Final Report
Project NV054

NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

Investigation of Preservative Treated Plantation Timber Fencing and Sleeper Markets in Bushfire Prone Areas

2024

Gippsland Centre

Funded by the Australian Government, Victorian Government & Industry Partners.
nifpi.org.au

NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION
GIPPSLAND

Investigation of Preservative Treated Plantation Timber Fencing and Sleeper Markets in Bushfire Prone Areas

Prepared for

National Institute for Forest Products Innovation

Gippsland

by

Paul England

Publication: Investigation of Preservative Treated Plantation Timber Fencing and Sleeper Markets in Bushfire Prone Areas

Project No: NIF144-2122 [NV054]

IMPORTANT NOTICE

ISBN: 978-1-922718-49-5

Researcher:
Paul England
EFT Consulting
UPWEY VIC 3158

This work is supported by funding provided to Forest and Wood Products Australia (FWPA) to administer the **National Institute for Forest Products Innovation** program by the Australian Government Department of Agriculture, Fisheries and Forestry and the Victorian Government.

Executive Summary

This is the final report from a project investigating the performance of treated timber fences and garden sleeper walls in bushfire prone areas which investigates recommendations made by state fire authorities and other government bodies, that only 'non-combustible' landscaping products should be used; effectively providing a market exclusion to traditional timber landscaping products.

The project has undertaken a program that:

- quantified the risks that may result from the of use timber fences and garden sleeper walls and how to address the perceived or real risks,
- undertook an analysis of post fire surveys to investigate whether there is statistical evidence of residential fencing and sleeper walls being major contributors to bushfire losses,
- reviewed and analyse published experimental studies, relating to simulated bushfire attack, identifying key issues impacting on the use of preservative treated timber products e.g., fire spread, sustained smouldering combustion (afterglow).
- undertook a large series of cone calorimeter fire tests to characterise the burning behaviour of various preservative treatments, and
- undertook full-scale bushfire testing to quantify the impact of burning fences and garden sleeper walls on buildings.

Key findings included the following

1) Residential fencing and sleeper walls were not major contributors to bushfire losses based on the reviewed statistical analyses, but, experimental studies identify scenarios where fencing and/or sleeper walls could present significant risks where mulch and other combustible debris collects around the base of fences and the walls of buildings. This study confirmed experimentally that mulch collecting at the base of a fence (or other elements of construction) impose a high heat flux and act as an accelerant. Without mulch accelerating fire spread fencing and sleeper walls were shown not to increase the net heat exposure of an element if located at least 900mm to 1000mm away from a building. It is therefore recommended that rather than applying regulatory restrictions to fencing and garden walls voluntary "good practice guidelines" should be produced suggesting appropriate detailing and separation distances.

2) If further regulation is deemed necessary over and above AS 3959 current requirements to address fire spread from combustible materials consideration should be given to restricting the use of combustible mulches and prohibiting garden beds close to buildings since these are likely to be more effective.

3) The cone calorimeter test method was adapted successfully to provide a bench scale test to screen and measure the impact of water-borne copper-based preservative treatments on sustained smouldering combustion. The method can be used to develop fire retardant treatments and / or preservative treatments that do not promote sustained smouldering combustion.

4) A potential area of research is to examine treatments that interfere with the catalytic effects of the copper based compounds.

5) Sustained smouldering combustion during large scale tests was demonstrated to lead to structural failure of posts and rails and subsequently collapse of sections of fencing and the slow consumption of sleepers over a period of several hours. Guidance should be issued indicating that if a building or part of a building is susceptible to damage from a falling fence the separation distance should not be less than the fence height. Further research should be undertaken to address the risk of structural failure of posts, rails and sleepers to avoid the need for separation distances greater than 900mm to 1000mm to address structural failures.

6) The results of the bench scale tests showed that the results of the time to ignition are affected by the moisture content of the timber element particularly when exposed to heat fluxes below $20kW/m^2$. Prewetting was also demonstrated to have an impact up to several hours after application of water. These results indicate that prewetting of timber elements may be an effective use of fire-fighting water applied either manually or automatically prior to the passage of the fire front. This could be a useful area of further research for all types of exposed wood products.

Table of Contents

Chapter 1 Overview of Australian Bushfire Risk Management Measures

Introduction

At the time of preparation of this report restrictions on the use of wood products, such as timber fencing and sleeper walls in Bushfire Prone Areas (BPAs), are either being imposed directly by means of local regulations or by reference to voluntary guides by local regulators. Voluntary guides may become de facto regulations if the relevant authorities specify the documents as a means of compliance without undergoing a regulatory impact assessment or other form of comprehensive net benefit assessment.

The objective of this project is to identify applications, material fire properties and design details for timber fencing and sleeper products in Bushfire Prone Areas (BPAs) that maintain acceptable risk levels for people and housing based on engineering principles. The impact of preservative treatments on the fire performance of timber products will be considered.

A risk-based approach was adopted, including a hazard identification process, applying engineering principles to determine the potential hazards presented by timber fencing and sleeper walls with an emphasis on preservative treated plantation radiata pine (*Pinus radiata*) timber fencing & sleeper products. The ability of timber fencing and sleeper walls to mitigate the risk from bushfires by shielding an adjacent building from ember, radiant heat and direct flame attack has also been considered as a secondary objective.

The results from previous studies were reviewed with a focus on the following areas.

- Probabilities of exposure to bushfire attack
- Quantification of exposure of fencing and sleeper walls to bushfire actions
    - Embers
    - Burning debris
    - Radiant heat
    - Direct flame contact from the fire front
    - Wind
- Building Surveys following bushfire events
    - Quantitative / statistical analysis of damage to property / building elements
    - Anecdotal evidence based on case studies / general observations of construction elements / buildings following bushfire events with emphasis on fencing and sleeper walls
- Investigations of life loss in and around buildings, fencing and sleeper walls
- Experimental studies of fencing, sleeper walls and other relevant elements exposed to simulated bushfire attack
- Relevant material properties of timber fencing and sleeper walls including the afterglow phenomena associated with some preservative treatments / treated timbers.

Estimates of the risk to buildings and people from bushfires relative to the distance from the bushfire threat were derived in Appendix 2 to provide a context for consideration of the recommendations provided at the end of this report.

Information was requested of fire authorities and regulators to obtain an understanding of current regulations and guidance documents applicable in States and Territories in Australia together with details of the supporting research and any net benefit analysis or similar studies that have been undertaken.

The technical part of the project was broken down into 3 stages:

- *Stage 1* included a literature review and hazard ID process in addition to an initial small-scale test program using a cone calorimeter to compare the general fire properties for a range of preservative treated radiata pine fencing and sleeper components with untreated radiata pine. The test procedures of ISO 5660.1 (ISO 2015) and AS 3837 (Standards_Australia 1998) were modified to obtain additional data to quantify the extent of sustained smouldering combustion / char oxidation (commonly referred to as afterglow) following removal of the heat source; which had been observed with some preservative treatments. The results were used to identify a representative treatment to be used for the remainder of the experimental program. The methods developed, summary of key results and analysis are included in Appendix 1.

- *Stage 2* Developmental testing and further literature review to investigate, fire properties of waterborne copper-based preservative treated radiata pine, different features and applications addressing any knowledge gaps identified in the hazard identification (ID) and literature review phases of Stage 1 to refine fencing and sleeper wall designs. Further information is also provided in Appendix 1 which consolidated the findings relating to the fire properties of waterborne copper-based preservative treated radiata pine based on the research undertaken in Stages 1 and 2.

- *Stage 3* Large-Scale Fire Tests were undertaken to evaluate timber fencing and sleeper walls where knowledge gaps were identified. These tests comprised full-scale fire tests based on the AS 1530.8.1 (Standards_Australia 2018) test methods. As AS 1530.8.1 does not currently address the testing of fences and sleeper walls, a number of innovative procedures needed to be developed; including provision of an instrumented and pre-calibrated reference building / structure to quantify the extent of shielding from the fences and sleeper walls plus any additional fire exposures on the building from the fences or sleeper walls if they are ignited which can be used to identify minimum separation distances if necessary. Performance criteria were developed based on the calibration runs prior to the testing the fences and walls. Additional tests were undertaken using an ember generator to examine potential vulnerabilities of timber fences and walls to ignition by embers / burning mulch and subsequent fire propagation under simulated wind conditions.

Review of Australian regulations and Guidelines

Overview of National Regulations

The administration of building and construction is the responsibility of the States and Territories under the Australian Constitution but to achieve national consistency with respect to technical building standards, there are inter-governmental agreements for these to be provided within the relevant volumes of the National Construction Code (ABCB 2020, ABCB 2020) which may call up technical standards such as AS 3959 (Standards_Australia 2018). Where variations cannot be avoided, they should be included in the relevant State Appendices to the National Construction Code. However, additional measures / guidelines are often specified at State or local government levels through other legislation or as non-mandatory guides that are often treated as quasi-regulations.

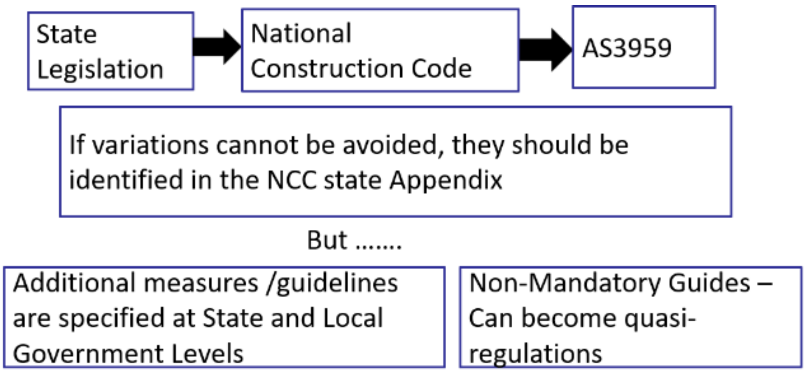


Figure 1 National regulatory structure applicable to buildings in Bushfire Prone Areas.

A national Review of Bushfire Building Regulations (Bell 2021) found that:

"There is no national agreement on how best to regulate for better building bushfire safety – be that in policy, regulation, application, or advice, as each jurisdiction responds differently to their own regulatory and political imperatives.

In consequence, regulatory practices vary widely across the spectrum of emergency response, planning approvals, construction requirements, from site assessments through to permissible construction materials.

The 'Classes' of buildings captured by bushfire regulations vary from the baseline residential (through application of AS 3959 from the National Construction Code) through to an increasing range of building types and uses in bushfire prone areas, restricting subdivisions to lower BAL's & assessing master-planning. There is no consistency in regulatory capture across jurisdictions.

Following these (20/21) bushfires, a new round of State (Victoria, NSW) and Federal (Royal Commission) bushfire enquires have been announced, which will doubtless lead to pressure for further bushfire re/building safety, through enhanced bushfire building regulations – be that through review of the NCC, AS 3959, AS5414 and/or bushfire shelters – as well as state-based planning and emergency services reviews.

Regarding timber usage within bushfire prone areas, all jurisdictions are now applying restrictions on external use (cladding, decking, window/door frames, etc) for classifications greater than BAL-29.

There appears to be no differentiation in timber usage across the jurisdictions with regards to the application of Appendix E of AS 3959-2018 (Timber Species and Densities). That is the 55 named hardwood species with density of 750 kg/m^3 (Table E1) compared to the 69 named hardwood species (Table E2) with lesser density of 650 kg/m^3."

At the time of preparation of this report, there are no Deemed-to-Satisfy (DTS) national requirements in the National Construction Code in conjunction with AS 3959 (Standards_Australia 2018) that restrict the use of timber for fencing and sleeper walls. A review of the provisions in each state and territory that may restrict the use of timber fencing and sleeper walls is included in the following sub-sections.

State and Territory variations to the National Construction Code (Volume Two) relating to Bushfire Provisions

NSW Variation to Clause H7D4 [2019: 3.10.5]

This variation prescribes AS 3959 as amended by *Planning for Bushfire Protection* (NSW_Rural_Fire_Service 2019) which is a 114 page publication that makes extensive changes to the national approach as defined in AS 3959.

Of specific relevance to this study is an additional performance criteria that requires that: *"proposed fences and gates are designed to minimise the spread of bushfire" with an acceptable solution stating "fencing and gates are constructed in accordance with section 7.6"*

Section 7.6 Fences and Gates states:

"Fences and gates in bush fire prone areas may play a significant role in the vulnerability of structures during bush fires. In this regard, all fences in bush fire prone areas should be made of either hardwood or non-combustible material.

However, in circumstances where the fence is within 6m of a building or in areas of BAL-29 or greater, they should be made of non-combustible material only".

Queensland Variation H7D4(3)

This variation provides a relaxation to the bushfire provisions for some vegetation classes and is not directly relevant to this study.

South Australia Variation H7D4(3)

This variation defines the bushfire attack level to be applied in accordance with the South Australian "Planning and Design Code" but is not directly relevant to this study.

Additional regulations and guidelines

The following is a summary of additional regulations that may impact on the use of timber fencing and sleeper walls for residential applications in various State and Territories

NSW

The primary legislation relating to construction in bushfire prone areas is the Environmental Planning and Assessment Act and EP&A Regulations (2019) and Rural Fires Act 1997 which requires the mandatory application of *Planning for Bushfire Protection* (NSW_Rural_Fire_Service 2019) throughout NSW with local government authorised to assess bushfire compliance up to BAL 29 but referral to the Rural Fire Service is required for buildings in areas classified as BAL 29 or greater.

The *Planning for Bushfire Protection* document makes significant modifications to the AS 3959 provisions including the application of additional construction requirements for:

- BAL 12.5 and BAL 19 construction
- BAL FZ construction requiring Performance Solutions
- Modification of failure criteria to AS 1530.8.1 and AS 1530.8.2 with respect to flaming.

The reasons for the modifications to the flaming criteria are explained in *Planning for Bushfire Protection* as follows:

"*Materials that allow flaming can be problematic and are not supported by the NSW RFS for the following reasons: flaming materials increase the exposure of other elements of construction and the adjoining structure to flame contact after a bush fire front has passed; and flaming materials will potentially increase the exposure of occupants of the building to radiant heat, direct flame contact, smoke after a bush fire front has passed.*

This increase in exposure can contribute to the risk of loss of life and compromise the ability of residents to defend their property and egress from the building once the bush fire front has passed.

In addition, it can reduce the ability of occupants to make safe and effective decisions about their safety.

Where there is potential for materials of construction to ignite as a result of bush fire attack, the proposed building solution generally fails the construction performance criteria for residential infill development."

The document then states the following requirements:

"For development which may be subject to flame contact (BAL-40 and BAL-FZ), systems tested in accordance with AS 1530.8.1 and AS 1530.8.2 respectively will be considered, except that there is to be no flaming of the specimen except for: window frames that have passed the criteria of AS 1530.8.1 and AS 1530.8.2, may be approved provided their flaming is not considered to compromise the safety of other elements of the building; and use of other minor elements which allow flaming may be considered provided they do not compromise the integrity of the fire safety of the building (examples include address numbers, house names, decorative artwork, etc). Flaming of other more significant elements of the building (such as aesthetic wall cladding) is considered to pose an unacceptable risk and will not be supported."

This effectively prohibits the external use of timber within BAL 40 and BAL FZ exposures when applied to buildings.

Whilst timber fencing and sleeper walls may not be part of a 'building', the following additional controls on the use of fencing and gates are applied in NSW.

"Fences and gates in bush fire prone areas may play a significant role in the vulnerability of structures during bushfires. In this regard, all fences in bushfire prone areas should be made of either hardwood or non-combustible material.

