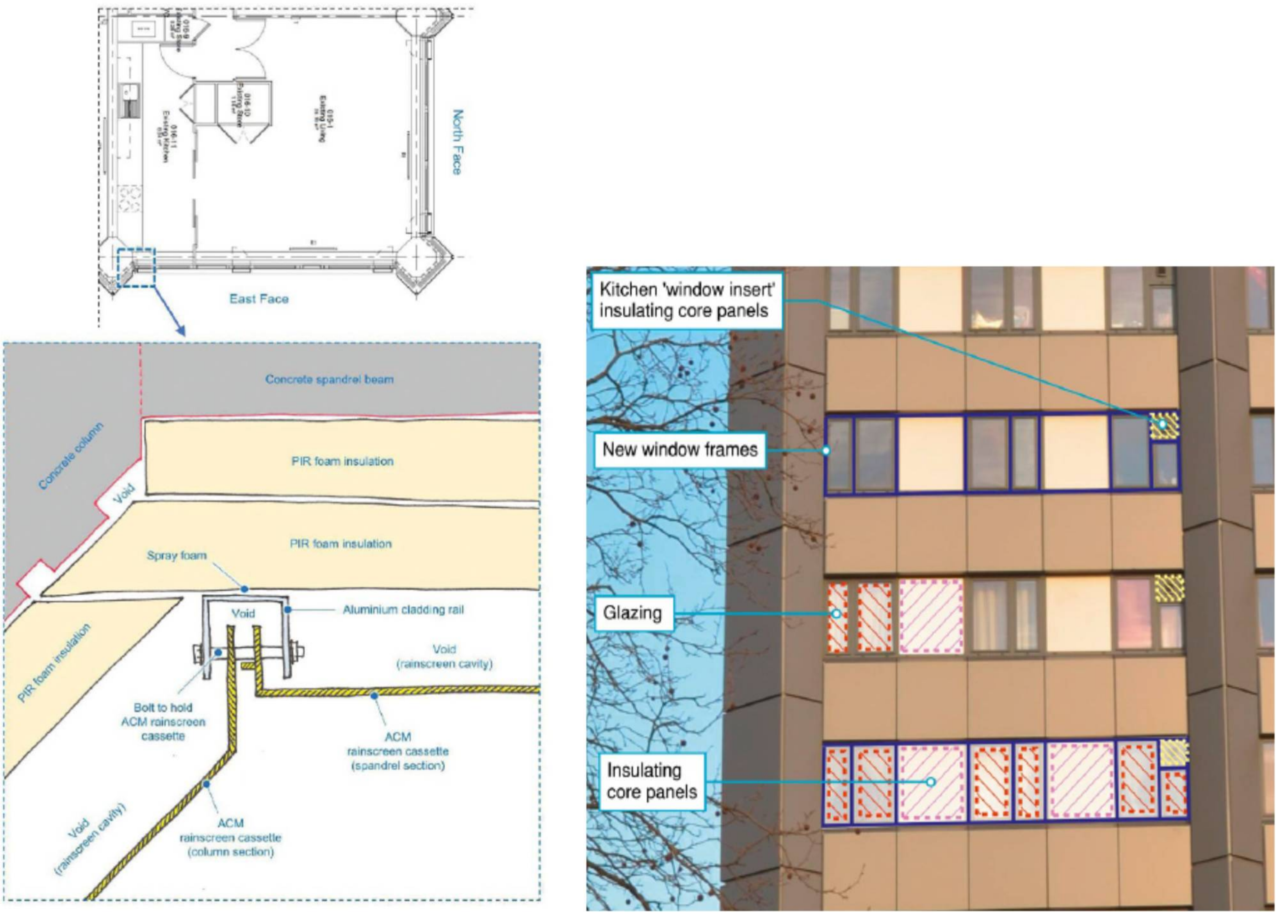


Figure 52. Grenfell tower cladding and insulation system arrangement (images from Grenfell Tower Inquiry Phase 1 report[62])

Figure 53. Grenfell tower fire spread (image from BBC News[64])

Figure 54. Grenfell Tower post fire damage (image from BBC News[64])

8.1.3 NEO200 FIRE, MELBOURNE, 2019, FEBRUARY 4[65-68]

Neo200 is 42 storey building located at 200 Spencer St Melbourne with entrances to both Spencer and Little Bourke Streets. It consists of

- Ground level - retail tenancies.
- Levels 1-7 – open deck car parking
- Level 8 – Podium level with common area facilities for resident use including an indoor heated pool & sauna, gymnasium, function room, BBQ area and outdoor terrace
- Levels 8- 41 – 371 residential apartments.

Designed by Hayball Architects, the building's construction was completed in 2007 by LU Simon builders. The fire safety engineer was Thomas Nicholas.

The building does not have a large coverage of combustible cladding installed. However, ACP is installed to the at least the following areas:

- Street level walls and awnings
- Level 8 podium/terrace walls
- Two single vertical strips (one on East elevation and one on West elevation) which extend vertically from Level 8 to top of building. These strips are external walls on balconies (forming one side of a vertical "U" shaped channel profile on building exterior).

Most of the rest of the building exterior appears to be concrete and glazing.

The building is sprinkler protected with no sprinkler protection to external covered balconies. The building is understood to be subject to fire engineered performance solutions which include two fire isolated stairs provided as a scissor stair arrangement and fire engineered smoke hazard management.

Newspaper reports state that from 2015 onwards (prior to the fire incident) the VBA had identified the presence of combustible cladding on the building, various authorities had assessed the risk of the combustible cladding to be Low to Moderate. A notice had been issued to the Owners Corporation requesting them to "show cause" why the combustible cladding should not be removed. A building order for minor works which required installation of additional fire detection and early occupant warning to apartments that could be directly affected by the ACP was also issued and completed. In addition, the building was added to the Metropolitan Fire Brigades (MFB) heightened fire response list for buildings with combustible cladding.

A detailed investigation report has not been publicly accessible, and the following account is based on newspaper articles which may have some inaccuracy.

- In early morning of 4 February 2019, a fire started on a Level 22 Balcony adjacent to the ACP Strip on the West (Spencer St) elevation. The fire was detected at ~ 5:43 am.
- Newspapers state that the cause of the fire was a cigarette. It appears that other combustibles were also stored on the balcony.
- The fire spread to the ACP vertical strip. Newspaper reports confirm this to be ACP-PE but do not provide details on other components of the wall system such as insulation. Based on photos the ACP clad walls were light weight steel framed construction.
- The MFB appear to have been notified early and responded with a heightened response of 15 fire trucks and approximately 60 fire fighters. The MFB arrived at the building FIP at ~ 5:50 am.
- MFB entered the building and promptly suppressed the fire by using internal fire hydrants and attacking from balcony levels above/adjacent to the fire location.
- By the time the fire was suppressed it had spread vertically on the ACP cladding to reach the 27th floor. Some flaming debris was reported but no significant secondary fires on levels below appear to have occurred.
- At least 200 residents were evacuated from the apartment tower.

Statements in newspaper reports indicate:

- Some ESM's including fire detection equipment.
- There were cases of apartments being over-occupied by multiple tenants.
- There were cases of occupants not evacuating promptly.
- The fire did not spread significantly internally on the levels affected however it appears balcony windows broke and sprinklers activated on multiple levels.

Although this fire incident provides another example of poor fire spread behaviour of ACP-PE, it also provides an example of how prior identification of combustible cladding risks on buildings, installation of appropriate interim safety measures including early detection and heightened/early response by fire brigades can have a positive effect on the fire incident outcomes.

Figure 55. NEO200 photos during fire and area of fire spread[66]

Figure 56. NEO200 post fire incident damage Left – Level 27 balcony, Right general area of ACP fire spread (MFB/AAP)

8.2 Key findings from review of past ACP fires

1. All fires identified appear to have involved ACP-PE. No fires identified in this report have been identified to involving ACP-FR, ACP-A2 or bonded laminated aluminium panels (as the key materials responsible for fire spread). However, the fire incident review is not exhaustive and not all fires are widely reported, this may particularly be the case for fires with minimal spread.
2. ACP-PE façade fires are commonly characterised by aggressive vertical fire spread to the top of the building (where successful fire brigade intervention does not occur) combines with large amounts of falling molten flaming debris which can start secondary fires on lower levels.
3. Most ACP-PE fires result in significant building damage and impacts to residents such as relocation until repairs are completed.
4. Fire safety systems in buildings are typically designed for internal building fires which start at a single location. ACP-PE façade fires which result in fire spread across multiple levels typically stretch other building fire safety systems such as sprinkler systems and evacuation systems beyond their designed mode of operation. Despite this, ACP façade fires do not always result in fatalities, particularly if other building fire safety systems continue to function beyond their intended design.
5. However, there have been some ACP façade fires with significant number of fatalities including Grenfell Tower, UK and Jecheon, South Korea.
6. Grenfell Tower provides an example of how a poor performing external wall system combined with deficiencies or lack of robustness of other fire safety systems and strategies for building can turn a fire incident which should be contained to the apartment of fire origin into a catastrophic event.
7. NEO200 provides an example of how prior identification of combustible cladding risks on buildings, installation of appropriate interim safety measures including early detection and heightened/early response by fire brigades can have a positive effect on the fire incident outcomes.

9 Summary Conclusions for each section

9.1 Types of ACP

1. Aluminium Composite Panel (ACP) was developed as an alternative to solid aluminum sheet and consists of a thin (~0.5 mm) aluminium sheet on the two external faces of the panel in composite with a lighter weight core material. This provides the benefit of reduced cost and mass to achieve a similar stiffness and look of solid aluminium sheet.
2. ACP has typically been installed as external wall cladding, canopies, signage and internal linings for buildings.
3. The most common type of ACP has a ~ 100% polyethylene core (ACP-PE) or polypropylene core (ACP-PP). Both polyethylene (PE) and polypropylene (PP) are thermoplastic materials, which exhibit melting and/or form flaming droplets when exposed to fire and have a very high heat of combustion, similar to that of gasoline**.** Ethylene-vinyl acetate (EVA) a very similar organic polymer is also common as the core polymer. Some panel core is a co-polymer of PE and EVA.
4. To improve fire performance of 100% PE ACP a variety of mineral fillers are typically added in varying concentrations. These typically include one (or a mixture) of the following most common minerals:
    a. Aluminium Hydroxide – an active fire retarded that endothermically decomposes producing water vapour. Gibbsite mineral is the common source and usually has few impurities.
    b. Magnesium Hydroxide – an active fire retarded that endothermically decomposes producing water vapour. Brucite is the common source and usually has other minerals present such as talc and calcium carbonate.
    c. A range of inert minerals such as Talc and calcium carbonate.
5. The proportion of mineral filler of an ACP organic polymer core varies greatly however these can be grouped based on industry product naming. The following list is in order from worst to best fire performance.

Common naming	**Typical organic polymer content (mass%)**	**Typical gross heat of combustion (MJ/kg)**	**ICA ACP risk categories**		**BRE ACP categories**	
			category	**Organic polymer content (mass%)**	**Category**	**Gross heat of combustion** Note 2 **(MJ/kg)**
PE	~ 100%	~46	A	30-100%	3	> 35 MJ/kg
FR	~ 30%	~13	B	8-29%	2	> 3 MJ/kg and ≤ 35 MJ/kg
A2	~5-7%	~2-3	C	1-7%	1	≤ 3 MJ/kg
Non-combustible Note 1	~0%	~0	D	0%	-	-

Note 1- Non-combustible is defined by NCC BCA 2019 Vol1 as not deemed combustible as determined by AS 1530.1. Organic polymer content (5) is not a measure of NCC BCA DtS compliance.

Note 2 – Gross heat of combustion as determined in bomb calorimeter ISO 1716:2002

This grouping has resulted from outcomes of international test requirements, the Building Research Establishment / Department for Communities and Local Government (BRE/DCLG) research which flowed into the protocol published by the Insurance Council of Australia (ICA), Fire Protection Association Aust (FPAA) and Engineers Australia (EA) hence forth known as the ICA protocol.

6. Bonded laminated materials are regulated by NCC BCA 2019, Vol 1 clause C1.9 e(vii). Some cladding materials achieve compliance via this clause. They typically comprise of thin (~0.5 mm) aluminium external facings with a thin aluminium core, consisting of either a "honeycomb" or an "egg box" profile that creates a significant volume of air pockets within the core. These are bonded together with a thin (less than 1 mm) layer of adhesive. The quantity of combustible material per unit area is relative to the thickness of the adhesive and is substantially less that ACP-PE. Typical ACP with 3 mm thick combustible core does not comply with NCC BCA 2019, Vol 1 clause C1.9 e(vii).
7. ACP with other core material types have been used to a lesser extent in Australia. One example is ACP with a core of cellulose fibre mixed with phenolic resin.
8. ACP is one *product* which forms part of a wall *system*. The polymer is a *material* that is used in the construction. Test methods are suitable for a *materials, product* or *system* and have differing pros and cons for regulation and assessment of risk.

9.2 NCC BCA requirements

1. The NCC BCA is a performance-based building code which permits compliance with *Performance Requirements* either via *Deemed-to-Satisfy (DTS)* provisions or *Performance Solutions* (based on adequate fire engineering assessment).
2. NCC BCA DTS provisions require that external walls for Class 2-9 Type A and B construction must be non-combustible. This has been a DTS requirement for more than the past two decades.
3. NCC 2016 and prior versions did include a DTS Specification C1.1, Clause C2.4 which permitted attachments to external walls to be combustible subject to satisfaction of additional criteria including fire hazard properties, potential to make exits unusable and an assessment that the attachment does not "*constitute an undue risk of fire spread to the façade".* BCA 2016 Amendment 1 and BCA2019 effectively delete this clause and replace it with a clause clarifying that an attachment is not to reduce the FRL of the building element to which it is attached (without reference to permitting combustible attachments).
4. BCA 2019 Clause C1.9 lists a number of materials that may be used wherever non-combustible materials are required. BCA 2019 Clause C1.14 lists ancillary elements (signs, awnings etc) which are permitted to be attached to an external wall that is required to be non-combustible. ACP with a 3 mm thick combustible core used for external wall cladding is not permitted by either of these clauses.
5. External walls for Type C construction and Class 1 and 10 buildings have significantly less stringent, to no reaction to fire requirements and combustible ACP is typically not prohibited by DTS provisions (except where proximity to adjacent buildings or location within a bushfire prone area provision applies).
6. Based on outcomes of the Victorian State-Wide Cladding Audit the use of combustible ACP for Class 2-9 Type A and B construction has proliferated over the past 2 decades, often without any DTS non-compliance being identified or Performance Solution being documented for approval of the building.
7. Since 2018 the NCC BCA Vol1 has been amended to clarify DTS requirements for non-combustible external walls and include CV3 as a non-mandatory *Verification Method* for *Performance Solutions* which sets requirements for full scale façade fire test AS 5113 EW classification in combination with additional sprinkler protection and cavity barriers.
8. A number of other DTS provisions (or building fire strategy components) that are prescribed to a particular building, influence the risk related to external wall fire spread. These include sprinkler protection, cavity barriers, separation of vertical openings, separation between buildings and compartmentation etc. However, reaction to fire of the external wall system must be considered the primary preventative control against external wall fire spread hazard.

9.3 Australian State-based bans, ministerial guidelines and the like applied to ACP

1. Section 4 of this report provides a summary of the current (as of 1/11/2019) Australian Federal and State based bans, ministerial guidelines and the like acting to limit the use of combustible ACP. It also provides a review of the cladding audits and other inquiries.
2. New South Wales, Queensland, Victoria and Western Australia have already introduced bans, ministerial guidelines or other state-based regulation which act to limit the availability or use of combustible ACP. The details of these state-based bans/guidelines vary including:
    a. PE content criteria of more than or equal to 30%
    b. Application to just Class 2-9 Type A and B construction, or other classes and types of construction.
3. Existing state-based ACP bans, ministerial guidelines or other regulations essentially do either or both of the following:
    a. Reinforce/restate NCC BCA 2019 Vol 1 DTS requirements which already prohibit the use of combustible cladding on external walls for Type A and B construction. An exception is the Queensland ACP ban, which came into effect October 2019, which limits ACP use beyond NCC BCA 2019 DTS requirements as it bans more than 30% PE from external walls applicable to all classes and types of construction including Type C and Class 1;

       and/or

    b. Imposes restrictions on the types of materials that are permissible for performance-based solutions. For example, bans act to exclude more than 30 % PE ACP use via performance-based solutions or (in the case of Western Australia) requires NCC BCA 2019 Vol 1 CV3 to be applied and no other form of performance-based assessment is accepted.
4. ACP bans, In-practice, primarily act to prevent use of banned materials on new construction or refurbishments. They do not generally automatically require removal/replacement of banned materials from existing buildings. In some cases, the bans may legislate or facilitate identification of existing buildings with ACP and determination of any remedial action required. For example, in the case of NSW, existing buildings identified to have banned ACP are issued an “affected building notice” and relevant Authorities then determine if any further remedial action is required.
5. ACP bans act to prohibit or limit use for combustible ACP types which are already non-compliant under NCC BCA Vol 1 DTS requirements for Type A and B construction.
6. Based on the Victorian state-wide cladding audit it is evident that where ACP-PE has been installed on existing Type A and B construction, often the DTS non-compliance has not been identified or performance solutions provided in building approval documentation. The Victorian Government issued the Ministerial Guideline 14 (MG-14) that prohibits a relevant building surveyor in approving a building of Type A or B construction that includes a Prescribed Combustible Product as part of their external wall system (including attachments), unless the building permit includes a determination from the Building Appeals Board that the Prescribed Combustible product complies with Act and Regulations. A Prescribed Combustible Product is identified as an ACP core with greater than or equal to 30% PE by mass, or Expanded Polystyrene (EPS) used as an insulation and finished system.
7. While the 2017 Interim Senate report on non-conforming building products “Aluminium composite cladding”, recommended a ban on PE ACP, subsequent reports such as the Shergold-Weir report (2018) and the final Senate report on non-conforming building products (2018) have not directly recommended a ban on ACP but have made numerous recommendations focused on rectification or elimination of root causes which have led to proliferation of non-compliant building product use. These focus on:

a. Registration and training of practitioners.
b. Integrity of private building surveyors.
c. Role and responsibilities of regulators and fire authorities.
d. Adequacy of, collection, sharing and post construction information management of building design, construction and approval documents.
e. Inspection regimes.
f. Addressing product safety via establishment of a compulsory product certification system for high risk building products.
g. National uniformity of approach to the above items administered by different states and jurisdictions

8. The Building Ministers Forum (BMF) is considering recommendations relating to establishment of a compulsory product certification system for high risk building products. However, such a system has not been enacted and no detailed framework for such a system has been released at this time.
9. ACP bans, guidelines or regulations generally focus on restrictions based on PE or polymer content (mass%) of the core *material*. This does not capture all other combustible polymers (EVA, phenolic etc.) that may potentially be used in ACP. Therefore, it may be more sensible to state such restrictions based on filler content (mass %) or on Gross heat of combustion (kJ/m^3).
10. However, stating restrictions based on filler content (mass %) does not capture the difference between "inert" fillers such as talc and "active fire retardant" fillers such as magnesium hydroxide or aluminium hydroxide and the impact that the ratio of these components may have on overall reaction to fire.
11. ACP bans, guidelines and the like recently introduced to Australia apply core PE content (mass%) as the criteria for restriction of new ACP use. The value is not a direct measure of fire behaviour and is a proxy for the fire risk of the material. The test methods, procedures and/or measurement uncertainty to be applied to determine PE content is not stated. A range of material characterisation methods typically applied to ACP cores are reviewed in Section 6. These methods are not defined by specific test standards to the same degree as existing small-scale and full-scale reaction to fire test. Currently different laboratories apply different material characterisation test methods and may also apply different laboratory procedures to the various test methods. The different methods and procedures have differing limitations and may result in some variation of accuracy/uncertainty.
12. Material characterisation tests to determine composition of ACP cores were introduced in Australia as a means of cost-effectively determining the type of ACP core installed to existing buildings (due to poor or unavailable construction records). For existing buildings this provides a practical way to roughly indicate the fire risk of installed ACP material via the Insurance Council of Australia (ICA) risk protocol. The ICA protocol ACP polymer content categories are very roughly (but not directly) aligned/correlated with EN13501 classifications.
13. The ICA protocol is a guide for preliminary risk assessment. The approved testing laboratories listed by the ICA contributed to a testing round robin set up by the ICA. The rigor of the round robin and ICA acceptance of the laboratories is relevant to the ICA objectives and guidelines and may not be relevant to the rigor required for regulatory compliance testing.
14. Assessment of core composition in this manner should be considered as only a proxy for, or an approximate indicator of likely small-scale reaction to fire tests. Small-scale reaction to fire test should only be considered as rough indicators (with significant limitations) of full-scale façade system performance.
15. CSIRO does not recommend any reduction of the existing NCC BCA 2019 Vol 1 DTS external wall requirements for Type A and B construction from the current non-combustibility requirements, as

these are suitably conservative for materials. CSIRO also does not suggest or recommend that new BCA DtS small scale reaction to fire test methods are required to regulate combustible ACP. However based on the above, If ACP bans are to be introduced, then it may be more sensible to either align the ban criteria with existing NCC BCA Vol 1 DTS requirements, or at minimum, apply the established small-scale reaction to fire tests (such as 1530.1, EN13501 classifications , ISO 1716:2002 or others) to impose any bans or revised regulations for new ACP cores in preference to measurement of core composition.

16. Bans which do not align directly with NCC BCA Vol 1 DTS requirements may have an unforeseen potential to result in some level of confusion for industry practitioners and broader society. Banning a group of products also implies acceptance of products not falling within the ban scope. ACP products not banned by the existing state-based bans may still fail to meet BCA DTS Non-combustibility requirements for Type A and B construction and are not compliant without an adequate performance-based solution. Any such confusion may impact on the selection of ACP products for new buildings and rectification of existing buildings where combustible cladding is being replaced.
17. The Shergold-Weir report (2018) identifies the root causes inherent to our building industry practises which have led to non-compliant ACP use proliferation. These root causes stem from inadequacies of licensing, education, training and competencies of building practitioners which lead to issues with integrity of to quality control, certification integrity and import of This ACP bans do not act to rectify these root causes which could potentially lead to future similar problems with non-compliant use of other products.

9.4 Reaction to fire tests applicable to ACP

1. The range of reaction to fire tests applied to ACP both in Australia and overseas (UK, US and NZ) have been reviewed.
2. Reaction to fire tests applicable to ACP can be broadly grouped into the following categories:
    a. Small-Scale – Fire tests on small specimens of material. The tests do not directly represent end system behavior and only measure limited aspects of reaction to fire behavior of a material under specific test conditions. Test exposure conditions often have reduced severity and do not directly correlate to possible real fire scenarios.
    b. Room corner fire tests - Intermediate scale internal tests typically applied to assess internal wall and ceiling lining product performance and not directly applicable to external walls. An example is the ISO 9705 test.
    c. Intermediate-scale –External wall Fire tests on specimens that attempt to represent the end wall system configuration of materials with a limited height/extent specimen. They typically apply a small-medium fire exposure scenarios that do not represent post flashover enclosure fires. Other than the ISO 9705 room corner test (for internal wall and ceiling linings) the NCC BCA does not reference any intermediate fire tests. International examples are the ISO 13785-1 and Factory Mutual Global (FM) 16 ft parallel panel tests.
    d. Large-scale – External wall fire tests on complete wall systems representing end use configuration over sufficient height to confirm if vertical fire spread will occur. Apply large ignition sources representing large external fires or post flashover compartment fires. These are more expensive than small and intermediate scale tests.
3. Small scale tests are the least expensive tests and can be used to regulate fire performance of materials, but require conservative, strict acceptance criteria to account for the above limitations. An example of this is the AS 1530.1 combustibility test.
4. The cone calorimeter testing can provide a useful measurement and comparison of ignition time and Heat Release Rate per unit area (HRRPUA) for different grades of ACP under different imposed radiant heat flux exposures. However, it does not directly indicate full façade system behavior. Tests must be done with aluminium skin removed as this will typically reflect radiant heat and prevent ignition of core. Test heat flux can be varied from 0-100 kW/m2 with 50 kW/m^2 being the

most typical test heat flux. Post flashover or large ignition fire scenarios with direct flame impingement may result in higher heat fluxes of the order of 100-200 kW/m^2.

5. The AS 1530.3 test has a low radiant heat flux exposure of 25 kW/m^2 maximum and has mostly been applied to ACP with aluminium skin in place in the past. This has resulted in very good test result indices being achieved by ACP-PE which are misleading and do not properly categorize the risk. This test fails to discern the hazardous fire behavior of ACP-PE and is not suitable for application to these types of materials.
6. Full-scale façade fire tests are the only tests that directly demonstrate reaction to fire of the **complete** façade system and interaction of components in response to a large fire exposure scenario. This makes them the most suitable type of test for accessing façade fire behaviour for a range of fire scenarios.

9.5 Material Characterisation testing for ACP.

1. The purpose of material characterization testing of ACP is either to determine the material composition of the core or apply other small-scale reaction to fire tests such as the bomb calorimeter that may be used to characterize the core.
2. Material characterization tests do not directly predict the fire risk associated with a complete combustible façade system.
3. Material characterization tests were originally introduced in Australia as a means to quickly sample ACP from existing buildings and determine the type of ACP installed (as records of ACP installed on existing buildings are often poor). It was not originally intended to be used for control or regulation of new ACP product.
4. There are a range of different materials characterization test methods than can be applied. Different laboratories in Australia currently apply different test methods.
5. There is no Australian standard for sampling and material characterization testing of ACP for existing buildings which specifies which test methods are to be applied and what level of accuracy is to be achieved.
6. Material characterization methods reviewed include:
    a. On site screening - rudimentary methods such as visual inspection of core colour, core density tests or small flames applied to a sample of exposed core. These tests are only suitable as a preliminary indication if the core is 100% PE. As 100% PE is the core type of worst fire performance this it may be reasonable to assume a core is 100% PE based on such indicative testes however these tests are not conclusive. If they identify that some amount of mineral filler may be present, then further quantitative laboratory testing is required.
    b. Ash content test – measures Ash mass%
    c. **Thermal Gravimetric Analysis (TGA)** and **Differential Scanning Calorimetry (DSC)** – Measure ash mass%, distinct mass loss and heat flow changes at specific temperatures
    d. **Attenuation Total Reflectance – Fourier Transform Infrared Spectroscopy (ATR-FTIR)** – Identifies chemical components but does not provide quantities
    e. **X-ray diffraction crystallography (XRD)** – Identifies and quantifies crystalline materials
    f. **X-ray fluorescence (XRF)** – identifies and quantifies elemental (not chemical) composition
    g. **Scanning electron microscope (SEM) with Energy Dispersive X-Ray Spectroscopy (EDS)** – provides high resolution imaging and identifies and quantifies elemental (not chemical) composition
    h. Bomb Calorimeter – measures gross heat of combustion
7. Each of the above test methods has differing limitations and uncertainty. Often multiple test methods must be used together to give a suitable level of confidence and accuracy as no one method alone is definitive.
8. Based on statistical review of a limited set of material characterization tests of ACP by CSIRO:
    a. 48% (116/244) samples were 0-25 mass% mineral (100-75 mass% organic polymer).
    b. 1% (3/244) samples were 25-55 mass% mineral (75-45 mass% organic polymer).

c. 24% (59/244) samples were 55-70 mass% mineral (45-30 mass% organic polymer).
d. 26% (64/244) samples were 70-85 mass% mineral (30-15 mass% organic polymer).
e. 1% (2/244) samples were 85-100 mass% mineral (15-0 mass% organic polymer).

9. It is expected that ~ 100% PE ACP is more prevalent in existing buildings than indicated above as often these samples would be excluded from being sent to CSIRO for further testing based on onsite inspection or screening tests by others.
10. There is a significant proportion of ACP (tested by CSIRO mainly from existing buildings) that falls within the 45-30 mass% polymer (55-70 mass% mineral) range. These are expected to have significantly improved reaction to fire performance compared to ~100% PE ACP but these would still be ranked as ICA Cat A.
11. A significant number of samples are very close to the 70% line which means the uncertainty range of the method/laboratory becomes a significant issue.
12. ACP-A2 appears to be rare in existing buildings (this may be changing as new buildings are constructed)

9.6 Known Performance of ACP in fire tests.

1. ACP-PE, ACP-FR and ACP-A2 are all typically deemed combustible when tested to AS 1530.1. This test and its acceptance criteria have been chosen as a conservative DTS requirement and is not intended to measure a difference in fire performance between these different grades of ACP.
2. The bomb calorimeter measures a difference between the different grades of ACP with the gross heat of combustion being approximately proportional to the PE or EVA mass% content.
3. The cone calorimeter applied to bare exposed core measures a difference between the different grades of ACP. Time to ignition generally decreases and HRRPUA generally increases with increasing polymer content.
4. AS 1530.3 test has a low radiant heat flux exposure of 25 kW/m^2 maximum and has mostly been applied to ACP in the past with aluminium skin in place which protects the polymer core resulting in very good test results being achieved by ACP-PE. This test does not discern the hazardous fire behavior of ACP-PE and is not suitable for application to these types of materials.
5. ISO9705 room corner fire tests have been applied for ACP for the purposes of internal wall and ceiling linings. This does not assess performance of a complete façade system combined with other materials such as cavity insulation. However, this test has discerned a difference in performance for the different ACP grades as follows:
    a. ACP-PE – Group 3 result (flashover within 2-10-minute exposure of 100 kW burner)
    b. ACP-FR – Different products have achieved either:
        i. Group 2 (flashover within 10-20 minutes during 300 kW burner)
        ii. Group 1 (no flashover but elevated total HRR compared to ACP-A2)
    c. ACP A2 – Group 1 (no flashover)
6. Intermediate scale façade tests such as ISO 13785-1 and FM 16 ft parallel panel test have measured a difference between ACP-PE (and ACP-PP), ACP-FR with combustible insulation, ACP-FR without combustible insulation, ACP-A2 with combustible insulation and ACP-A2 without combustible insulation.
7. The ISO 13785-1 ignition source of 100 kW is too small to represent a large ignition fire scenario.
8. Intermediate scale tests demonstrated:
    a. ACP-PE (and ACP-PP) is by far the worst performer with fast, aggressive ignition and fire growth resulting in very high HRR.
    b. ACP-FR performs significantly better than ACP-PE with delayed ignition and fire growth and limited fire spread, resulting in a measurable but low HRR
    c. ACP—FR when combined with combustible insulation in the cavity behind still performs significantly better than ACP-PE but exhibits an increase in HRR which appears to be due to not just the burning of the insulation but a possible enhancement of burning between the ACP-FR and the insulation in the vertical cavity arrangement.

d. ACP A2 generally performs well exhibiting limited HRR or flame spread even when combined with PIR or phenolic insulation.

9. FM Global has identified a possible limitation of the **National Fire Protection Association (NFPA)** 285 full scale façade test possibly passing some external wall systems that would not pass other international test method such as BS8414/BR135. They have concluded that the FM 16 ft parallel panel test may provide a better test for ACP wall systems as it provides a higher and more suitable heat flux exposure.
10. The BRE/DCLG post Grenfell BS8414 tests provide the best publicly available evidence of the fire performance of the different grades of ACP in combination with combustible and non-combustible insulation. These indicate that:
    a. ACP-A2 passed the BRE135 criteria when tested with PIR insulation or with mineral wool insulation. It did not support any significant flame spread beyond the crib impingement area.
    b. ACP-FR with MW insulation passed the BRE135 criteria but did support some flame spread beyond the crib impingement area and some flaming debris, however this was significantly less compared to ACP-PE.
    c. ACP-FR with PIR or Phenolic insulation did not pass the BRE135 criteria. These showed some enhancement of fire spread and resulting fire size, compared to ACP-FR/MW, due to burning of the insulation within the cavity and this possibly enhancing the burning of the ACP-FR. Both tests failed BR135 classification criteria due to flames extending above the top of the test rig (however temperature criteria which only apply during the first 15 minutes of test were not exceeded. Fire spread was significantly less aggressive and was delayed compared to ACP-PE tests.
    d. ACP-PE supports aggressive vertical fire spread, with significant flaming debris and formation of pool fires, regardless of the type of insulation behind. Flames extended several meters above the test rig at the time of early test termination. This demonstrates that ACP-PE clearly has unacceptable façade fire performance.
    e. The above tests all included mineral wool cavity barriers. Results may vary without cavity barriers. This may be of particular concern for ACP-FR combined with combustible insulation.

9.7 Past fire incidents involving ACP.

1. This report has reviewed numerous façade fire incidents involving ACP from around the world.
2. Lacrosse Docklands, Grenfell Tower UK and NEO200 Spencer street are key incidents which have had a critical impact on Australian awareness and regulatory authority actions on ACP in Australia.
3. All fires identified appear to have involved ACP-PE. No fires with significant (multi-level) fire spread have been identified involving ACP-FR, ACP-A2 or bonded laminated aluminium panels (as the key materials responsible for fire spread). However, the fire incident review is not exhaustive and not all fires are widely reported or have detailed investigation.
4. ACP-PE façade fires are commonly characterised by aggressive vertical fire spread to the top of the building (if successful fire brigade intervention had not occurred) combined with large amounts of falling molten flaming debris which can start secondary fires on lower levels.
5. Most ACP-PE fires result in significant building damage and impacts to residents such as evacuation until repairs are completed.
6. Fire safety systems in buildings are typically designed for internal building fires which start at a single location and are often contained to the fire compartment or level of origin. ACP-PE façade fires which result in fire spread across multiple levels typically stretch or overwhelm other building fire safety systems such as sprinkler systems and evacuation systems beyond their designed range of operation as well as fire brigade response. Despite this, ACP façade fires do not always result in fatalities, particularly if other building fire safety systems continue to function beyond their intended design.

7. There have been some ACP façade fires with significant number of fatalities including Grenfell Tower, UK and Jecheon, South Korea.
8. Grenfell Tower provides an example of how a poor performing external wall system combined with deficiencies or lack of robustness of other fire safety systems and strategies for building can turn a fire incident which should be contained to the apartment of fire origin into a catastrophic event.
9. When compared to Grenfell Tower, NEO200 had a relatively small coverage of ACP limited to isolated vertical strips. However the NEO200 provides an example of how prior identification of combustible cladding risks on buildings, installation of appropriate interim safety measures including early detection and heightened/early response by fire brigades prevented further fire spread that had a positive effect on the fire incident outcomes.

10 General Conclusions

1. The most common type of ACP previously used in Australia has an organic polymer core of polyethylene or ethylene vinyl acetate. In some cases, mineral filler is mixed with the polymer to improve reaction to fire behaviour.
2. ACP can be grouped based on polymer mass% content or gross heat of combustion (MJ/kg). The groupings in order from highest polymer content (worst performance) to lowest polymer content are defined by the Insurance Council of Australia risk ranking and are commonly named ACP-PE (~100% polymer), ACP-FR (~30% polymer) ACP-A2 (~5-7% polymer) and non-combustible.
3. NCC BCA DTS Vol 1 provisions have required that external walls for Class 2-9 Type A and B construction must be non-combustible. This has been a DTS requirement for more than the past two decades.
4. Based on outcomes of the Victorian State-Wide Cladding Audit the use of combustible ACP for Class 2-9 Type A and B construction has proliferated over the past 2 decades, often without any DTS non-compliance being identified or performance solution being provided for approval of specific buildings.
5. Small-scale tests on individual materials do not directly predict real fire behavior of complete façade systems but can provide initial risk ranking of the individual material components.
6. Small scale tests are the least expensive tests and can be used to regulate fire performance of materials, but require conservative, strict acceptance criteria to account for the above limitations. An example of this is the AS 1530.1 combustibility test.
7. A review of published small, intermediate and full-scale fire tests on ACP external wall systems has concluded the following:
    a. ACP-PE supports aggressive vertical fire spread, with significant flaming debris and formation of pool fires, regardless of the type of insulation behind. ACP-PE clearly has unacceptable façade fire performance.
    b. ACP-FR combined with non-combustible insulation and cavity barriers can support some very limited fire spread and flaming debris but has passed BS8414 BR135 full scale façade test criteria (may not pass AS 5113 criteria relating to debris etc.). Intermediate and full scale tests reviewed indicate that ACP-FR combined with substrate and cavity materials of limited combustibility do not appear to represent a risk of rapid vertical fire spread away from the area of fire origin This indicates that, particularly where installed to existing buildings, fire behavior may be adequate on a performance solution or risk basis.
    c. ACP-FR combined with combustible PIR or phenolic insulation and cavity barriers demonstrated some enhancement of fire growth (although still significantly less than ACP-PE). This failed BS8414 BR135 full scale façade test criteria. It is possible that other types of combustible insulation such as polyester batts and EPS boards may adversely affect the fire performance of ACP-FR wall systems however published tests specifically investigating these combinations were not found or summarized in this report. This indicates that such a system is unlikely to be suitable for new buildings and care should be taken when undertaking performance-based assessment of such systems on existing buildings, particularly where cavity barriers are not installed.
    d. ACP-A2 passed the BRE135 criteria when tested with PIR insulation or with mineral wool insulation. It did not support any significant flame spread beyond the crib impingement area. This indicates that this material is likely to be acceptable on a performance basis for new or existing buildings. However ACP-A2 wall systems may not pass AS5113 requirements for mass of debris.
8. Review of ACP external wall fire incidents around the would re-enforce the conclusion that ACP-PE has unacceptable façade fire performance, with fire incidents commonly characterised by aggressive vertical fire spread to the top of the building (where successful fire brigade intervention

does not occur) combines with large amounts of falling molten flaming debris. No significant fire incidents involving ACP-FR, ACP-A2 or bonded laminated aluminium panels were identified.

9. The various types of testing that may be applied for regulation of ACP, can be prioritised based on direct prediction/correlation to real fire scenario performance in the following order (from most relevant to least):
    a. Full scale façade fire testing applied to complete system
    b. Intermediate scale façade fire testing applied to complete system
    c. Small scale reaction to fire tests (on each material component including bare exposed core)
    d. Material characterisation tests to determine core composition
10. ACP core material characterization testing (to quantify the core chemical composition) and the ICA risk ranking protocol were originally introduced in Australia as a means to quickly sample ACP from existing buildings and determine the type of ACP installed. It was not originally intended to be used for control or regulation of new ACP product.
11. There are a range of different materials characterization test methods than can be applied. Different laboratories in Australia currently apply different test methods. There is no Australian standard for sampling and material characterization testing of ACP for existing buildings which specifies which test methods are to be applied and what level of accuracy is to be achieved.
12. NSW, Queensland, Victoria and Western Australia have introduced bans, ministerial guidelines or other state-based regulation which act to limit the availability or use of combustible ACP with ~more than 30% PE content.
13. Existing state-based ACP bans, ministerial guidelines or other regulations essentially do either or both of the following:

    a. Re-in force/re-state NCC BCA 2019 Vol 1 DTS requirements which already prohibit the use of combustible cladding on external walls for Type A and B construction. An exception is the QLD ACP ban , which came into effect Oct 2019, which limits ACP use beyond NCC BCA 2019 DTS requirements as it bans more than 30% PE from external walls applicable to all classes and types of construction including Type C and Class 1;

    and/or

    b. Imposes restrictions on the types of materials that are permissible for performance-based solutions. For example, bans act to exclude more than30 %PE ACP use via performance-based solutions or (in the case of Western Australia) requires NCC BCA 2019 Vol 1 CV3 to be applied and no other form of performance based assessment is accepted.

14. The following potential issues have been identified for the state-based ACP bans:
    a. The bans do not align with NCC BCA 2019 DTS requirements. ACP products not banned by the existing state-based bans may still fail to meet NCC BCA DTS Non-combustibility requirements for Type A and B construction and are not compliant without an adequate performance-based solution
    b. There are some inconsistencies in detail between the different state bans.
    c. They state restrictions based on PE content (mass%). This does not capture all other combustible polymers that may potentially be used in ACP.
    d. They do not define the Material characterisation test methods or measurement accuracy that are to be applied. Methods (and possibly resulting accuracy) used between different labs currently varies.
    e. ACP bans do not directly address root causes of noncompliant product use and therefore may not prevent similar issues with other types of non-compliant product in future.
15. There is a significant proportion of ACP (from samples from existing buildings) that fall within the 30-45% polymer (55-70% mineral) content range. These are expected to have significantly improved reaction to fire performance compared to ~ 100% PE ACP, but these would still be ranked as ICA Cat A. Information reviewed in this report has not identified any testing or research which focuses specifically on understanding the fire performance of this range of ACP. Such understanding would be valuable for development of suitable performance solutions for rectification where such ACP is present on existing buildings.

16. A distinction should be made between performance solution assessment of ACP for new and existing buildings:
    a. For new buildings:
        i. Given the evidence presented above it would be most prudent to either comply with BCA DTS or apply combustible ACP as part of a complete external wall system as a performance solution for type A or B construction only where it is supported by an acceptable level of full-scale façade fire test performance, as is the case of ACP-A2 systems tested under BS 8414 BRE135 (but may not meet acceptance criteria under AS 5113.1 mainly due debris criteria).
        ii. ACP-FR when combined with combustible insulation or other combustible materials can exhibit an enhancement of fire spread. Whilst this still performs significantly better than ACP-PE, unless an appropriate full scale façade fire test demonstrates acceptable performance for a specific FR wall system with combustible insulation, it would be prudent to avoid use of this material for new buildings in cases where it is combined with combustible insulation or cavity barriers are not installed without .
        iii. ACP-PE clearly has unacceptable external wall performance and should not be used on new buildings for this purpose.
    b. For existing buildings.
        i. A careful assessment of cost vs benefit/risk of cladding rectification performance solutions on a SFAIRP basis is recommended.
        ii. Where full scale façade tests are not available for the specific installed system, testing to identify core composition, cavity materials and fixing/construction details combined with comparison against limited available published full and intermediate scale façade fire test data for similar systems may provide a rough indication of expected performance.
        iii. However, based on holistic fire engineering assessment of the extent, location, orientation of cladding, ignition source hazards and other building fire safety systems, there may be cases where poorer performing existing external wall systems (such as ACP-PE or ACP-FR with combustible insulation) may be assessed as suitable for retention on a risk and cost basis. This would typically require limited continuity and extent of such wall systems.

11 Knowledge gaps and recommendations for further research.

The following knowledge gaps related to ACP fire performance and recommendations for further research to close these gaps have been identified. They mostly relate to providing publicly available test data to aid risk assessment and rectification of existing buildings.

1. A range of ACP wall systems including different ACP core types, different fixings and construction and different cavity insulation and other materials have been used on Australian buildings. It would be highly beneficial to industry to have a suite of publicly available 'common wall systems' comprising various ACP types, insulation, cavity barriers and substrate configurations tested to AS 5113 and/or intermediate scale façade fire tests. This may be similar to the suite of tests undertaken by BRE post Grenfell, but more specifically tailored to the Australian built environment and code requirements – for example cavity barriers are rarely observed in existing buildings in Australia. Other types of insulation used in Australia including Polyester blanket and foil faced polystyrene board could be considered for inclusion.
2. There are several examples of existing buildings with poorer performing types of ACP (eg 100% PE ACP) installed in vertically broken bands, such as balcony balustrades, or in other limited continuity/extent arrangements. Publicly available intermediate or full-scale façade fire tests on a well selected range of broken ACP cladding arrangements would assist understanding of fire spread and risk assessment for these types of arrangements.
3. There appears to be a significant amount of ACP product used on existing buildings with 55% to less than 70% mineral filled cores. These are expected to have significantly improved reaction to fire performance compared to ~100% PE ACP but these would still be ranked as ICA Cat A. Whilst the performance of >70% mineral filled ACP (ICA Category B or better) and 100% PE ACP products is reasonably well understood, there is limited intermediate or full scale test data available for 55% to less than 70% mineral filled cores. Publicly available testing on such products would assist in assessing there fire performance and risk.
4. Development of a consistent standard for both the sampling of ACP from existing buildings and the materials characterization testing of these samples would improve consistency of testing approaches from different labs and also provide a clear scope for NATA accreditation in this area. It would be useful if such a standard also covered material characterization test methods for other types of combustible cladding components including foam polymer insulation etc.
5. A variety of Polymer/timber composites have also been used as cladding on existing buildings in Australia but to a lesser extent than ACP. Whilst this is not directly related to the topic of this report it has been noted by CSIRO during inspections and sample testing of buildings impacted by ACP. There is limited publicly available test data on these products. Providing publicly available fire testing of a range of polymer/timber composites would improve understanding and assessment.

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Appendix A Other NCC BCA Vol 1Performance requirements which may be relevant to external wall fire safety.

The following other performance requirements in addition to CP2, CP4 and GP5.1 (stated in Section 3) may also be relevant to external wall fire performance of class 2-9 buildings (but is not limited to these):

CP1 - Structural stability during a fire

A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to—

(a) the function or use of the building; and
(b) the fire load; and
(c) the potential fire intensity; and
(d) the fire hazard; and
(e) the height of the building; and
(f) its proximity to other property; and
(g) any active fire safety systems installed in the building; and
(h) the size of any fire compartment; and
(i) fire brigade intervention; and
(j) other elements they support; and
(k) the evacuation time.

CP7 - Fire protection of emergency equipment

A building must have elements, which will, to the degree necessary, avoid the spread of fire so that emergency equipment provided in a building will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.

CP8 - Fire protection of openings and penetrations

Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained—

(a) where openings, construction joints and the like occur; and
(b) where penetrations occur for building services.

CP9 - Fire brigade access

Access must be provided to and around a building, to the degree necessary, for fire brigade vehicles and personnel to facilitate fire brigade intervention appropriate to—

(a) the function or use of the building; and
(b) the fire load; and
(c) the potential fire intensity; and
(d) the fire hazard; and
(e) any active fire safety systems installed in t–e building; and
(f) the size of any fire compartment

EP1.4 - Automatic fire suppression systems

An automatic fire suppression system must be installed to the degree necessary to control the development and spread of fire appropriate to—

(a) the size of the fire compartment; and
(b) the function or use of the building; an–
(c) the fire hazard; and
(d) the height of the building.

E2.2 - General requirements (smoke hazard management)

(a) A building must comply with (b), (c), (d) and—
    (i)Table E2.2a as applicable to Class 2 to 9 buildings such that each separate part complies with the relevant provisions for the classification; and
    (ii)Table E2.2b as applicable to Class 6 and 9b buildings such that each separate part complies with the relevant provisions for the classification.
(b) An air-handling system which does not form part of a smoke hazard management system in accordance with Table E2.2a or Table E2.2b and which recycles air from one fire compartment to another fire compartment or operates in a manner that may unduly contribute to the spread of smoke from one fire compartment to another fire compartment must—
    (i)be designed and installed to operate as a smoke control system in accordance with AS 1668.1; or
    (ii)
        (A)incorporate smoke dampers where the air-handling ducts penetrate any elements separating the fire compartments served; and
        (B)be arranged such that the air-handling system is shut down and the smoke dampers are activated to close automatically by smoke detectors complying with clause 7.5 of AS 1670.1; and

    for the purposes of this provision, each sole-occupancy unit in a Class 2 or 3 building is treated as a separate fire compartment.
(c) Miscellaneous air-handling systems covered by Sections 5 and 6 of AS 1668.1 serving more than one fire compartment (other than a carpark ventilation system) and not forming part of a smoke hazard management system must comply with that Section of the Standard.
(d) A smoke detection system must be installed in accordance with Clause 6 of Specification E2.2a to operate AS 1668.1 systems that are provided for zone pressurisation and automatic air pressurisation for fire-isolated exits.

Appendix B Building code requirements for other countries summarised.

This Appendix provides a summary of the prescriptive requirements relating to combustible exterior wall assemblies, particularly ACP for other countries.

The following key aspects of regulation have been identified to have significant impact on performance of exterior wall assemblies and fire risk and therefore the review has focussed primarily on these aspects:

1. Reaction to fire requirements for exterior wall assemblies and materials
2. Fire stopping/barrier requirements both in and behind exterior walls
3. Separation of buildings, in terms of minimum separation of unprotected openings from a relevant boundary.
4. Separation of openings between stories
5. Requirements for sprinkler protection – which influences the risk of an initiating compartment fire and fire spread into compartments

B.1 New Zealand Building code requirements

The New Zealand Building Code is a performance-based building code which specifies prescriptive requirements called Acceptable Solutions (AS) but also permits performance based alternative solutions provided that these alternative solutions are demonstrated by fire engineering analysis to satisfy the codes performance requirements.

Acceptable solutions (prescriptive requirements) are detailed in the separate documents (amended in June 2019) as listed in the following table for different types of buildings.

Table 29. New Zealand Acceptable solution documents for different building types

Acceptable solution document	Risk Group	Building type	Applies to	Comment
C/AS1	SH	Single household units and small multi-unit dwellings	Houses, townhouses and small *multi-unit dwellings* Limited area outbuildings	Outside of scope of this report
C/AS2	SM	Sleeping (non institutional)	Permanent accommodation e.g., apartments Transient accommodation e.g., hotels, motels, hostels, Backpackers, education accommodation	
	SI	Care or detention	Institutions, hospitals (excluding special care facilities), residential care, rest homes, medical day treatment (using sedation), detention facilities (excluding prisons)	
	CA	Public access and educational facilities	Crowds, halls, recreation centres, public libraries (<2.4 m storage height), cinemas, shops, personal services (e.g., dentists and doctors except as included above, beautician and hairdressing salons), schools, restaurants and cafes, *early childhood centres*	
	WB	Business, commercial and low level storage	Offices (including professional services such as law and accountancy practices), laboratories, workshops, manufacturing (excluding *foamed plastics*), factories, processing, cool stores (capable of <3.0 m storage height) and warehouses and other storage units capable of <5.0 m storage height, light aircraft hangars	
	WS	High level storage and other high risks	Warehouses (capable of 5.0 m storage height), cool stores (capable of 3.0 m storage height), trading and bulk retail (3.0 m storage height)	
	VP	Vehicle storage and parking	Vehicle parking – within a *building* or a separate *building*	Outside scope of this report

B.1.1 PRESCRIPTIVE REQUIRMENTS

External wall reaction to fire

The acceptable level of fire performance of external wall systems depends on the building type, building height, and the distance from the relevant boundary of the allotment.

Table 30 NZ Building code requirements for external wall fire performance (for C/AS2 buildings)

Building height	Requirement	
	Distance to boundary < 1.0 m	**Distance to boundary ≥ 1.0 m**
Single level	Type A	No Requirement
≤ 10 m	Type A	Type B for risk group SI (care or detention) No requirement for other risk groups
> 10 m	Type A	Type A

Where Type A and Type B are determined by the following Cone Calorimeter test requirements at irradiance of 50 kW/m2 for duration of 15 minutes:

- Type A = Peak HRR shall not exceed 100 kW/m2 and total heat released shall not exceed 25 MJ/m2.
- Type B = Peak HRR shall not exceed 150 kW/m2 and total heat released shall not exceed 50 MJ/m2.
- Materials with metal facing with a melting point of less than 750 °C covering a combustible core are to be tested without the metal facing present. However, rendered EIFS and steel faced ISP appear to be tested with the facing in place.

However, the requirements in the above table do not apply if:

a) *Surface finishes* are no more than 1 mm in thickness and applied directly to a *non-combustible* substrate, or
b) The entire wall assembly has been tested at full scale in accordance with NFPA 285 and has passed the test criteria.

Fire stop barriers

Fire stopping is required for all interior gaps at fire compartment (fire cell) boundaries. This includes gaps between slabs and external wall systems such as curtain walls. The fire stopping must have a fire resistance rating equivalent to that required for the fire compartment boundary.

Mineral wool firestop barriers (at least 50 mm thick) are required for buildings of three or more storeys fitted with combustible external insulation. The fire stop barriers must be installed across the insulation at intervals of not more than two storeys. Where the insulation is fixed to a light weight framed wall the fire stopping must continue across the wall frame cavity of be aligned with a timber blocking cavity barrier.

Separation between buildings

The critical distance for separation of buildings from the boundary in terms of protection of openings and fire performance of external cladding is 1 m. At less than 1 m separation all openings (windows) must be protected by fire rated glass. At greater than 1 m the percentage of unprotected opening area permitted for external walls gradually increases (dependant on angle, width of fire cell and sprinkler protection) with no requiring for protection at a separation distances ranging from 3 m for SI (Care or detention) to 16 m for high risk storage and Public access and educational facilities

Separation of vertical openings

Openings (windows) in external walls that are above openings in the fire compartment below must be separated by a combination of spandrels and/or horizontal projections having the same FRL as the floor separating the upper and lower fire compartments.

Table 31. Permitted combinations of horizontal projection and spandrel separation of openings

Horizontal Projection (m)	Spandrel height (m)
0.0	1.5
0.3	1.0
0.45	0.5
0.6	0.0

The above separation of vertical openings is not required where the building is internally sprinkler protected.

Sprinkler protection

Sprinkler protection is generally required for most building types where the height exceeds 25 m or where maximum compartment size limits are exceeded. Sprinkler protection is generally required for all care or detention type buildings.

B.2 UK Building code requirements

The Building Regulations 2010 for England and Wales state the performance requirements with regards to fire safety. Approved Document B states prescriptive requirements for fire safety which achieve compliance with the Building Regulations 2010. Alternative solutions supported by fire engineering analysis are permitted.

In response to the Grenfell Tower fires that occurred in June of 2017, an independent review of the current state of the Building Regulatory environment was undertaken and a final report was published on May 2018 (Hackitt report)[63]. The report identified issues and challenges facing both UK's and international regulatory frameworks and listed several recommendations for reform.

A 2018 amendment to Approved Document B volume 2 took effect on 21 December 2018, for use in England. The Amendment focuses on the requirements for external wall fire spread but appear to not significantly change the basic requirements but provide further clarification of the existing requirements.

A new clarified Approved Document B (Fire safety) 2019 edition, volume 2: Buildings other than dwellings appears to have been release in April 2019 and comes into Force on 30 August 2019

Key changes with the recent amendments of Approved Document B include:

- Introduction of Regulation 7, which applies to buildings with an effective height of 18 m or more which have a residential or institution (hospital, aged car or the like with sleeping accommodation), requires all external materials to be European Classification A2-s1, d0 or Class A1 and does not permit other materials including systems which meet the performance criteria given in BRE report BR 135 for external walls using full-scale test data from BS 8414-1 or BS 8414-2.
- General clarification on external wall fire spread requirements and impacts such as building change of use.

B.2.1 PRESCRIPTIVE REQUIRMENTS

External wall reaction to fire

Approved Document B, Section 12 states external wall reaction to fire requirements.

Regulation 7

- Regulation 7 applies to "relevant buildings" which are buildings with a storey at least 18m above ground level and which contains one or more dwellings; an institution; or a room for residential purposes (excluding any room in a hostel, hotel or a boarding house). This includes student accommodation, care homes, sheltered housing, hospitals and dormitories in boarding schools.
- It requires that all materials (other than exempted materials) which become part of an external wall or specified attachment achieve class A2-s1, d0 or class A1.
- Exempted materials include membranes, seals, gaskets, fixings, backer rods, thermal break materials, window frames and glass, door frames and doors, electrical installations etc.
- Systems which fail to achieve class A2-s1, d0 but meet the performance criteria of BR 135 using full-scale test data from BS 8414-1 or BS 8414-2 are not permitted for 'relevant buildings'.

For buildings other than those prescribed as 'relevant buildings' in Regulation 7, external walls must either:

a. meet the following requirements for:
    i. external surfaces.
    ii. materials and products.
    iii. cavities and cavity barriers.
b. meet the performance criteria of BR 135 using full-scale test data from BS 8414-1 or BS 8414-2

External surfaces

The external surfaces (i.e. outermost external material) of external walls must comply with table below.

Table 32. Reaction to fire requirements for external surface of walls, taken from Approved Document B Volume 2 2019, Table 12.1

Building type	Building height	Less than 1000mm from the relevant boundary	1000mm or more from the relevant boundary
'Relevant buildings' as defined in regulation 7		Class A2-s1, d0(1) or better	Class A2-s1, d0(1) or better
Assembly and recreation	More than 18m	Class B-s3, d2(2) or better	From ground level to 18m: class C-s3, d2(3) or better From 18m in height and above: class B-s3, d2(2) or better
	18m or less	Class B-s3, d2(2) or better	Up to 10m above ground level: class C-s3, d2(3) or better Up to 10m above a roof or any part of the building to which the public have access: class C-s3, d2(3) or better(4) From 10m in height and above: no minimum performance
Any other building	More than 18m	Class B-s3, d2(2) or better	From ground level to 18m: class C-s3, d2(3) or better From 18m in height and above: class B-s3, d2(2) or better
	18m or less	Class B-s3, d2(2) or better	No Provisions

Numbered Table Notes:

1. The restrictions for these buildings apply to all the materials used in the external wall and specified attachments
2. Profiled or flat steel sheet at least 0.5 mm thick with an organic coating of no more than 0.2mm thickness is also acceptable.
3. Timber cladding at least 9mm thick is also acceptable.
4. 10m is measured from the top surface of the roof.

General Table notes

- Class refers to classification in accordance with EN 13501-1. See Section C.1.4 for description of EN 13501-1 (Euro Class) testing and classification.

Materials and Products

In a building with a storey 18m or more in height any insulation product, filler material (such as the core materials of metal composite panels, sandwich panels and window spandrel panels but not including gaskets, sealants and similar) etc. used in the construction of an external wall should be class A2-s3, d2 or better (this restriction does not apply to masonry cavity walls compliant with other specific requirements).

Note the wording of this requirement does not make it clear if this restriction also applies to other insulation materials used externally (EIFS) or within cavities that are not "core materials", but it appears to be intended to extend to these other insulation materials.

Fire stop barriers

Cavity barriers are required in external walls at:

- the edges of cavities, including around openings (such as windows, doors and exit/entry points for services).
- the junction between an external cavity wall and every compartment floor and compartment wall.

Cavity barriers must provide 30 minutes fire resistance integrity and 15 minutes fire resistance insulation. However, cavity barriers formed around openings may be formed by either (and not achieve the above fire resistance):

- Steel, a minimum of 0.5mm thick.
- Timber, a minimum of 38mm thick.
- Polythene-sleeved mineral wool, or mineral wool slab, under compression when installed in the cavity.
- Calcium silicate, cement-based or gypsum-based boards, a minimum of 12mm thick.
- Cavity barriers provided around openings may be formed by the window or door frame if the frame is constructed of steel or timber of the above minimum thickness

Fire stop barriers within core of EIFS and ISP are not explicitly specified in approved document B but are recommended in BR135.

Separation between buildings

The critical distance for separation of buildings from the boundary in terms of protection of openings and fire performance of external cladding is 1 m. At less than 1 m separation all openings (windows) must be protected by fire rated glass. At greater than 1 m the percentage of unprotected opening area permitted for external walls gradually increases to 100 % at a separation distances of 6 meters for small residential buildings, 12.5 m for larger residential, office, assembly and recreation and 25 for retail/commercial, industrial, storage and other non-residential type buildings.

Separation of vertical openings

There is no requirement for vertical separation of openings in external walls between each level.

Sprinkler protection

Sprinkler protection is generally required for all building types where the height exceeds 30 m excluding institutional, other residential and car parks or where maximum compartment size limits are exceeded (as detailed in Table 8.1 of Approved Document B). Sprinklers are generally required to blocks of flats (apartments) where the height exceeds 30 m. It is noted Approved Document B provides a wide range of concessions for other fire safety requirements where sprinklers are provided in buildings below 30m and, whilst not mandatory, these other considerations may drive sprinkler protection of buildings other than effective height.