However, in circumstances where the fence is within 6m of a building or in areas of BAL-29 or greater, they should be made of non-combustible material only."

The outcome of this are significant restrictions relating to the use of timber fencing, and potentially sleeper walls, within 6m of a building if sleeper walls are considered in a similar way to fences.

ACT

It is expected that much of the ACT planning policies and practices in the future will be compatible with NSW requirements as established by the RFS *Planning for Bushfire Protection* document as noted by (Bell 2021) and therefore no further discussion is provided.

Victoria

The Building Regulations (Victorian_Government 2018) requires a building surveyor to accept the bushfire attack level (BAL) nominated in a planning scheme irrespective of the bushfire attack level that may be determined by application of AS 3959 (refer Clause 156 from the regulations below). In addition, regulation 157 requires a building to be constructed to BAL-12.5 requirements even if it is classified as BAL-LOW.

156 Relevant building surveyor must accept bushfire attack level in planning scheme or site assessment for planning permit

(1) Despite anything to the contrary in the BCA, if a building is to be constructed in a designated bushfire prone area and the bushfire attack level for the site is specified in a planning scheme applying to that site, the relevant building surveyor must accept that bushfire attack level for the purpose of determining the construction requirements that are applicable to the building.

(2) Despite anything to the contrary in the BCA, if a building is to be constructed in a designated bushfire prone area and—

(a) a planning permit is required for the construction of the building; and

(b) a site assessment for the purpose of determining the bushfire attack level for the site has been considered as part of the application for the planning permit—

the relevant building surveyor must accept that site assessment for the purpose of determining the bushfire attack level of the site and the construction requirements that are applicable to the building.

157 Relevant building surveyor must accept bushfire attack level of 12.5

(1) Despite anything to the contrary in the BCA, the relevant building surveyor must accept that the bushfire attack level is 12.5 when determining the construction requirements that apply to a building if—

- (a) *the building is to be constructed in a designated bushfire prone area; and*
- (b) *the bushfire attack level for the site—*
  - *(i) is determined as LOW by the relevant building surveyor; or*
  - *(ii) must be accepted by the relevant building surveyor as LOW under regulation 156.*

(2) In this regulation ***building*** *means—*

- *(a) a Class 1, 2 or 3 building; or*
- *(b) a Class 10a building that is associated with a Class 1, 2 or 3 building; or*
- *(c) a deck that is associated with a Class 1, 2 or 3 building; or*
- *(d) a specific use bushfire protected building.*

In areas of Victoria where Bushfire Management Overlays (BMOs) apply, additional requirements are nominated in planning regulations which can vary between municipalities and within municipalities.

Typically, these include:

- Minimum BAL levels for construction
- Requirements for defendable space (apply over a significant distance from a building and typical default distances are 30m)
- Static water supply requirements
- Requirements for vehicle access
- Minimum separation of outbuildings of 10 m or the provision of the following
  - Separation from the adjacent building by a wall that extends to the underside of a non-combustible roof covering and:
  - has a FRL of not less than 60/60/60 for loadbearing walls and
  - -/60/60 for non-load bearing walls when
    - tested from the attached structure side, or
    - is of masonry, earth wall or masonry-veneer construction with the masonry leaf of not less than 90 mm thick.

The following requirements apply to the defendable space:

- Grass must be short cropped and maintained during the declared fire danger period.
- All leaves and vegetation debris must be removed at regular intervals during the declared fire danger period.
- *Within 10 metres of a building, flammable objects must not be located close to the vulnerable parts of the building*.
- Plants greater than 10 centimetres in height must not be placed within 3 metres of a window or glass feature of the building.
- Shrubs must not be located under the canopy of trees.
- Individual and clumps of shrubs must not exceed 5 square metres in area and must be separated by at least 5 metres.
- Trees must not overhang or touch any elements of the building.
- The canopy of trees must be separated by at least 5 metres.
- There must be a clearance of at least 2 metres between the lowest tree branches and ground level.

In summary these requirements potentially extend the application of bushfire precautions substantially beyond the minimum requirements of AS 3959 as there is potential for defendable space provisions to be interpreted as restricting the use of timber fences and sleeper walls if they are deemed "flammable objects" under dot point 3 above.

Northern Territories

Bell noted (Bell 2021) there is no centralised government bushfire organisation with remit and staff to plan for and control bushfires; and there is no mention of 'bushfire' or 'bushfire regulations' within planning or building documents available on-line. Therefore, no restrictions are expected to be applied to timber fencing or sleeper walls.

Queensland

The following observations of the Queensland regulatory system have been extracted from the Bell review: (Bell 2021):

Queensland generally has established it's own sophisticated bushfire hazard assessment system prioritising vegetation classifications that has little connection to AS 3959 methodology. Queensland seeks defendable space and separation from bushfire hazards by 100 metres or 10 kW/m² for buildings housing vulnerable occupants (e.g. schools and hospitals). These provisions have some similarities to planned modifications to the NCC.

Similarly, whilst there are statements of the need for emergency access, urban design, fuel-reduced landscaping, and fire-fighting water supply etc. there appears to be no mandated requirement as much relies upon local government. Emphasis is entirely upon new development and remains silent on retrofitting existing building stock for better bushfire safety. Whilst there are restrictions upon building locations (where identified within the bushfire overlay), requirements for stored water for fire-fighting, and separation to classified vegetation, there is little reference to bushfire construction standards or controls through AS 3959-2018 but, compliance with the NCC and hence AS 3959-2018 construction standards is expected for new buildings

Although the NCC and AS 3959 do not place specific limitations on timber fences and sleeper walls in bushfire prone areas a guide has been published as a joint initiative by the Queensland Government and CSIRO: Bushfire Resilient Building Guidance for Queensland Homes (2020). It provides the following guidance:

Fences and garden walls can be used as a barrier to block embers, flame, radiant heat, and the spread of debris. They are also effective at ensuring the safe exit of occupants during a bushfire event, by shielding pathways and accessways.

Consider installing a non-combustible fence or garden wall between buildings and the likely direction of the bushfire hazard. Once installed, make sure to keep the surrounding area clear of combustible materials.

- *Use non-combustible materials, such as concrete, stone, brick, or metal.*
- *Avoid combustible materials, such as timber, bamboo, or brushwood, close to vulnerable building elements.*
- *Use non-combustible fences or garden walls as heat shields between bushfire hazards, buildings, and key access routes.*

- *Do not install combustible fences or garden walls close to buildings.*
- *For smaller lots (or where neighbouring buildings are located close together), a solid, non-combustible wall can reduce radiant heat (depending on the situation).*
- *Non-combustible walls can be used to enclose vulnerable objects, such as gas cylinders, electricity generators, water pumps and piles of garden waste.*
- *Set walls and fences into the ground (using concrete or deep-set posts) so they can withstand wind attack.*
- *Avoid permeable fence styles such as horizontal or vertical slatted fences, etched metal screens, picket fences, lattices, and wire fences—these styles can be visually appealing, but they offer little protection against bushfire attack and may trap occupants or otherwise restrict movement during a bushfire.*
- *Ensure boundary walls and fences have appropriately located and designed gates and accessways; ensure these features are clear of vegetation and other combustible elements.*

Tasmania

The Planning legislation and associated documents apply additional constraints to construction in bushfire prone areas and limits the application of the NCC / AS 3959 DTS solutions to BAL-29 on existing sites, BAL-19 for a lot created under the Bushfire-Prone Areas Code or BAL-12.5 for vulnerable or hazardous uses. For higher BALs, Performance Solutions are required. Refer Bushfire Hazard Advisory Note No 6 (Harper 2018) for further information.

The term “Hazard Management Area” is adopted for the area between a habitable building and the predominant vegetation which is required to be maintained in compliance with a bushfire hazard management plan (BHMP) and formal agreements are required to be in place where this includes adjoining lots.

The planning regulations also include requirements for water supply for firefighting purposes.

There are no specific limitations on the use of timber fencing or sleeper walls, but restrictions could be imposed as part of a Performance Solution.

South Australia

Ministerial Building Standard MBS 008 (2020) includes a delineation of designated bushfire prone areas that permits a simpler procedure than the BAL assessment procedures of AS 3959 in some applications and requires the following additional fire safety provisions to those of the NCC for bushfire resistance for new Class 1 to 3 buildings. These relate primarily to water supply requirements and fire-fighting equipment.

Construction requirements apply the NCC and AS 3959 provisions and therefore currently do not apply additional requirements to fencing and sleeper walls.

Western Australia

A staged review of bushfire mapping and planning regulations is underway at the time of preparation of this report. The latest updated guidelines (2021) indicate that the State provisions for single dwellings generally accept the NCC and AS 3959 DTS provisions and only the building permit process need be followed (development approval not required under planning regulations) if the allotment size is less than 1,100m^2 or the site is classified as BAL-

29 or less. For BAL-40 or BAL-FZ exposures on allotments greater than 1,100m^2, a development approval is required in addition to a building permit.

For applications where a development approval is required (i.e. planning legislation applies) the following additional criteria apply:

Element 1 Location – generally seeks to minimise exposure to BAL-29 or less

Element 2 Siting – Asset protection zone (APZ) intended to minimise exposure to BAL-29 or less. The APZ includes the separation distance from the predominant vegetation to a building typically 20-30m but may be higher in some circumstances. <u>Fences within this zone are required to be constructed from non-combustible materials</u> (for example, iron, brick, limestone, metal post and wire, or bushfire-resisting timber referenced in Appendix F of AS 3959)

Element 3 Vehicular Access

Element 4 Water

Element 5 Vulnerable tourism land uses

Local Municipalities may also nominate additional requirements.

General guidelines applying constraints on fencing materials

CSIRO Bushfire Best Practice Guide states the following in relation to fences and garden walls.

- *Fences and garden walls can be used to shield the home during bushfire*
- *Fences and garden walls can protect against the four main modes of bushfire attack (embers, heat, flame, and wind).*

If possible, consider installing a solid, non-combustible fence to screen the house and garden from bushfire attack. If you have an existing fence, keep the area around the fence clear of combustible materials.

It also provides the following advice:

Do's

- *Keep fences clear of overhanding trees and shrubs, and free of vines and other creeping plants.*
- *If possible, use solid non-combustible materials, such as brick, stone, concrete, or galvanised iron.*
- *Timber fences should be treated using an appropriate fire retardant.*
- *Fences and walls can be sited to protect people and buildings from bushfire (see Screen plantings). Similar principles apply to both natural and artificial barriers.*
- *Timber fences should be sited away from vulnerable building elements, such as windows, doors, decks, and eaves. All timbers can burn under intense bushfire conditions.*

Don'ts

Do not store garden waste or combustible mulches next to fences.

If possible, avoid combustible building materials, such as timber and brushwood – timber fencing can ignite and spread fire to other parts of the property.
Avoid porous designs such as chain linked fences and gapped picket-fences. This style of fence is ineffective as a barrier and may restrict movement.

The CFA Landscaping for Bushfire (2022) publication indicates that landscaping for bushfire takes account of a number of factors including;

- creating defendable space
- the location of plants within the garden
- the flammability of individual plants
- the need for ongoing maintenance.

The publication defines defendable space as an area of land around a building where vegetation is modified and managed to reduce the effects of flame contact and radiant heat associated with bushfire. It breaks up the continuity and reduces the amount of fuel available to a bushfire.

Under the design principle of removing flammable objects from around the house the publication states:

Within 10 metres of a building, flammable garden materials (such as plants, mulches, and fences) must not be located close to vulnerable parts of the building (such as windows, doors, decks, pergolas and eaves). The intention is to prevent flame contact on the house.

Instead of timber use steel, concrete, masonry or rocks for hard landscape features such as garden edges or sleeper walls.

Conclusions from review of current regulations and guidelines

Based on a review of the relevant regulations and guidelines, there are significant inconsistencies in the application of AS 3959 across Australia with additional requirements being introduced at State and Territory Level and also at municipal government levels.

For example, additional restrictions on the use of timber fences are imposed via regulation in NSW.

Various guides are provided to assist residents maintain vegetation around properties in a manner that does not encourage spread. Terms such as ‘defendable space’ are adopted and despite the focus on vegetation, recommendations for the use of non-combustible fencing within prescribed distances up to 10m of a building are stated.

Chapter 2 Hazard Identification and Quantification

Bushfire losses associated with housing

A general analysis of bushfire losses relating to houses is provided in Appendix 2. The main outcomes were:

Approximate losses between 2009 and 2020 were:

- 450 houses lost per annum due to bushfires across Australia,
- an average of 6 civilian fatalities per annum associated with housing within a bushfire prone area.

Using these estimates, the probabilities of house loss and the risk of a fatality associated with a house in a bushfire prone area were estimated as shown in Table 1 and Table 2 respectively. AS 3959 does not prescribe any measures for buildings more than 100m from predominant vegetation; but Victorian regulations issued following the Royal Commission into the 2009 fires, require the BAL−12.5 classification and construction standards to be applied to new houses in Bushfire Prone areas including buildings beyond 100m of the interface with predominant vegetation. Since most of the houses lost pre-date the application of AS 3959 or were not required to be constructed in accordance with the standard, it has been assumed that AS 3959 construction requirements had not been applied beyond 100m from the predominant vegetation when using survey results from previous fires unless the ages and construction standards are included in the survey results.

Table 1 Estimates of probability of house loss due to Bushfires within various distance bands from predominant vegetation with 10% of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Proportion of houses[1]	Est Num of houses	Prob of house loss existing / y - Aus
<20	Mainly BAL–FZ	2.9%	288,550	7.6×10^{-4}
20-50m	BAL–29 / BAL–40	1.2%	119,400	7.9×10^{-4}
50-100m	BAL–12.5 to 19	1.9%	189,050	3.1×10^{-4}
100-200	Low Ember Attack	3.2%	318,400	2.0×10^{-4}
200-700	Very Low ember attack	11.1%	1,104,450	1.0×10^{-5}
Total	0-700m	20.3%	2,019,850	2.2×10^{-4}

Note 1 Proportion of houses within the typical BAL classification

Table 2 Estimates of risk to life associated with housing in bushfire prone areas within various distance bands from predominant vegetation with 10% of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL class / Ember hazard	Prop. of houses.	Est pop. at 2.6 people / house	Prop / number of fatalities [1]	Risk of fatality within a house
<20	Mainly BAL FZ	2.9%	750,230	87% / 5.22	7.0×10^{-6}
20-50m	BAL 29 / BAL 40	1.2%	310,440	8% / 0.48	1.5×10^{-6}
50-100m	BAL 12.5 - 19	1.9%	491,530	2% / 0.12	2.4×10^{-7}
100-200	Low Ember Attack	3.2%	827,840	2% / 0.12	1.4×10^{-7}
200-700	Very Low ember attack	11.1%	2,871,570	1%/0.06	$2. \times 10^{-8}$
Total	0-700m	20.3%	5,251,610	100% / 6	1.1×10^{-6}

Note 1 Percentage of fatalities inside structures derived from cumulative loss profile of fatalities inside a structure v distance from forest in Life and House Loss Database (Blanchi R, Leonard J et al. 2012)

The probability of house loss for buildings not constructed to AS 3959 and those constructed to AS 3959-2009 or later has been calculated in Table 3 assuming:

- within areas classified as BAL–12.5 to 29, the probability of loss of buildings constructed before application of AS 3959:2009 was 40% and for buildings constructed to AS 3959:2009 or later versions 10%, and
- within areas classified as BAL–40 and BAL–FZ the probability of loss of buildings constructed before application of AS 3959:2009 was assumed to be 90% and for buildings constructed to AS 3959:2009 or later versions 30%.