B.3 Façade regulations in Nordic countries

Strömgren et al[69] have provided a comparative analysis of façade regulations in Nordic countries. This analysis was based on a reference building of 4 stories which is considered to be a typical Nordic building. The following summaries of acceptable solution requirements are taken from Strömgren et al.

Requirements for exterior wall materials

The reaction to fire requirements for exterior wall materials in Nordic countries generally apply European-classifications as summarised in Table 33**Error! Reference source not found.**. Acceptable solutions vary from non-combustible materials (A2-s1,d0) to only fulfilling variations of Euroclass B. In Sweden, full-scale testing to SP Fire 105 is also accepted as an alternative. Some countries allow some parts of the façade to be of a lower class, i.e. D-s2,d0.

Table 33. Nordic requirements for exterior wall reaction to fire

Country	Protection against fire spread along the façade	Reaction to fire requirements for components in the external wall	Protection against falling objects
Sweden	A2-s1,d0 Certain exceptions allow D-s2,d2, for instance if sprinklers are installed in the building or only limited areas of the facade. or Compliance can be shown by testing with SP Fire 105	A2-s1,d0 or Fire stops preventing fire spread required at each floor unless the whole external wall. or Compliance can be shown by testing with SP Fire 105.	Compliance can be shown by testing with SP Fire 105
Denmark	Covering class K1 10 B-s1, d0 or K1 10 D-s2 d2 (depending on building height) Certain exceptions allow D-s2,d2 for lower buildings. Insulation materials with D-s1,d0 or lower poorer than material class D-s2,d2 (material level) must be protected with a covering class K1 10 B-s1, d0 or a construction class EI/REI30 or a construction class EI/REI30 and A2-s1,d0 (depending on building height) on each side.	See "Protection against fire spread along the façade"	No requirements
Norway	Cladding of class B-s3,d0. However, D-s3,d0 in low rise (maximum 4 stories, depending on risk class and hazard class) and if the fire risk in the facade is limited and the risk of fire spread to other buildings is low.	Insulation must be of class A2-s1,d0. External insulation systems for existing building: Testing according to SP Fire 105. However not pre-accepted in hazard class 3 (more than 4 stories) and risk class 6 (hospitals, hotels etc.)	No Specific requirements. Compliance can be shown by testing with SP Fire 105
Finland	3-8 floors (apartment and office buildings): B-s2,d0 generally and D-s2,d2 if building sprinklered (excluding first floor) Higher buildings: B-s1,d0 +Certain exceptions allow D-s2, d2 for minor areas	In designing the constructions of external walls, the hazard of fire spreading within the construction and through the joints shall be considered. P1 class buildings (number of floors: 3 – unlimited): Thermal insulation which is inferior to class B–s1, d0 shall be protected and positioned in such a manner that the spread of fire into the insulation, from one fire compartment to another and from one building to another building is prevented. In these cases, rendering or a metal sheet is generally not a sufficient protection. Protected combustible insulation can be allowed in certain cases. For example,	Applies only when D-s2,d2 class cladding (wood) is used in 3-8 floor buildings

		coverings fulfilling fire resistance EI 30 or large scale or some experimental/calculation evidence on protective performance/ no contribution to fire spread. A2-s1,d0 or B-s2, d0 if the load bearing construction is combustible (buildings with 3-8 floors).	

Fire Stop Barriers

There is some variation between Nordic countries however Fire stop barriers are generally required at each floor between the slab and the rear/inside of the exterior wall. Where combustible exterior insulation is applied fire stops must generally be imbedded in the insulation at each floor level (unless suitable performance is demonstrated in the large scale SP105 test).

Separation between buildings

Requirements relating to this item have not been determined.

Separation of vertical openings

Separation distance between windows is only explicitly required in Sweden, which requires 1.2 m spandrel separation or windows with 30 minutes fire resistance. Norway has special requirements that is connected to fire resistance solutions. Finland has no requirements whereas Denmark requires a risk evaluation if the façade is sloping.

Sprinkler protection

Requirements relating to this item have not been determined

B.4 International Building Code (IBC), USA

The International Building Code (IBC) is a model building code developed by the International Code Council (ICC). It has been adopted throughout most of the United States. In many cases the IBC may only be adopted in part or with modifications in various States within America.

Buildings are classified into 5 different types of construction having a decreasing level of fire resistance in the following order; Type I, Type II, Type III, Type IV and Type V. Building classes having lower levels of fire resistance are limited to low building heights. Type V construction has the lowest fire resistance and is typically timber framed construction.

Requirements for exterior wall materials

The general performance requirement for combustible exterior wall systems is that for buildings of Type I, II, III or IV construction that are greater than 12.192 m in height must be tested and comply with NFPA 285 full scale façade test (IBC Section 1403.5)

However, the IBC also gives the following detailed reaction to fire requirements for specific types of materials. It is presumed that if these specific requirements are met then demonstration of compliance with the NFPA 285 test is not required.

Combustible exterior wall coverings

Buildings of Type I, II, III or IV construction are permitted to have combustible exterior wall coverings if they meet the following requirements

- Combustible coverings ≤ 10% of exterior wall surface area where fire separation distance is ≤ 1.524 m
- Combustible coverings limited to 12.192 m in height
- Fire retardant treaded wood is not limited in area at any separation distance and is permitted up to 18.233 m in height

- Ignition resistance – combustible exterior wall coverings must be tested in accordance with NFPA 268 applying the following criteria (wood based products and combustible materials covered with a listed acceptable material of low combustibility are excluded)
  - Fire separation ≤ 1.524 m –combustible coverings shall not exhibit sustained flaming
  - Fire separation more than 1.524 m - the acceptable fire separation distance is dependent on the maximum radiant heat flux that does not cause sustained flaming and ranges from 1.524 m separation at 12.5 kW/m^2 to 7.62 at 3.5 kW/m^2.

Foam Plastic Insulation (ICC Section 2603)

Foam plastic insulation in or on exterior walls without a thermal barrier separation from the interior is permitted for one storey buildings with the following requirements:

- Flame spread index of ≤ 25 and a smoke developed index of ≤450 (ASTM E 84 or UL 723).
- Foam plastic thickness ≤ 102 mm
- Foam plastic covered by ≥ 0.81 mm aluminium or ≥ 0.41 mm steel
- Building must be sprinkler protected.

Any Height

- Separated from building interior by approved thermal barrier 12.7 mm Gypsum wall board or equivalent.
- Insulation, exterior facings and coatings shall be tested separately to ASTM E 84 or UL 723 and shall have a flame spread index of ≤ 25 and a smoke developed index of ≤450. (aluminium composite panels of ≤ 6.4 mm are permitted to be tested as an assembly)
- Potential heat of foam plastic shall be determined applying NFPA 259. The potential heat of the foamed plastic in the installed walls shall not exceed that of the material tested in the full-scale façade test.
- The complete wall assembly must be tested and comply with NFPA 285 full-scale façade test

Special Approval – Special approval may be provided without compliance with the above requirements based on large scale room corner tests such as NFPA 286, FM 4880, UL 1040 or UL 1715 if these tests are determined to be representative of the end use configuration.

Light transmitting plastic wall panels (ICC Section 2607)

Table 34. Summary ICC reaction to fire requirements for light transmitting plastic wall panels

Type I, Type II, Type III and Type IV Buildings	
Height	**Requirement**
Installed to a maximum height of 22.86 m (75 ft) or unlimited height if building is sprinkler protected	• Not permitted for building classes Assembly (A-1, A-2), High Hazard, Institutional (I-2, I-3) • Not permitted on exterior walls required to have a fire resistance rating (by other provisions of code) • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723) • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929) • Be either CC1 (burn length ≤ 25 mm and self extinguishment) or CC2 (burning rate of ≤ 1.06 mm/min) when tested to ASTM D 635 • Than maximum area of exterior wall covered by plastic panels must be limited as stated in Table 37 or the maximum area of unprotected openings permitted (whichever is less). The maximum area of single plastic panels and minimum separation distance between panels must be limited as stated in Table 37. • For sprinkler protected buildings the maximum area of exterior wall covered and maximum area of single panels may be increased by 100%. However maximum area of exterior wall covered must not exceed 50% of the area of unprotected openings permitted (whichever is less)
Type V Building	
Requirement for any height	Same as above except there is no limitation on area of coverage or required separation of panels

Fibre-reinforced polymer

Table 35. Summary ICC reaction to fire requirements for fibre-reinforced polymer wall panel

Height	Requirement
Installed to a maximum height of 12.19 m	• Comply with same requirements as for combustible exterior wall covering. • Flame spread index of ≤ 200 (ASTM E 84 or UL 723) • fire blocking of any concealed space in the exterior wall.
Any Height - Option 1	• Comply with same requirements as for foam plastic insulation , • fire blocking of any concealed space in the exterior wall.
Any Height - Option 1	• Cover < 20% of exterior wall area • Flame spread index of ≤ 25 (ASTM E 84 or UL 723). • fire blocking of any concealed space in the exterior wall • Be installed directly to a non-combustible substrate or be separated from the exterior wall by steel(0.4 mm), aluminium (0.5 mm) or other approved non-combustible material

Metal composite materials (MCM) (section 1407)

Table 36. Summary ICC reaction to fire requirements for MCM wall panels

Type I, Type II, Type III and Type IV Buildings	
Height	**Requirement**
Installed to a maximum height of 12.19 m (40 ft)	• Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723) • Cover < 10% or exterior wall area where the horizontal separation from the boundary is ≤ 1525 mm, or • No Limit on area where . horizontal separation from the boundary is > 1525 mm
Installed to a maximum height of 15.24 m (50 ft)	• Continuous areas of panels must not exceed 27.8 m^2 and must be separated from other continuous areas of panels by at least 1220 mm; and • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929 standard test method for determining ignition temperature of plastics); and; • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)
Installed to a maximum height of 22.86 m (75 ft) or unlimited height if building is sprinkler protected	Option 1 • Not permitted for building classes A-1, A-2, H, I-2, I-3 • Not permitted on exterior walls required to have a fire resistance rating (by other provisions of code) • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723) • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929) • Be either CC1 (burn length ≤ 25 mm and self extinguishment) or CC2 (burning rate of ≤ 1.06 mm/min) when tested to ASTM D 635 • Than maximum area of exterior wall covered by MCM panels must be limited as stated in Table 37 or the maximum area of unprotected openings permitted (whichever is less). The maximum area of single MCM panels and minimum separation distance between panels must be limited as stated in **Error! Reference source not found.** • For sprinkler protected buildings the maximum area of exterior wall covered and maximum area of single panels may be increased by 100%. However maximum area of exterior wall covered must not exceed 50% of the area of unprotected openings permitted (whichever is less)

	Option 2 • MCM must not be installed on any wall where separation distance <9.144 m or, Separation distance < 6.096 m for sprinkler protected building • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723) • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929) • Be either CC1 (burn length ≤ 25 mm and self extinguishment) or CC2 (burning rate of ≤ 1.06 mm/min) when tested to ASTM D 635 • The area of exterior wall covered shall be ≤ 25%. The area of a single MCM panel 1 story or more above grade shall not exceed 1.5 m2 and the vertical dimension of a single MCM panel shall not exceed 1.219 m. • Vertical separation between panels shall be provided by flame barriers which extend 762 mm beyond the exterior wall or a vertical separation distance of 1.219 m. • If the building is sprinkler protected then the area of exterior wall covered shall be ≤ 50% and there is no limit to single panel size and no requirement for vertical separation of panels.
Any height	• Compliance with NFPA 285 full scale façade test, And; • Flame spread index of ≤ 25 and a smoke developed index of ≤450 (ASTM E 84 or UL 723). • Separated from building interior by approved thermal barrier 12.7 mm Gypsum wall board or equivalent. Thermal barrier not required if MCM system tested and approved to either UL 10 40 or UL 1715
Type V Building	
Requirement for any height	Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)

Table 37. ICC requirements for percentage of wall coverage, panel area and separation between panels for MCM or plastic panels

Fire Separation distance (feet)	Combustibility class of MCM or plastic wall panel	Maximum percentage area of Exterior Wall covered with MCM plastic panels	Maximum single area of MCM or plastic panels (square feet)	Minimum separation of MCM or plastic panels (feet)	
				Vertical	Horizontal
< 6	-	Not Permitted	Not Permitted	-	-
6 or more but < 11	CC1	10	50	8	4
	CC2	Not Permitted	Not Permitted	-	-
11 or more but < 30	CC1	25	90	6	4
	CC2	15	70	8	4
>30	CC1	50	Not Limited	3	0
	CC2	50	100	6	3

EIFS

EIFS must meet the requirements of ASTM E2568[70]

High Pressure Laminates

High pressure laminates (HPL) must meet the following requirements (ICC section 1409)

Table 38. Summary ICC reaction to fire requirements for HPL wall panels

Type I, Type II, Type III and Type IV Buildings	
Height	**Requirement**
Installed to a maximum height of 12.19 m (40 ft)	• Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723) • Cover < 10% or exterior wall area where the horizontal separation from the boundary is ≤ 1525 mm, or • No Limit on area where . horizontal separation from the boundary is > 1525 mm
Installed to a maximum height of 15.24 m (50 ft)	• Continuous areas of panels must not exceed 27.8 m^2 and must be separated from other continuous areas of panels by at least 1220 mm; and • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929 standard test method for determining ignition temperature of plastics); and; • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)
Any height	• Compliance with NFPA 285 full scale façade test, And; • Flame spread index of ≤ 25 and a smoke developed index of ≤450 (ASTM E 84 or UL 723). • Separated from building interior by approved thermal barriers 12.7 mm Gypsum wall board or equivalent. Thermal barrier not required if HPL system tested and approved to either UL 10 40 or UL 1715
Type V Building	
Requirement for any height	Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)

Fire Stop Barriers

Internal gaps (e.g. between compartment floors the inside face of a wall such as a curtain wall) must be fire stopped with an approved material having a fire resistance at least equivalent to the compartment (ICC Section 715)

Fire Blocking, using non-combustible materials such as mineral wool is to be installed within concealed spaces of exterior wall coverings at maximum intervals of 6.096 m (both horizontally and vertically) so that the maximum concealed space does not exceed 9.3 m^2.

Use of fire stop barriers imbedded in EIFS may be specified in ASTM E2568

Separation between buildings

For non-sprinkler protected buildings, no unprotected openings are permitted at a separation distance of less than 5 ft. The percentage of unprotected openings permitted increases to no limit at 30 ft.

For sprinkler protected buildings, no unprotected openings are permitted at a separation distance of less than 3 ft. The percentage of unprotected openings permitted increases to no limit at 20 ft.

Separation of vertical openings

For buildings more than 3 stories in height which are not sprinkler protected openings must be separated from openings in the storey above by (IBC Section 705.8.5) either:

- the lower storey opening has a protection rating of at least ¾ hour, or
- A 915 mm spandrel with 1 hour fire resistance ,or
- A 760 mm horizontally projecting barrier with 1 hr fire resistance.

Sprinkler protection

Typical thresholds above which sprinkler systems are required in the *International Building Code* (IBC) include:

- Mercantile: Over 12,000 ft^2 (1115 m^2) in one fire area, or over 24,000 ft^2 (2230 m^2) in combined fire area on all floors, or more than 3 stories in height
- High-Rise: All buildings over 75 ft (22.86) m in height. However, sprinklers are also required for all buildings with a floor level having an occupant load of 30 or more that is located over 55 ft (16.8 m) in height (IBC 903.2.11.3)
- Residential Apartments: All buildings except townhouses built as attached single-family dwellings

B.5 NFPA 5000, USA

NFPA 5000 was developed as an alternative building code to the IBC. However, in practice NFPA 5000 is not adopted by most states of America. The IBC is the model building code currently most adopted within the USA.

Buildings are classified into 5 different types of construction, the same as for the IBC.

Requirements for exterior wall materials

NFPA 5000 Section 7.2 states that the general flammability requirement for all exterior walls for building class Type I, Type II, Type III and Type IV are required to meet the requirements of the large scale façade test NFPA 285.

However, the following specific requirements for different types of exterior wall materials are also stated.

Foam plastic Insulation requirements are stated in NFPA 5000 section 48.4.1. Foamed plastics used in exterior walls for Type I, Type II, Type III and Type IV buildings must comply with all requirements in Table 39.

Table 39. Foamed plastic insulation requirements for Type I, Type II, Type III and Type IV buildings

Property	Requirement
Thermal barriers	Foam plastic insulation must be separated from the building by an acceptable thermal barrier such as 13 mm gypsum board or a material meeting temperature transmission and integrity requirements of NFPA 275.
Flame spread index and smoke developed index	Insulation, exterior facings and coatings shall be tested separately to ASTM E 84 or UL 723 and shall have a flame spread index of ≤ 25 and a smoke developed index of ≤450. (aluminium composite panels of ≤ 6.4 mm are permitted to be tested as an assembly)
Wall assembly flammability	The complete wall assembly must be tested and comply with NFPA 285 full-scale façade test
Potential heat content	Potential heat of foam plastic shall be determined applying NFPA 259. The potential heat of the foamed plastic in the installed walls shall not exceed that of the material tested in the full-scale façade test.
Ignition characteristics	Exterior wall shall not produce sustained flaming when tested to NFPA 268 (ignitability of exterior walls using radiant heat). This requirement does not apply when the assembly is protected on the outside facing with complying facings such as 13 mm gypsum board, 9.5 mm glass reinforced concrete, 22mm Portland cement plaster, 0.48 mm metal faced panels or 25 mm concrete or masonry.

Insulation other than foamed plastic, including vapour barriers and reflective foil insulation, must comply with the following requirements when tested to ASTM E 84 or UL 723 (NFPA 5000 Section 8.16):

- Concealed insulation – flame spread index of ≤ 75 and a smoke developed index of ≤450.
- Exposed insulation - flame spread index of ≤ 25 and a smoke developed index of ≤450.

Light transmitting plastic for exterior wall assemblies must comply with the following (NFPA 5000 Section 48.7)

- Self ignition temperature ≥ 343 °C (tested to ASTM D 1929 standard test method for determining ignition temperature of plastics);
- Smoke developed index of ≤450 (ASTM E 84 or UL 723);
- Be either CC1 (burn length ≤ 25 mm and self extinguishment) or CC2 (burning rate of ≤ 64 mm/min) when tested to ASTM D 635.

The CC1 or CC2 result impacts on the maximum area of plastic wall panels permitted and the minimum separation requirements.

Metal composite materials (MCM) must meet the following requirements (NFPA 5000 Section 37.4)

Table 40. Metal composite material requirements

Type I, Type II, Type III and Type IV Buildings	
Height	**Requirement**
Installed to a maximum height of 12 m	Must either: • Cover < 10% or exterior wall area where the horizontal separation from the boundary is ≤ 1525 mm, or • Flame spread index of ≤ 75 and a smoke developed index of ≤450 (ASTM E 84 or UL 723).
Installed to a maximum height of 15 m	• Continuous areas of panels must not exceed 27.8 m^2 and must be separated from other continuous areas of panels by at least 1220 mm; and • Have a self ignition temperature ≥ 343 °C (tested to ASTM D 1929 standard test method for determining ignition temperature of plastics); and; • Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)
Any height	• Compliance with NFPA 285 full scale façade test, And; • Flame spread index of ≤ 25 and a smoke developed index of ≤450 (ASTM E 84 or UL 723).
Type V Building	
Requirement for any height	Flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (ASTM E 84 or UL 723)

EIFS must be specified and installed in accordance with EIMA 99A (NFPA 5000 Section 37.5).

Fire stop barriers.

Internal gaps (e.g. between compartment floors the inside face of a wall such as a curtain wall) must be fire stopped with an approved material having a fire resistance at least equivalent to the compartment

Use of fire stop barriers imbedded in EIFS or internal cavities of exterior wall systems are not specifically stated but would typically be required for compliance with the full scale façade fire test and EIFS Standards/guidelines specified.

Separation between buildings

The critical distance for separation of buildings from the boundary in terms of protection of openings is 3 m. No unprotected openings are permitted at a separation distance of 3 m or less. At greater than 3 m the percentage of unprotected opening area permitted for external walls gradually increases to 100 % at a separation distances of more than 10 m for most building types and more than 30 m for industrial and storage type buildings with ordinary and high hazard contents.

Separation of vertical openings

For buildings more than 4 stories in height which are not sprinkler protected openings must be separated from openings in the storey above by (NFPA 5000 Section 37.1.4) either:

- Protection of openings sect 7.3, or
- A 915 mm spandrel with 1 hour fire resistance
- A 760 mm horizontally projecting barrier with 1 hr fire resistance.

Sprinkler protection

Typical thresholds above which sprinkler systems are required in NFPA 5000, *Building Construction and Safety Code*, 2012 Edition include:

- Mercantile: Over 12,000 ft^2 (1115 m^2) in gross fire area or three or more stories in height
- High-Rise: All buildings over 75 ft (22.9 m) in height
- Residential Apartments: All buildings except those in which each unit has individual exit discharge to the street

B.6 UAE Fire & Safety Code

The 2011 version of the Fire and Life Safety Code of practice did not state any specific requirements for combustible exterior wall systems. In response to a spate of fire incidents (primarily involving metal composite materials), Annexure A.1.21 of the UAE fire & life safety code was released which provides specific requirements for reaction to fire of exterior wall cladding and passive fire stopping.

Requirements for exterior wall materials

UAE Code Annexure A.1.21 states the following requirements for reaction to fire for combustible exterior wall systems to be tested as complete assemblies.

Table 41. UAE Code Annexure A.1.21 requirements for reaction to fire for combustible exterior wall systems

Building types	Requirements
Mid rise (15-23 m high) or High Rise (>23 m high) or Low rise (< 15 m high) having a horizontal separation of less than 3 m from boundary	• Class A when tested to ASTM E-84 (flame spread ≤ 25 and smoke development ≤ 450) • Class 1 or A1 when tested to FM 4880 • Class B1 or A2 when tested as per DIN 4102 and EN 13501-1 or ISO 9705 • BS 8414 Parts 1 or 2 as appropriate and classified in accordance with BR135. • 'Non Combustible' when tested to ASTM E 136 OR other equivalent test standards.
Low rise (< 15 m high) having a horizontal separation of 3 m or more from boundary	• Class B or Class II rating when tested as per NFPA 255 or ASTM E 84 or UL 723 (flame spread ≤ 75 and smoke development ≤ 450) • Class 0 when tested as per BS 476 part 6 & 7 • Class B2 when tested as per DIN 4102 • Class B as per EN 13501-1 • 'Equivalent of flame spread of less than 50' when tested to other equivalent test standards.

The document does not clearly state if wall systems for mid/high rise buildings are to be:

1. Only tested to one of the tests listed (either small scale or full scale façade test), or
2. Test to at least of the listed small scale tests AND the full scale test.

Comments from Exova Warringtonfire indicate that option 2 is the intended test requirement

In addition to the above:

- For metal composite materials used as exterior walls, minimum exterior skin (0.5 mm and interior skin (0.25 mm) thicknesses and maximum panel thicknesses 0f 6.3 mm are required
- EIFS are to be in accordance with ANSI/EIMA 99-A, ASTM 1397 and ETAG 004. However, it is not clear if compliance with all or only one of these standards/guidelines is required.

Fire stop barriers.

Internal gaps (e.g. between compartment floors the inside face of a wall such as a curtain wall) must be fire stopped with an approved material having a fire resistance at least equivalent to the compartment

Use of fire stop barriers imbedded in EIFS or internal cavities of exterior wall systems are not specifically stated but would typically be required for compliance with the full scale façade fire test and EIFS Standards/guidelines specified in Annexure A.1.21.

Separation between buildings

The critical distance for separation of buildings from the boundary in terms of protection of openings is 3 m. No unprotected openings are permitted at a separation distance of 3 m or less. At greater than 3 m the percentage of unprotected opening area permitted for external walls gradually increases to 100 % at a separation distances of more than 10 m for most building types and more than 30 m for industrial and storage type buildings with ordinary and high hazard contents.

Separation of vertical openings

UAE Code Annexure A.1.21 states openings must be separated from openings in the storey above by either:

- A 915 mm spandrel with 1 hour fire resistance
- A 760 mm horizontally projecting barrier with 1 hr fire resistance.

No dispensation for sprinkler protected buildings is stated (however it is expected to be likely based on current design of UAE high rise buildings).

Sprinkler protection

Sprinklers are required for assembly buildings, day care, healthcare, correctional, hotels/dormitory and residential board car buildings of nay height.

Sprinklers are required for educational. Mercantile, industrial and staff/labour accommodation more than 3 stories or 15 m high

Sprinklers are required for residential/apartments and business/office buildings more than 23 m high.

Sprinklers are also required when maximum compartment sizes are exceeded or fire resistance levels are reduced.

Appendix C Reaction to fire test methods for ACP applied to external walls

This section reviews the small-scale, intermediate-scale and full scale fire test methods that can be applied to ACP for external walls.

Table 42. BCA Volume 1 referenced reaction to fire test methods relevant to ACP or external wall systems (Original table from SFS Practice guide façade/external wall fire safety design[20], edited by CSIRO)

Test standard or application	BCA Reference	Test Description	Criteria	Comments
AS 1530.1-1994 Combustibility test for materials	Clause A1.1 Definitions. The BCA defines non-combustible as: • Applied to a material – not deemed combustible as determined by AS 1530.1 – Combustibility Test for Materials; and • Applied to construction or part of a building – constructed wholly of materials that are not deemed combustible Clause C1.9(a): In a building required to be of Type A or B construction, External walls and their components must be non-combustible	A small-scale material property test to expose 5 specimens to >750 °C within a conical tube furnace. Parameters of the specimen as follows: • Diameter of 45 mm • Height of 50 mm • Volume of 80 cm3	Combustibility Criteria: • Mean duration of sustained flaming > 0 s • Mean furnace thermocouple temperature rise >50°C • Mean specimen surface temperature rise >50°C	This method is a small-scale test for each component or element of the system. This does not assess the whole wall system response. The test is pass/fail.
AS 5113-2016 – Fire propagation testing and classification of external walls of buildings.	CV3 CV3 is a non-mandatory verification method that may be used to demonstrate compliance with CP2 in relation to the avoidance of spread of fire via the external wall of a building. CV3 has several clauses, one of which requires that the external wall system be tested for external wall (EW) performance in accordance with AS5113 and has achieved the classification EW. In addition to achieving an EW rating, additional requirements such as cavity fire barriers, sprinkler protection to balconies and specific sprinkler design criteria apply and are dependent on effective height of building.	A full-scale test method which requires testing the whole façade system to BS 8414 or ISO 13785-2. In practice all Australian test labs are currently applying BS 8414 and not ISO 13785-2. The specimen tested is a full-scale wall test with a form of construction that is representative of the intended installation including cavities, substrates, fixings and cavity barriers. Each wall assembly includes a wing wall to account for re-radiation. BS 8414 applies a timber crib (AS 5113 permits this to be constructed of radiata pine) 1.5 m wide x 1 m deep x 1 m high having a nominal heat output of 4500 MJ over 30 minutes and a peak HRR of 3±0.5 MW The EW classification is achieved when a series of performance criteria that have been satisfied.	All the following performance criteria shall be satisfied: a. Temperatures 5 m above the opening measured 50 mm from the exposed specimen face shall not exceed 600°C for a continuous period greater than 30 s. b. Temperatures at the mid-depth of each combustible layer or any cavity 5 m above the opening shall not exceed 250°C for a continuous period of greater than 30 s. c. Where the system is attached to a wall that is not required to have an FRL of –/30/30 or 30/30/30 or more, the temperature on the unexposed face of the specimen 900 mm above the opening shall not exceed a 180 K rise. Five thermocouples equally spaced at 500 mm centres with insulating pads, fitted in accordance with the requirements of AS 1530.4 for the measurement of surface temperatures shall be used. d. Where the system is attached to a wall not required to have a fire resistance of –/30/30, 30/30/30 or more, flaming or the occurrence of openings in the unexposed face of the specimen above the opening shall not occur. e. Flame spread beyond the confines of the specimen in any direction, as determined during the post-test examination, shall not occur. The examination shall include flame damage such as melting, charring but not smoke discolouration or staining of the surface, any intermediate layers and the cavity. NOTE: The confines of the specimen is the minimum specimen size specified in the 'Dimensions of test specimen' clause in BS 8414, Parts 1 and 2. The specimen may be constructed larger than the minimum size in which case spread is determined at the positions associated with the minimum specimen size. f. Continuous flaming on the ground for more than 20 s from any debris or molten material from the specimen shall not occur. g. The total mass of debris falling in front of the specimen shall not exceed 2 kg. The mass shall be measured after the end of the test.	The strength of the method is that it gives highly relevant information of the whole system and potential interaction of various building products and their arrangement when directly exposed to fire. The test applies a severe/large ignition source which reasonably represents a post flashover compartment fire with flames emerging from an opening and impinging on the external wall AS 5113 applies more onerous test criteria than the BRE 135 (applied in UK to BS8414 tests). It is known for DTS compliant external wall systems or other wall systems which do not support vertical fire spread beyond the limits of the test to sometimes fail some of the other criteria relating to debris, cavity temperatures or back face temperatures. However, such tests may still be applied as inputs to a performance-based assessment. The limitation of this test method is the results apply to the system tested and extrapolation to assemblies with similar materials but are not identical to the tested prototype is challenging. Further research and standards are currently being developed outside Australia.

Test standard or application	BCA Reference	Test Description	Criteria	Comments
AS1530.3	*Clause C1.9(e) - The following materials must be used wherever a non-combustible material is required:* *(v) Pre-finished metal sheeting having a combustible surface finish not exceeding 1 mm thickness and where the Spread-of-Flame Index of the product is not greater than 0.* *(vii) Bonded laminated materials where—* *(A) each lamina, including any core, is non-combustible; and* *(B) each adhesive layer does not exceed 1 mm in thickness and the total thickness of the adhesive layers does not exceed2mm; and* *(C) the Spread-of-Flame Index and the Smoke-Developed Index of the bonded laminated material as a whole do not exceed 0 and 3 respectively.*	A small-scale test to expose 6-9 specimens to radiant heat and small pilot flame. Depending on the time to ignition (when movement of the specimen towards the radiant heat panel stops) specimens may be exposed to radiant heat flux ranging from a minimum of 2.5 kW/m^2 up to a maximum of 25 kW/m^2. Parameters of the specimen as follows: • Width of 450 mm • Height of 600 mm	Four indices are generated; • Ignitability • Spread of Flame • Heat Evolved (referred to as heat release in NCC DTS) • Smoke Developed BCA Clause C1.10 and Specification C1.10 uses the spread of flame, and smoke developed indices to regulate the fire hazard properties of a very limited number of materials and assemblies that are not floor linings and floor coverings, and wall and ceiling linings. It is applied to “other materials” such as insulation (other than in external wall systems) and fixed seating in public building audience areas of public buildings AS 1530.3 is also referenced in Clause C1.9 for - bonded laminate materials.	This test has failed to correctly determine the fire hazard of ACP materials due to the low maximum heat flux of 25 kW/m2[80] imposed and past testing with the aluminium skin in place. It fails to determine the fire behavior of a complete façade system. The fire indices results do not directly relate to fundamental material flammability properties and are of little to no use as inputs to performance based fire engineering assessment. This test method does not properly identify fire risk for materials that have a metal or reflective facing and thermoplastic components.
Internal lining	Clause C1.10 applies to internal linings.			The following 3 standards apply to internal wall and ceiling linings. Whilst they may provide some information on fire performance of materials, the tested systems do not represent complete external wall systems and there are substantial limitations.
AS 5637.1	Specification C1.10 Clause 4(b) requires the determination of the group number for wall and ceiling linings to be determined in accordance with AS 5637.1	This standard provides requirements for determination of material group numbers for regulation of internal wall and ceiling linings based on the test methods AS 3837, ISO 5660 and AS ISO 9705	Criteria for determination of material group number is provided. ISO 9705 is the primary test method for determination of group number based on time to flashover. In some cases, cone calorimeter testing (AS 3837 or ISO 5660) may be applied to predict group number based on an empirical correlation. However, there are significant limitations to this correlation. Prediction of group number based on cone calorimeter tests is not permitted where a material does not have a confirmed correlation. Specific cases where the correlation fails are provided. This includes materials which melt and materials with reflective metal facings	The information gathered from the BCA wall lining test methods may provide information on potential flame spread however this may not fully assess risk of external wall systems.
AS ISO 9705	This test method is a secondary reference via AS 5637.1. It is the primary test method for determination of group numbers by time to flashover for internal wall and ceiling linings	An Intermediate-full-scale test to expose internal wall and ceiling lining specimens in a room 2.4 x 3.6 x 2.4 m high to a gas burner of 100-300 kW. Several parameters are measured as follows: • Heat release rate vs time • Time to flashover • Smoke production • CO and CO_2 production	A group number and Smoke growth rate index ($SMOGRA_{RC}$) is determined for lining materials. Group 4 materials which cannot be used in class 2-9 buildings. Group 1 (no Flashover) is the best performing category.	The information gathered from the BCA wall lining test methods may provide information on potential flame spread however this may not fully assess risk of external wall systems. This method has fewer limitations than the smaller scale test methods.
AS 3837 (or ISO 5660)	This test method is also a secondary reference via AS 5637. It is the secondary test method for determination of group numbers and may only be applied where a correlation between this small-scale test and time to flashover in the ISO 9705 test has been shown to exist.	A small-scale test to expose 3-6 specimens (each 100 x 100 mm) to radiant heat in the presence of a spark ignition source. Several parameters are measured as follows: • Time to ignition • Heat release rate per unit area • Smoke production. • CO and CO_2 production (optional) The method has limitations for laminates such as ACP which require each layer to be tested individually or the whole composite tested to AS ISO 9705. Testing ACP with aluminium skin in place reflects radiant heat and results in non-ignition, therefore the bare exposed core must be tested. AS 5637.1 states that group number prediction is not suitable from cone calorimeter tests for materials with reflective	A group number and Average specific extinction area can be determined for some lining materials that are suitable for the small-scale test and prediction method. Predicted time to flashover in AS ISO 9705 test is used to determine group number of 1 to 4.	The information gathered from the BCA wall lining test methods may provide information on potential flame spread however this may not fully assess risk of external wall systems. AS 3837 is similar to ISO 5660 Group 1 is the best performing category but is not equivalent to non-combustibility.

Test standard or application	BCA Reference	Test Description	Criteria	Comments
		facings and materials which melt or shrink when exposed to flame		

C.1 Small scale fire tests

C.1.1 COMBUSTABILITY TESTS

Combustibility tests are essentially used to determine if materials are combustible or non-combustible (will not contribute significantly to fuel load). The relevant Australian standard is AS 1530.1. Various standard test methods exist around the world including (ISO 1182, BS 476 part 4, ASTM E136 & ASTM E2652)[71-75] however they are all fairly similar with some differences in specimen dimensions, configurations, furnace temperature and failure criteria.

In AS 1530.1 small specimens (45 mm diameter, 50 mm high cylindrical) are exposed to a temperature of 750 °C within a small conical tube furnace. Criteria for combustibility are typically:

- The mean duration of sustained flaming (flaming longer than 5 s), is other than zero.
- The mean furnace thermocouple temperature rise exceeds 50°C.
- The mean specimen surface thermocouple temperature rise exceeds 50°C.

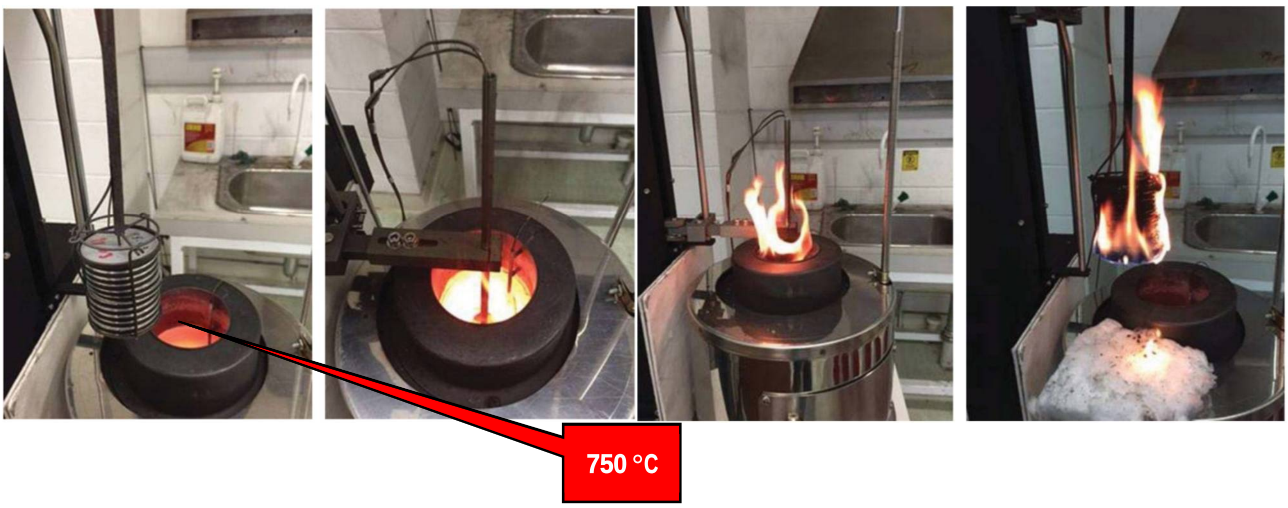


Figure 57. AS 1530.1 (note – indicative test applied to complete ACP-PE specimens. Standard test required testing of each component/layer separately). Photos by CSIRO

Many building codes around the world deem materials such as gypsum plaster suitable for use where non-combustible materials are required as they don't necessarily meet the above test criteria for items such as flaming. or mass loss (required by international standards but not AS 1530.1).

External wall assemblies constructed entirely of non-combustible materials do not generally pose any hazard relating to enhanced fire spread.

C.1.2 CONE CALORIMETER

The cone calorimeter[76] is a small-scale oxygen consumption calorimeter. Specimens, 100 mm square are supported horizontally on a load cell and exposed to a set external radiant heat flux in ambient air conditions. The radiant heat source is a conically shaped radiator that can be set to impose any heat flux in the range 0-100 kW/m2 on the specimen surface. Ignition is promoted using a spark igniter. Combustion gases are extracted in an exhaust duct where instrumentation measures exhaust gas flow, temperature,

O_2, CO and CO_2 concentrations and smoke optical density. From these measurements the following key quantities are calculated:

- heat release rate per unit area.
- mass loss rate.
- effective heat of combustion.
- smoke production can be calculated.
- Time to ignition at set heat flux exposures is determined by observation.

The cone calorimeter apparatus and procedure are described in ISO 5660, AS/NZS 3837 and ASTM E 1354[77-79].

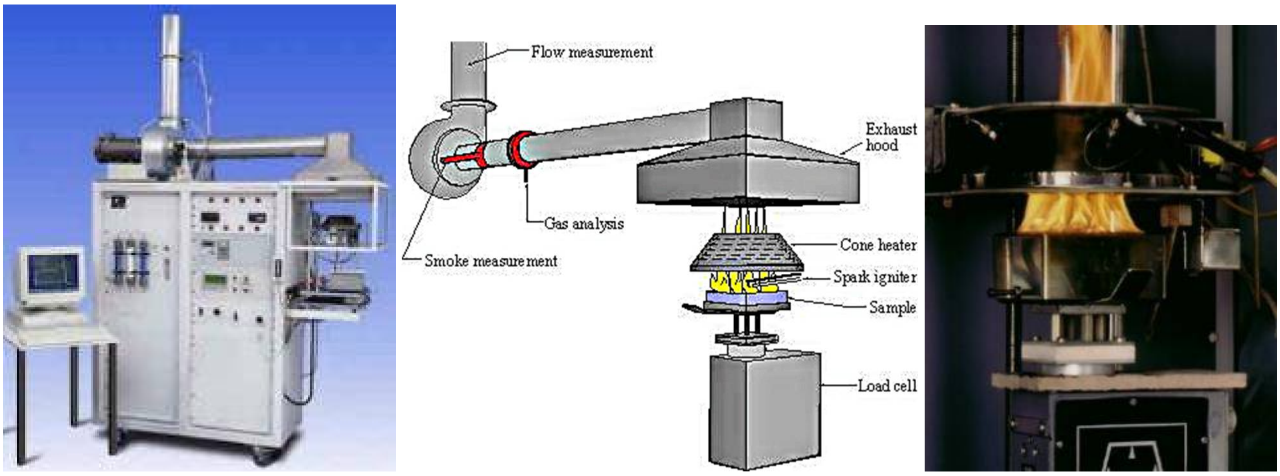


Figure 58. Cone Calorimeter (CSIRO)

The cone calorimeter attempts to measure fundamental flammability properties of materials that are required to predict material behaviour in real fires. Much research has been focused on predicting real fire behaviour based on cone calorimeter results, however the ability to make such predictions remains very limited. Some reasons for this are:

- The cone calorimeter method measures properties under set conditions which affect the properties attempting to be measured.
- The cone calorimeter does not directly measure all fundamental properties that may be required such as heat of volatilisation, heat capacity and thermal conductivity.
- The theoretical link between fundamental properties and real fire behaviour is complex and not well developed.

For materials which are complex composites with protective external layers that have a low combustibility or reflects radiant heat the cone calorimeter often fails to predict the true hazard of the combustible core material which may become exposed in a full-scale fire due to fail of joints etc. The cone calorimeter also has similar limitation when testing materials with reflective surfaces due to the large amount of heat reflection. This limitation of a protective facing is applicable to testing of ACP. The cone calorimeter has similar limitations when testing materials which significantly melt or shrink away from the heat source (especially prior to ignition) as this can significantly reduce the heat flux received at the surface of the specimen.
The Cone calorimeter is applied by the NCC BCA 2019 Vol 1 DTS and AS5637.1 to predict time to flashover, expressed as “material group number” in the AS/ISO 9705 room corner test for wall and ceiling linings. However, there are significant limitations to this prediction correlation resulting in the correlation not being valid for ACP. Therefore, Group Numbers for ACP should be determined by ISO 9705 tests.

The cone calorimeter is a very complex apparatus requiring more maintenance and calibration than other small-scale fire apparatus. Erroneous data can easily be generated if the operator does not have a high level of competency.

Despite these limitations the cone calorimeter is still one of the most useful tools for determining reaction to fire properties for materials and can provide useful information on the reaction to fire properties of ACP cores with the facing material removed.

C.1.3 AS 1530.3 (EARLY FIRE HAZARD TEST)

AS 1530.3, known as the early fire hazard test was originally intended for testing flammability of internal wall linings. A specimen 450 × 600 mm is mounted vertically opposite a vertical gas fired radiant panel (set to produce a heat flux of 2.4 + 0.1 kW/m^2 measured 850 mm in front of panel. The specimen is incrementally advanced towards the radiant panel at a prescribed rate. A small pilot flame is applied to the specimen surface to ignite pyrolysis gases. Movement of the specimen stops upon ignition. A radiometer measures radiant heat produced by ignition of the specimen. Smoke is collected in a hood and rises through a vertical duct where optical density is recorded. These measurements are used to express performance in terms the following Index's (the lower the index the better the result):

- Ignitability Index (0-20)
- Spread of Flame Index (0-10)
- Heat Evolved Index (0-10)
- Smoke Developed Index (0-10).

These index results are not directly related to fundamental flammability properties or real fire performance. In the past this test has been applied to floor and ceiling linings and internal wall linings but has been demonstrated as inappropriate for these materials and to provide a poor assessment of hazard for materials that melt, materials with reflective facings or non-combustible skins. Similarly, this test does not provide suitable assessment or prediction of façade fire spread performance.

Depending on the time to ignition (when movement of the specimen towards the radiant heat panel stops) specimens may be exposed to radiant heat flux ranging from a minimum of ~2.5 kW/m^2 up to a maximum of 25 kW/m^2[80]. This is significantly less than the typical heat flux exposure to an external wall that can result for window fire plumes or large external fires with flame immersion of the external wall and does not reasonably predict degradation of aluminium facings on ACP to expose combustible core materials.

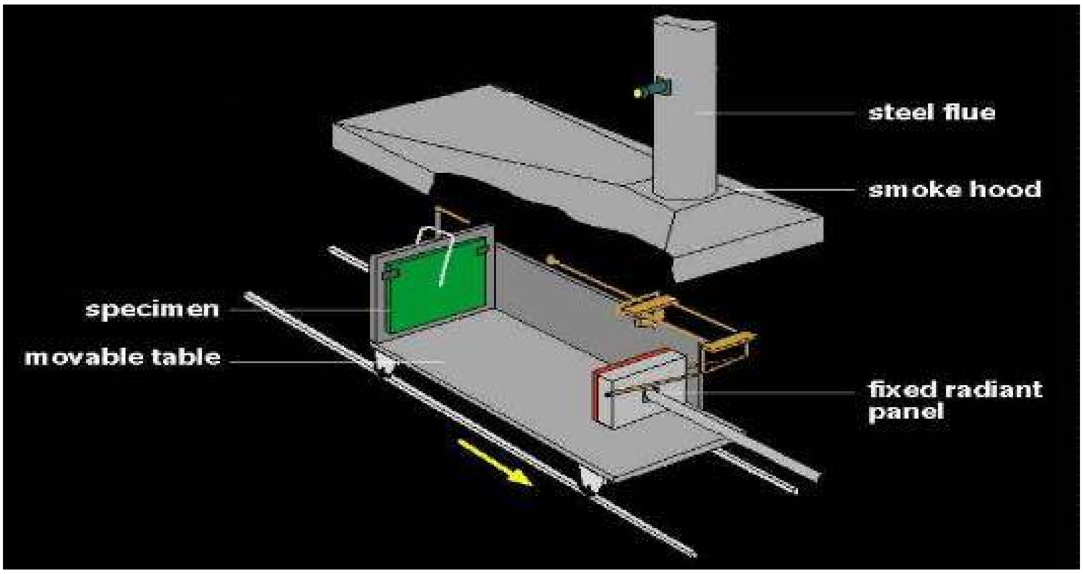


Figure 59. AS 1530.3 test.

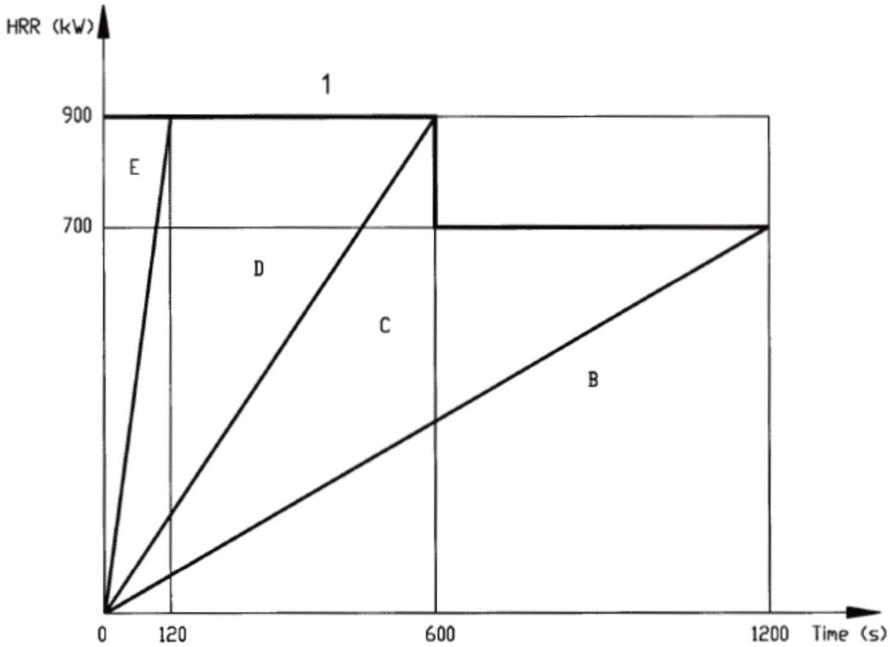
C.1.4 EUROCLASS TESTS

The Euroclass system for characterising reaction to fire behaviour of construction products is applied throughout most of Europe and is specified in EN 13501-1[34]. The Euroclass system was designed for controlling flammability of internal materials and does not specifically address external wall systems. However due to a lack of any uniform approach throughout Europe to control external wall systems via harmonised requirements for either small or large scale testing, individual European countries have resorted to either relying on Euroclasses or national large scale façade tests for control of external wall systems.

It is often applied to external wall systems.

For non-flooring materials the Euroclass system applies a range of small-scale tests and is intended to classify materials in terms of contribution to fire development for a scenario of a fire starting in a small room by a single burning object. As follows:

- Class A1 products are essentially non-combustible and will not contribute to fire growth nor to the fully developed fire
- Class A2 products have a very low combustibility and will not significantly contribute to the fire growth and fuel load in a fully developed fire
- Class B products are combustible, will not lead to a flashover situation but will contribute to a fully developed fire. Whilst this is typically true for most Class B materials, Class B relies upon small scale tests and does not require ISO 9705 room corner fire testing. Therefore, flashover may be possible for some Class B materials.
- Class C-E products may lead to flashover at the reference scenario test times shown in Figure 60



Key
1 - Flashover
B - Class B/A2
C - No flashover for 100kW but flashover
D - Flashover after more than 2 min for 100 kW ignition source
E - Flashover before 2 min for 100 kW ignition source

NOTE HRR from the specimen exludes the burner

Figure 60. Relationship between Euroclasses and ISO 9705 room corner test time to flashover[34]

For non-flooring materials the four following tests are applied to determine the classification

EN ISO 1182 Non Combustibility[71] – See Section C.1.1

EN ISO 1716, Gross calorific value[81]

This is an Oxygen Bomb Calorimeter test where a specified mass of material is burnt under standardised conditions within a confined volume combustion chamber with high oxygen concentration. The Gross calorific potential (heat of combustion) is calculated based on the measured temperature rise of the combustion chamber taking into account heat loss.

EN 13823 Single Burning Item (SBI) test[82]

The SBI test is an intermediate scale corner test conducted under an exhaust hood fitted with oxygen consumption calorimetry equipment and smoke meters (typically inside a test room with controlled makeup ventilation). Heat release rate (kW), total heat release (MJ) and smoke production rate (m^2/s) are measured. Flame spread and burning droplets are observed visually. The specimen is installed in a corner with a 1m wide x 1.5 m high long wing and a 0.49 m x 1.5 m high short wing. A 30 kW gas burner is located in the corner and the total test time is 21 minutes.

Figure 61. SBI test[83]

EN ISO 11925-2 small flame test[84]

- The specimens are ignited with a 20 mm high propane gas flame. The flame is impinged on the bottom edge of the specimen (edge exposure) or 40 mm above the bottom edge (surface exposure) or both. The specimen is exposed to flame for 15 seconds or 30 seconds.
- For each test specimen it is recorded whether an ignition occurs (flaming longer than 3 s), whether the flame tip reaches 150 mm above the flame application point and the time at which this occurs. The occurrence of burning droplets/particles is also observed.
- For each exposure condition a minimum of six specimens (250 mm x 90 mm) of the product shall be tested, three cut lengthwise and three crosswise

Materials are classified based on the above tests as shown in the following table.

Table 43. EN 13501-1 Classes of reaction to fire performance for construction products excluding flooring and linear pipe thermal insulation products.

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 [a] and	$\Delta T \leq 30$ °C; and $\Delta m \leq 50$ %; and $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2,0$ MJ/kg [a] and $PCS \leq 2,0$ MJ/kg [b c] and $PCS \leq 1,4$ MJ/m^2 [d] and $PCS \leq 2,0$ MJ/kg [e]	-
A2	EN ISO 1182 [a] or	$\Delta T \leq 50$ °C; and $\Delta m \leq 50$ %; and $t_f \leq 20$ s	-
	EN ISO 1716 and	$PCS \leq 3,0$ MJ/kg [a] and $PCS \leq 4,0$ MJ/m^2 [b] and $PCS \leq 4,0$ MJ/m^2 [d] and $PCS \leq 3,0$ MJ/kg [e]	-
	EN 13823	$FIGRA \leq 120$ W/s and LFS < edge of specimen and $THR_{600s} \leq 7,5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
B	EN 13823 and	$FIGRA \leq 120$ W/s and LFS < edge of specimen and $THR_{600s} \leq 7,5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
C	EN 13823 and	$FIGRA \leq 250$ W/s and LFS < edge of specimen and $THR_{600s} \leq 15$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$mm within 60 s	
D	EN 13823 and	$FIGRA \leq 750$ W/s	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
E	EN ISO 11925-2 [i]: Exposure = 15 s	$F_s \leq 150$ mm within 20 s	Flaming droplets/particles [h]
F	No performance determined		

[a] For homogeneous products and substantial components of non-homogeneous products.
[b] For any external non-substantial component of non-homogeneous products.
[c] Alternatively, any external non-substantial component having a $PCS \leq 2,0$ MJ/m^2, provided that the product satisfies the following criteria of EN 13823: $FIGRA \leq 20$ W/s, and LFS < edge of specimen, and $THR_{600s} \leq 4,0$ MJ, and s1, and d0.
[d] For any internal non-substantial component of non-homogeneous products.
[e] For the product as a whole.
[f] In the last phase of the development of the test procedure, modifications of the smoke measurement system have been
introduced, the effect of which needs further investigation. This may result in a modification of the limit values and/or parameters for the evaluation of the smoke production.
s1 = $SMOGRA \leq 30$m^2/s^2 and $TSP_{600s} \leq 50$m^2; **s2** = $SMOGRA \leq 180$m^2/s^2 and $TSP_{600s} \leq 200$m^2; **s3** = not s1 or s2
[g] **d0** = No flaming droplets/ particles in EN 13823 within 600 s;
d1 = no flaming droplets/ particles persisting longer than 10 s in EN 13823 within 600 s;
d2 = not d0 or d1.
Ignition of the paper in EN ISO 11925-2 results in a d2 classification.
[h] Pass = no ignition of the paper (no classification);
Fail = ignition of the paper (**d2** classification).
[i] Under conditions of surface flame attack and, if appropriate to the end–use application of the product, edge flame attack.

C.1.5 BRITISH CLASSIFICATION TESTS

In addition to the non-combustibility test the UK Approved Document B previously applied the following British small-scale tests to external walls. However recent revisions to UK Approved Document B now only apply Euroclass tests to regulate external wall fire spread (in addition to BR135/BS8414 full scale façade fire test where applicable).

BS 476 part 6[85]

This fire propagation test was developed primarily for interior wall linings. The result is given as a fire propagation index. The test specimens measure 225 mm square and can be up to 50 mm thick. The apparatus comprises a combustion chamber attached to a chimney and cowl (with thermocouples). The chamber is heated using electrical elements and a gas burner tube is applied to the bottom of the test specimen. The test specimens are subjected to a prescribed heating regime for a duration of 20 minutes and the index obtained is derived from the flue gas temperature compared to that obtained for a non-combustible material.

BS 476 part 7[86]

This surface spread of flame test is used to determine the tendency of materials to support lateral spread of flame. The test specimen is rectangular, 925 mm long x 280 mm wide with thickness up to 50 mm. The vertical specimen is mounted perpendicular to a large 900 mm square gas-fired radiant panel. The radiant heat flux along the specimen decreases from 30 kW/m^2 at the near end to 5 kW/m^2 at the far end. Depending on the extent of lateral flame spread along the specimen, the product is classified as Class 1, 2, 3 or 4 with Class 1 representing the best performance.

BS 476 Part 11[87]

This test is very similar to the BS 476-part 4 non-combustibility test. Small samples are exposed to 750 °C in a small tube furnace and the occurrence of any flaming, specimen surface temperature, furnace temperature and specimen mass loss at end of test are measured. UK Approved document B uses this test to classify materials as having limited combustibility.

C.1.6 US BUILDING CODE TESTS

NFPA 268 – Determining ignitability of exterior wall assemblies using a radiant heat energy source[88]

This test evaluates the propensity for ignition of an exterior wall assembly when exposed to a radiant heat flux of 12.5 kW/m^2 and a pilot ignition source over a 20-minute test period. The test specimen must be 1.22 m wide x 2.44 m high. The gas fired radiant panel is 0.91 m x 0.91 m. The radiant panel is stationary, and the specimen is mounted on a trolley. The radiant heat flux exposure is controlled by the separation distance. This test only assesses risk of ignition from an external radiant heat source. It does not assess risk of ignition or flame spread from direct flame exposure.

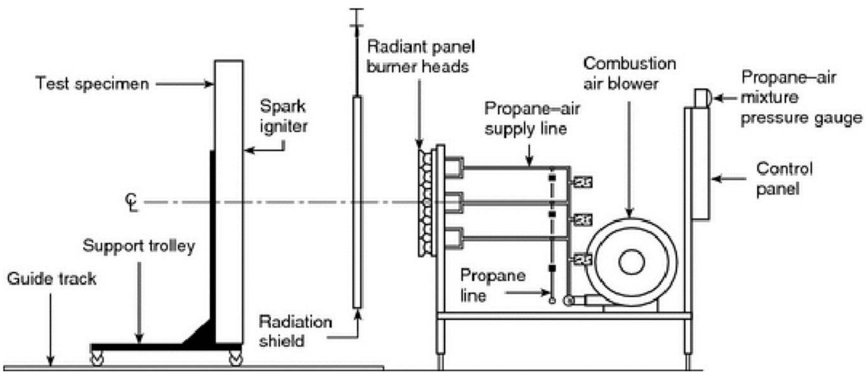


Figure 62. NFPA 268 test side view (from NFPA 268[88])

ASTM E 84, UL 723, NFPA 255 – Steiner tunnel test[89-91]

This test was originally developed for interior wall and ceiling linings and measures both flame spread and smoke production. The test is conducted inside a non-combustible horizontal tunnel/box that is 7.3 m long x 0.056 m wide x 0.305 m high. The specimen is mounted to the ceiling of the tunnel. Gas burners at one end of the tunnel provide a heat output of 89 kW and air and combustion products are drawn through the tunnel in the direction of fire spread at a controlled velocity of 73 m/min. The test duration is 10 minutes. Flame spread is measured by observation and smoke optical density is measured by an obscuration meter located in the exhaust duct. Results are expressed in terms of a flame spread index and a smoke developed index. Both indices are based on arbitrary scales where cement board has a value of 0 and red oak has a value of 100.

These indices cannot be easily used as basic fire engineering properties or correlated to performance in an exterior wall end use. This test does not properly assess thermoplastic materials which may tend to melt away from the assembly rather than spread flame in the horizontally prone test orientation.