Table 3 Estimated Probability of loss of housing

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Prob of loss of pre-AS 3959 :2009 /y	Prob of loss of post AS 3959 :2009 /y
<20	Mainly BAL–FZ	7.6×10^{-4}	2.5×10^{-4}
20-50m	BAL–29 / BAL–40	7.9×10^{-4}	2.6×10^{-4}
50-100m	BAL–12.5 to 19	3.1×10^{-4}	7.8×10^{-5}
100-200	Low Ember Attack	2.0×10^{-4}	2.0×10^{-4}
200-700	Very Low ember attack	1.0×10^{-5}	1.0×10^{-5}

An approximate estimate of the average loss / annum and average loss over the design life of houses constructed to pre-AS 3959:2009 standards and post AS3959:2009 standards is provided in Table 4 assuming an average cost to clear a site and rebuild of $750,000 and a design life of 50 years and ignoring depreciation.

Table 4 Estimated average loss per house per annum and over a 50 year design life.

Distance from Pred. Veg. m	Typical BAL classification / ember hazard	Av loss per annum @ current worth		Av loss over design life @ current worth	
		Pre AS3959 2009 house	Post AS3959 2009 house	Pre AS3959 2009 house	Post AS3959 2009 house
<20	Mainly BAL–FZ	$570	$187	$28,500.00	$9,375.00
20-50m	BAL–29 / BAL–40	$593	$195	$29,625.00	$9,750.00
50-100m	BAL–12.5 to 19	$233	$59	$11,625.00	$2,925.00
100-200	Low Ember Attack	$150	$150	$7,500.00	$7,500.00
200-700	Very Low ember attack	$8	$8	$375.00	$375.00

These results indicate that with reasonable / good levels of compliance and application of AS3959:2009 or later standards, losses at distances between 50-100m from the predominant vegetation (typically approximating to BAL–12.5 and 19 classifications) would be approximately 60% less than houses located 100-200m from predominant vegetation which generally do not require mandatory construction standards to address the bushfire risk in most States and Territories. Within 50m of the predominant vegetation (typically approximating to

BAL–29 to BAL– FZ classifications) losses are expected to be 30% higher than the losses for unprotected buildings between 100m and 200m from the predominant vegetation.

These results indicate that the major focus should be on increasing levels of compliance with AS 3959 construction standards and voluntary upgrades of existing buildings constructed before the introduction of AS 3959:2009 to reduce losses further rather than the introduction of measures beyond the AS 3959:2009 requirements unless significant reductions in losses can be clearly demonstrated together with a net benefit.

When considering these average values, it should be noted that there are substantial variations in losses with many years having minimal losses, but severe fire seasons have resulted in losses of 2000 houses in a single season in the 2009 Black Saturday fires and 2019-20 fire season based on houses predominately constructed to pre-AS 3959:2009 building standards.

Summary of hazards identified by key stakeholders associated with timber fences and sleeper walls

Meetings were held with fire services from the States and Territories to gain an understanding of potential hazards associated with timber fences and sleeper walls. These results will be reported separately with the key hazard identification findings summarised in Table 5.

Table 5 Hazards identified by key stakeholders

Ref	Hazard	Sub-category	Scenario
1	Ignition and fire propagation from ember attack	Ember / mulch build up	- At vertical surfaces - At dwelling walls or deck - Connections to fences or sleeper walls - At re-entrant details
2	Burning characteristics of timber	Reduced time to ignition	- Impact of density, moisture content, preservative treatment
		Increased heat release rate HRR during flaming combustion	- Impact of density, moisture content, preservative treatment
		Smouldering combustion / afterglow	- Extended smouldering combustion associated with treated pine and potential for reignition and spread
3	Fire spread from fences and sleeper walls attached to a house or in close proximity to vulnerable parts of an adjacent house.	Flame contact /convection radiation ember attack	- Fence parallel to wall with various separation distances - Impact due to structural failure of fence breaking window and allowing ember entry - Fence perpendicular to wall and attached - Fence perpendicular to a wall and separated
4	Toxicity (outside scope of current projects)	CCA treated timber was highlighted but this equally applies to hazards associated with burning vegetation, debris building materials and personal possessions.	- During burning - Post fire clean up
5	Fire Fighter access/safety	Visual and physical barrier	- Presents a barrier for access and egress from a building and impacts visibility
		Flaming fence	- Presents a potential hazard to fire fighters unless alternative pathways are provided.
6	Evacuation paths and fire-fighting access for occupants	Flaming fence	- Presents a potential hazard to occupants trying to evacuate or fight fire.

Anecdotal evidence from case studies and surveys relating to fencing and sleeper walls

Anecdotal evidence is commonly based on examination of lost and damaged houses where much of the evidence has been destroyed and the cause of house loss is open to interpretation. In some cases, this may be supplemented by formal or informal interviews with witnesses.

The performance of wood products is particularly open to interpretation. For example, if timber elements of construction are part of a building or in close proximity to it and the building has been lost, there is a tendency to assign the loss to the presence of timber when other potential causes may present a greater risk (more likely cause) such as adjacent poorly managed vegetation or entry of embers through pre-existing openings and openings formed due to thermal exposure as the fire front passes.

In most cases wood products require some form of external heat source to maintain flaming combustion (Bartlett 2018) and smouldering combustion (Crielaard, van de Kuilen et al. 2019) either from adjacent burning materials or the bushfire front itself. This behaviour can be modified by some forms of preservative treatments (e.g. CCA) which can exhibit sustained afterglow (Gardner and White 2009). Afterglow is defined in ISO 13943 (ISO 2017) as the persistence of glowing combustion after both removal of the ignition source and cessation of any flaming combustion.

Often there is a tendency to automatically assume that there has been an intervention rather than consider self-extinguishment where an area of timber is charred or discoloured.

Notwithstanding the above limitations, anecdotal evidence may help identify the potential causes of house loss or perceived causes of house loss involving timber fencing or sleeper walls that can be evaluated further.

The following are typical observations from some published studies.

1983 Ash Wednesday fires and January 1994 fires in NSW (Ramsay, McArthur et al. 1996)
"Personal interviews revealed that people were able to save their houses by extinguishing burning materials around the houses - woodheaps, fence posts, trees and other burning buildings - and by extinguishing small ignitions of the house itself before these small fires became uncontrollable. In many cases, residents carried out these salvage operations on their own houses and their neighbours' houses after the fire front had passed. Further houses were saved by fire brigade action, although because of the speed of the fire such actions were generally limited."

Canberra 2003 fires (Blanchi and Leonard 2005)

Typical observations from the survey are summarised below:

Survey work has revealed that many houses are ignited from radiation and flame contact from adjacent burning buildings or features such as timber fences. The duration of the radiation and flame exposure from adjacent burning structures may be for a significantly longer period (an hour or more) compared to the exposure to the fire front itself (a few minutes).

The initial vegetation and structural fires in Duffy created an even more concentrated and *enduring ember attack for those homes further downwind. Some of the structural fires provided direct flame attack and radiation impact on adjacent structures also. These impacts persisted for hours rather than the few minutes it takes for a flame front to pass. This effect was exacerbated by the placement of relatively large houses on medium sized blocks, and the presence of timber fences and vegetation between the closely orientated structures.*

Timber fencing and vegetation adjacent to houses has the potential to break windows and ignite combustible features of the home. In a number of cases, the fence was responsible for spreading the flame up between houses.

A common fence design provides re-entrant corners ideal for ember lodgement and transition to flaming.

Wye River / Separation Creek area (Leonard, Opie et al. 2016)

Whilst the fire weather conditions were less severe than the design fire conditions used to determine the fire exposure in accordance with AS 3959, the severity of the fire exposure was increased by the limited management of vegetation around buildings facilitating fire spread through the settlement. Also, the classification of the BAL levels for some recently constructed houses was below the levels assessed before the bushfire and confirmed after the bushfire by (Boura 2016). Determining manual suppression of specific timber elements may have been complicated by heavy rainfall occurring shortly after the bushfire but before the survey was undertaken. Notwithstanding the above qualifications, the observations from the survey summarised below identified potential scenarios that will be considered as part of the hazard assessment.

The survey, including the following extract from Schedule 1 to the neighbourhood character overlay of the Colac Otway Planning Scheme, helps explain the continuous vegetation through the settlement and potential conflicts between legislative requirements with respect to management of vegetation:

"The existing and preferred character of the township is characterised by buildings nestled within the often steep topography and the indigenous and native vegetation. The buildings sit below the tree canopy height, and there is sufficient space around them to accommodate substantial vegetation, as well as clearances required for wildlife management. The buildings are of varying low scale designs but contain elements that respond to the coastal location including the predominance of non-masonry materials, metal roofing, balconies and transparent balustrades. Buildings typically have flat or single pitch roofs, and while often being two-storey or split level, they do not dominate the surrounding. A lack of or transparent styles of fencing enables the vegetation to flow across the boundaries and between public and private domains, and roads with unmade edges add to the informal feel of the township."

The survey noted that *"Native vegetation is contiguous throughout, fences are uncommon, open decking and balustrades abound and natural timber cladding is frequently used."*

The survey also postulated that *"...localised ember spread within the townships was not as prevalent as other surveyed bushfire events involving house losses of more than 100 houses. This may be due to the relatively low wind speeds within the townships at the time of fire activity. The low wind speeds also appeared to exacerbate the prevalence of house-to-house ignitions at distances previously considered sufficient. These spread mechanisms supported the initial progression of fire within the townships and provided flame contact as follows:*

- *interaction between fine surface fuels and heavy fuel elements adjacent to houses*

• interaction between fine surface fuels and combustible elements on the houses themselves
• interaction between fine surface fuels and LPG pressure vessels providing the potential for gas flares and explosions.

Heavy fuel elements then interacted with each other in the advanced stage of fire development within the township through the following mechanisms:
• flame contact from one heavy fuel element to another
• radiant heat transfer from burning heavy fuel elements to other nearby elements, e.g. sleeper walls, fences or house cladding
• flame or radiant heat transfer to LPG pressure vessels providing the potential for gas flares and explosions.

The interaction of fire with established tall trees also increased the risk of tree and branch strike because fire weakens knots and flaws in trees."

Since there were no further mentions of fencing or any examples of flame spread due to fencing in the report the remaining discussion will focus on sleeper walls.

General comments in the report relating to sleeper walls include;

"Where timber (in particular treated pine) sleeper walls were in contact with or within a few metres of a building, their combustion is likely to have contributed to house loss.

"Where treated pine is used there is also the risk of toxic smoke emissions during the fire and toxic ash residue on the ground and blown by the wind after the fire. Timber sleeper walls also provided a direct threat to buildings, or subsequent ignition or heat exposure to other adjacent elements, such as LPG pressure vessels."

"Heavy fuel elements then interacted with each other in the advanced stage of fire development within the township through the following mechanisms:
• flame contact from one heavy fuel element to another
• radiant heat transfer from burning heavy fuel elements to other nearby elements, e.g. sleeper walls, fences or house cladding
• flame or radiant heat transfer to LPG pressure vessels providing the potential for gas flares and explosions."

"BAL-29 allow combustible stumps, bearers, flooring, decking, stair and balustrades within close proximity to the ground. These elements were either directly threatened by fire spread through typical levels of fine fuel and grasses within the townships or ignited by typical heavy fuel elements that resided under or adjacent to the buildings. The typical elements included sleeper walls, stored materials, vegetation, plastic water tanks and vehicles.
Some of these weaknesses are only specifically addressed in BAL-40 and BAL-FZ (flame zone) construction levels, which specify that heavy fuel elements should not be located under or adjacent to BAL-40 and BAL-FZ buildings."

A series of case studies were included in the appendices. Two typical examples are described below which highlight some of the difficulties in identifying the primary cause of fire losses. These case studies will be considered when designing a test program to evaluate the potential fire risks associated with timber sleeper walls.

The following case studies relating to sleeper walls were referenced in the body of the report.

Case A1 constructed to BAL-40 survived with damage to its decking and decking support structure. The report stated that:

"...the main threat to the house and decking was from the combustion of treated pine retaining walls adjacent to and below the structure and deck. The house's steel support structure and non-combustible subfloor, cladding, window frames and doors were effective in resisting ignition in combination with aerial suppression activities."

Photographs of the retaining walls included in the report showed that some parts of the retaining walls had not ignited, some had charred, and others had been completely consumed or removed before the survey.

The report stated that: *"During active burning of these retaining walls, aerial water bombing drops washed down over the retaining walls and under the building. This water bombing appeared to be effective at supressing the burning of the retaining walls and limiting the duration and intensity of flame exposure on the buildings and attached deck."*

A figure was referenced to justify this statement, but examination of the photograph showed that the sleeper wall had either been fully consumed or possibly removed before the survey. No discussion was provided in the report to justify discarding the potential for water runoff from the heavy rainfall that occurred after the fire but before the survey in lieu of the fire brigade intervention theory.

The report did not include dimensions of the distance between the sleeper wall and the face of the building but if the supporting joists were at 450mm centres, the sleeper wall would have likely been approximately 1m from the building based on the number of joists.

Case A2 was stated to be constructed in 2005 and photographs of fully consumed sleeper wall elements. Whilst the report describes a scenario involving spread from the adjacent sleeper walls, due to the substantial damage to the site, clear evidence is not available and other likely scenarios cannot be discounted such as fire spread via the vegetation leading to window breakage and ignition within the house.

Review to determine adequate means to prepare a property (Penman, Eriksen et al. 2013).

The study considered a broad range of variables and provided the following comments and recommendations relating to timber fences.

"Combustible fences have the potential to move fire quickly through a property and to transfer significant heat loads to a built structure, potentially igniting it. Wooden fences should be at least the height of the fence from a built structure, whereas any brushwood fences should be three times the height of the fence from the built structure. Similarly, wooden sleepers used as garden edges or retaining walls should not be within 1 m of the built structure."

Chapter 3 Previous studies of timber fencing, sleeper walls and other relevant elements exposed to simulated bushfire attack

Performance of Residential Boundary Fencing Systems (Leonard, Blanchi et al. 2006)

Overview

This was a collaborative project between BlueScope Steel Limited and the Bushfire CRC undertaken by CSIRO Bushfire Research to:

- investigate the performance of the most common commercial fencing systems made from pre-painted and metallic-coated sheet steel and timber. These fencing systems are mostly used as residential boundary fencing in urban and urban–rural interfaces in the built environment in Australia.
- investigate the potential of using fencing systems as protection for houses and residential-type buildings against attack from radiant heat, burning debris and flame impingement during bushfires.
- investigate experimentally whether the behaviour of fencing systems contributes to the risk of house loss or risk to life.

The copies of the report distributed by the Bushfire CRC exclude the appendices which contain additional graphical data, details of the design and installation of these fencing systems, instrumentation, and additional photographs of the test. The appendices could not be obtained at the time of preparation of this report and the following descriptions and analysis are based on data in the body of the report.

Small scale - cone calorimeter tests

A series of tests were performed using a cone calorimeter that is described in AS NZS 3837 (Standards_Australia 1998). The specimens were nominally 95 to100mm wide x 100mm long x 12 to 14mm thick and were tested in the horizontal orientation when mounted in an edge frame at an irradiance of 25kW/m^2.

Three conditioning criteria were adopted in the series:

- Standard conditions prescribed by AS/NZS 3837 whereby the specimens where conditioned to constant mass at an ambient temperature of 23°C and a relative humidity of 50%. (Typical moisture content 9.6%)
- Modified conditions whereby the specimens where conditioned to constant mass at an ambient temperature of 40°C and a relative humidity of 20%. (Typical moisture content 5.1%)
- Modified conditions whereby the specimens were conditioned to constant mass in accordance with AS /NZS 3837 requirements and then conditioned for a further 6 hours at 40°C and a relative humidity of 20%

The tests were performed on old and new hardwood and softwood palings. The old hardwood was stated to be messmate (*Eucalyptus obliqua*), sampled from a fence estimated to be approximately 20 years old. The new hardwood was alpine ash (*E. delegatensis*).

Both the old and new softwood samples were stated to be copper chrome arsenate (CCA) treated radiata pine (*Pinus radiata*). The old, treated pine was sampled from an in-use fence approximately 10 years old, and the new treated pine was purchased direct from a supplier.

The results from the tests are summarised in Table 6. Leonard et al, noted that based on the time to ignition, a material exposed for six hours to 40°C and 20% relativity humidity had:

> *"similar fire properties to the same material when conditioned at the same temperature and relative humidity until moisture equilibrium was achieved. This highlights a significant point that the fire behaviour of these specimens was influenced more by the surface moisture content rather than the average moisture content of the specimens, and hence the weather conditions on the day of fire impact will have a significant effect on the fire performance of timber elements."*

The mean ignition times for the different specimens are plotted in Figure 2. The heat release rate (HRR) is also a fire property that significantly influences the potential for fire spread. This parameter has been plotted for comparison in Figure 3 using data available and the variation between differently conditioned samples of the same species is relatively minor indicating that the impact of moisture content is predominantly related to the time to ignition with the post ignition behaviour being less sensitive to moisture content. This highlights the potential for pre-wetting treated pine fencing during days of high fire risk as a method to reduce the risk of ignition if exposed to bushfire attack to reduce the sensitivity to environmental conditions.

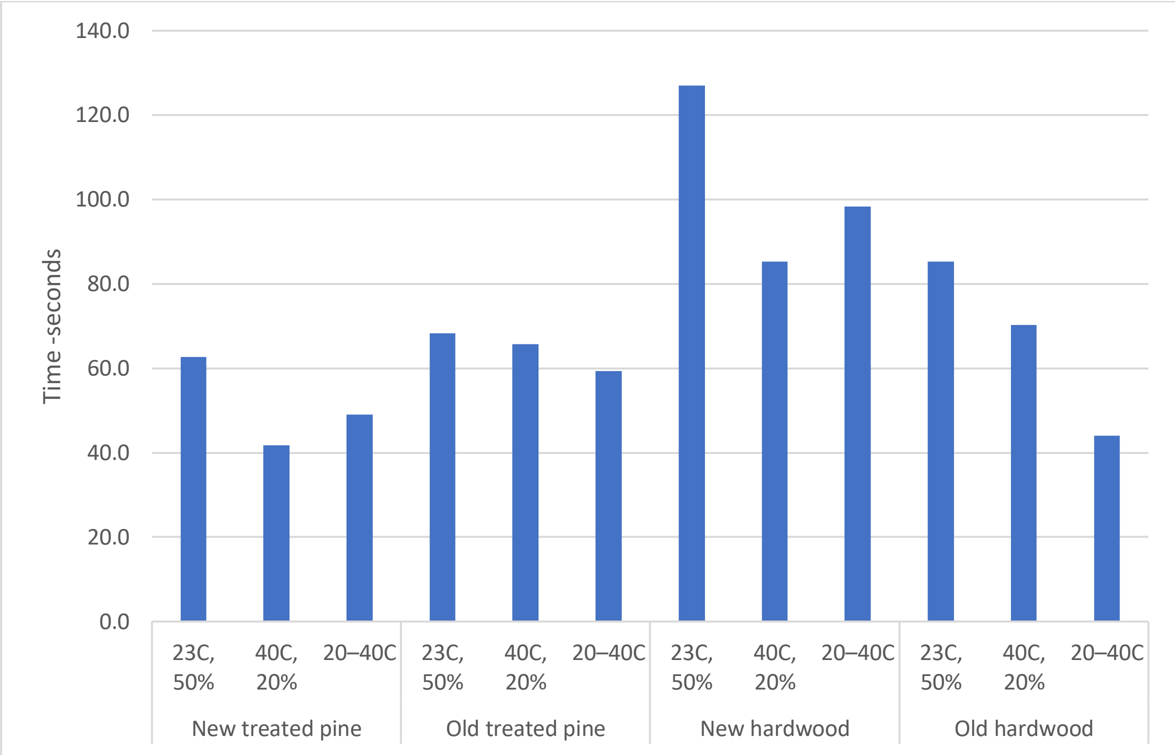


Figure 2 Mean time to ignition for samples of timber palings - derived from data presented in (Leonard, Blanchi et al. 2006)

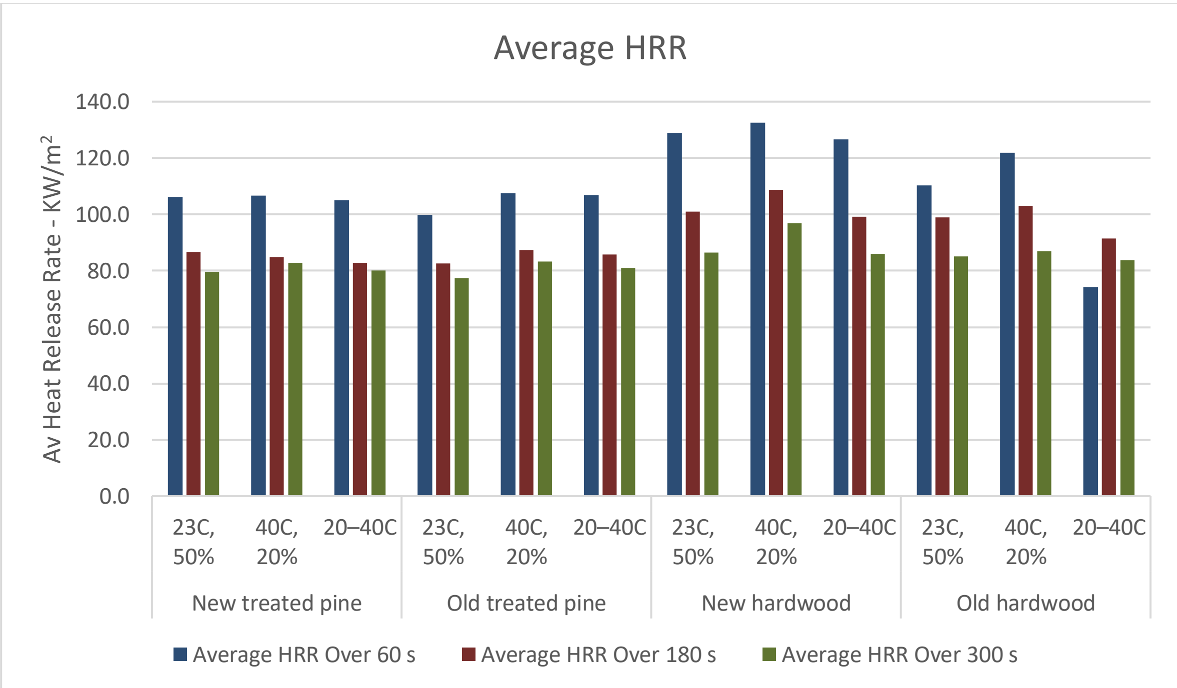


Figure 3 Average HRR for timber palings for periods after ignition when exposed to 25kW/m^2 - derived from data presented in (Leonard, Blanchi et al. 2006)

Table 6 Cone Calorimeter results for hardwood and softwood palings derived from (Leonard, Blanchi et al. 2006)

Material	Temp., RH	Spec. no.	Ign. time (s)	End of experi-ment (s)	Total heat evolved (MJ/m^2)	Peak HRR (kW/m^2)	Time of peak HRR (s)	Average HRR[a] Over 60 s	Average HRR[a] Over 180 s	Average HRR[a] Over 300 s
New treated pine	23°C, 50%	D6	65	625	60.3	171.5	474	118.3	99.2	94.4
		E2	62	630	51.8	156.8	470	100.4	83.5	76.4
		E7	61	645	41.9	120.8	70	99.6	77.0	68.2
		mean	62.7	633.3	51.3	149.7	338.0	106.1	86.6	79.7
		Std dev	2.1	10.4	9.2	26.1	232.1	10.6	11.4	13.4
	40°C, 20%	C8	42	526	38.9	134.2	52	102.5	76.1	75.9
		E3	47	525	45.9	149.3	380	107.8	88.3	88.5
		F6	36	600	50.5	131.5	50	109.6	90.2	84.1
		mean	41.7	550.3	45.1	138.3	160.7	106.6	84.9	82.8
		Std dev	5.5	43.0	5.8	9.6	190.0	3.7	7.7	6.4
	20–40°C	D3	49	636	50.8	135.4	60	106.3	81.5	74.7
		C7	45	520	43.1	162.1	405	98.6	76.5	77
		E6	53	550	50.9	167.8	415	110.5	90.6	88.6
		mean	49.0	568.7	48.3	155.1	293.3	105.1	82.9	80.1
		Std dev	4.0	60.2	4.5	17.3	202.1	6.0	7.1	7.5
Old treated pine	23°C, 50%	OPD8	72	660	55.3	156	485	99.8	82.1	78.4
		OPF1	59	655	54.3	149.2	490	105.1	85.5	78.2
		OPE5	74	695	57.8	156.2	515	94.6	80.1	75.4
		mean	68.3	670.0	55.8	153.8	496.7	99.8	82.6	77.3
		Std dev	8.1	21.8	1.8	4.0	16.1	5.3	2.7	1.7
	40°C, 20%	OPF6	69	595	47.9	146.4	435	108.8	86.3	83.1
		OPE8	67	705	57.3	134	80	111.9	93.6	86.1
		OPD1	61	625	49.4	151.2	410	102.2	82.2	80.5
		mean	65.7	641.7	51.5	143.9	308.3	107.6	87.4	83.2
		Std dev	4.2	56.9	5.1	8.9	198.1	5.0	5.8	2.8
	20–40°C	OPD5	51	555	48	163.4	440	106.3	86.4	82
			54	635	58.7	180.6	420	105.9	85.5	81.3
		OPF3	73	615	46.5	132.3	85	108.3	85.2	79.6
		mean	59.3	601.7	51.1	158.8	315.0	106.8	85.7	81.0
		Std dev	11.9	41.6	6.7	24.5	199.4	1.3	0.6	1.2
New hardwood	23°C, 50%	HE13	92	955	85.6	162.4	105	131.7	109.5	95.9
		HA10	166	1000	76	159.9	180	129.1	99.0	83.5
		HB9	127	965	75.6	151.7	140	120.6	94.6	81.2
		HB10	123	930	76.6	155.8	135	134.1	100.3	85.2
		mean	127.0	962.5	78.5	157.5	140.0	128.9	100.9	86.5
		Std dev	30.3	29.0	4.8	4.7	30.8	5.9	6.3	6.5
	40°C, 20%	HB1	79	710	68.7	175.7	510	131.4	103.8	94.1
		HC1	91	860	79.3	162.7	100	138.8	111.3	96.2
		HA5	86	815	76.3	150.5	100	127.7	111.1	100.8
		mean	85.3	795.0	74.8	163.0	236.7	132.6	108.7	97.0
		Std dev	6.0	77.0	5.5	12.6	236.7	5.7	4.3	3.4
	20–40°C	HB4	91	845	72.5	157.8	105	124.6	98.5	85.9
		HB3	104	805	67.7	155.8	120	128	96.7	84.6
		HC3	100	960	80.1	154.2	115	127.2	102.2	87.7
		mean	98.3	870.0	73.4	155.9	113.3	126.6	99.1	86.1
		Std dev	6.7	80.5	6.3	1.8	7.6	1.8	2.8	1.6
Old hardwood	23°C, 50%	OHA1	74	915	79.3	199.2	760	103.4	85.4	72.3
		OHC2	82	1175	110.8	206.2	860	108	103.2	90.6
		OHC7	100	1025	94.1	185.5	850	119.4	108.3	92.3
		mean	85.3	1038.3	94.7	197.0	823.3	110.3	99.0	85.1
		Std dev	13.3	130.5	15.8	10.5	55.1	8.2	12.0	11.1
	40°C, 20%	OHC9	84	1020	85.2	189.8	850	124.2	104.1	86
		OHA5	54	940	79.8	162.7	690	115.6	92.7	79.3
		OHC10	73	1045	96	206.7	805	125.8	112.5	95.3
		mean	70.3	1001.7	87.0	186.4	781.7	121.9	103.1	86.9
		Std dev	15.2	54.8	8.2	22.2	82.5	5.5	9.9	8.0
	20–40°C	OHA11	61	890	81.8	189.5	735	113.5	95.3	82
		OHC3	9	930	99.3	233.2	760	0.9	77.8	81.6
		OHC4	62	1170	101.2	172.8	825	108	101.3	87.7
		mean	44.0	996.7	94.1	198.5	773.3	74.1	91.5	83.8
		Std dev	30.3	151.4	10.7	31.2	46.5	63.5	12.2	3.4

Note: Based on an examination of the times to ignition it is assumed that the average HRR were reported based on the time from ignition in line with general practice rather than the start of test.

The investigation also sampled gases to explore production rates of toxic species during combustion with the results indicating that both the timber specimens and painted steel produce toxic species. The detailed consideration of toxic species lies outside the scope of this project. It is noted that toxic species will be produced by combustible materials including vegetation during a bushfire and that residents and fire fighters should avoid exposure to smoke as far as practical. In addition, after fires at the urban interface, precautions should be taken until affected sites have been cleared.

Full-scale tests

A series of simulated bushfire exposure tests was performed by CSIRO on 1.8m high timber fencing specimens using the configuration shown in Figure 4. The series included the following types of timber fencing:

- Capped open paling hardwood (stringybark or mahogany)
- Capped open paling treated pine
- Closed paling hardwood (stringybark or mahogany)
- Closed paling treated pine

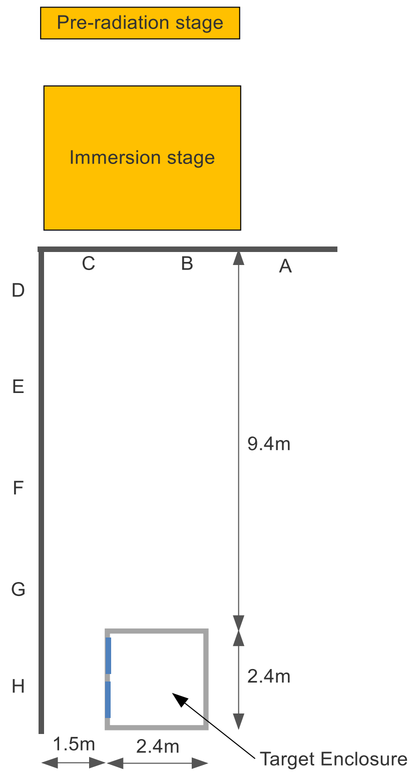


Figure 4 Test Configuration used for bushfire simulation testing derived from the description provided in (Leonard, Blanchi et al. 2006)

Four types of bushfire exposures were performed on these fencing systems which were identified as the following:

Leaf litter exposure

Leaves and small twigs from eucalypts were conditioned at 40°C and 20% relative humidity and approximately 100 L of leaf litter was spread along the base and rails of the outside of the fencing and 20 L along the base of the inside of the fencing, particularly in the corner. The leaf litter was then ignited using a portable propane burner. The test was terminated when significant combustion or involvement of the fencing ceased.

The report is not specific about the number of ignition points and period of exposure to the portable burner at the various ignition points. Based on the observations in the report it is likely that the leaf litter was ignited at multiple locations along the fencing and there could have been a contribution to ignition from the propane burner.