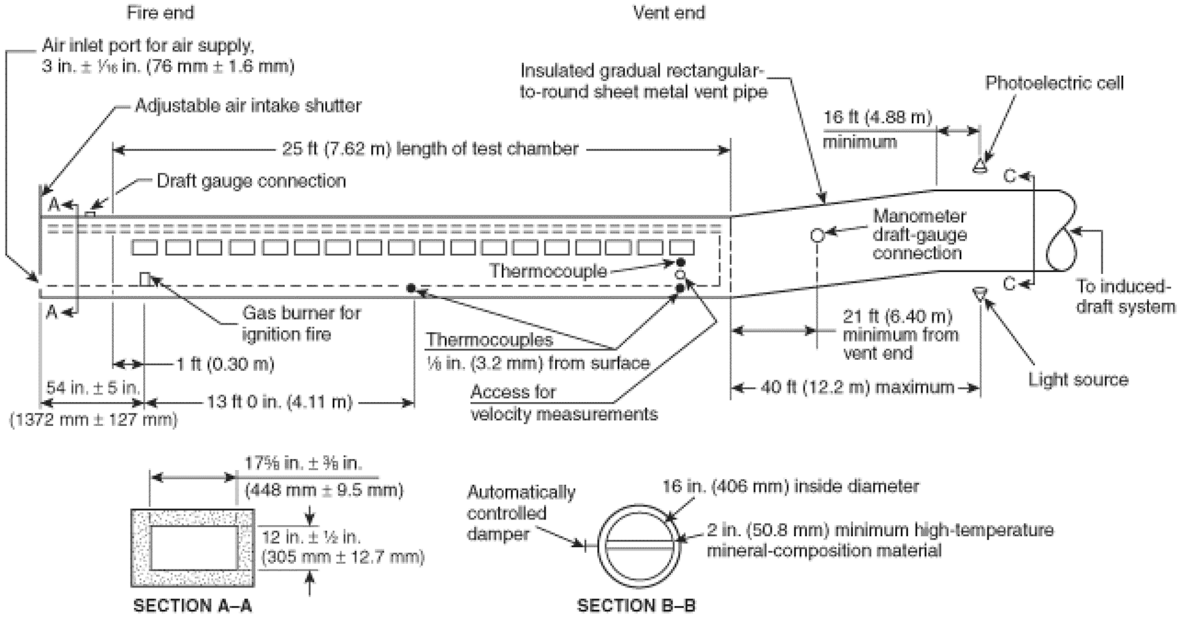


Figure 63. Steiner Tunnel Test (from NFPA255[90])

NFPA 259 – Potential heat of building products[92]

This test uses an oxygen bomb calorimeter to determine the heat of combustion for a material. It also specifies placing the same material in a muffle furnace at 750 °C for two hours and then testing the residue in a bomb calorimeter to determine the potential heat of the residue.

ASTM D 1929 standard test method for determining ignition temperature of plastics[93]

This test exposes small pellets of plastic materials to a controlled flow rate of heated air inside a tube furnace. This test measures the two following properties;

- Flash-Ignition Temperature – the lowest initial exposure air temperature at which the combustible gas evolved from the specimen can be ignited by a small external pilot flame.
- Spontaneous-ignition (Self-ignition) temperature -The lowest initial exposure air temperature at which unpiloted ignition of the specimen occurs indicated by an explosion, flame or sustained glow.

C.1.7 SMALL FLAME SCREENING TESTS

Small flame tests have been used and misused to test the flammability of materials since the 1930s. During the 1950s and 1960s there was an increased reliance on small flame tests but in recent years this reliance has decreased as new test methods that produce more useful measurements have been introduced[94]. Small flame tests have originated from a need to perform quick and cheap screening tests (such as holding a match to a material to see if it burns) Some methods have become overly complex given these origins. These methods assess the ease of ignition and the ability to sustain flaming under set laboratory conditions but do not provide useful data that can be used to predict fire behaviour for real fire scenarios. They can only be used for screening. Dripping of materials can unseat and extinguish flaming in these tests producing a good test result however in real fire scenarios the material may be orientated or restrained so that it either forms a molten pool or drips onto other combustible materials which may increase hazard of flame spread.

AS 1530.2 is an example of a small flame test which is applied by the NCC BCA 2019 Vol 1 DTS to regulate sarking material.

ASTM D 635[95] is an example of one small flame test which is used in the US IBC relating to external wall assembly including plastic panels and metal composite materials. This tests specimens 125 mm long x 13 mm wide in the horizontal position. A Bunsen burner flame is applied for a specified time and time to flame extinguishment, burn distance, linear burning distance and occurrence of flaming droplets are recorded. Other similar small flaming tests that may test in either the horizontal or the vertical position include UL94, IEC 60707, IEC 60695-11-10, IEC 60695-11-20, ISO 9772 and ISO 9773, and EN ISO 11925-2.

C.2 Room corner fire tests

A range of standard room corner test methods exist around the world. These tests simulate the scenario of an interior localised fire occurring in one corner of a room with a ventilation opening (typically a door) and they evaluate the propensity for fire spread on interior wall and ceiling linings resulting in flashover. In some tests the wall and ceiling linings are fixed to a non-combustible lined test room substrate and in others, materials such as insulated sandwich panels are constructed as a self-supporting, free standing test room so that structural integrity and collapse can also be evaluated under fire conditions. (Opening up of joints in such systems can significantly influence fire growth).

AS ISO 9705[96] is applied in Australia by the NCC BCA DTS Vol 1 regulate interior wall and ceiling linings based on material group number.

Room corner tests should be applied for determination of group numbers of ACP for application as internal wall or ceiling linings.

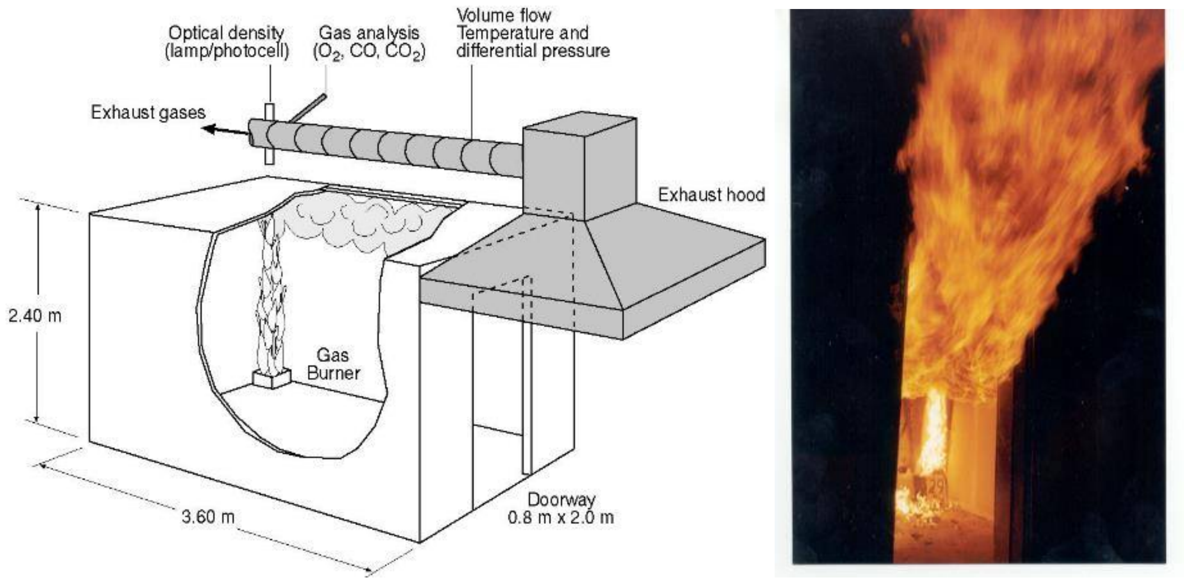


Figure 64. ISO 9705 room corner test layout and resulting flashover (CSIRO)

Room corner tests certainly are not intended to assess fire performance of external walls and facades. However, test results showing good performance of a material in a room corner test are sometimes used (particularly by fire engineers justifying an alternative solution) to indicate a level of fire performance. Whilst this may give some degree of confidence in performance the following issues must be considered:

- The ignition source HRR for a room corner test simulates a localised pre-flashover fire and is significantly lower than the worst-case scenario identified for external wall assemblies, being a post flashover fire with flames ejecting from an opening.
- The orientation and exposure of materials in the room fire test can be significantly different to an external wall system.
- Room corner tests do not expose or test the edge treatment/design of the window opening and therefore the propensity for fires to spread into the internal cavity of the wall system via this opening is not tested.

The following table provides a brief summary of the various room corner test methods.

Table 44. Summary of room corner test methods

Test Method	Fixed linings inside non-combustible test room or free standing room test	Room dimensions	Ventilation opening	Ignition source	Measurements
ISO 9705[96]	Fixed	2.4m wide x 2.4 m high x 3.6 m long	0.8 m x 2.0 m doorway	Gas burner with output of 100 kW for 0-10 min and 300 kW for 10-20 min	HRR Smoke optical density Temperatures at ceiling level and opening Heat flux at floor level
NFPA 286[97]	Fixed	2.44m wide x 2.44 m high x 3.66 m long)	0.78 m x 2.02 m doorway	Gas burner with output of 40 kW for 0-5 min and 160 kW for 5-15 min	HRR Smoke optical density Temperatures at ceiling level and opening Heat flux at floor level
UBC 26-3[98]	Fixed	Interior dimensions 2.44m wide x 2.44 m high x 3.66 m long)	0.78 m x 2.13 m doorway	Douglas Fir timber crib 13.6 kg, 381 mm square base area, each stick 38 mm square. 5 sticks per tier.	Temperatures at ceiling level and opening Internal panel temperatures Visual observation of fire spread, flashover damage and smoke.
ISO 13784 Part 1[99]	Free standing	2.4m wide x 2.4 m high x 3.6 m long	0.8 m x 2.0 m doorway	Gas burner with output of 100 kW for 0-10 min and 300 kW for 10-20 min	HRR Smoke optical density Temperatures at ceiling level and opening Heat flux at floor level Internal panel temperatures
ISO 13784 Part 2[100]	Free standing	4.8m wide x 4.0 m high x 4.8 m long	4.8 m x 2.8 m doorway	Gas burner with output of 100 kW for 0-5 min and 300 kW for 5-10 min and 600 kW for 10-15 min	Internal and surface panel temperatures Visual observation of fire spread, flashover and damage
LPS 1181 Part 1 and Part 2[101, 102]	Free standing	Large free standing room fire test (10 m L x4.5 m W x 3 m H). Applies timber crib	2.25 x 4.5 m W opening.	Redwood/Scots Pine timber crib. 70 Sticks of 50 mm x 25mm x 750 mm	Temperatures at ceiling level and opening Internal panel temperatures Visual observation of fire spread, flashover and damage

C.3 AS 1530.8.1 and AS 1530.8.2 Bushfire test method

The NCC BCA and AS 3959 regulates building construction in bushfire prone areas based on an assessed Bushfire Attack Level (BAL) for the building site. The following BAL categories exist:

BAL category	Description
BAL—LOW	There is insufficient risk to warrant any specific construction requirements but there is still some risk.
BAL—12.5	The construction elements are expected to be exposed to a heat flux not greater than 12.5 kW/m^2.
BAL—19	The construction elements are expected to be exposed to a heat flux not greater than 19 kW/m^2.
BAL—29	The construction elements are expected to be exposed to a heat flux not greater than 29 kW/m^2.
BAL—40	The construction elements are expected to be exposed to a heat flux not greater than 40 kW/m^2.
BAL—FZ	There is an extremely high risk of ember attack and burning debris ignited by windborne embers, and a likelihood of exposure to an extreme level of radiant heat and direct exposure to flames from the fire front exceeding 40 kW/m^2

AS 3959 specifies DTS requirements for construction for the above BAL categories. For construction outside of the prescribed DTS solutions AS 1530.8.1 or AS 1530.8.2 is required as a performance-based test.

AS 1530.8.1 is required for BAL 12.5 to BAL 40 and exposes test specimens to a radiant heat exposure which peaks at the prescribed BAL radiant heat level. This is combined with application of a pilot flame and timber cribs at specified location on the exposed face of the specimen. Specimens such as walls must be tested as complete 3 m x 3 m wall system specimens exposed to a 3 m x 3 m radiant panel (formed by a steel sheet panel over an AS 1530.4 furnace.

Note that the same sized radiant heat panel source is adopted by AS 5113 to determine Building to Building (B2B) radiant heat classification however the range of levels of radiant heat exposure for AS 5113 (B2B) is higher, at a maximum of 80 kW/m^2 compared to AS 1530.8.1. Smaller elements such as penetrations or small windows are permitted to be tested using smaller pilot scale radiant panels.

Failure criteria include:

- Formation of an opening through which a 3 mm probe can penetrate.
- Sustained flaming on the non-fire side.
- Flaming on the fire-exposed side at the end of the 60 min test period.
- Radiant heat flux 365 mm from the non-fire side of the specimen in excess of 15 kW/m2 from glazed and uninsulated areas during the 60 min test.
- Mean and maximum temperature rises greater than 140 K and 180 K, respectively, on the non-fire side during the 60 min test, except for glazed/uninsulated areas for which the radiant heat flux limits are applicable.
- Radiant heat flux 250 mm from the fire-exposed face of the specimen, greater than 3 kW/m2 between 20 min and 60 min after the commencement of the test.
- Mean and maximum temperatures of the internal faces of construction including cavities, exceeding 250°C and 300°C respectively between 20 min and 60 min after the commencement of test.

BAL –FZ requires AS 1530.8.2 which is essentially an AS 1530.4 fire resistance test to an FRL of -/30/30 with some additional requirement. AS 1530.8.2 includes some failure criteria which are more onerous than AS 1530.4 relating to permitted gap formation size, flaming on fire exposed side between 60 and 90 minutes and temperature limits on internal faces of constructions including cavities.

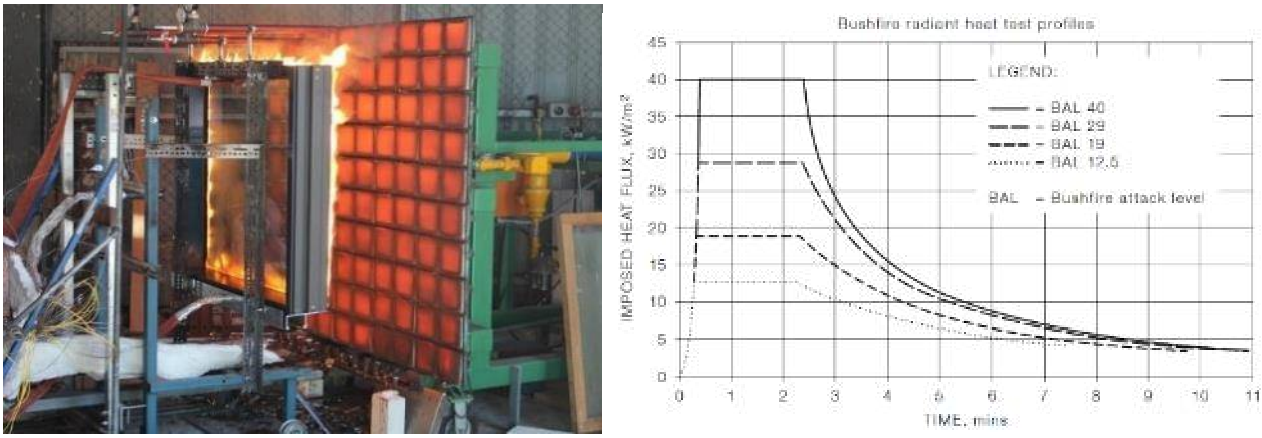


Figure 65. CSIRO pilot scale AS 1530.8.1 test (left), BAL radiant heat test profiles (right)

AS 1530.8.1 and AS 1530.8.2 are intended for determination of bushfire performance and should not be used to directly assess façade external fire spread performance for the following reasons:

- AS 1530.8.1 is predominantly a radiant heat exposure only combined with cribs representing relatively small quantities of burning debris. It does not represent direct flame impingement from larger fuel loads. It does not examine upwards external flame spread. A tested system can undergo significant flaming of the external surface and still be acceptable so long as the fire does not spread to the cavity or the non-exposed side, or exceed temperature failure criteria (not on exposed face).
  .
- AS 1530.8.2 is predominantly a fire-resistant barrier integrity and insulation test with some more stringent criteria. This does not represent a typical façade exterior fire exposure or examine vertical external flame spread. A tested system can undergo significant flaming of the external surface and still be acceptable so long as the fire does not spread to the cavity or the non-exposed side, or exceed temperature failure criteria (not on exposed face).

C.4 Intermediate scale façade fire spread tests

There are a limited number of intermediate scale façade fire spread test methods around the world such as ISO 13785:2002 Part 1 – Intermediate scale facade test[103] and vertical channel tests [104, 105] are not actively being used to regulate ACP but have been applied in some research experiments. Whilst DIN 4102-20 may possibly be considered as intermediate scale due to its ignition source size of ~ 320 kW it is summarised in the large-scale test method section due to the size and arrangement of the specimen.

12.1.1 ISO 13785:2002 PART 1 – INTERMEDIATE SCALE FACADE TEST[103]

The test façade is installed as a re-entrant corner "L" arrangement with a total specimen height of 2.4 m, a rear wall width of 1.2 m and side wall width of 0.6 m. The façade is installed representing the end use with all cavity insulation, air gaps and fixings include. The fire source is a linear propane burner 1.2 m x 0.1 m in area which is located 0.25 m below the bottom edge of rear wall. The burner has a constant 100 kW output which is sufficient to achieve direct flame impingement on the bottom 200 mm of the rear wall façade. Temperatures are measured vertical intervals of 0.5 m on the centre of both façade wall surfaces. Heat Flux is measured at the top of the rear façade wall. Fire spread is observed.

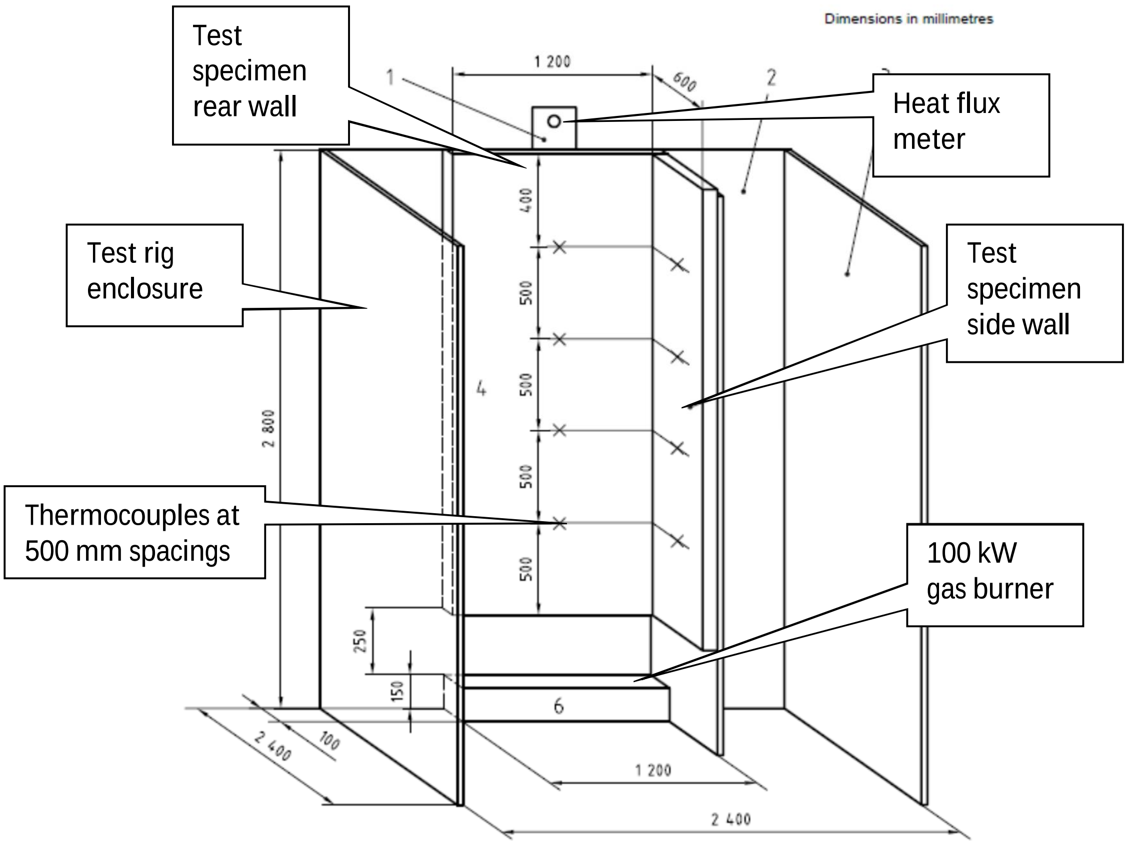


Figure 66. ISO 13785 Part 1 test rig[103]

The test standard does not provide any acceptance criteria and does not provide details of any correlation between performance in the Part 1 test and the Part 2 test. The ignition source is significantly smaller than for full scale tests. How this test does provide a useful and less expensive method for quickly screening and comparing alternative systems.

C.4.1 FM TEST METHOD FOR FIRE SPREAD WITHIN CAVITY WALL SYSTEMS.[106, 107]

FM 4411[106] specifies approval requirements for cavity wall systems such as rain screen cladding with a wall cavity air gap behind, particularly where the cavity may be lined with combustible insulation such as EPS or other foamed polymer materials. FM4411 specifies an intermediate test for fire spread within a wall cavity system. This test method is specified in more detail in a paper by FM global[107]. The test apparatus consists of two parallel panels, each 1.2 m wide x 2.4 m high consisting of 13 mm glass faced gypsum board or other suitable non-combustible board. The cavity insulation material is placed within the cavity representative of the system being tested.

- If approval is desired with a 24-51 mm air gap, then the construction is tested as a 51 mm air gap. A 51 mm x 305 mm propane sand burner with a heat output of 5.8 kW is loc–ted at the centre bottom of the cavity.
- If approval is desired with a >51 - 102 mm air gap, then the construction is tested as a 102 mm air gap. A 102 mm x 305 mm propane sand burner with a heat output of 9.5 kW is located at the centre bottom of the cavity.

The test is conducted under a fire calorimetry hood with oxygen consumption calorimetry. The gas burner is applied for a 15-minute exposure. During this time the specimen contribution must not exceed an HRR of 100 kW and must not exceed a visible flame height of 1.8 m.

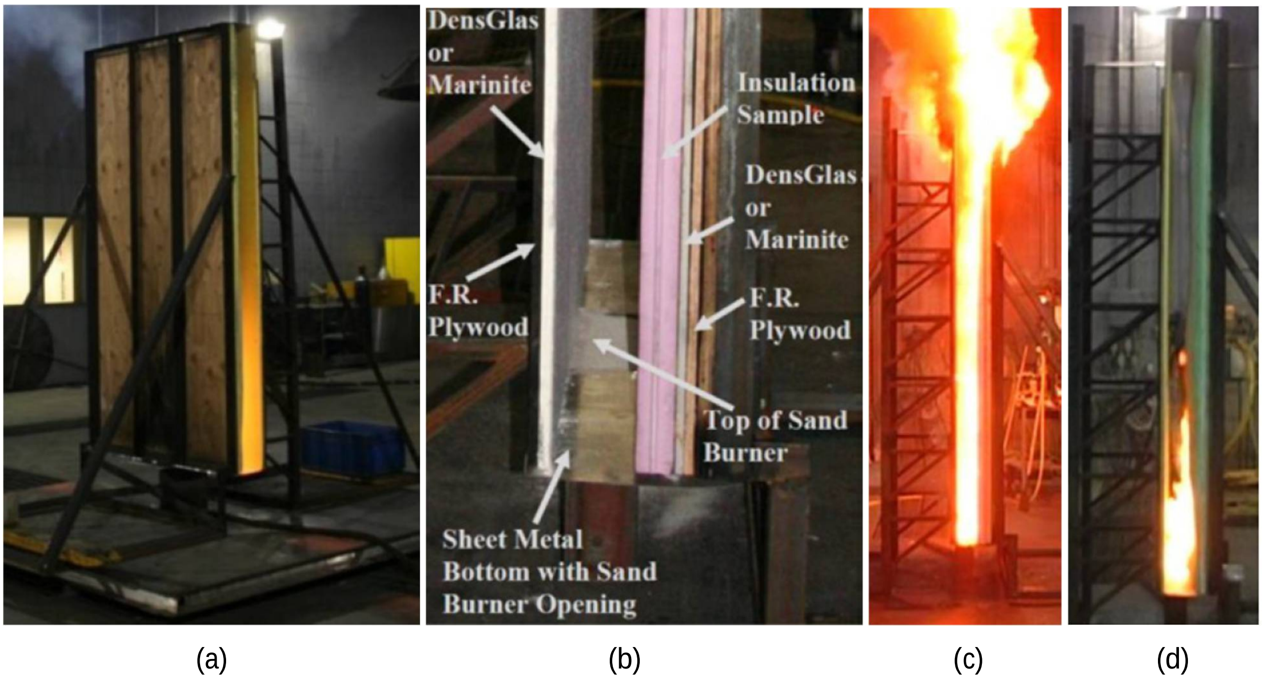


Figure 67. FM 4411 Cavity fire spread test. (a) and (b), apparatus. (c) poor performing insulation. (d) good performing insulation

FM 4411 applies this test method for approval of combustible cavity insulation tested contained within non-combustible wall lining/cladding. However, this method could potentially have application in assessing/understanding fire spread performance of ACP exposed to small cavity fires where the back face of the ACP is exposed to the cavity (with or without additional combustible insulation).

C.4.2 FM 16 FT (4.9 M) PARALLEL PANEL TEST[108-110]

FM Global has developed a parallel panel test as an intermediate scale test to predict results for the 25 ft. and 50 ft. corner tests. The parallel panel test apparatus consists of two parallel panels, each 4.9 m high by 1.1 m wide, separated by 0.5 m. A sand burner, 1.1 m by 0.5 m by 0.3 m high, is located at the bottom of the panels. The total heat release rate from the burning panels during the test is measured by a 5 MW capacity oxygen consumption calorimetry exhaust hood. The burner exposure is controlled to 360 kW to provide a maximum heat flux to the panels of 100 kW/m^2. This corresponds to the maximum heat flux measured at the panels at the top of the crib in the 25 ft. corner test.

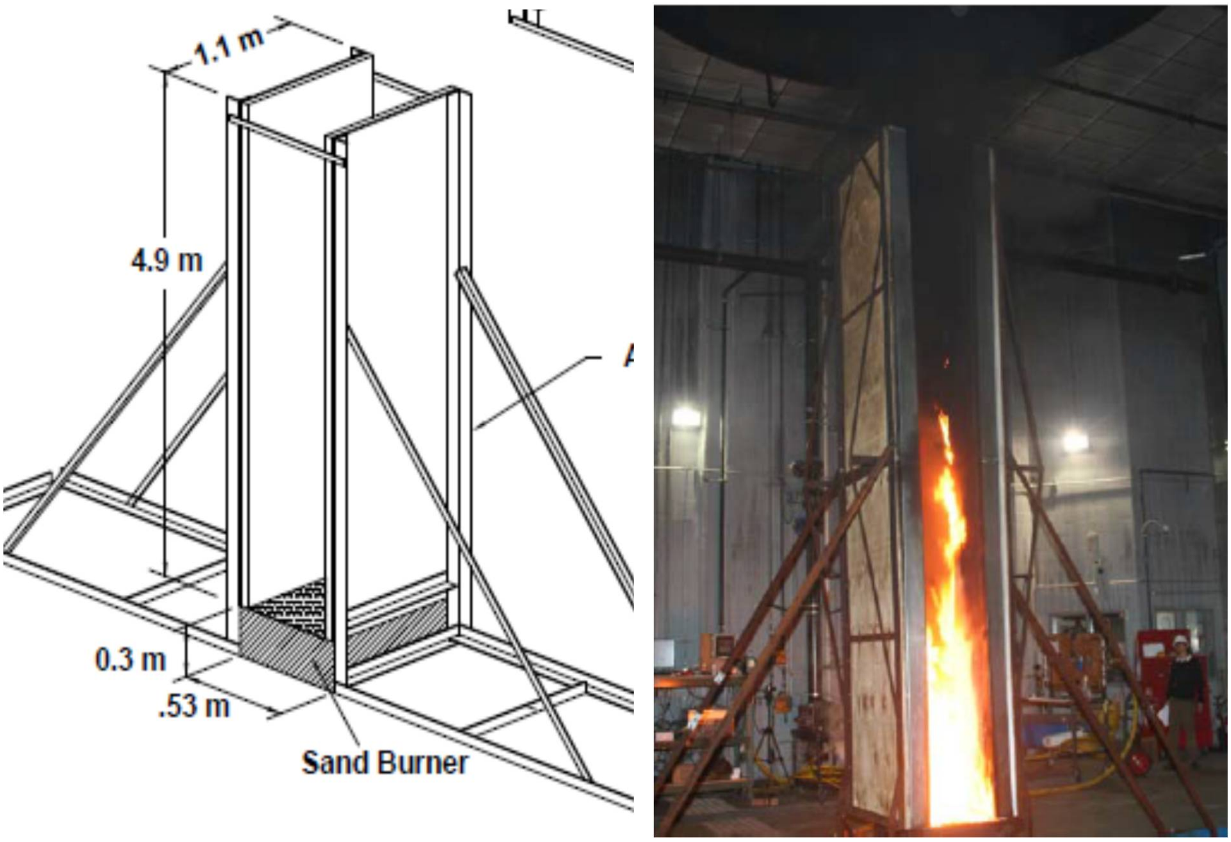


Figure 68. FM Global Parallel Panel Test[110]

A measured HRR of 1100 kW in the parallel panel test was found to represent fire spread to the top of the panels and this criterion is used in additional to visual observation of fire spread which is often difficult due to smoke production.

It was concluded that fire will not propagate to the end of the test array in the 25-ft corner test with combustible wall panels and a non-combustible ceiling if the HRR in the parallel panel test is less than 1100 kW; fire will not reach the top of the test array in the 50-ft corner test if the HRR in the parallel panel test is less than 830 kW; fire propagation will not reach the ends of the horizontal ceiling in the 25-ft corner test with both combustible wall and ceiling panels if the HRR in the parallel panel test is less than 830 kW.

FM 4880 approval and classification of external wall systems requires a range of test including small scale flammability tests, on component materials , room corner tests and 25 ft or 50 ft full scale corner tests dependant on the type of wall system and the height limit classification being sought. In some cases, FM Approvals will apply the FM 16 ft (4.9 m) Parallel Panel test may be applied (in lieu of the larger 25 ft or 50 ft full scale corner tests) with the following criteria being applied:

Table 45. FM 4880 approval criterial for external wall assemblies applied to 16 ft parallel panel tests.

Approval Height	Test criteria
50 ft (15.2 m)	830 kW < Peak HRR ≤ 1100 kW
Unlimited height	≤ 830 kW

12.1.2 VERTICAL CHANNEL TEST

The vertical channel test was originally developed by NRC to provide a cost effective intermediate test than the full scale CAN/ULC S134 test method. The intent was to achieve the same exposure conditions as the full-scale test. A series of tests carried out by NRC demonstrated that the vertical channel test correlated well with the full scale test[104]. The test method was published as an ASTM Draft proposed rest method[111].

The ASTM Vertical channel test is conducted on a single wall with façade, cladding or exterior wall system that is 800 mm wide and 7.32 m high. The specimen is installed representative of the end use including all insulation, cavity air gaps and fixing details. The test specimen wall is located at the rear of a channel formed by non-combustible 500 mm wide vertical projections one each side of the specimen wall. The purpose of this channel is to enhance the fire exposure conditions to the reduced width specimen produced by a reduced fire source size.

The fire source is intended to simulate flame spread from a compartment fire via a window opening. The fire source is two propane gas burners located in a combustion chamber 1.9 m high x 1.5 m deep x 0.8 m wide located at the base of the test wall. The combustion chamber has two openings across the widths of the chamber at the front in line with the front of the test wall. The lower opening is 440 mm high and is an air inlet. The top opening is 630 mm high and is a flame outlet. The burners are controlled to achieve a heat flux of 50 ±5 kW/m^2 at 0.5 m above the opening and 27 ± 3 kW/m^2 at 1.5 m above the opening averaged over a 20 minute period of steady burner output. This is typically achieved with a propane supply of 25 g/s (1.16 MW). During the test heat flux is measured at the front face of the test wall 3.5 m above the opening and temperatures are measure at the front surface and at each intermediate layer at intervals of 1 m starting at 1.5 m above the opening. The test duration is 20 minutes.

The test acceptance criteria are:

- Flame does not spread more than 5 m above the bottom of the specimen
- Heat flux 3.5 m above the opening does not exceed 35 kW/m^2

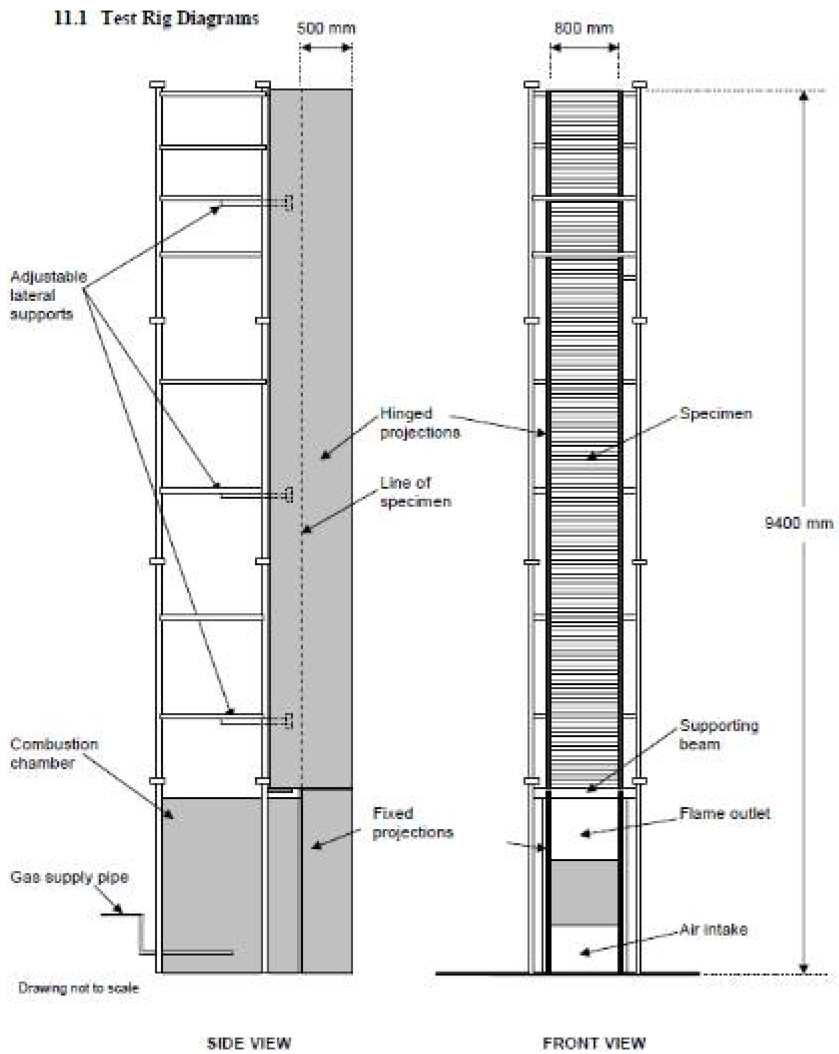


Figure 69. ASTM Vertical Channel test rig [111].

In 2005, BRANZ developed a modified version of the vertical channel test and undertook a series of tests investigating the use of the cone calorimeter test as a pre-screening test for external combustible wall linings[112]. The main changes to the vertical channel test by BRANZ were:

- Reduction of the specimen wall height to 5 m
- Some modification to gas supply rate and combustion chamber ventilation conditions to better match the full scale test exposure.

C.5 Full scale façade fire spread tests

There are a significant number of large-scale façade fire spread test methods around the world. These have been previously reviewed by White et al[2]. Please refer to Appendix B for a table which summarises the main international full-scale façade fire test methods. This section provides details of the following key test methods as they are applied for combustible external walls in the relevant countries:

- AS 5113:2016 incorporating Amendment No 1 – Australia.
- BS 8414 – UK.
- NFPA 285 – USA.
- DIN 4102-20 – Germany.

C.5.1 AS 5113[113]

AS 5113 provides a test methodology for classifying fire performance of external walls in terms of two distinctly different parameters:

- External Wall (EW) – Fire spread performance in response to an ignition fire directly impinging on the wall.
- Building-to-building (BB) – ignition and fire spread performance in response to radiant heat exposure from an adjacent building fire.

External wall classification

External wall tests may be performed according to either ISO 13785-2 or BS 8414. AS 5113 specifies additional test requirements and acceptance criteria. In practice, all Australian test labs are currently only testing according to BS 8414 as this is more commonly adopted internationally. Only the application of BS8414 is discussed below.

The timber crib is the same crib as specified in Annex A of BS8414 and the timber is permitted to be pinus silvestris or pinus radiata. AS 5113 specifies that all the following classification criteria for BS 8414 tests must be satisfied:

a. Temperatures 5 m above the opening measured 50 mm from the exposed specimen face shall not exceed 600°C for a continuous period greater than 30 s.
b. Temperatures at the mid-depth of each combustible layer or any cavity 5 m above the opening shall not exceed 250°C for a continuous period of greater than 30 s.
c. Where the system is attached to a wall that is not required to have an FRL of –/30/30 or 30/30/30 or more, the temperature on the unexposed face of the specimen 900 mm above the opening shall not exceed a 180 K rise. Five thermocouples equally spaced at 500 mm centres with insulating pads, fitted in accordance with the requirements of AS 1530.4 for the measurement of surface temperatures shall be used.
d. Where the system is attached to a wall not required to have a fire resistance of –/30/30, 30/30/30 or more, flaming or the occurrence of openings in the unexposed face of the specimen above the opening shall not occur.
e. Flame spread beyond the confines of the specimen in any direction, as determined during the post-test examination, shall not occur. The examination shall include flame damage such as melting, charring but not smoke discolouration or staining of the surface, any intermediate layers and the cavity.
NOTE: The confines of the specimen is the minimum specimen size specified in the 'Dimensions of test specimen' clause in BS 8414, Parts 1 and 2. The specimen may be constructed larger than the minimum size in which case spread is determined at the positions associated with the minimum specimen size.
f. Continuous flaming on the ground for more than 20 s from any debris or molten material from the specimen shall not occur.
g. The total mass of debris falling in front of the specimen shall not exceed 2 kg. The mass shall be measured after the end of the test.

The above criteria are different and more stringent than the BR 135 criteria applied to BS8414 tests in the UK.

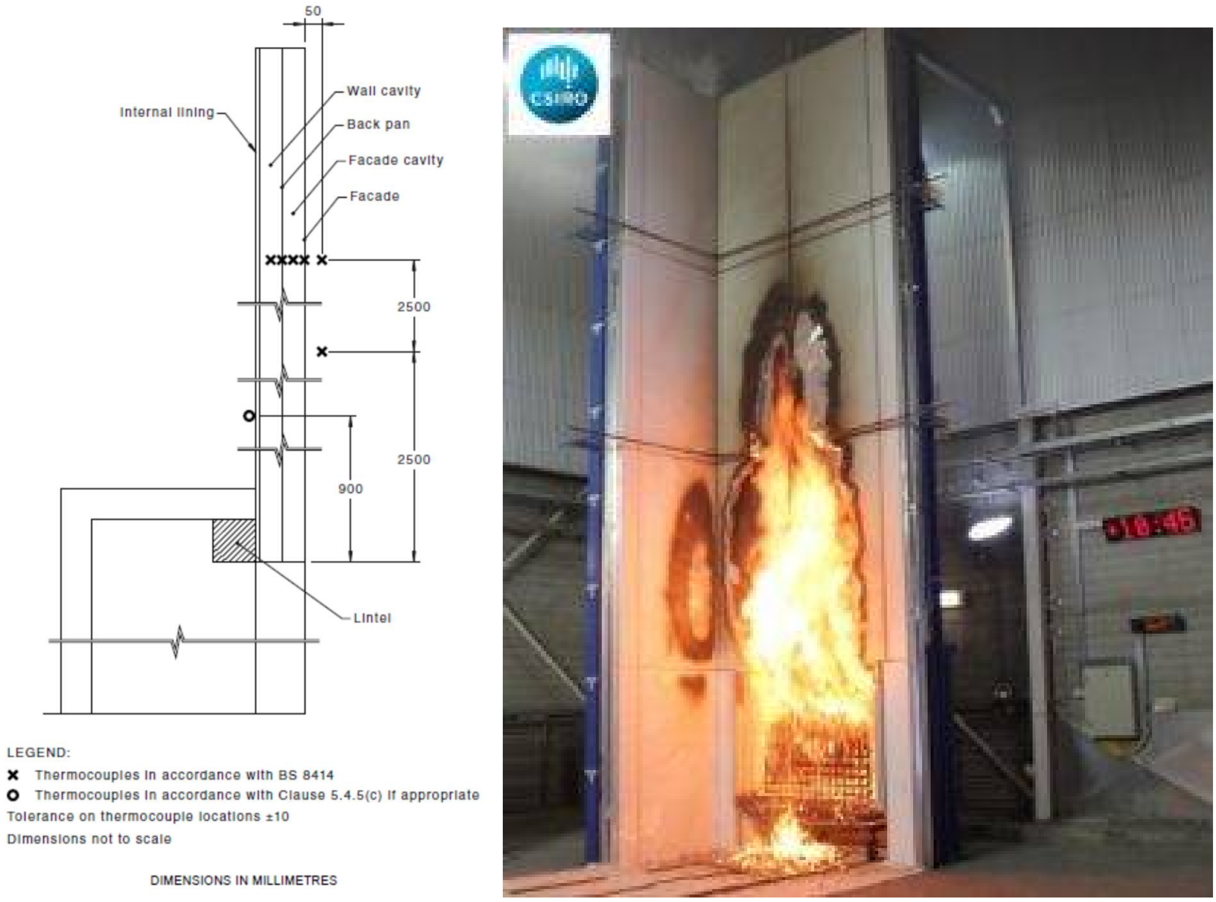


Figure 70. AS5113 thermocouple locations (left), CSIRO AS5113/BS8414 test rig (right)

Building-to-building classification

A representative external wall system specimen at least 3 m x 3 m is exposed to the prescribed radiant heat exposure level which is achieved via an AS 1530.4 fire resistance furnace with a sheet steel closure forming a radiant heat source at least 3 m x 3 m. The heat flux exposure level is subject to the BB classification being tested.

Table 46. BB classification radiant heat flux levels.

BB classification	Heat flux, kW/m²
BB80	80
BB40	40
BB20	20
BB10	10

The specimen shall be exposed to the required heat flux for a minimum of 30 min plus 10 minutes heat up phase (i.e. total test duration at least 40 min allowing for the heat up phase). A small 25 mm long pilot ignition flame is applied to the exposure face of the specimen during the test

All the following performance criteria shall be satisfied:

a. Temperatures at the mid-depth of each combustible layer or any cavity shall not exceed 250°C for a continuous period of greater than at least 30 s.
b. Where the system is attached to a wall not required to have a fire resistance of –/30/30, 30/30/30 or more, temperatures on the unexposed face of the wall specimen shall not exceed a 180 K rise.

c. Where the system is attached to a wall not required to have a fire resistance of –/30/30, 30/30/30 or more, flaming or the occurrence of openings in the unexposed face of the specimen shall not occur.
d. Continuous flaming on the side of the specimen exposed to radiant heat exceeding 30 s shall not occur.
e. Continuous flaming on the ground for more than 20 s from any debris or molten material from the specimen shall not occur.
f. The total mass of debris falling in front of the specimen shall not exceed 2 kg. The mass shall be measured after the end of the test.

C.5.2 BS 8414 PART 1 AND PART 2[114, 115]

BS 8414 part 1 and part 2 were developed by BRE. BS 8414-1 is a full-scale fire test for non-load bearing external cladding systems applied to the face of a solid external building wall. The test simulates the scenario of flames emerging from a compartment fire via a window at the base of the wall. The test façade is installed as a re-entrant corner "L" arrangement. The test rig has a masonry block wall construction as the substrate for mounting test specimens to. The test wall extends at least 6 m above the window soffit. The main wall is at least 2.6 m wide and the wing wall is at least 1.5 m wide. The window opening is at the base of the main wall and is 2 m wide x 2 m high. The façade is installed around the window down to the bottom of the window. The façade is installed representative of the end use including all insulation, cavity air gaps, fixings and window details. The tested façade must be at least 2.4 m wide on the main wall and 1.2 m wide on the wing wall.

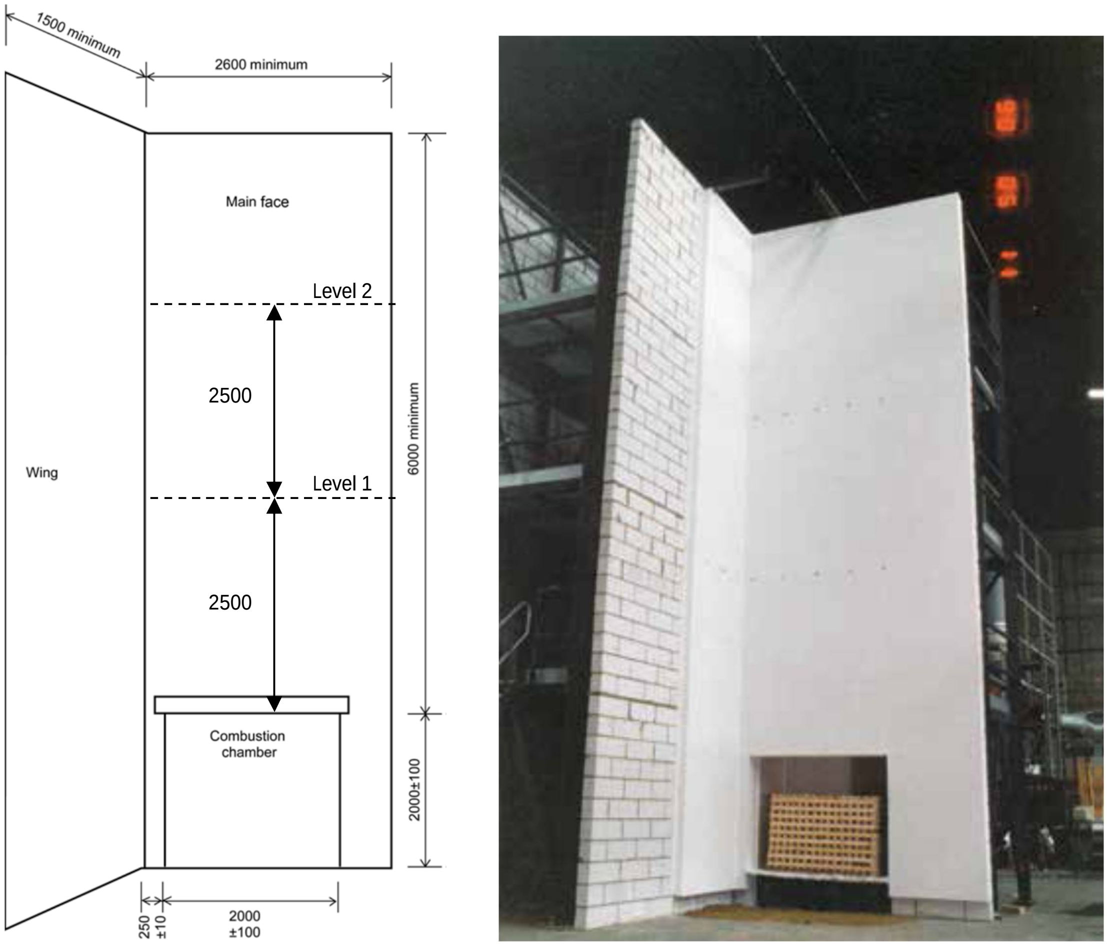


Figure 71. BS8414-1 test rig (from BRE report BR135[116])

The fire enclosure is 2 m wide x 1 m deep x 2.23 m high with a lintel at the front opening reducing the soffit height of the opening to 2 m. The standard fire source is a timber crib constructed of softwood sticks having a cross sectional area of 50 mm x 50 mm. The constructed timber crib is nominally 1.5 m wide x 1 m deep x 1 m high. The crib sits on a platform 400 mm above the base of the test frame and the front of the crib sits 100 mm in front of the outside surface of the masonry support wall. Therefore, the front of the crib is directly 600 mm under the soffit of the tested façade. The crib has a nominal heat output of 4500 MJ over 30 minutes and a peak HRR of 3±0.5 MW. A previous 2002 edition of the standard included an Annex which stated the ignition source should achieve the following calibrated exposure:

- The mean temperature across the top of the combustion chamber opening measured at 3 thermocouple locations exceeds 600 °C above ambient over a continuous 20 minute period. The variation between mean temperature and any individual thermocouple temperature shall not exceed ±20 °C
- The mean temperature at level 1 height on the main wall face exceeds 500 °C above ambient over a continuous 20 minute period.
- Mean heat flux measured at 1 m above the window soffit on the main wall shall remain within the range of 45-95 kW/m^2 over a continuous 20 minute period and typically achieves a steady state peak mean heat flux of approximately 75 kW/m^2 within this period.

However, the above details were removed from the current 2015 edition of the standard.

During the test temperatures are measured at the external surface at the test façade on the main and wing walls at level 1 (2.5 m above the window soffit) and level 2 (5 m above the window soffit). Internal thermocouples are only located at level 2 on the main and wing wall and are positioned at the centre of each combustible layer >10 mm thick or cavity. No heat flux is measured during the test.

The fire source is extinguished 30 minutes after ignition and observations and measurements are continued for a total test period of 60 minutes or until all flaming ceases. However, the test shall also be terminated early before 30 minutes (early) if:

a) Flame spread extends above the test facility; or
b) There is a risk to the safety of personnel or impending damage to equipment.

Key observations are extent of flame spread on all surfaces, intermediate layers and cavities, the extent of burn away or detachment for the cladding system and any collapse or partial collapse of the cladding system. The performance criteria for BS8414-1 is given in BRE Report BR135[116] and is:

- Classification can only be undertaken for a system tested to the full test-duration requirements of BS 8414-1 without any early termination of the full fire-load exposure period. This effectively means that tests where flame spread extends above the test facility and are terminated less than 30 minutes after ignition are not classified and are effectively a failure result.
- The fire spread start time is defined as the time when the temperature measured by any external thermocouple at level 1 exceeds 200 °C above ambient.
- Failure due to external fire spread is determined when any external thermocouple at level 2 exceeds 600°C above ambient for a period of at least 30 s, within 15 minutes of the fire spread start time.
- Failure due to internal fire spread is determined when any internal thermocouple at level 2 exceeds 600°C above ambient for a period of at least 30 s, within 15 minutes of the fire spread start time.

BS8414-2 is a full-scale fire test for non-load bearing external cladding systems fixed to and supported by a structural steel frame. This test is essentially the same as BS8414-1 except that the test façade is mounted directly to a steel support frame without the masonry substrate. This tests curtain wall type construction where a solid concrete or masonry wall is not present. The dimensions of the test rig, the fire source and the test procedure are the same as for BS8414-1. The performance criteria for BS8414-2 is given in BRE Report BR135[116] and is the same as for BS8414-1 except for the following additional criteria for internal fire spread.

- Failure due to internal fire spread is also determined when burn through of the façade system with continuous flaming duration of at least 60 s is observed on the non-exposed side of the facade at a height of 0.5 m or greater above the window soffit within 15 minutes of the fire spread start time.

Figure 72. BS8414-2 test rig (from BRE report BR135[116])

There are no failure criteria set for mechanical performance by the BS8414 standards or the BRE report BR135. However, observation of mechanical behaviour including system collapse, spalling, flaming debris, formation of pool fires etc. should be recorded.

C.5.3 DIN 4102-20[117]

Please note that Authors have not had access to DIN 4102-20. The following description has been determined from descriptions provided in other reports[118, 119].

This test simulates the scenario of flames emerging from a compartment fire via a window at the base of the wall. The test façade is installed as a re-entrant corner "L" arrangement. The test rig has a light weight concrete wall construction as the substrate for mounting test specimens to. The test wall extends at least 5.5 m high. The main wall is at least 2 m wide (using the burner) or 1.8 m wide (using the crib) and the wing wall is at least 1.2 m wide using the crib. The fire enclosure and opening is nominally 1 m wide x 1 m high and is located at the base of the main wall at the intersection of the wing wall. The façade is typically installed around the opening down to floor level. The façade is installed representative of the end use including all insulation, cavity air gaps, fixings and window details.

The fire source has a peak HRR of ~ 360 kW and is achieved by either a gas burner or a 30 kg timber crib. The timber crib appears to be most commonly used in practice.

- Wood crib: 30 ± 1.5 kg with density after conditioning 475 ± 25 kg/m³, sawn softwood (e.g. spruce) in rods of 40 ± 2 mm x 40 ± 2 mm x 500 -10 mm, wood air ratio of 1:1, base area of the crib: 500 mm x 500 mm, air supply to chamber: 400 ± 40 m³/h from the back side.
- Gas burner: burner housing is made of 2 mm steel plates, dimensions: 800 mm x 312 mm x 200 mm (length x width x depth), the fuel is propane, supply rate is 7.4 ± 5 % g/s propane and 24 ± 5 % m³/h air with 4 bar.

The fire source was selected to be a medium sized source which would not result in flame immersion more than one level above the fire opening. This is ~ 10 times smaller in terms of peak HRR and mass compared to the BS8414 and AS 5113 crib.

The fire source achieves a maximum temperature of approximately 780-800 °C measured 1 m above the opening soffit on a non-combustible wall. Flames from the fire source are understood to extend a maximum height of 2.5 m above the opening soffit on non-combustible wall.

The gas burner is turned off or wood crib is supressed after 20 minutes for combustible facades. Measurements and observations continue until all burning and smoke production ceases, or until 60 minutes.

The test performance criteria are:

- No burned damaged (excluding melting or sintering) above a height of 3.5 m or more above the opening soffit.
- Temperatures on the wall surface or within the wall layers/cavities must not exceed 500 °C at a height of 3.5 m or more above the opening soffit.
- No observed continuous flaming for more than 30s at a height of 3.5 m or more above the opening soffit.
- No flames to the top of the specimen at any time.
- Falling of burning droplets and burning and non-burning debris and lateral flame spread must cease with 90 s after burners are turned off.

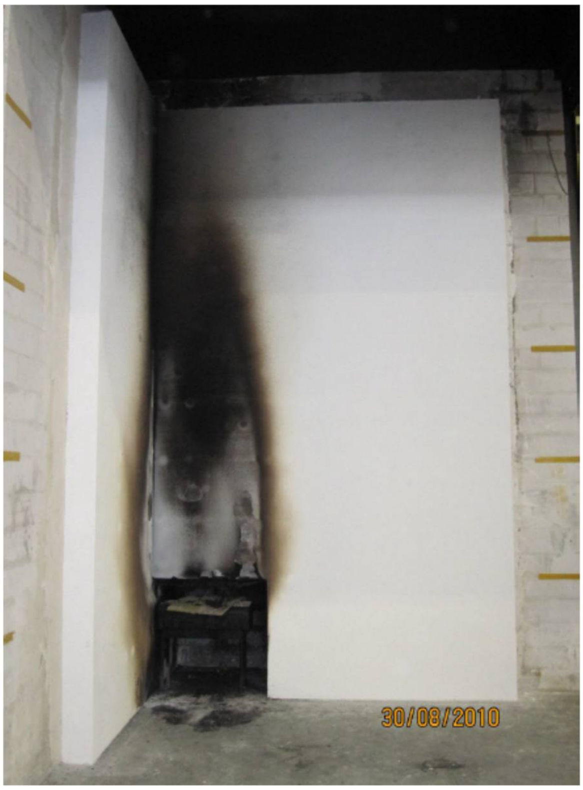


Figure 73. DIN 4102-20 (Draft) test rig (From BRE Global[118])

Note – Germany also developed a larger 200kg crib façade test which is now being used to specifically regulate EIFS.

C.5.4 NFPA 285[120]

This method tests façade claddings or complete external wall systems. The test wall is installed as a single wall surface. No re-entrant corner is installed. The test rig is a two-storey steel framed structure with an open fronted test room on each storey constructed of concrete slabs and walls. Each test room has internal dimensions of approximately 3 m wide x 3 m deep x 2 m high. The bottom test room serves as the fire enclosure and the top test room simulates an enclosure on the level above with no window.

The installed test wall is at least 5.3 m high x 4.1 m wide. The wall tested is a complete system including any external cladding, insulation, external substrate framing and internal wall membrane. The test wall construction and fastening to the test rig must be representative of the end use. The test wall is typically installed on a movable steel frame which is then attached to the front of the test rig concrete slabs. The test wall includes a single opening 1.98 m wide x 0.76 m high. The opening soffit is located 1.52 m above the fire enclosure floor.

The fire source consists of two separate pipe type gas burners. One burner is placed in the centre of the fire enclosure and the other burner in a 1.52 m long linear burner located near the soffit of the opening. The room burner output is gradually increased from approximately 690 kW to 900 kW over the 30 minute test duration. The window burner is ignited 5 minutes after the room burner and is gradually increased from 160 kW to 400 kW over the remaining 25 minute test period. The burners are calibrated to achieve average heat fluxes at the surface of a non-combustible test wall of approximately 40 kW/m^2 at 0.6 m and 0.9 m above the opening and 34 kW/m^2 at 1.2 m above the opening during the peak fire source period of 25-30 minutes.

During the test temperatures are measured at the front of the test wall and also in the cavity and insulation spaces within the wall at 305 mm intervals vertically from the opening soffit. Temperatures within the fire enclosure, at the rear of the test wall in the second storey test room are also measured. No Heat flux measurement is made during the test.

The NFPA 285 standard provides a very detailed set of performance criteria which are briefly summarised as follows.

- Temperatures at exterior of wall must not exceed 538 °C at a height of 3.05 m above the opening soffit.
- Exterior flames must not extend vertically more than 3.05 m above the opening soffit.
- Exterior flames must not extend horizontally more than 1.52 m from the opening centreline.
- Fire spread horizontally and vertically within the wall must not result in designated internal wall cavity and insulation temperatures exceeding stated temperature limits. The position of the designated thermocouples and temperature limits depends on the type and thickness of insulation materials and whether or not an air gap cavity exists.
- Temperatures at the rear of the test wall in the second storey test room must not exceed 278 °C above ambient.
- Flames shall not occur in the second storey test room
- Flames must not occur horizontally beyond the intersection of the test wall and the side walls of the test rig.

As the test does not include a wing wall geometry care should be taken when applying NFPA 285 test results to assess facades to be installed with vertical re-entrant corner geometries.