The results of the test are summarised in Table 7.

Table 7 Abridged summary of leaf litter exposure tests derived from (Leonard, Blanchi et al. 2006)

Type of fencing	Key Observations	Resulting damage	Time of failure
Hardwood, capped open paling	No significant involvement of fencing except for light flaming at base of paling in one location, which ceased when leaf litter burnt out.	None	N/A
Hardwood, closed paling	Started smouldering with small flames 0.5 m high at inside corner mostly due to leaf litter with limited involvement of hardwood at 2 min. Flames burnt out by 4 min.	None	N/A
Treated pine, closed paling	Immediate ignition of pine, with slow flame spread and smouldering that eventually consumed majority of fencing. Window cracked at approx. 90 min due to impact of fencing and resulting direct flame contact. Increased flaming occurred where protected from wind, i.e. inside corner. Treated pine easily supported smouldering and low intensity flaming. Once flames spread to top of fencing, lateral spread by smouldering and flames was much slower.	Entire fencing except for panels A & B consumed or collapsed. Window failed due to collapse of fence panel onto the window.	Half corner panels C & D consumed in 15 min. Corner panels C & D completely consumed in 30 min. Half panels E & B consumed in 60 min. Panel G slumped against house & window in 90 min. Panel F collapsed in 100 min.
Treated pine, capped open paling	Immediate ignition of pine. Increased flaming occurred where protected from wind at inside corner. Treated pine easily supported smouldering and low intensity flaming. Once flames spread to top of fencing, lateral spread from corner by smouldering and flames was much slower. Limited smouldering and consumption of palings near post between panels A & B. Panel D collapsed. Further spread ceased but effected by wind and early collapse of whole panel.	Palings/railing consumed at corner. Panel D collapsed. Limited palings consumed at intersection of panels A and B.	Panel D collapsed in 20 min.

Based on the observations it can be concluded that a small ignition source instigated the eventual collapse of some treated pine posts, but lateral flame spread along a fence line from a single point ignition was not demonstrated.

It appears that the failure criteria applied was primarily collapse of the fencing. It is noted that the burning fence laying against the simulated house in the closed paling test may have initiated a crack in a plain glass window, but the pane was not dislodged, and embers would not have been able to penetrate the window.

The relevance of the criteria depend on the objective. The focus of the CSIRO study was the extent of additional protection provided by fencing and hence collapse of fencing is a critical performance parameter. If however, the performance criteria are focussed on not compromising the performance of an adjacent building, collapse may be less critical.

The mode of failure of the supporting posts was not identified in the body of the report limiting the potential to investigate the cause of collapse. It is noted that the fixing of the posts at ground level was not representative of normal practice.

Bushfire pre-radiation exposure

Similar quantities of leaves and small twigs were applied to the timber fences and then ignited and then the pre-radiation stage burners were ignited and controlled to follow the target profile listed below at the centre of one of the panels facing the burner array;

- 5 kW/m^2 for 3 minutes
- 10 kW/m^2 for 2 minutes
- 30 kW/m^2 for 2 minutes
- 10 kW/m^2 for 1 minute
- 5 kW/m^2 for 1 minute

The burners were then turned off.

The test was terminated when significant combustion or involvement of the fencing ceased. The measurements and observed damage are summarised in Table 8.

Table 8 Abridged summary of pre-radiation exposure tests derived from (Leonard, Blanchi et al. 2006)

Type of fencing	Resulting damage	Peak measurements (time of peak measurement in brackets)											
		At house		Outside fencing			Inside fencing			1 m behind fencing		1 m behind fire front	
		RAD 1 (kW/m^2)	TC 2 (°C)	RAD 10 (kW/m^2)	TC 50 (°C)	TC 51 (°C)	RAD 9 (kW/m^2)	TC 46 (°C)	TC 48 (°C)	RAD 5 (kW/m^2)	TC 43 (°C)	RAD 8 (kW/m^2)	TC 40 (°C)
Hardwood, capped open paling	Charing of panels A, B, C, D	1.9 (340)	42.5 (375)	63.2 (380)	194.4 (380)	254.8 (380)	3.8 (375)	114.6 (380)	145.4 (380)	3.4 (375)	48.5 (380)	/	254.7 (380)
Hardwood, closed paling	Consumption of fencing at corner join of panels C & D and extending along panel C	0.5 (325)	28.5 (165)	94.5 (420)	237.1 (425)	409.9 (425)	64.5 (2630)	402.5 (1380)	640.6 (2595)	3.8 (2640)	49.6 (2505)	36.0 (395)	92.4 (430)
Treated pine, closed paling	Panels B, C, D destroyed; significant damage to joint of panel F–G; panel G fell on simulated residence, breaking window	0.9 (375)	41.6 (1755)	40.6 (900)	481.0 (2585)	575.5 (3260)	15.3 (1500)	155.7 (2500)	672.6 (1855)	8.5 (765)	69.4 (1505)	14.5 (410)	88.2 (540)

The hardwood fence did not collapse with charring restricted to the panels directly exposed to the pre-radiation exposure and the panels directly fixed to them. The exposure of the building was minimal and 1m behind the panels directly exposed to the pre-radiation the maximum duration peaked at $3.8kW/m^2$. Substantially below a heat flux that would threaten a building,

The behaviour of the treated pine closed paling specimen was more complex because smouldering combustion continued from the ignited leaf litter on the fencing adjacent to the simulated building distant from the panels exposed to the pre-radiation test.

The maximum heat flux measured 1m behind the fencing directly exposed to the pre-radiation test (peak exposure $30kW/m^2$) was $8.5kW/m^2$. The peak heat flux at the house was 0.9 kW/m^2. Indicating a low risk to adjacent property.

However smouldering combustion continued at the fencing adjacent to the simulated house and fence panels fell against the building breaking the plain glass window. From the limited photographs in the main body of the report the cause of the structural failure is likely to have been initiated by smouldering combustion at the mortice joints and base detail of the post. Without structural failures the fencing would be unlikely to have broken the window of the adjacent property.

It is also significant that the failure was initiated by fire spread from a local ignition point not spread along the fencing.

Bushfire passage flame immersion exposure

The pre-radiation stage in conjunction with the flame immersion stage was used for these tests.

Similar quantities of leaves and small twigs were applied to the timber fences as the leaf litter test but not ignited prior to exposure to the radiant heat and flame immersion stages for panels A to C. The leaf litter applied to panels D to H was ignited at the start of the test.

The following test conditions were then applied:

- 5 kW/m^2 for 3 minutes.
- 10 kW/m^2 for 2 minutes
- 30 kW/m^2 for 2 minutes
- Flame immersion stage on for 11 seconds (stated exposure 10MW/m)
- Flame immersion stage turned off, but a further 40 seconds was required for all gas within the distribution system to burn
- 5 kW/m^2 for 2 minute

The test was terminated when significant combustion or involvement of the fencing ceased. The measurements and observed damage are summarised in Table 9.

Table 9 Abridged summary of flame immersion exposures derived from (Leonard, Blanchi et al. 2006)

Type of fencing	Resulting damage	Peak measurements (time of peak measurement in parentheses)											
		At house		Outside fencing			Inside fencing			1 m behind fencing		1 m behind fire front	
		RAD 1 (kW/m^2)	TC 2 (°C)	RAD 10 (kW/m^2)	TC 50 (°C)	TC 51 (°C)	RAD 9 (kW/m^2)	TC 46 (°C)	TC 48 (°C)	RAD 5 (kW/m^2)	TC 43 (°C)	RAD 8 (kW/m^2)	TC 40 (°C)
Treated pine, capped open paling	Panels A, B, C, D, E destroyed; play equipment destroyed	5.7 (445)	45.2 (805)	125.6 (450)	666 (470)	794.5 (460)	193.6 (445)	964.7 (455)	1125.7 (450)	68.9 (445)	151.9 (445)	138.3 (450)	699.8 (450)
Hardwood, closed paling	No significant damage sustained; charring to outside of panels A, B, C; hole burnt at joints A–B and B–C	2.5 (505)	37.7 (520)	128.9 (500)	435.0 (520)	1016.0 (520)	13.4 (520)	79.8 (520)	368.6 (525)	14.2 (505)	51.5 (520)	63.6 (515)	81.3 (525)
Treated pine, closed paling	All fencing consumed with the exception of panels A and G; panel G fell onto simulated residence	2.8 (550)	44.3 (805)	134.4 (550)	627.5 (515)	1045.1 (555)	72.5 (695)	898.2 (780)	840.2 (695)	25.0 (755)	232.3 (810)	95.1 (570)	137.3 (575)

Panels A to E were consumed exposing the play equipment indicating that the treated pine fencing with open palings can be expected to offer only partial protection against direct flame impingement from a fire front reducing the incident heat flux 1m behind the fence to 68.9kW/m^2 compared to the peak heat flux 1m behind the simulated fire front of 138kW/m^2.

The test was then discontinued with ongoing combustion of the fencing approximately 40 minutes after the start of the test.

For the hardwood closed paling fence, the pre-ignited litter did not ignite the fencing materials in panels D to H. Once the flame immersion burners were turned on, after 8 minutes 30 seconds the fencing ignited when flame impingement occurred. After 20 minutes the test was terminated with no significant sustained flaming and no damage to the simulated residential building or plastic play equipment and chair. The peak heat flux 1m behind the exposed area of the fence was 14.2 kW/m^2 and the maximum temperature at 1m behind the fence was approximately 52°C.

For the closed paling treated pine test, there was evidence of smouldering combustion over panels D to H prior to ignition of the fencing after 5 minutes 30 seconds of the test at the outside corner of panels C and D which would have been exposed to radiant heat from the simulated approaching fire. The following observations were reported:

Time – mins	Observation
8.5	Flame spread across panels C and D commenced prior to full immersion
9	After full immersion burners had been turned off a large hole was observed in panel C but most of panel D was intact.
12	the majority of the palings in panels B and C were burnt through with charred rails and posts still standing, and most of panel D was flaming
14	flaming of panels, A to D had ceased but flaming at other points continued.
15.67	panel D collapsed and the paling at the intersections of panels D–E and E–F had been consumed
18.5	panel E collapsed
26	panel F collapsed. At this stage panels G and H adjacent to the window were flaming
34	panel G collapsed outwards away from the simulated building.
47	Panel H continued flaming and collapsed onto the simulated building
49	the window that the burning fencing was leaning against broke. This appeared to be due to thermal stress as burning timber was in direct contact with the window
60	the remaining smouldering material was suppressed and the experiment was stopped. All of the fencing panels except for half of panel A were consumed. Damage to the residential objects consisted of the chair being completely melted down but not consumed, the toy trailer had melted down to 20% of its original height, and the front edge of plastic wading shell had strands of plastic drooping but no significant damage.

Structural fire exposure

No leaf litter was applied, and the fencing was exposed to the following test conditions:

Flame immersion stage on for 30 minutes with a stated fire line intensity of 5MW/m.

The burners were then turned off. The measurements and observed damage are summarised in Table 10.

Table 10 Abridged summary of structural fire exposures derived from (Leonard, Blanchi et al. 2006)

Type of fencing	Resulting damage	Peak measurements (time of peak measurement in parentheses)								
		At house		Inside fencing			1 m behind fencing		1 m behind fire front	
		RAD 1 (kW/m²)	TC 2 (°C)	RAD 9 (kW/m²)	TC 46 (°C)	TC 48 (°C)	RAD 5 (kW/m²)	TC 43 (°C)	RAD 8 (kW/m²)	TC 40 (°C)
Hardwood, capped open paling	Panels B, C, D destroyed; 60% of panel A destroyed	4.8 (215)	76.5 (220)	/	1090.6 (115)	1041.4 (70)	55.2 (70)	335.1 (255)	/	819.6 (280)
COLORBOND, sawtooth profile	Damage to panels B and C; play equipment destroyed	4.1 (320)	51.4 (125)	34.7 (420)	259.3 (145)	324.3 (470)	20.6 (140)	125.2 (465)	136.5 (145)	769.8 (140)
COLORBOND, sawtooth profile	Charing to exposed surfaces; minimal structural damage; some melting of plastic toys	1.9 (40)	31.8 (115)	35.0 (120)	180.7 (125)	225.8 (155)	16.7 (125)	66.7 (120)	126.5 (110)	211.6 (120)
Hardwood, closed paling	Panels A, B, C, D and 50% of E destroyed; toys destroyed	7.9 (505)	147.6 (515)	184.5 (450)	1066.8 (435)	1124.0 (465)	/	755.3 (550)	206.0 (70)	659.7 (30)

The immersion stage burners were turned on at the start of these experiments. Key observations from the test on the closed paling hardwood fence subjected to the structural fire exposure are summarised below:

Time – mins	Observation
0	Flames immediately impinged on the outside surfaces of panels B and C, with flames penetrating through the palings and emerging from the rear of the panels
0.5	Rear of panels B and C began producing significant amounts of smoke. The burner flames leaned towards the fencing and impinged on most of the outside of panel D due to the prevailing wind.
4	Majority of the rear of panels B and C were involved in flame
6	Many gaps started to appear in panels B and C as palings were consumed. At this stage all the plastic play equipment had melted and there were flames on the inside of panel D
8	All the palings on panels B, C and D had been consumed with charred posts and rails still remaining,
8.8	Panel A collapsed
9.67	Remains of panel D collapsed
11.5	Edge of panel E ignited
20	Half the palings on panel E had been consumed after this there was no significant flame spread
30	Burners are turned off. Panels A, B, C and D and half of panel E were destroyed. All plastic play equipment was destroyed. There was no damage to the simulated residential building.

The report concluded the following with respect to the performance of timber in the large-scale experiments:

> *Although hardwood is combustible, closed paling hardwood fencing maintained a radiant heat barrier during radiation-only exposures, resulting in a greater than three times reduction in radiant heat received at the structure. In exposures where flame contact of the fencing occurred, flame emission from the fencing provided additional radiant heat exposure on the structure. Open paling hardwood fencing systems were effective in attenuating incident radiation when flames did not contact the fencing systems, however they provided little barrier during direct flame contact. Neither fencing configuration supported lateral flame spread to the extent that would expose the structure to direct flame*

contact. Under structural fire exposure conditions, the fencing quickly burnt away leaving no barrier to the impinging flames.

Treated pine had the worst performance, as its integrity under leaf litter attack resulted in potential for loss of the adjacent structure due to lateral flame spread. Its performance as a heat barrier was good until ignition of the fencing occurred, after which point additional heat impact was received by all elements behind the fencing. Significant risk of house loss occurred during all experimental exposures, either through thermal exposure or mechanical impact as the fencing collapsed onto the structure. Under structural fire exposure conditions, the fencing quickly burnt away leaving no barrier to the impinging flames.

A major contributor to the poor performance of the treated pine specimens may have been the fixing details (e.g. rails to posts and post fixing to the ground). Full details were not provided in the version of the report available for general distribution, but further information may have been provided in the Appendices which have not been able to be accessed.

Evaluation of Cost Effective Forms of Bushfire Construction for Buildings Project 4 – Fencing and Project 5 – Minor Features (Chow and England 2010)

The objective of these studies was to investigate the performance of lapped and paling treated-pine fencing in shielding radiation and if ignited measure the potential exposure of other objects to heat released from the fencing.