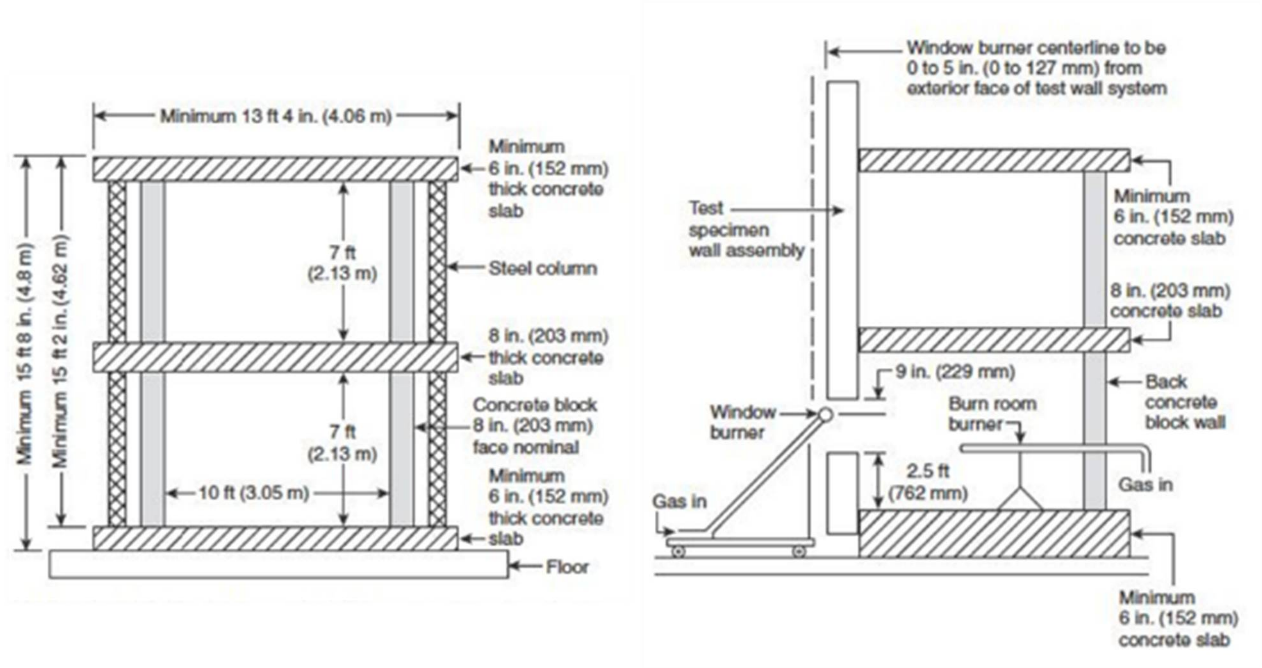


Figure 74. NFPA 285 test apparatus front view without test wall (left) and side view (right) (from NFPA 285-2012)[120]

Figure 75. Front view of typical NFPA 285 test (from Hansbro[121])

The NFPA 285 test method is related to a larger façade test developed in 1980 which used a 26 ft. (8m) two storey outdoors building. A 1285 lb timber crib was used as the fire source in the lower floor which resulted in flames exiting the window and exposing the exterior face of the wall assembly at approximately 5 minutes. This test method was published in the 1988 UBC as test standard 17-6 and in the 1994 UBC as UBC test standard 26-4. In the early 1990s a reduced scale, indoors version of the UBC 26-4 test was developed which replaced the wood crib with two gas burners to produce the same exposure. Testing was done to confirm that similar results were achieved for the same materials on the original large and new reduced scale tests. The reduced scale test became UBC 26-9 which eventually replaced UBC 26-4. NFPA 285 is technically equivalent to UBC 26-9.

12.1.3 ISO 13785:2002 PART 2[122]

The two parts of ISO 13785 provide two test methods:

- Part 1 is an intermediate scale test intended as a less expensive screening test for product developers to assess and eliminate materials or sub-components which fail prior to undertaking a full-scale test (described in Section 0).
- Part 2 is a full-scale faced test (described in this section)

These tests are applicable only to façades and claddings that are non-load bearing. No attempt is made to determine the structural strength of the façade or cladding under fire conditions.

For ISO 13785 -2 the test façade is installed as a re-entrant corner "L" arrangement or wing wall. The fire source is flames emerging from a compartment fire via a window. The height of the tested façade is at least 4 m above the window lintel. The main façade is at least 3 m wide and the wing façade is at least 1.2 m wide. The window is on the main wall with one edge at the wing wall and is 2 m wide x 1.2 m high. The façade is installed around the window down to the bottom of the window. The façade is installed representative of the end use including all insulation, cavity air gaps, fixings and window details.

The fire source is located within a fire enclosure and may be any source which is calibrated to achieve an average total heat flux of 55 ± 5 kW/m^2 at a height of 0.6 m above the window and an average total heat flux of 35 ± 5 kW/m^2 at a height of 1.6 m above the window. The fire source has a 4-6 minute growth phase and a similar decay phase. The total test duration is 23-27 minutes. The standard fire source is series of large perforated pipe propane burners installed in an enclosure approximately 4 m wide x 4 m deep x 2 m high with a total output of 5.5 MW. Alternative fire sources are permitted and the fire enclosure may any volume in the range 20 m^3 – 30 m$^{3.}$

During the test total heat flux is measured across the façade surface at 0.6 m, 1.6 m and 3.6 m above the window. Thermocouples are located on the outside surface of the façade immediately above the window and also at 4 m above the window. Thermocouples are also inserted into intermediate layers of material and cavity air gaps at height of 4 m above the window. Fire spread is observed.

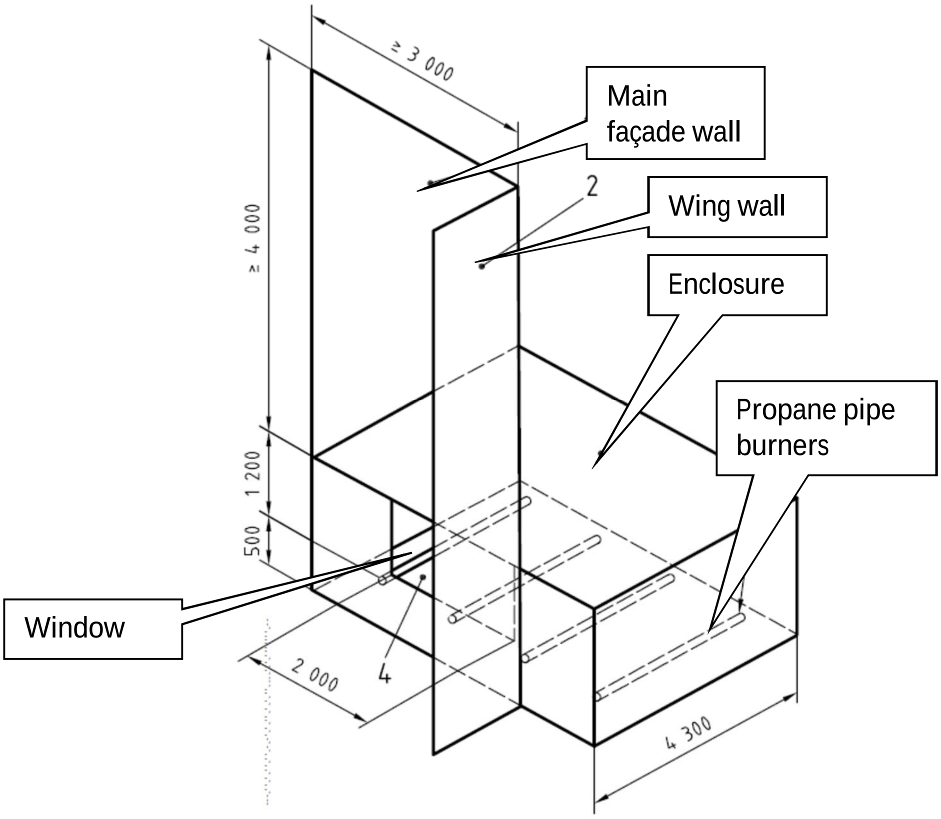


Figure 76. ISO 13785 Part 2 test rig with standard fire source[122]

Potential problems with this test method may include the significant space and gas supply required for the large standard enclosure and fire source. The use of permissible alternative enclosure sizes and fire sources may alleviate this. However, this results in a lower intensity fire exposure to the external façade when compared with some other large scale tests. Also, the allowable variance of the fire source including the growth and decay times may result in some variance to test exposures.

C.5.5 FM 4880 25FT AND 50 FT CORNER TESTS[108]

FM 4880 details the FM Approvals process for testing of insulated wall or wall and roof/ceiling assemblies, plastic interior finish materials, plastic exterior building panels, wall ceiling and coating systems and interior or exterior finish systems. Part of this evaluation process details (dependant on end use application and height):

- 16 ft. (4.9 m) High Parallel Panel Test.
- A 25 ft high corner test to be applied for acceptance of assemblies for an end-use maximum height of 30 ft (9.1 m).
- A 50 ft high corner test to be applied for acceptance of assemblies for an end-use maximum height of 50 ft (15.2 m) or unlimited height.

Although FM 4880 states that it is applicable a range of external wall systems, the use of the above tests is mostly applied to assessing insulated sandwich panels, however FM-Global has done some work assessing other façade materials including EIFS . These tests and are not specifically external façade tests and are not referred to by building codes for regulation of external facades. However, these test methods are summarised here as they do provide a possible method for assessing performance in response to severe external fire sources (such as back of house fires for commercial/industrial buildings).

Both tests simulate an external (or internal) fire source located directly against the base of a re-entrant wall corner

C.5.6 25 FT (7.6 M) HIGH CORNER TEST

The test apparatus structure consists of a two column and girt wall frames and a ceiling frame of joists and metal furring strips to which test wall and ceiling assemblies can be mounted. There is no non-combustible substrate such as concrete or masonry. The height to the underside of the ceiling frame is 7.54 m. One wall is 15.7 m wide and the other wall is 11.96 m wide. For tests on wall assemblies only, corrugated steel decking is installed to the underside of the ceiling frame. The test wall is installed representative of the end use, which typically involves through bolting of insulated sandwich panels directly to the frame. Test walls are installed to top half (above 3.8 m) extending over the entire width of each wall. Test walls are installed to the bottom half (below 3.8 m) extending only 6 m from the corner on each wall. The remaining sections of the wall are clad with gypsum board.

The fire source is 340 ± 4.5 kg crib constructed of 1.065 m 1.065 m oak pallets stacked to a maximum height of 1.5 m and located in the corner 305 mm from each wall. The crib is ignited using 0.24 L of gasoline at the base of the crib. The standard does not state any calibrated heat flux or temperature requirements for the fire source. However, it is understood that the maximum heat flux is 100 kW/m^2 or greater.

Thermocouples are located on the test walls on 2.5 m grid spacing. The test duration is 15 minutes.

The performance requirement for this test is that the tested assembly shall not result in fire spread to the limits of the test structure as evidenced by flaming or material damage.

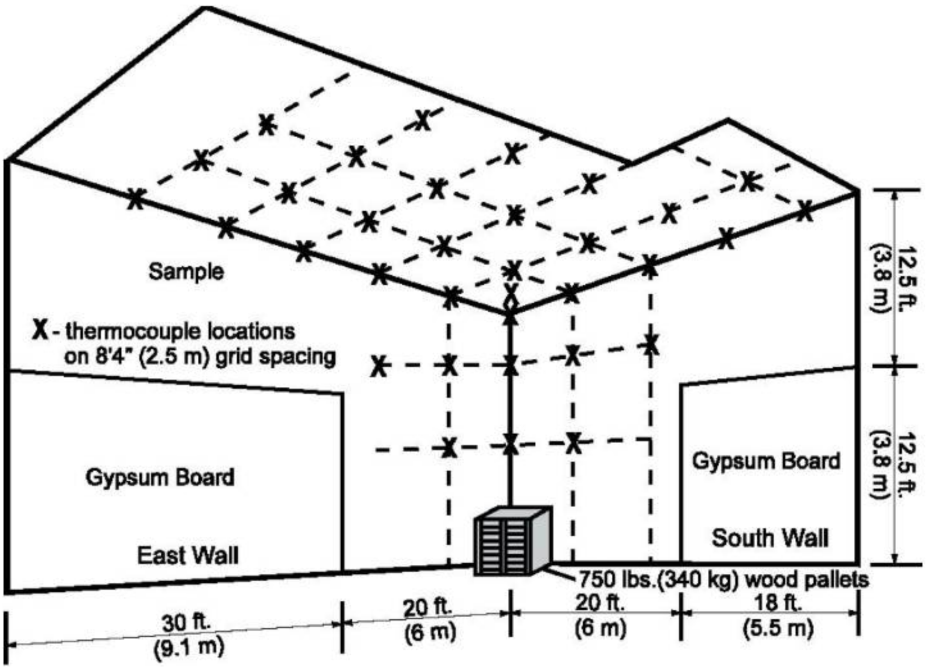


Figure 77. 25 ft (7.6 m) test apparatus (from FM 4880[108])

C.5.7 50 FT (15.2 M) HIGH CORNER TEST

The test apparatus structure consists of two wall frames and a ceiling frame to which test wall and ceiling assemblies can be mounted. There is no non-combustible substrate such as concrete or masonry. The height to the underside of the ceiling frame is 15.2 m. Both walls are 6.2 m wide. For tests on wall assemblies only, corrugated steel decking is installed to the underside of the ceiling frame. The test wall is installed representative of the end use, which typically involves through bolting of insulated sandwich panels directly to the frame. Test walls over the entire height and width of the test frame

The same fire source as for the 25 ft high corner test is used.

Thermocouples are located near the intersection of the top of the walls and the ceiling both at the corner and 4.6 m out from the corner. The test duration is 15 minutes.

The performance requirements for this test are:

- The tested assembly shall also meet the requirements of the 25 ft corner test.
- For acceptance to a maximum height of 50 ft (15.2 m) the tested assembly shall not result in fire spread to the limits of the test structure as evidenced by flaming or material damage.
- For acceptance to an unlimited height the tested assembly shall not result in fire spread to the limits of the test structure or to the intersection of the top of the wall and the ceiling as evidenced by flaming or material damage.

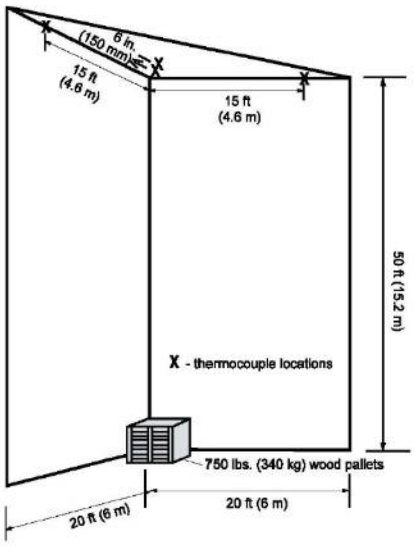


Figure 78. 50 ft (15.2 m) test apparatus (from FM 4880[108])

C.5.8 LARGE SCALE FAÇADE FIRE TEST SUMMARY TABLE

		Full-scale façade tests									
Test Standard		**AS 5113 : 2016 Amdt 1 (EW classification) applying BS8414 method**	**ISO 13785 Part 1:2002**	**BS 8414 part 1**	**BS 8414 part 2**	**DIN 4102-20**	**NFPA 285**	**SP FIRE 105**	**CAN/ULC S134**	**FM 25 ft high corner test**	**FM 50 ft high corner test**
Country used		Australia	International	UK	UK	Germany	USA	Sweden	Canada	US/International	US/International
Test Scenario		Same as for BS 8414	flames emerging from a flashover compartment fire via a window	flames emerging from a flashover compartment fire via a window	flames emerging from a flashover compartment fire via a window	flames emerging from a flashover compartment fire via a window	flames emerging from a flashover compartment fire via a window	flames emerging from a flashover compartment fire via a window		external (or internal) pellet fire located directly against the base of a re-entrant wall corner	external (or internal) pellet fire located directly against the base of a re-entrant wall corner
Summary geometry of test rig	Number of walls	Same as for BS 8414	two walls in re-entrant corner “L” arrangement	two walls in re-entrant corner “L” arrangement	two walls in re-entrant corner “L” arrangement	two walls in re-entrant corner “L” arrangement	one wall	one wall	one wall	two walls in re-entrant corner “L” arrangement. Ceiling over top of walls	two walls in re-entrant corner “L” arrangement. Ceiling over top of walls
	number of openings	Same as for BS 8414	1 (fire source opening)	1 (fire compartment opening)	1 (fire compartment opening)	1 (fire compartment opening)	1 (fire compartment opening)	2 (fire compartment opening and fictitious window above)	1 (fire compartment opening)	0	0
Fire source	Standard source	Same as for BS 8414 (construction from Pinus Radiata permitted)	Series of large perforated pipe propane burners. Total peak output 120 g/s (5.5 MW) within standard fire enclosure.	Timber crib 1.5 m wide x 1 m deep x 1 m high. Nominal heat output of 4500 MJ over 30 min. Peak HRR = 3±0.5 MW. Crib located on platform 400 mm above base of test rig.	Same as BS 8414 part 1	320 kW constant HRR linear gas burner located approx. 200 mm below soffit of opening.	Rectangular pipe gas burner in fire compartment (room burner). 1.52 m long pipe gas burner near opening soffit (window burner). Room burner increases from 690 kW to 900 kW over 30 min test period. Window burner ignited 5 min after room burner and increases from 160 kW to 400 kW over remaining 25 min test period	Heptane fuel tray, 0.5 m wide x 2.0 m long x 0.1 m high. Filled with 60 l Heptane.. Approx 2.5 MW peak	Four 3.8 m long linear propane burners. Total output 120 g/s propane (5.5 MW)	340 ± 4.5 kg crib constructed of 1.065 m 1.065 m oak pallets, max height 1.5 m. Located in corner 305 mm from each wall. Ignited using 0.24 L gasoline at crib base.	same as FM 25 ft test
	Alternative source	N/A	Liquid pool fires or 16 x 25 kg timber cribs distributed on floor of standard fire enclosure	permitted but must achieve calibration requirements	Same as BS 8414 part 1	25 kg timber crib, 0.5m x 0.5 m x 0.48 m, using 40 mm x 40 mm softwood sticks	Not specified or permitted by standard	permitted but must achieve calibration requirements	wood cribs of kiln dried pine with total mass of 675 kg	Not specified or permitted by standard	Not specified or permitted by standard

		Full-scale façade tests									
Test Standard		**AS 5113 : 2016 Amdt 1 (EW classification) applying BS8414 method**	**ISO 13785 Part 1:2002**	**BS 8414 part 1**	**BS 8414 part 2**	**DIN 4102-20**	**NFPA 285**	**SP FIRE 105**	**CAN/ULC S134**	**FM 25 ft high corner test**	**FM 50 ft high corner test**
Fire exposure	Calibrated heat flux exposure (with non-combustible wall)	N/A	55 ± 5 kW/m² at a height of 0.6 m above opening 35 ± 5 kW/m2 at a height of 1.6 m above opening	Mean within range of 45-95 kW/m2 at height of 1 m above opening over continuous 20 min period. Typical steady state mean of 75 kW/m2 at height of 1 m above opening within this period.	Same as BS 8414 part 1	60 kW/m2 at 0.5 m above opening 35 kW/m2 at 1.0 m above opening 25 kW/m2 at 1.5 m above opening	38 ± 8 kW/m² at 0.6 m above opening during peak fire source period 25 -30 min 40 ± 8 kW/m2 at 0.9 m above opening during peak fire source period 25 -30 min 34 ± 7 kW/m² at 1.2 m above opening during peak fire source period 25 -30 min	15 kW/m² at 4.8 m above opening during at least 7 min of the test. 35 kW/m2 at 4.8 m above opening during at least 1.5 min of the test. < 75 kW/m2 at 4.8 m above opening at all times	45 ± 5 kW/m2 at 0.5 m above opening averaged over 15 min steady state period. 27 ± 3 kW/m2 at 1.5 m above opening averaged over 15 min steady state period.	Not specified	Not specified
	Calibrated temperature exposure (with non-combustible wall)	N/A	> 800 Deg C at 50 mm above opening	> 600 Deg C above ambient within fire compartment. > 500 Deg C above ambient on exterior of non-combustible wall 2.5 m above opening.	Same as BS 8414 part 1	maximum temp. of 780-800 deg C on exterior of non-combustible wall 1 m above opening soffit	average 712 Deg C on exterior of non-combustible wall 0.91 m above opening. average 543 Deg C on exterior of non-combustible wall 1.83 m above opening.	Not specified	-	Not specified	Not specified
	Maximum height of flames extending above opening for non-combustible wall	Same as for BS 8414	-	Approx. 2.5 m	Same as BS 8414 part 1	Approx 2.5 m	Approx. 2.0 m	-	Approx 2.0 m	-	-
	Duration	Same as for BS 8414	23-27 minutes. 4-6 minute growth phase, approx 15 minute steady state phase, 4-6 minute decay phase	30 min (approx 7 min growth phase)	Same as BS 8414 part 1	20 min (gas burner) 30 min (crib)	30 min	Approx 15 minutes	25 minutes. 5 min growth phase, 15 min steady state phase, 5 min decay phase.	approx 15 minutes	same as FM 25 ft test
Detailed geometry of test rig	Total height of apparatus	Same as for BS 8414	≥ 5.7 m	≥ 8.0 m	Same as BS 8414 part 1	≥ 5.5 m	≥ 5.33 m	6.71 m	10.0 m	7.6 m	15.2 m
	Height of test wall above fire compartment opening	Same as for BS 8414	≥ 4.0 m	≥ 6.0 m	Same as BS 8414 part 1	≥ 4.5 m	≥ 4.52 m	6.0 m	7.25 m	N/A	N/A
	Width of main test wall	Same as for BS 8414	≥ 3.0 m	≥ 2.5 m	Same as BS 8414 part 1	≥ 2.0 m (using gas burner) ≥ 1.8 m (using crib)	≥ 4.1 m	4.0 m	5.0 m	15.7 m (specimen installed to full width over top 3.8 m and to 6 m out from corner for bottom 3.8 m)	6.2 m
	Width of wing test wall	Same as for BS 8414	≥ 1.2 m	≥ 1.5 m	Same as BS 8414 part 1	≥ 1.4 m (using gas burner) ≥ 1.2 m (using crib)	N/A	N/A	N/A	11.96 m (specimen installed to full width over top 3.8 m and to 6 m out from corner for bottom 3.8 m)	6.2 m

		Full-scale façade tests									
Test Standard		**AS 5113 : 2016 Amdt 1 (EW classification) applying BS8414 method**	**ISO 13785 Part 1:2002**	**BS 8414 part 1**	**BS 8414 part 2**	**DIN 4102-20**	**NFPA 285**	**SP FIRE 105**	**CAN/ULC S134**	**FM 25 ft high corner test**	**FM 50 ft high corner test**
Detailed geometry of test rig *(continued)*	Height of fire compartment opening above bottom of test wall	Same as for BS 8414	0.5 m	0 m	Same as BS 8414 part 1	0 m	0.76 m	0 m	1.5 m	N/A	N/A
	Height of fire compartment opening	Same as for BS 8414	1.2 m	2 m	Same as BS 8414 part 1	1 m	0.76 m	0.71 m	1.37 m	N/A	N/A
	Width of fire compartment opening	Same as for BS 8414	2 m	2 m	Same as BS 8414 part 1	1 m	1.98 m	3.0 m	2.6 m	N/A	N/A
	Horizontal distance of opening from wing wall	Same as for BS 8414	50 mm	250 mm	Same as BS 8414 part 1	0 mm	N/A	N/A	N/A	N/A	N/A
	fire compartment dimensions	Same as for BS 8414	4 m wide x 4 m deep x 2 m high with 0.3 m deep soffit across opening Alternative sizes permitted in range of 20 m3 – 30 m3	2 m wide x 2 m high (depth not specified)	Same as BS 8414 part 1	1 m wide x 1 m high	3 m wide x 3 m deep x 2 m high	3.0 m wide x 1.6 m deep x 1.3 m high.	5.95 m wide x 4.4 m deep x 2.75 m high	N/A	N/A
Test wall substrate		Typically same as for Same as for BS 8414 part 2	Details of substrate or supporting frame not specified by standard	Masonry	steel frame (open) to support complete test wall assembly	aerated concrete	steel frame and concrete floor slabs (open) to support complete test wall assembly	steel frame (open) to support complete test wall assemblies. Light weight concrete substrate to support claddings which require such a substrate.	Concrete	steel frame (open) to support complete test wall assembly	steel frame (open) to support complete test wall assembly
Test measurements	Heat flux at surface test wall	Not required	0.6 m, 1.6 m and 3.6 m above opening	not required	Same as BS 8414 part 1	-	not required	2.1 m above opening (centre of ficticiuos 1st storey window)	3.5 m above opening.	Not required	Not required
	Temperatures	Same as for BS 8414 Plus non exposed (rear face) surface temperatures 900 mm above combustion chamber opening	wall exterior and intermediate layers/Cavities immediately above window and at 4 m above window	wall exterior at 2.5 and 5.0 m above opening. Intermediate layers and cavities at 5.0 m above opening.	Same as BS 8414 part 1	wall exterior and intermediate layers/Cavities at 3.5 m above opening	Wall exterior and intermediate layers/cavities at 305 mm intervals vertically above opening. At rear of test wall within 2nd storey room enclosure	minimum 2 thermocouples measuring gas temperatures at top of wall on underside of 500 mm non combustible eave	Within fire enclosure and at opening 0.15 m below soffit. Wall exterior and intermediate layers/cavities at vertical intervals of 1 m starting from 1.5 m above opening. Gas temperatures 0.6 m in front of the top of the test wall.	exterior of exposed side of test walls on a 2.5 m grid spacing	near intersection of top of walls and ceiling, both at the wall corner and 4.6 m out from the wall corner.

Test Standard		Full-scale façade tests AS 5113 : 2016 Amdt 1 (EW classification) applying BS8414 method	ISO 13785 Part 1:2002	BS 8414 part 1	BS 8414 part 2	DIN 4102-20	NFPA 285	SP FIRE 105	CAN/ULC S134	FM 25 ft high corner test	FM 50 ft high corner test
Performance criteria	External Fire spread	Temperatures 5 m above the opening measured 50 mm from the exposed specimen face shall not exceed 600°C for a continuous period greater than 30 s. Applies over entire test duration	Reported - Criteria not specified by standard	Fire spread start time = time external temp at level 1 (2.5 m above opening) exceeds 200 Deg C above ambient Level 2 external temp (5 m above opening) must not exceed 600 Deg C above ambient (over > 30 s), within 15 min of fire spread start time	Same as BS 8414 part 1	• No burned damaged (excluding melting or sintering) ≥ 3.5 m above opening. • Temperatures on wall surface or within the wall layers/cavities must not exceed 500 Deg C ≥ 3.5 m above opening. • No observed continuous flaming for more than 30s ≥ 3.5 m above opening. • No flames to the top of the specimen at any time.	• Wall exterior temp must not exceed 538 Deg C at 3.05 m above opening. • Exterior flames must not extend vertically more than 3.05 m above opening. • Exterior flames must not extend horizontally more than 1.52 m from opening centreline. • Flames must not occur horizontally beyond the intersection of the test wall and the side walls of the test rig.	No fire spread (flame and damage) > 4.2 m above opening (bottom of 2nd storey ficticious window) Temps at the eave must not exceed 500 DegC for more than 2 min or 450 Deg C for more than 10 min. Additionallay , for buildings >8 storeys high or hospitals of any height, Heat flux at 2.1 m above opening must not exceed 80 kW/m2.	Flame spread distance less than 5 m above the opening soffit Heat flux 3.5 m above opening must be less than 35 kW/m2.	the tested assembly shall not result in fire spread to the limits of the test structure as evidenced by flaming or material damage	Must meet requirements for 25 ft test • For acceptance to maximum height use of 50 ft (15.2 m), tested assembly shall not result in fire spread to limits of test structure as evidenced by flaming or material damage. • For acceptance to unlimited height use tested assembly shall not result in fire spread to the limits of the test structure or to the intersection of the top of the wall and the ceiling as evidenced by flaming or material damage.
	Internal fire spread	Temperatures at the mid-depth of each combustible layer or any cavity 5 m above the opening shall not exceed 250°C for a continuous period of greater than 30 s. Applies over entire test duration. Where the system is attached to a wall that is not required to have an FRL of –/30/30 or 30/30/30 or more, the temperature on the unexposed face of the specimen 900 mm above the opening shall not exceed a 180 K rise Where the system is attached to a wall not required to have a fire resistance of –/30/30, 30/30/30 or more, flaming or the occurrence of openings in the unexposed face of the specimen above the opening shall not occur		Level 2 internal temp (5 m above opening) must not exceed 600 Deg C above ambient (over > 30 s), within 15 min of fire spread start time	Same as BS 8414 part 1 Plus, Flaming (>60 s) must not occure on non-exposed side of the test wall at height of ≥ 0.5 m within 15 minutes of fire spread start time.	• No burned damaged (excluding melting or sintering) ≥ 3.5 m above opening. • Temperatures within the wall layers/cavities must not exceed 500 Deg C ≥ 3.5 m above opening	• Fire spread horizontally and vertically within wall must not exceed designated internal wall cavity and insulation temp limits. Position of designated thermocouples and temp limits depends on type/thickness of insulation and whether or not an air gap cavity exists. • Temp at the rear of test wall in 2nd storey test room must not exceed 278 Deg C above ambient. • Flames shall not occur in the second storey test room	No fire spread (flame and damage) > 4.2 m above opening (bottom of 2nd storey ficticious window)	Flame spread distance less than 5 m above the opening soffit	the tested assembly shall not result in fire spread to the limits of the test structure as evidenced by flaming or material damage	Must meet requirements for 25 ft test • For acceptance to maximum height use of 50 ft (15.2 m), tested assembly shall not result in fire spread to limits of test structure as evidenced by flaming or material damage. • For acceptance to unlimited height use tested assembly shall not result in fire spread to the limits of the test structure or to the intersection of the top of the wall and the ceiling as evidenced by flaming or material damage.

		Full-scale façade tests									
Test Standard		**AS 5113 : 2016 Amdt 1 (EW classification) applying BS8414 method**	**ISO 13785 Part 1:2002**	**BS 8414 part 1**	**BS 8414 part 2**	**DIN 4102-20**	**NFPA 285**	**SP FIRE 105**	**CAN/ULC S134**	**FM 25 ft high corner test**	**FM 50 ft high corner test**
		Flame spread beyond the confines of the specimen in any direction, as determined during the post-test examination, shall not occur. The examination shall include flame damage such as melting, charring but not smoke discolouration or staining of the surface, any intermediate layers and the cavity. Confines of specimen = 2.4 m horizontally on main test wall, 1.2 m horizontally on wing wall, 6 m vertically above top of combustion chamber opening									
	Burning debris and dropplets	Continuous flaming on the ground for more than 20 s from any debris or molten material from the specimen shall not occur	Reported - Criteria not specified by standard	Reported - Criteria not specified	Same as BS 8414 part 1	Falling burning droplets and burning and non-burning debris and lateral flame spread must cease with 90 s after burners off	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard
	Mechanical behaviour	The total mass of debris falling in front of the specimen shall not exceed 2 kg. The mass shall be measured after the end of the test.	Reported - Criteria not specified by standard	Reported - Criteria not specified	Same as BS 8414 part 1	Reported - Criteria not specified	Reported - Criteria not specified by standard	No large pieces may fall from the façade	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard	Reported - Criteria not specified by standard
Comments		Application of ISO 13785 Part 1 (with different criteria) is also permitted but not applied in practice in Australia.						Includes two fictitious window details in test wall and level 1 and level 2 blacked at rear with non combustible lining		Mostly only used for insulated sandwich panel	Mostly only used for insulated sandwich panel

Appendix D Summary of advisory report recommendations

D.1 Recommendations from Senate Non-Conforming building products– Interim report: Aluminium composite cladding (September 2017)

- Recommendation 1 - The committee recommends the Australian government implement a total ban on the importation, sale and use of Polyethylene core aluminium composite panels as a matter of urgency.
- Recommendation 2 - The committee recommends that the Commonwealth government work with state and territory governments to establish a national licensing scheme, with requirements for continued professional development for all building pracitioners.
- Recommendation 3 - The committee recommends that the Building Minister's Forum give further consideration to introducing nationally consistent measures to increase accountability for participants across the supply chain.
- Recommendation 4 - The committee strongly recommends that the Commonwealth government consider making all Australian Standards and codes freely available.
- Recommendation 5 – The committee recommends the Commonwealth government consider imposing a penalties regime for non-compliance with the National Construction Code such as revocation of accreditation or a ban from tendering for Commonwealth funded construction work and substantial financial penalties
- Recommendation 6 – The committee recommends the Commonwealth government ensure the Federal Safety Commissioner is adequately resourced to ensure the office is able to carry out its duties in line with the new audit function and projected work flow.
- Recommendation 7 – The committee welcomes the Commonwealth government's decision to give further consideration to Director Identification Numbers and recommends that it expedites this process in order to prevent directors from engaging in illegal phoenix activity.
- Recommendation 8 - The committee recommends that state and territory governments work together to develop a nationally consistent statutory duty of care protection for end users in the residential strata sector.

D.2 Recommendations From Shergold-Weir Report "Building Confidence" (February 2018)

- Recommendation 1 - That each jurisdiction requires the registration of the following categories of building practitioners involved in the design, construction and maintenance of buildings:
    - Builder
    - Site or Project Manager
    - Building Surveyor
    - Building Inspector

- Architect
  - Engineer
  - Designer/Draftsperson
  - Plumber
  - Fire Safety Practitioner.
- Recommendation 2 - That each jurisdiction prescribes consistent requirements for the registration of building practitioners including:
  - certificated training which includes compulsory training on the operation and use of the NCC as it applies to each category of registration;
  - additional competency and experience requirements;
  - where it is available, compulsory insurance in the form of professional indemnity and/or warranty insurance together with financial viability requirements where appropriate; and
  - evidence of practitioner integrity, based on an assessment of fit-and-proper person requirements
- Recommendation 3 - That each jurisdiction requires all practitioners to undertake compulsory Continuing Professional Development on the National Construction Code.
- Recommendation 4 - That each jurisdiction establishes a supervised training scheme which provides a defined pathway for becoming a registered building surveyor.
- Recommendation 5 - That each state establishes formal mechanisms for a more collaborative and effective partnership between those with responsibility for regulatory oversight, including relevant state government bodies, local governments and private building surveyors (if they have an enforcement role).
- Recommendation 6 - That each jurisdiction give regulators a broad suite of powers to monitor buildings and building work so that, as necessary, they can take strong compliance and enforcement action.
- Recommendation 7 - That each jurisdiction makes public its audit strategy for regulatory oversight of the construction of Commercial buildings, with annual reporting on audit findings and outcomes.
- Recommendation 8 - That, consistent with the International Fire Engineering Guidelines, each jurisdiction requires developers, architects, builders, engineers and building surveyors–to engage with fire authorities as part of the design process.
- Recommendation 9 - That each jurisdiction establishes minimum statutory controls to mitigate conflicts of interest and increase transparency of the engagement and responsibilities of private building surveyors.
- Recommendation 10 - That each jurisdiction put in place a code of conduct for building surveyors which addresses the key matters which, if contravened, would be a ground for a disciplinary inquiry.
- Recommendation 11 - That each jurisdiction provides private building surveyors with enhanced supervisory powers and mandatory reporting obligations.
- Recommendation 12 - That each jurisdiction establishes a building information database that provides a central–sed source of building design and construction documentation.
- Recommendation 13 - That each jurisdiction requires building approval documentation to be prepared by appropriate categories of registered practitioners, demonstrating that the proposed building complies with the National Construction Code.

- Recommendation 14 - That each jurisdiction sets out the information which must be included in performance solutions, specifying in occupancy certificates the circumstances in which performance solutions have been used and for what purpose
- Recommendation 15 - That each jurisdiction provides a transparent and robust process for the ap–roval of performance solutions for constructed building work.
- Recommendation 16 - That each jurisdiction provides for a building compliance process which incorporates clear obligations for the approval of amended documentation by the appointed building surveyor throughout a project.
- Recommendation 17 - That each jurisdiction requires genuine independent third party review for specified components of designs and/ or certain types of buildings.
- Recommendation 18 - That each jurisdiction requires on-site inspections of building work at identified notification stages.
- Recommendation 19 - That each jurisdiction requires registered fire safety practitioners to design, install and certify the fire safety systems necessary in Commercial buildings.
- Recommendation 20 - That each jurisdiction requires that there be a comprehensive building manual for Commercial buildings that should be lodged with the building owners–and made available to successive purchasers of the buildings.
- Recommendation 21 - That the Building Ministers' Forum agrees its position on the establishment of a compulsory product certification system for high-risk building product
- Recommendation 22 - That the Building Ministers' Forum develop a national dictionary of terminology to assist jurisdictions, industry and consumers to understand the range of terminology used to describe the s–me or similar terms and processes in different jurisdictions.
- Recommendation 23 - That the Building Ministers' Forum acknowledges that the above recommendations are designed to form a coherent package and that they be implemented–by all jurisdictions progressively over the next three years.
- Recommendation 24 - That the Building Ministers' Forum prioritise the preparation of a plan for the implementation of the recommendations against which each jurisdiction will report annually

D.3 Recommendations from Senate Non-Conforming building products Final report: the need for a coherent and robust regulatory regime (December 2018)

- Recommendation 1 – The committee recommends that the Building Ministers' Forum develop improved consultative mechanisms with industry stakeholders. In addition, the Building Ministers' Forum should amend the terms of reference for the Senior Officers' Group and the Building Regulators Forum to include annual reporting requirements on progress to address non-conforming building products.

- Recommendation 2 - The committee recommends that the Australian Government develop a confidential reporting mechanism through which industry and other stakeholders can report non-conforming building products.

- Recommendation 3- The committee calls on the Building Ministers' Forum to expedite its consideration of a mandatory third-party certification scheme for high-risk building products and a national register for these products.

- Recommendation 4 - The committee recommends that where an importer intends to import goods that have been deemed high-risk, the Australian Government require the importer, prior to the importation of the goods, to conduct sampling and testing by a NATA accredited authority (or a NATA equivalent testing authority in a another country that is a signatory to a Mutual Recognition Arrangement).

- Recommendation 5 - The committee recommends that the Building Ministers' Forum, through the Senior Officers' Group, examine international approaches—including the European Union's regulations and processes—for testing of high-risk products prior to import and determine if they can be suitably adapted to benefit and enhance Australian requirements.

- Recommendation 6 - The committee recommends that the Building Ministers' Forum give further consideration to introduce a nationally consistent approach that increases accountability for participants across the supply chain. Specifically, the committee recommends that other states and territories pass legislation similar to Queensland's Building and Construction Legislation (Non-conforming Building Products–Chain of Responsibility and Other Matters) Amendment Act 2017.

- Recommendation 7 - The committee recommends that the Australian Government work with state and territory governments to establish a national licensing scheme, with requirements for continued professional development for all building practitioners.

- Recommendation 8 - The committee strongly recommends that the Australian Government consider making all Australian Standards freely available.

- Recommendation 9 - The committee recommends that the Australian Government consult with industry stakeholders to determine the feasibility of developing – national database of conforming and non-conforming products.

- Recommendation 10 - The committee gives in-principle support to Recommendation 12 of the Shergold and Weir Report 'that each jurisdiction establishes a building information database that provides a centralised source of building design and construction documentation' so regulators are better placed to identify where non-compliant building products have been installed.

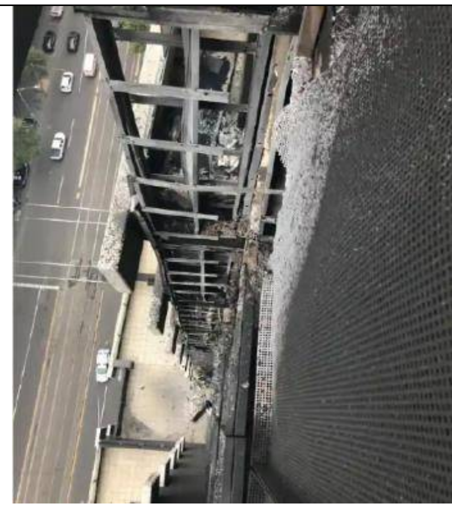
  The committee has also identified a range of specific recommendations (numbers: 2, 4, 7, 8, 9, 11, 12, and 13) that it believes are best placed for government to progress and, as indicated earlier, a number of these have been proposed in earlier interim reports.

- Recommendation 11 - The committee recommends the Australian Government consider imposing a penalties regime for non-compliance with the National Construction Code such as revocation of accreditation or a ban from tendering for Commonwealth–funded construction work and substantial financial penalties.

- Recommendation 12 - The committee recommends that the Australian Government consider the merits of requiring manufacturers, importers and suppliers to hold mandatory recall insurance for high-risk building products.

- Recommendation 13 - The committee recommends that the Australian Government review the Customs Act 1901 (and other relevant legislation) to address the challenges of enforcing the existing importation of asbestos offence, with the aim to close loopholes and improve the capacity of prosecutors to obtain convictions against entities and individuals importing asbestos. This review should include consideration of increasing the threshold required to use 'mistake of fact' as a legal defence.

Appendix E Fire Incidents involving ACP

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
NEO200[65-68]	200 Spencer St, Melbourne , Australia	2019, February 4	Residential apartments	42 storeys 371 SOUs	PE	Yes (not on balconies)	Building already identified to have combustible cladding via state wide cladding audit with interim measures including additional fire detection, occupant warning and inclusion on fire brigade enhanced response list enacted prior to fire incident. Fire started on level 22 balcony adjacent ACP-PE forming vertical strip connecting between balcony levels. Fire spread to level 27 but fire brigade responded quickly with enhanced response and suppressed the fire using internal hydrants from adjacent/above fire. Sprinklers activated on multiple levels and prevented fire spread to building interior At least 200 residents were evacuated. Building sprinkler protected but no sprinkler protection to balconies	No deaths or injuries. Apartments directly impacted by fire spread not habitable	 
Jecheon , South Korea[123-126]	Jecheon, South Korea	2017, December 22	Fitness / sports centre	8 Storeys	Possibly PE Possibly rendered EPS	Yes, but not functioning	Reports for this fire are not detailed and some contain conflicting information The building had several restaurants and leisure facilities, including a gym, the public bath and an indoor golf practice facility. A fire started on ground level car park. The cause is stated to be electrical fault from heating wires installed in ceiling at this location. The fire spread to parked vehicles. It also spread via the external wall cladding. Twenty of those killed were trapped in a sauna on the second floor. Reports state that exits were blocked with stored goods/lockers and sprinklers were installed but not functioning correctly. There are conflicting reports on the type of cladding. Some reports state it to be "PE Material" comparing it to Grenfell. Other reports state it to be a "DryVit system" which is a type of EIFS and compare it to a fire in Uijeongbu, Korea, 2015. It is not possible to confirm cladding type for newspaper photos.	29 fatalities 36 injured	  

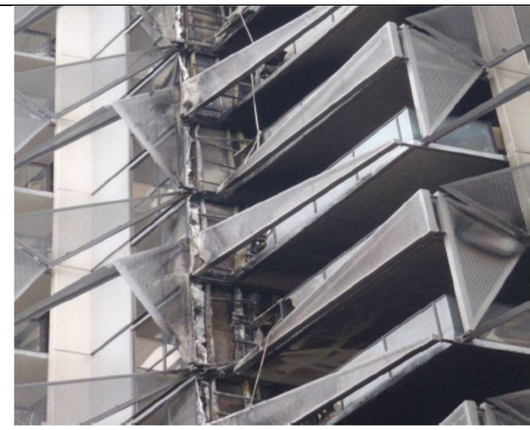
Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Marina Torch[127-129]	Dubai, UAE	2017, August 4	Residential apartments	79 stories 337 m tall 676 SOUs	PE	Yes	Was the tallest residential building in the world when completed in 2011, but since been exceeded in height by subsequent buildings. Same building had previous ACP cladding fire in 2015. Fire initiated at 1 am and fire brigade had fire under control by 3.30 am. There are conflicting reports on the starting location and cause for the fire. The fire spread rapidly vertically and damaged ~the top 60 levels. Videos also show flaming molten material falling to ground level. No injuries or fatalities reported. Internal sprinklers appear to have assisted preventing fires propagating internally.	No injuries Fire spread over 60 levels	  
Marco Polo Apartments[130-132]	Honolulu, Hawaii, US	2017, July 14	Residential apartments	36 stories	Non-Combustible Concrete	No	**This fire did not involve ACP and had noncombustible concrete façade**. It is included here to clarify details of this incident (as it has been referenced in façade fire papers by others[133] Building was reinforced concrete construction built in 1971. It did not have sprinklers (which were not required at the time of construction). The external walls were non-combustible. A fire began within a living room of an apartment on the 26th floor. The fire propagated from the room of origin, spreading internally and with flames projecting from broken windows to the exterior of the building. The noncombustible concrete exterior construction limited the external fire propagation to the 28th floor. It took approximately 2 hours for the fire brigade to bring the fire under control during this time the fire spread was limited to two floors. All deaths occurred on the floor of fire origin.	3 dead 12 injured	 
Grenfell Tower[61] [62, 64]	London, UK	2017, June 14	Residential apartments	24-storey, 67.3 m tall	PE	No	Fire started at 4th floor as internal apartment fire starting with electrical fault in kitchen fridge. Fire spread to external cladding via uPVC windows into wall cavity. Ten spread rapidly on external wall system consisting of ACP-PE, cavity with poorly installed cavity barriers and PIR Insulation. Fire spread over the majority of the external wall and spread back into the building on multiple levels via broken windows, uPVC cavity fillers around windows and plastic kitchen exhaust fans. Building not sprinkler protected.	71 dead 70 injured Building not habitable	  

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Address Downtown Hotel [134-140]	Dubai, UAE	2016, December 31 (new Year's Eve)	Hotel and residential Apartments	63-story, 302.2 m tall	PE	Yes	Newspapers report conflicting details of location and cause of fire start. Initial reports state that fire started on 20th floor whilst later reports state that investigations conclude fire was caused by electrical short circuit of wires for external spotlight between 14th and 15th floor. Fire was not caused by new year's eve fireworks scheduled for later that night. Fire started at ~ 9.25 PM resulting in rapid fire spread to top of building and burning falling debris. All occupants were evacuated. It is reported that fire brigade had fire under control within 4 hours, however photos show building continuing to smoke with small spot fires after dawn the next morning. Ironically the nearby fireworks went ahead at midnight. The building was sprinkler protected and sprinklers operated as designed however some reports state the sprinkler system was overwhelmed due to external fire spread over more than 40 floors causing multiple sprinklers to activate with water supply exhausted with ~ 15 minutes. Fire doors and compartmentation in SOU's was reported to perform well minimizing smoke and fire spread. Fire did not appear to spread internally beyond the SOU's directly adjacent to the cladding fire Significant damage over more than 40 level of exterior and within interior adjacent to fire. Hotel was closed for 2 years during repairs. * It is reported that one person suffered a heart attack while exiting the building, but this is not considered a fatality directly caused by the fire	0 Deaths* 16 minor injuries	  
Sulafa Tower[141-144]	Dubai Marina, UAE	2016, July 20	Residential apartments	75 storey	PE	Not confirmed	Fire started at ~ 2.30 pm. Spread vertically up the building. Fire also spread down the building via burning debris due to ACP-PE cladding. Conflicting reports on start location with some stating fire started on 61st floor and some stating fire started on 35th floor. Fire was reported to have spread over more than 30 floors and was brought under control by fire brigade after ~ 3 hours.	0 Deaths 3-13 injuries	 

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Ajman Tower 1.[145-147]	Arjman, UAE	2016 March 28	Residential apartments	26-storey	PE	Not confirmed	The building was a series of 8 towers connected by a common open terrace area at level 4. Fire started in a pile of construction rubbish located at base of tower 8 adjacent to ACP-PE cladding. Fire spread on cladding of tower 8 to top of tower and also spread to ACP-PE cladding on adjacent tower 6 due to strong winds. Initially reported that discarded Shisha coals were discarded in the rubbish pile and started fire but subsequent reports state that this cannot be confirmed as exact cause	0 deaths 0 Injuries	 
Al Bandary Twin Towers[148-150]	Sharjah, UAE	2016, February 11	Residential apartments	23-storey	PE	Not confirmed	Fire started ~ 11 am. Reported to start on 13th floor of tower B. Did not appear to spread to adjacent tower A. ~ 120 families evacuated from Tower A	0 deaths 1 injury	
Alshamsi Building[151-153]	Deira, UAE	2015, November 23	Residential apartments	5 storey	PE	Not confirmed (appeared not to be installed)	Fire started shortly after 5 pm. Exact cause and location of fire start not reported. Fire started in block B and spread to Blocks A and C. reports and photos indicate external fire spread on ACP-PE cladding with internal fire spread burning out apartments on all levels. Building completely evacuated. Fire took ~ 5 hours to put out. Fire halted service on adjacent metro train line	0 deaths 0 injuries (reports not clear)	 

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Nasser Tower[154-156]	Sharjah, UAE	2015, October 1	Residential apartments	32 storey	PE	Not confirmed (if installed may not have been functioning correctly)	Fire started ~ 1.40 PM. Clear details on fire cause and start location not reported. Fire spread via ACP-PE cladding to top of building. Fire brigade took ~ 2 hours to put fire out. 7-14 cars parked on adjacent roof top car park reported to be destroyed by burning debris. Reports indicate fire equipment including detection systems, fire hoses and sprinklers may not have been functioning correctly	0 deaths Casualties not clearly reported	  
Marina Torch[157, 158]	Dubai, UAE	2015, February 21	Residential apartments	79 stories 337 m tall 676 SOUs	PE	Yes	Fire started at 2.00 am. Reports not clear on exact cause or fire start location but appears to have started at mid height of building around level 50. Fire spread rapidly enhanced by strong winds. Flaming material fell to ground level. Fire damage extended from 50th floor to top of building with 101 apartments uninhabitable. Seven people were treated at the scene for smoke inhalation. No reported injuries or fatalities. Internal sprinklers appear to have assisted preventing fires propagating internally.	No injuries Fire spread extended from 50th floor to top. 101 SOU's Damaged	 

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Baku apartment building [159-162]	Baku, Azerbaijan	2015, May 19	Residential apartments	16 storeys	Not ACP PU	No	Fire occurred at ~ 10 am on 16 storeys residential apartment. Cause of fire not found in reports. The building was a soviet era concrete building which had be renovated with combustible cladding installed. There are conflicting reports on the type of cladding with some suggesting "Styrofoam" or PE ACP however the majority of the reports (including the most detailed reports) identify the cladding to be Polyurethane panels. Reports of the material being removed describe it as "crumbly" which indicates foamed PU insulation board. Post fire photos indicate that it was installed over light steel battens/frame with air cavity between PU panels and concrete walls. Initial reports of number of deaths varied but official number of deaths is 15. A similar fire had erupted in Baku a few days earlier, on 10 April 2015, but there were no injuries and casualties. The reason for both fires is indicated as low quality combustible facade material used in the renovation. It is reported than more than 200 apartment buildings in Baku have renovated with the same type of cladding.	16 dead 63 injured	  
Daebong Green Apartment[163-165]	Uijeongbu, north of Seoul, Korea	2015, January 10	Residential apartments	10 story	Not confirmed May have been Rendered EPS	Not confirmed	Reports for this fire are not detailed. This incident is included as it initially appeared to be related to ACP-PE Fire started ~ 9.30 am. Caused by person applying lighter flame attempting to un-freeze a key box of 4 wheel motorcycle located in first floor parking lot within building. Fire spread through the building aided by combustible cladding. Fire also spread to two adjacent buildings. Occupants were rescued from rooftop via helicopter. Took fire brigade > 2 hours to control fire. There are conflicting reports on the type of cladding. Some reports state it to be "PE Material" but most reports state it to be a "DryVit system" which is a type of EIFS It is not possible to confirm cladding type for newspaper photos.	4 dead >100 injured 9 Billion Won	  

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Lacrosse	Docklands, Melbourne, Australia	2014, November 25	Residential apartments	21 storeys 56.7 m tall	PE	Yes (not on Balconies)	Fire started on level 8 Balcony. Rapidly spread via ACP-PE cladding on balcony external walls to top of building and also down to Balcony on level 6 via falling burning debris. Sprinklers activated on multiple levels and operated well above design capacity to prevent fire spread back into the building. Fire brigade able to establish areal appliance on adjacent road bridge/overpass to just reach top of building externally with hose stream and suppress remaining fire. All occupants (~ 400 people) had to be evacuated from the building. Building sprinkler protected but no sprinkler protection to balconies	No injuries Owners claimed >$12.7M damages. VCAT awarded $5.7M damages so far	 
Hafeet Tower 2	Sharjah, UAE	2013, April 22	Residential apartments	20 storeys	PE	Not confirmed	Fire started ~ 2 pm. Reports indicate cause as cooking fire which spread to balcony and ACP cladding.	Destroyed 10 apartments	  
Grozny-City Towers [166-168]	Chechnya, Russia	2013, April 3	Residential apartments /Hotel (under construction)	40 storeys 145 m tall	PE *		The building was a 145 m high, 40-storey high rise building that was unoccupied. It had just completed construction and may have had final construction works underway. The fire is thought to have started due to a short circuit in an air conditioner on the upper floors. The fire systems for the building had not been commissioned and there appeared to be no water supply to sprinklers or hydrants. The fire spread to engulf 18,000 m2 of the façade from ground level to the roof. No details of the façade material are reported other than being "plastic insulating plates". Based on photos and videos the material appears to be ACP and burnt with molten flaming droplets indicating PE ACP but this has not been verified. The fire took 8 hours for fire brigades to extinguish.	Fire spread to all levels	

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Tamweel Tower [169-171]	Jumeirah Lakes Dubai, UAE	2012 November 18	Residential Apartments	34 storey 160 m tall 3 storey	PE		The ACP was also used as a decorative feature on the roof top. On 18 November 2012 at 1.30 am a fire started at the roof level, possibly near air conditioning equipment. The fire then spread down the exterior of the building. It burned two separate broad vertical bands of exterior cladding from ground to roof level Based on photos and video it appears that the downward fire spread was due to molten flaming debris from the cladding falling onto lower level balconies and igniting the façade at lower levels. The fire was suppressed by fire brigades at around 8:20 am. No Fatalities were identified in reports reviewed. A fire ignited which.	Fire spread to all levels Repair works have begun after 3 years	  
Saif Belhasa Building [172, 173]	Tecom, Dubai, UAE	2012, October 6	Residential Apartments	13 storey 156 SOU	PE	Not confirmed	Fire started on the fourth floor. The fire rapidly spread to reach the top of the building. This resulted in at least 2 injuries, nine separate flats and their contents were destroyed and at least 5 cars parked at street level below were damaged by falling burning debris. Fire fighting teams including a truck with crane were dispatched at 9.35 am and the fire was suppressed by 10.57 am. Photos appear to show that vertical spread was centred on vertical channel profiles created by balconies.	2 injured Fire spread to all levels 9 flats destroyed Debris damaged 5 vehicles at street level	  

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Polat Tower[174-177],	Istanbul, Turkey	2012, July 17	Mixed use residential apartments, office and retail	42 storey 152 m tall >400 SOUs	PE	Yes	Newspaper reports state fire may have been caused by a faulty air conditioning unit. Location or time of fire start not reported. Fire occurred during day time Based on photos fire spread vertically to top of building and also produced a large amount of falling burning debris. Newspapers state that building had fire detection system, sprinklers and stair pressurization. Newspapers state that sprinklers successfully prevented internal fire spread. Building fully evacuated. Fire under control after ~ 2 hours	No Deaths No injuries Fire spread over entire building height	
Mermoz Tower [178-181]	Roubaix France,	2012, May 14	Residential Apartments	18 storey	PE		Building refurbishment in 2003 included installation of ACP vertically continuous over entire building height including exterior walls within balconies. On first storey only, “formo-phenolic” decorative boards were installed. Fire started as a domestic fire on a 2nd storey balcony. This resulted in rapid vertical flame spread to the top of the building within a few minutes. Video of the fire shows that the fire spread appeared to be enhanced by the vertical U-shaped channel profile created by the balconies, with flames moving in-and-out of balconies on each level as the fire spread upwards. Windows on the exposed façade were broken resulting in smoke filling into the building interior. Video also shows molten flaming debris from the façade panels falling to the ground and lower level balconies.	1 dead 6 injured Fire spread to all levels	

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
Al Tayer Tower [172, 173],	SharJah, UAE	2012, April 28	Residential apartments	34 residential floors, 6 parking storeys 408 SOU	PE		Fire started on a balcony on the 1st floor. The fire is believed to have started from discarded cigarette landing on the balcony which contained cardboard boxes and plastics. This resulted in vertical fire spread on the metal composite cladding to the top of the building. It also resulted in damage to 45 vehicles parked near the building due to burning falling debris. Newspaper reports also state that this resulted in a significant housing shortage for displaced occupants. No deaths or injuries reported	Fire spread to all levels 45 vehicles at street level damaged	 
Al Baker Tower 4[182-184]	Sharjah. UAE	2012 January 25	Residential apartments	24 storey	PE	Not confirmed	Fire started at ~ 2 am on level 1. A police report stated a cigarette was thrown off an upper floor balcony and landed on the balcony of room 101 on the first floor, which was littered with clothes and papers. The fire caught hold. It spread rapidly on ACP-PE cladding to top of building. ~ 125 families were displaced. The building was ~ 2 years old at time of fire	0 Deaths 0 injuries Fire spread over entire height of building 14 cars parked at street destroyed	 
Wooshin Golden suites[185-188]	Busan, South Korea	2010, October 1	Residential apartments	38 storeys 140 m tall	PE	Yes	The building construction was completed in December 2005. It had a steel structure with reinforced concrete structure in part. The building had 38 stories above ground and 4 stories underground and had a total floor area of 68,917 m^2. The 1st floor was for commercial/retail use, the 2nd and 3rd floors were shared facilities including gym, pool and meeting rooms. The 4th floor was a plant and equipment level and floors 5 to 38 were mostly residential with some office. The building was constructed with a curtain wall façade with metal composite panels consisting of aluminium with a 3 mm polyethylene core. As the name indicates the panels were gold in colour. The fire was examined in detail in a “fire science and technology” journal article[187]. This presented a cross section of the façade which indicates glass wool thermal insulation. However some newspaper articles indicated that the thermal insulation may have been EPS. The fire is reported to have started on the fourth floor due to a spark from an electrical outlet igniting nearby objects. The building was reported to be sprinkler protected but not to have sprinklers in the room of fire origin. The fire spread to the exterior façade and then spread vertically upward on the façade reaching the top of the building within 20 minutes, destroying the roof top sky lounge, penthouse and some units on the 37th floor. The vertical fire spread was centred around a vertical “U” shaped channel in the external	4 Residents injured 1 Fire fighter injured Total interior fire spread floor area = 1,134 m^2 Fire spread to most levels	 

Building	Location	Date	Building type	Building size	ACP Type	Sprinklers	Description	Damage	Photos
							profile of the building (near the central stairways). This appeared to enhance the fire spread through re-radiation and chimney effect. The fire spread may also have been enhanced by the strong wind blowing in from the sea with wind impinging on the side of the building an blowing up thought the "U" shaped external profile. The fire brigade use helicopters to evacuate some occupants from the roof and also to water bomb the exterior of the building from the air. The fire in the room of fire origin was suppressed by 1 pm and the fire for the entire building was suppressed by 6.48 pm.		
Water Club Tower, Borgata Casino hotel [189]	Atlantic City, USA	2007, September 23	Residential Hotel (Under construction)	41 storeys	PE*		The building was under construction and nearing completion at time of fire. The fire started as an internal fire on the 3rd floor. The panels were white in colour and were intended to appear like a sail on the side of the new high-rise tower. Fortunately, there was a concrete shear wall six feet behind these exterior panels that prevented major fire and smoke spread into the interior of the building. There were no direct openings into the interior portion of the void space other than on the third floor and the roof on the 41st floor. The fire spread vertically and rapidly reached the top of the building on one side of the building. The fire brigade reported that Within 10 to 15 minutes of their arrival, the bulk of the fire had subsided due to rapid consumption of the available fuel. A significant amount of falling structural debris occurred within about a quarter-mile of the building.	Fire spread to all levels	 
Te Papa Museum of New Zealand[190, 191]	Wellington, NZ	1997	Museum	6 storey 36,000 sqm	PE	Unknown at time of construction	Fire incident reported in FCRC PR 00-03 report. in 1997 a fire occurred while building was under construction involving ACP-PE over polystyrene insulation and sarking. A worker, heat welding a roofing membrane, ignited the cladding, insulation or sarking and this quickly spread up the exterior façade involving the polystyrene and cladding panel. There were no deaths or injuries associated with the fire. The building was opened in 1998. Recent newspaper articles have identified that ACP is still present on the building	No deaths No injuries	 

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