Closed paling and lapped paling treated radiata pine fences exposed to the BAL 19 heating regime of AS 1530.8.1 with Type A timber cribs applied

Tests were performed based on the exposure conditions of AS 1530.8.1 (Standards_Australia 2007) approximating to BAL-19 and including a Type A timber crib to simulate simultaneous burning debris at the base of the wall. The specimens comprised treated pine fences nominally 1.8m high and 3.0m wide. One specimen had lapped palings and the other with closed paling (but with small gaps between the palings where they butted together simulating typical practice and conditions after shrinkage of palings). Posts were provided at the edge of each wall with rails spanning between the posts. Observations from the test were provided over a period of 30 minutes after exposure together with radiant heat data and photographs from which the data presented in Table 11 have been derived.

It can be seen that the lapped fence fully shielded the simulated exposure to radiant heat from the fire front and the radiant heat at a distance of 900mm was below 2 kW/m^2 except for occasional spikes whilst the flaming combustion reduced. At the end of the 30-minute test there was a substantial section of the wall remaining.

The closed paling face again provided some protection from the radiant heat source reducing the peak exposure 900mm from the fence to approximately $8kW/m^2$ but the palings were substantially consumed at the end of the test.

Table 11 Key observations and data from paling fence tests when exposed to radiant heat and flaming source (AS 1530.8.1 Type A crib) extracted from (Chow and England 2010).

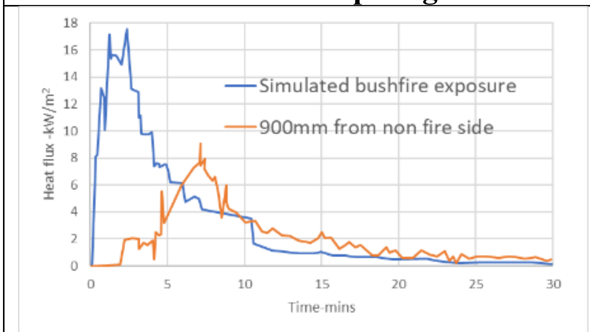
Closed paling with palings loosely butted

Time mins	Visual Observations
1	Flames projecting onto non-fire side through the small gaps between palings at the crib position
2	¾ of specimen flaming to full height of test frame
3.5	Flames 500mm above fence
4.5	Flames 1000mm above fence
5	Section of fencing fell away
7	Full width of fence eroded at mid height
9	Only timber rails remain
20	Both posts flaming
30	One post continuing to flame – Tests stopped

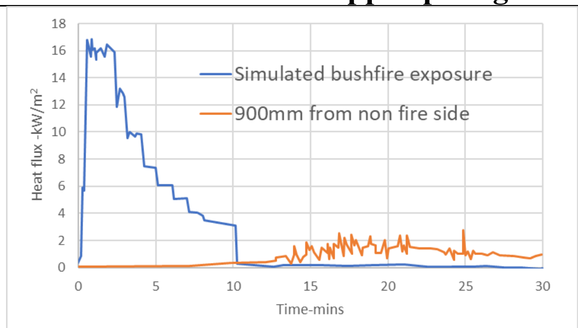
Lapped paling fence

Time mins	Visual Observations
1.33	Post on fire exposed face adjacent to crib ignited.
2	Flames above fence height at post position adjacent to crib.
5	Flames on exposed side extending 500mm above fence
6	Increase in flaming on crib side of specimen
7	Flaming on non-fire side next to post exposed to crib
8.75	Approximately 1/3 of fence on exposed side flaming
9.75	Flames approx. 300mm on crib side of specimen
11.5	Paling next to post adjacent to crib burnt through and fell off.
21	Embers fell from post
25	Flames at the top of fence moving towards centre
28	Flames diminishing at the top of the fence
29	No flaming above the middle of the fence at the top
30	Test stopped

Radiant heat flux data - palings



Radiant heat flux data lapped palings



Non fire side view at end of test

Non fire side view near end of test

These tests provide useful information of the performance of treated pine closed and lapped paling fences and show that under a scenario where the fence is intact when exposed to the fire front, some protection can be expected whilst the fire front passes and direct exposure from the burning fence at a distance of 900mm would be less than exposure to BAL-12.5 (as defined in AS 1530.8.1). Issues such as the behaviour of posts and smouldering combustion may require further consideration for treated pine.

Intermediate Scale paling fence exposed to the AS 1530.4 standard heating regime

The evaluation of cost-effective forms of bushfire construction for buildings project included results from intermediate scale tests (nominally 1.2m x 1.2m) with sections of fencing exposed to the standard AS 1530.4 (Standards_Australia 2014) heating regime for 10 minutes. The standard heating regime with an exposure period of 30 minutes is adopted by AS 1530.8.2 (Standards_Australia 2018) to evaluate and classify the performance of building elements potentially exposed to direct flame attack from the fire front.
AS 1530.8.2 acknowledges that flame contact duration from the fire front is expected to be less than 2 minutes, but a 30-minute exposure period has been nominated to allow for potentially higher transient temperatures from the fire front and also provides resistance to large burning items adjacent to the element of construction.

The majority of the palings were substantially consumed at the end of the 10-minute exposure to the standard heating regime or shortly afterwards. Therefore, adjacent paling fences are not expected to provide significant additional protection to a building where there is substantial direct flame exposure from other sources for a lengthy period. Some shielding may be provided but a generalised estimate cannot be provided since the fire front is likely to substantially exceed the height of the wall under extreme conditions and the flames may envelop the fence irrespective of the thermal properties of the materials used providing minimal protection to the adjacent building or structure.

90mm x 90mm square treated Radiata Pine posts exposed to the AS 1530.8.1 BAL-29 heating regime.

The project also included tests on 90mm x 90mm square treated Radiata Pine posts exposed to the AS 1530.8.1 BAL-29 heating regime with a Class A crib applied at the base. Non-loadbearing tests were undertaken on the following:

- No protection
- Galvanised steel stirrup with a width of 75mm, a height of 110mm and a thickness of nominally 3mm
- Sleeve created by 0.3mm thick aluminium flashing (200mm wide) wrapped at base of post.

The whole of the face exposed to radiant heat was ignited whilst exposed to 29kW/m^2 but flaming reduced as the incident radiant heat flux was reduced in accordance with the AS 1530.8.1 profile and a protective char layer formed. After 30 minutes, flaming combustion had ceased but there was evidence of smouldering combustion for all specimens.

There was significant charring at the base for the unprotected post compared to the post with the aluminium flashing or stirrup which may explain in part the structural failure in the previous study reviewed undertaken by (Leonard, Blanchi et al. 2006).

Fire resistance of preservative-treated slash pine fence posts (Evans, Beutel et al. 1994)

An experimental investigation was carried out by (Evans, Beutel et al. 1994) to investigate the fire resistance of CCA treated slash pine fence posts including observations of sustained smouldering (afterglow) behaviour. The program comprised a series of tests on 97mm diameter slash pine posts which included water repellant versions of CCA (CCA-wax and

CCA-oil) in addition to water-based CCA and these were compared to creosote treated posts and untreated slashed pine controls.

Two air dried straw ignition sources were used:
1kg extending to approximately 767mm up the post (burning time approx. 5 minutes) and
4kg extending to approximately 835 mm up the post (burning time approx. 7.5 minutes)

The key findings were:

- There was an insignificant effect of the CCA preservative treatments on the time that the posts were flaming, and the flaming time was similar for the untreated pine. The flaming time was longer for the creosote treated posts which may have been due to volatilization and ignition of the creosote rather than combustion of wood.
- The smouldering time was typically 20-minutes for the untreated posts but could be more than 18 hours for the CCA treated posts. Creosote treated posts did not show sustained smouldering behaviour.
- The fuel load of the ignition source had a significant impact on the flaming and smouldering times of the posts.
- Failure (deemed to occur when a 97mm post fell over) did not occur for the untreated posts or creosote treated posts but did occur for the CCA treated posts for both ignition source fuel loads. The rate of smouldering was slower (less intense) for the CCA oil treated posts than the other CCA treatments tested.
- The probability of failure (deemed to occur when a 97mm post fell over) of the CCA treated posts with the 1kg fuel load was approximately 0.5 increasing to approximately 0.9 with the 4kg fuel load.

Whilst there may be differences in the CCA treatments, the configuration of the timber elements, and moisture content of the timber, the tests described above clearly demonstrate the greater probability of self-extinguishing behaviour of untreated timber and posts protected with creosote and higher probability of sustained smouldering behaviour with CCA treatments.

The above findings are consistent with the screening cone calorimeter tests undertaken for this project.

Assessing the ability of a large-scale fire test to predict the performance of wood poles exposed to severe bushfires and the ability of fire retardant treatments to reduce the loss of wood poles (Gardner and White 2009)

Two large scale test methods to evaluate the performance wood poles exposed to severe bushfire attack were evaluated to determine, amongst other things, if they can identify the occurrence of sustained smouldering combustion.

The ENA pole fire test method (as described by (Gardner and White 2009)) exposed the specimen to a 60 kW/m^2 heat flux for ten minutes and flame contact from a 40 kW ring burner for the last five minutes of the test. After the fire test exposure, specimens were subjected to a 2 m/s wind for up to three and three quarter hours.

CCA-treated hardwood specimens tested to this method were seriously damaged and creosote-treated hardwood specimens survived with minimal damage. The 2 m/s wind exposure was needed to reliably result in severe damage to CCA-treated hardwood specimens. This research also demonstrated the greater susceptibility to fire damage of CCA-treated radiata pine poles, as CCA-treated radiata pine specimens were seriously damaged without being subjected to the 2 m/s wind after exposure to a 30 kW/m^2 heat flux.

AS 1530.8.1 (Standards_Australia 2007) was used for poles that will be exposed to bushfires where they are unlikely to be exposed to flame contact from the fire front but will be exposed to lower heat fluxes from the fire front and/or flame contact from adjacent burning vegetation. The BAL-40 exposure conditions were adopted with the Class C crib applied to the base of the pole with the following modifications to procedures and performance criteria.

- Maximum surface temperature of specimens is monitored by scanning them with an infrared camera following the fire test exposure and up to a maximum of four hours after the AS 1530.8.1 test start.
- Unless the test has been terminated at or before four hours after the AS 1530.8.1 test start, specimens will be retained in the laboratory and examined 24 hours after the test start.
- The test shall be terminated when:
  a) There is no evidence of combustion, and the maximum surface temperature is less than 200°C, or
  b) The specimen is so severely damaged it is considered likely to collapse, or
  c) Twenty-four hours have elapsed after the test start, whichever occurs first.
- Specimens shall be inspected after test termination and rated for performance.
  Specimens shall be rated:
  a) Excellent, if damage is limited to charring of less than 5 mm depth for hardwoods and 10 mm for softwoods generally on the fire-exposed face of the specimen. Charring to a depth of 20 mm for hardwoods and 50 mm for softwoods shall be permitted adjacent to the crib position.
  b) Fair, if damage exceeds the criteria for excellent, but the damage is considered to be insufficient to cause structural failure if it were present in a pole in service.
  c) Poor – if the specimen is severely damaged and the damage is considered to be sufficient to cause structural failure if it were present in a pole in service.
- A minimum of two and a maximum of three specimens shall be tested. Duplicate results shall be required for a test outcome.

Both test methods were recommended to the ENA; for severe fire attack (direct flame from the fire front) and the AS 1530.8.1 variant where direct flame contact from the fire front is unlikely.

Selected results from the ENA tests are shown in Table 12 through Table 17 which have been derived from (Gardner and White 2009) .

The creosote treatments did not show any evidence of sustained smouldering combustion within 1-hour of exposure.

Table 12 Time to ignition for specimens exposed to heat fluxes of 30 to 60 kW/m² from (Gardner and White 2009)

Specimen	Fire retardant treatment	Replicates	Heat flux (kW/m²)	Time to ignition (s)		
				Minimum	Maximum	Mean
Creos/BB(1)	Nil	2	60	5	15	10
Creos/SG(2)	Nil	1	40			209
Creos/SG	Nil	1	50			149
Creos/SG	Nil	2	60	25	54	40
CCA/SG(3)	Nil	3	40	181	300	209
CCA/SG	Nil	1	50			100
CCA/SG	Nil	5	60	18	52	31
CCA/SG	Chartek 7	2	60	300	300	300
CCA/SG	FireGuard	3	60	300	345	317
CCA/SG	FireTard 120	2	60	38	48	43
CCA/SG	FRX	3	60	30	56	45
CCA/RP(4)	Nil	1	30			300
CCA/RP	Nil	1	60			17
CCA/RP	FireGuard	2	60	303	303	303
CCA/RP	FRX	2	60	147	302	225

Notes:
1 - Creos/BB = creosote-treated blackbutt, 2 - Creos/SG = creosote-treated spotted gum
3 - CCA/SG = CCA-treated spotted gum’ 4 - CCA/RP = CCA-treated radiata pine

Table 13 Maximum surface temperature of specimens one hour after ENA pole fire test start (Gardner and White 2009)

Specimen	Fire retardant treatment	Replicates	Heat flux (kW/m²)	Wind exposure	Max. surface temperature (°C)		
					Minimum	Maximum	Mean
Creos/BB(1)	Nil	1	60	No			47
Creos/BB	Nil	1	60	Yes			24
Creos/SG(2)	Nil	1	50	No			70
Creos/SG	Nil	1	60	No			40
Creos/SG	Nil	1	60	Yes			21
CCA/SG(3)	Nil	1	40	No			542
CCA/SG	Nil	1	40	Yes			773
CCA/SG	Nil	1	50	No			416
CCA/SG	Nil	3	60	No	515	639	563
CCA/SG	Nil	2	60	Yes	681	804	743
CCA/SG	Chartek 7	2	60	Yes	26	40	33
CCA/SG	FireGuard	3	60	Yes	24	719	622
CCA/SG	FireTard 120	2	60	Yes	734	806	770
CCA/SG	FRX	3	60	Yes	470	770	613
CCA/RP(4)	Nil	1	30	No			560
CCA/RP	Nil	1	60	No			545
CCA/RP	FRX	2	60	Yes	21	27	24
CCA/RP	FireGuard	2	60	Yes	745	764	755

Notes:
1 - Creos/BB = creosote-treated blackbutt; 2 - Creos/SG = creosote-treated spotted gum
3 - CCA/SG = CCA-treated spotted gum, 4 - CCA/RP = CCA-treated radiata pine

Table 14 Maximum surface temperature of specimens four hours after ENA pole fire test start (Gardner and White 2009)

Specimen	Fire retardant treatment	Replicates	Irradiance (kW/m^2)	Wind exposure	Max. surface temperature (°C)		
					Minimum	Maximum	Mean
Creos/BB(1)	Nil	1	60	No			TT1(5)
Creos/BB	Nil	1	60	Yes			TT1
Creos/SG(2)	Nil	1	50	No			TT1
Creos/SG	Nil	1	60	No			TT1
Creos/SG	Nil	1	60	Yes			TT1
CCA/SG(3)	Nil	1	40	No			516
CCA/SG	Nil	1	40	Yes			837
CCA/SG	Nil	1	50	No			TT2(6)
CCA/SG	Nil	2	60	No	370	513	442
CCA/SG	Nil	2	60	Yes	850	920	885
CCA/SG	Chartek 7	2	60	Yes			TT1
CCA/SG	FireGuard	2	60	Yes	745	772	759
CCA/SG	FireTard 120	1	60	Yes			738
CCA/SG	FRX	2	60	Yes	453	778	616
CCA/RP(4)	Nil	1	30	No			538
CCA/RP	Nil	1	60	No			531
CCA/RP	FRX	2	60	Yes			TT1
CCA/RP	FireGuard	2	60	Yes			TT1

Notes:
1 - Creos/BB = creosote-treated blackbutt, 2 - Creos/SG = creosote-treated spotted gum
3 - CCA/SG = CCA-treated spotted gum, 4 - CCA/RP = CCA-treated radiata pine
5 - TT1 = test terminated at one hour, 6 - TT2 = test terminated at two hours

Although data was not tabulated, it was noted that at the end of 24 hours, the CCA-treated radiata pine specimen was severely damaged and almost completely converted to ash, as occurred with the specimen after the ENA pole fire test.

Table 15 Time to ignition and ignition temperature for specimens tested to AS 1530.8.1

Specimen	Fire retardant treatment	Time to ignition (s)	Ignition temperature (°C)
Creos/SG(1)	Nil	38	557
CCA/SG(2)	Nil	48	338
CCA/SG	Chartek 7	45	335
CCA/SG	FireGuard	63	476
CCA/SG	FireTard 120	46	327
CCA/SG	FRX	50	441
CCA/RP(3)	FireGuard	83	517
CCA/RP`	FRX	50	473

Notes:
1 - Creos/SG = creosote-treated spotted gum
2 - CCA/SG = CCA-treated spotted gum
3 - CCA/RP = CCA-treated radiata pine

Table 16 General AS 1530.8.1 general criteria (not applicable to poles) absence of flaming and maximum radiant heat performance criteria

Specimen	Fire retardant treatment	No flaming at 60 minutes	Radiant heat less than 3 kW/m^2
Creos/SG[1]	Nil	Pass	Pass
CCA/SG[2]	Nil	Pass[4]	Fail (30 min)
CCA/SG	Chartek 7	Pass	Fail (24 min)
CCA/SG	FireGuard	Pass	Fail (22 min)
CCA/SG	FireTard 120	Pass[4]	Fail (37 min)
CCA/SG	FRX	Pass[4]	Pass
CCA/RP[3]	FireGuard	Pass	Pass
CCA/RP`	FRX	Pass	Fail (25 min)

Notes:
1 - Creos/SG = creosote-treated spotted gum, 2 - CCA/SG = CCA-treated spotted gum
3 - CCA/RP = CCA-treated radiata pine, 4 - Specimen not flaming but still smouldering at 60 minutes

Table 17 Maximum surface temperature at one, two, three and four hours after AS 1530.8.1 test start

Specimen	Fire retardant treatment	Maximum surface temperature (°C) at			
		One hour	Two hours	Three hours	Four hours
Creos/SG[1]	Nil	153			
CCA/SG[2]	Nil	520	440	438	470
CCA/SG	Chartek 7	260	78		
CCA/SG	FireGuard	373	47		
CCA/SG	FireTard 120	573	563	581	592
CCA/SG	FRX	500	539	499	485
CCA/RP[3]	FireGuard	260	193		
CCA/RP	FRX	523	354	256	112

Notes:
1 - Creos/SG = creosote-treated spotted gum, 2 - CCA/SG = CCA-treated spotted gum
3 - CCA/RP = CCA-treated radiata pine, the maximum surface temperature for most specimens was recorded adjacent to the position where the crib was mounted.

The performance of the fire-retardant treatments applied to CCA treated spotted gum and radiata pine poles is summarised in Table 18.

Table 18 Efficacies of fire retardant treatments determined by testing to ENA pole fire test and AS 1530.8.1 methods

Fire retardant	Pole specimen	Rating	
		ENA pole fire test	AS 1530.8.1
Chartek 7	CCA SG[1]	Excellent	Excellent
FireGuard	CCA SG	Fair	Excellent
FireGuard	CCA RP[2]	Poor	Excellent
FireTard 120	CCA SG	Poor	Poor
FRX	CCA SG	Fair	Poor
FRX	CCA RP	Excellent	Excellent

Notes: 1 - CCA/SG = CCA-treated spotted gum, 2 - CCA/RP = CCA-treated radiata pine

The test program results demonstrated the ability of the test methods to identify sustained smouldering of CCA treated poles and highlighted the impact that wind can have on smouldering rates. The successful use of a combination of fire retardant treatments and preservative treatments to prevent sustained smouldering combustion was demonstrated.

Experimental Study on Smouldering of CCA treated timber (Wu, Hidalgo et al. 2021)

This is a relevant reference in that the techniques used where similar to those adopted for the screening tests used to characterise the various treatments in this study with respect to tendency for sustained smouldering combustion (also known as afterglow) and similarities with respect to ignition times and heat release rates.

Amongst other things, Wu reported cone calorimeter and thermogravimetric analysis (TGA) of CCA-treated slash/Caribbean pine to investigate the conditions to induce sustained smouldering combustion with no external heat source.

Findings included;

- The presence of CCA in treated timber did not affect flaming behaviour compared to the non-treated timber under the same experimental condition at the retentions tested
- An experimental methodology was developed to induce self-sustained smouldering and to quantify its severity by measuring mass-loss after a controlled burning period. This method will be useful for assessing the smouldering potential of different timber species or treatments
- Critical heat fluxes for smouldering ignition and flaming ignition of CCA-treated Slash/Caribbean pine were 7.5 kW/m^2 and 11.5 kW/m^2 respectively, compared to 10.5 kW/m^2 and 13.5 kW/m^2 for untreated samples
- CCA acts as a catalyst to affect smouldering by lowering the activation energy so that smouldering occurs at a lower temperature
- Less dense CCA-treated timber exhibits more severe mass loss during the self-sustained smouldering under 20 kW/m^2 heat flux
- CCA-treated timber subjected to a high heat flux of 50 kW/m^2 with the same mass loss prior to removal of the heat supply did not sustain smouldering this was attributed to arsenic (V) oxides reacting with the copper and chromium and effectively preventing the metal oxides acting as catalysts
- No self-sustained smouldering was observed in non-treated timber subjected to all heat fluxes with the same amount of burning time, despite its lower density, and
- Preheating time appears to play a more critical role in inducing self-sustained smouldering than fire intensity (i.e. heat flux), enabling self-sustained smouldering even for higher density timber samples.

Generally, the above findings are consistent with the screening / characterisation tests undertaken for this project.

Ignition of timber fencing by exposure to ember showers

The large scale studies described in this report that were undertaken to evaluate the performance of fencing and other features indirectly considered the impact of burning embers (Firebrands) by assuming there is a collection on or adjacent to the fencing and that it is ignited by embers. The AS 1530.8.1 procedure applies pre-ignited cribs and controls gap sizes to prevent entry of burning embers into buildings but does not evaluate the potential for embers to become lodged on a fence causing ignition. The fencing experiments undertaken by CSIRO simulated the effects of burning embers by applying leaf litter along the base and on horizontal surfaces of rails of the fencing assemblies and ignited this using a portable propane burner.

To provide more realistic conditions, NIST developed a Firebrand Generator which has been described in various publications including (Manzello 2014). The Firebrand Generator is designed to generate controlled, repeatable firebrand showers that can simulate wind-driven firebrand showers including flaming firebrands.

A study was undertaken to evaluate the ignition of wood fencing assemblies exposed to continuous wind-driven firebrand showers (Suzuki, Johnsson et al. 2016). Western Red Cedar and Redwood fencing assemblies were exposed to a simulated firebrand shower and fine fuels that may be present near fencing assemblies were simulated by dried shredded hardwood mulch beds placed adjacent to the fencing assemblies. Flat and corner sections of fencing assemblies were evaluated.

The flat wood fencing assemblies varied from 0.91 m to 1.83 wide and were 1.83 m high and the corner assemblies were 0.91 m by 0.91 m by 1.83 m in height. For all tests where mulch was included, flaming ignition of the mulch bed occurred and spread to involve the fencing. The extent of subsequent fire spread was not reported. The results from the tests with mulch beds are summarised in Table 19.

Table 19 Results of experiments on fences with mulch beds exposed to firebrand showers; derived from (Suzuki, Johnsson et al. 2016)

Configuration	Species	Time to Flaming Ignition (s)		Number of firebrands that landed on mulch beds (/s)
		of fencing after ignition of mulch beds	of mulch from time first firebrand landed	
0.91 m wide flat wall assembly	Cedar	14	103	11
Inside corner assembly	Cedar	25	78	14
Inside corner assembly	Redwood	23	59	14
Outside corner assembly	Cedar	29	82	13
1.83 m wide flat wall assembly	Cedar	9	104	8

At ignition, the average number of fire brands that impacted the 1.39m^2 mulch bed was approximately 1,010 with a standard deviation of 150.

Experiments were also undertaken without mulch beds and in these cases the firebrands produced smouldering ignition of the fencing assemblies which transitioned to flaming combustion with wind conditions applied. Ignition occurred within 20 minutes. The results are summarised in Table 20.

Table 20 Results of experiments on fences without mulch beds exposed to firebrand showers; derived from (Suzuki, Johnsson et al. 2016)

Configuration	Species	Ignition position	
		Bottom	At joints of lateral bracing and fence boards
0.91 m wide flat wall assembly	Cedar	Ignited but not sustained	Ignited and sustained
Inside corner assembly	Cedar	Ignited but not sustained	Not applicable (no corner detail)
V- corner assembly	Cedar	Ignited but not sustained	Ignited and sustained

It was observed in these tests that firebrands accumulated at the base of the fencing assemblies causing smouldering ignition initially because of accumulation of heat from firebrands. These ignitions were observed to be unsustainable because holes developed, and firebrands subsequently passed through the holes and did not accumulate further.

At joints of lateral bracing and fence boards, firebrands tended to be trapped at the corner leading initially to smouldering ignition with occasional transitions between smouldering and flaming combustion.

An option to reduce the frequency of ignition, is to modify details at corners / intersections and bases of fences.

Further work examining the production of fire brands from mulch at the base of fences and the fencing has been undertaken by NIST and has been reported by (Johnsson and Maranghides 2016, Butler, Johnsson et al. 2020) reinforcing the hazards associated with combustible mulch at the base of fences.

Chapter 4 Hazard Assessment Findings

Summary of Hazards Identified with Radiata Pine preservative treated timber fencing and sleeper walls

Potential fire hazards associated with the use of preservative treated radiata pine timber fencing and sleeper walls have postulated in previous research and investigations. These have been summarised below with possible mitigation measures described. Selected mitigation measures were investigated in the later stages of the project

Hazard - Ignition

- Ignition of radiata pine fencing and sleeper walls leading to fire spread across timber surfaces presenting an exposure hazard to dwellings, people trying to evacuate and fire fighters.
- Surface drying due to hot weather increasing risk of ignition and subsequent fire spread
- Waterborne, copper-based preservative treatments may reduce the probability of self-extinguishment due to the promotion of sustained smouldering combustion if a minor ignition occurs.

Potential Mitigation - adjusting material properties

- Pre-wetting wooden fences / sleeper walls on high-risk days increasing surface moisture content – (something to include in guides)
- Identification and selection of preservative treatments that do not promote sustained smouldering combustion
- Use compatible fire-retardant treatments

Potential Mitigation – Construction details

- Separation distances for dwellings / paths of travel from exits
- Separation from other combustibles including combustible mulch
- Adequate separation distance from bushfire threat
- Detailing to avoid lodgement of embers at connections, corners, and wall bases (ember shedding)
- Protection or selection of materials with improved fire properties for vulnerable details.
- Provide non-combustible barrier at base of walls / fences

Hazard - Fire spread

Once ignited, fire spread may be relatively rapid across radiata pine surfaces and be accelerated by wind presenting hazard to adjacent structures and blocking paths of travel around the perimeter of a building. Embers may also be generated by burning fences and walls.

Potential Mitigation methods

- Use of fire-retardant treatments (outside scope of current project)

- Design detailing:
    - limit height,
    - provide fire break details in fencing to break long runs and retard upward fire spread
    - provide adequate separation from vulnerable structures,
    - select timber profiles that do not facilitate fire spread

Hazard - Sustained Smouldering Combustion (afterglow hazard)

If a treated timber element is prone to sustained smouldering combustion, self-extinguishment may not occur and eventually the element may fail if there is no intervention This may open up an adjacent structure if the fence collapses or induce land slip if used for a substantial retaining wall. If the element supports a deck / walkway egress from a building may be compromised.

Under some combinations of environmental conditions and geometries flaming combustion may be re-established and facilitate flame spread.

Potential mitigation measures

- Manage consequences of structural failure
    - Provide more than one exit from a building with independent paths of travel
    - Provide separation of fencing or retaining walls from a critical building so that failure will not impact the building
- Prevent occurrence of sustained combustion leading to collapse of critical framing members
    - Use materials not susceptible to afterglow for critical members (e.g. high density, durable hardwoods, fire retardant treated timbers, non-combustible materials)
    - Reduce exposure such that sustained smouldering combustion is not initiated
    - Protect critical members to avoid ignition and subsequent sustained smouldering combustion

Design solutions

Design Options for fencing

Three basic options for construction of waterborne copper-based preservative treated radiata pine fences in bushfire prone areas were identified comprising:

- a basic system with minimal changes to design practices
- an enhanced system with non-combustible plinth and protection to posts,
- an enhanced system with naturally durable plinth, posts, and framing members.

For the basic system the fence posts and plinths should be treated to Hazard Class H4 because they will be in contact with the ground and other components should be treated to hazard class H3.

It is expected that elements with a larger cross-section will tend to be more resistant to structural failure if smouldering and flaming combustion occurs. Treated pine posts with thicknesses less than 70 mm have therefore been excluded and will not be recommended or tested. For intermediate posts the Timber Queensland (Timber_Queensland 2014) minimum size of 90mm x 70mm was therefore selected as a minimum size.

Square posts with minimum dimensions 90mm x 90mm are recommended for corner / end posts and gate posts in the Timber Queensland guide and this arrangement will be adopted reducing the risk of poor detailing at corners introducing vulnerabilities to bushfire attack. Rail sizes 70mm x 45mm will be specified as minimum dimensions for bushfire prone areas to provide greater resilience to smouldering combustion / charring than 35mm sections. The fence height for the tests will be 2m.

Key components are summarised in Table 21 and construction details are shown in Figure 5 and Figure 6. These are consistent with "Timber Queensland technical data sheet 20 (Timber_Queensland 2014)"

Table 21 Components of lapped paling fences

Ref	Description	Basic system (a)
1	Post (note posts should be supplied in lengths of at least 2.5m for 2 m high fences)	Corner posts Treated pine – 90mm x 90mm (H4) Intermediate posts treated pine 90mm x 70mm (H4)
2	Rail	Treated pine-70mm x 45mm (H3) lengths of at least 4.2m to allow to span between 2 posts. Rails should be rebated and notched finishing flush with the face of the post to avoid the formation of pockets / cavities for collection of embers. A typical detail is shown in Figure 7
3	Ember protection (wedges)	Not required for the basic system
4	Capping (optional)	Not required for the basic system
5	Plinth	Treated pine 150mm x 35mm (H4). For enhanced systems other materials are used and plinth heights greater than 150mm may be required
6	Post protection	None for basic system
7	Palings (1.8m high)	Treated pine 100mm x 12mm typical (H3). For lapped a combination of 150mm butted palings in the lower layer and 100mm palings covering the butt joints with 50mm spacing will be adopted

Refer Figure 5 and Figure 6 for general arrangement of components.

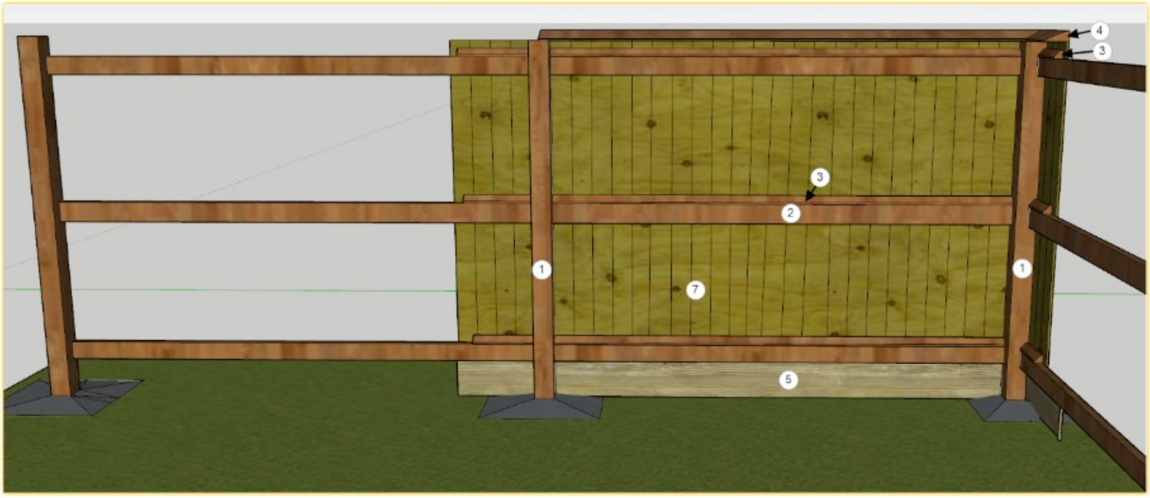


Figure 5 Paling fence viewed from house side. Note components 3 and 4 are not used for the basic system.

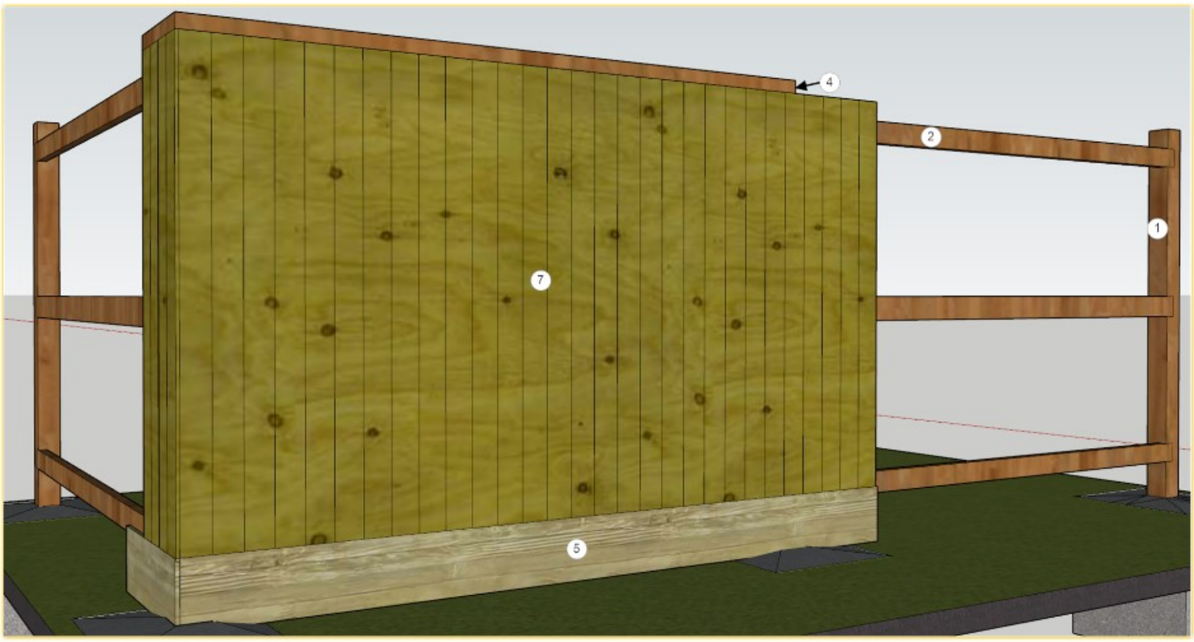


Figure 6 Paling fence system with ember shedding and timber plinth viewed from predominant vegetation side.

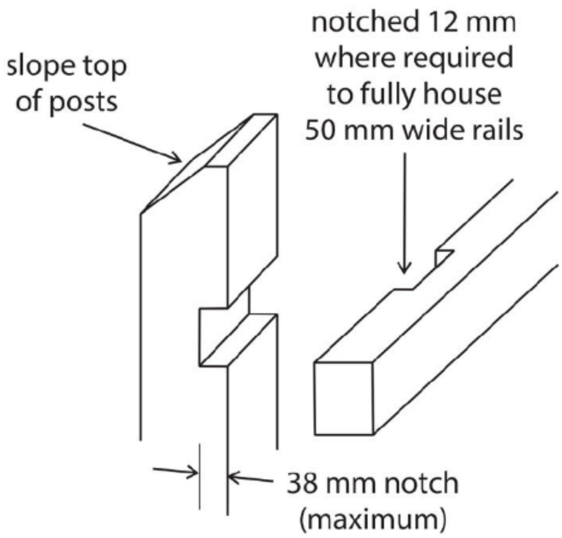


Figure 7 Notched joint from Timber Queensland technical data sheet 20 residential fences.

There was a preference from the project sponsors to minimise any changes from current construction practices and to utilise waterborne copper-based preservative treated radiata pine components, as far as practicable.

Basic system with minimal changes to traditional design practices

It was therefore decided to focus the large-scale testing part of the project on tests using predominantly water borne copper based preservative treated radiata pine components and

- testing lapped timber paling fences nominally 2m high with minor modifications to the lapping arrangement to avoid the creation of pockets in which embers and debris can collect and,
- to test sleeper garden walls of maximum height 1m supported by steel I-section posts

Once the above decisions had been made the mitigation options based on construction requirements were essentially limited to varying the separation distances between fences and buildings.

There was a preference to base these on minimum separation distances from boundaries required by the National Construction Code and therefore the large-scale test program would focus on separation distances of 0.9 to 1.0 m.

Test configurations and instrumentation were subsequently defined to provide data to assess the impact of variations in separation distances if there were unacceptable risks associated with separation distances of 0.9 to 1.0m

Other mitigation methods that are available, if only minor changes are considered to traditional practice, involve human factors to limit ignition and fire spread by minimising the build-up of combustibles around fencing and human intervention by pre-wetting radiata pine members before exposure to the fire front.

The Stage 2 test program included investigations into the time to ignition, heat release rates and sustained smouldering combustion of radiata pine and the impact of pre-wetting radiata pine to inform decisions involving these mitigation measures.

Enhanced designs for fences

Potential enhancements including ember shedding features such as rail wedges and non-combustible plinths were also developed as shown in Figure 9 but could not be accommodated in the original large scale testing program.

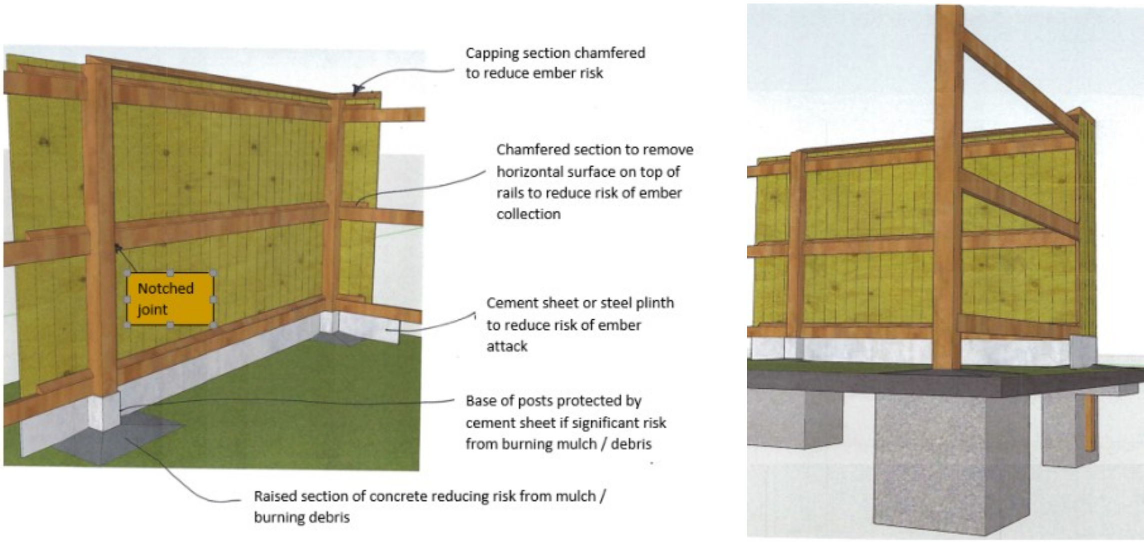


Figure 8 Paling fence designed to shed embers and resist ignition by collections of burning debris at the base of the fence

A supplementary test program was undertaken using an ember generator and applied air flows to compare the performance of the above system with a more basic design. Refer Chapter 7 Large-Scale Test for further details.

Other enhancements including hybrid systems such that use of naturally resistant timbers / rails and plinths in conjunction with preservative treated palings were also considered but evaluation of these options could not be included within the large scale testing program.

Design Options for sleeper walls

The sleeper walls will be a maximum of 1 m high and be located a minimum of 0.9m from the building envelope simulating a typical garden wall that can be constructed without the need for a building permit in many applications and jurisdictions. The construction will comprise 50mm x 200mm H4 waterborne copper-based preservative treated radiata pine sleepers with steel posts. The steel posts should be hot-dipped galvanized steel.

Selected preservative treated pine sleepers will be instrumented with internal thermocouples to provide information on char rates during the test exposures. This data and other observations may provide information to assess options for the use of timber posts and potential use of timber covers to protect steel posts. Figure 9 shows typical design options using steel posts. Further details of wall construction methods are provided in WoodSolutions Design Guide 41 (Timber_Queensland 2017).

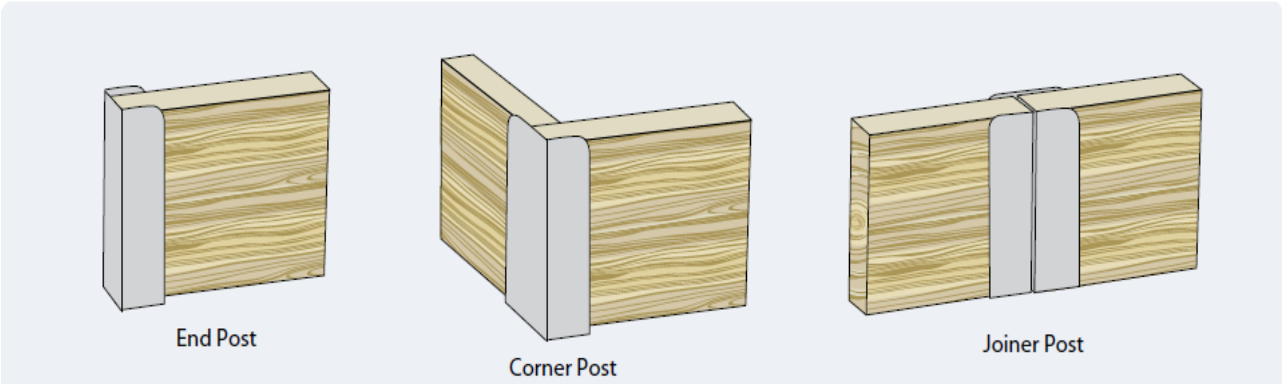


Figure 9 Timber Sleepers with Steel Posts

Chapter 5 Determination of Fire Properties of Preservative Treated Timber

This chapter provides an overview of work undertaken during this project to determine the fire properties of preservative treated timbers to provide an understanding of the likely behaviour of preservative treated timber when exposed to bushfires. For the investigation, each treatment/specimen was given a specific alpha-numeric code (A* to E*) to enable tracking during treatment testing and reporting without identifying specific proprietary products enabling identification of a treatment that could provide results suitable for general application to water-borne copper based preservative treatments More detail of the test program is provided in Appendix 1.

Test protocols to determine the extent of sustained smouldering combustion

Test protocols were initially developed to identify, under laboratory conditions, if waterborne copper-based preservative treated radiata pine increases the likelihood and extent of sustained smouldering combustion compared to untreated radiata pine and if so, compare the likelihood and extent of sustained smouldering combustion for different waterborne copper-based treatments.

The initial protocols developed are provided in Appendix 1 and successfully demonstrated the increased likelihood and extent of sustained smouldering combustion with copper-based treatments and enabled the performance of the different treatments to be compared.

Key features of the protocol included:

- termination of heating prior to full consumption of the timber samples
- continuous monitoring of samples for mass loss (and other criteria if appropriate) for 60 minutes after heating is terminated and measuring specimen masses 24 hours after termination of heating
- measurement of the rear face temperature of the specimens during heating and for 1-hour afterwards
- thin samples (12mm nominal thickness) were tested at an irradiance of 25kW/m^2 with 10 minutes exposure and thick samples (38mm-46mm) were tested at an irradiance of 50kW/m^2 for 30 minutes prior to monitoring for sustained smouldering combustion.

The irradiances were selected for compatibility with common classification criteria for timber products (50kW/m^2 for determination of NCC Group numbers for internal linings and 25kW/m^2 for evaluation of bushfire-resisting timbers).

These protocols effectively differentiated the occurrence and extent of sustained smouldering combustion enabling the selection of a treatment that could provide fire test results that would be expected to be generally applicable to other waterborne copper-based treatments.

The protocol for thick samples had greater resolution because thinner samples, even with the exposure time reduced to 10 minutes after ignition, were substantially consumed prior to termination of heating and differences in sustained combustion were therefore small.

It was identified that the extent of sustained smouldering combustion may be impacted by a number of variables including retention rates, proportion of sapwood, duration of heating, irradiance levels, density and moisture content and thickness of timber. The effect of copper compounds as a catalyst for sustained smouldering combustion may be affected by the rate of heating especially in formulations where the copper compounds may react with other chemicals such as arsenic instead of increasing the char oxidation.

The program was therefore modified to include further comparative testing with the following enhancements to the protocols.

For testing thin, 12mm specimens and thick, 38-46mm specimens:

- Samples of the treated specimens are to be forwarded to an accredited testing laboratory for testing and comparison against AS 1604.1 (Standards_Australia 2021) specifications for preservative treatments.
- For each set of three samples the specified irradiance was applied to the three samples after 3, 5 and 10 minutes after flaming ignition rather than testing all three samples for the same period (e.g. 10 minutes after ignition). The 3-minute exposure times were considered more representative of, although still greater than, the flame residency periods for most bushfires.
- Heat flux values were varied to correspond to the radiant heat fluxes associated with the bushfire attack levels prescribed in AS 3959 with the flexibility to select other values to evaluate the sensitivity of findings to different heat fluxes. The further comparative studies were undertaken at an irradiance of 19kW/m^2.

The protocol enhancements for thick specimens also included testing a fourth sample exposed for 30 minutes after flaming ignition with additional internal thermocouples to obtain data on the progression of the char depth. The additional internal thermocouples can be viewed as a voluntary addition to the general protocol predominantly for research purposes.

The additional comparative testing on the 12mm samples at an irradiance of 19kW/m^2 indicated that the control specimen was effectively fully consumed when exposed to 19kW/m^2 for 5 and 10 minutes after ignition and treatments A, C and the untreated sample all self-extinguished when exposed to 19kW/m^2 for 3 minutes after ignition (or a total of typically 8 minutes if the pre-ignition time is included) . These results indicate that there may be effectively little difference in the fire properties of the untreated and waterborne copper-based treatment for thin sections of radiata pine (12mm or less) which are likely to be consumed if the exposure is greater than 5 minutes after ignition at an irradiance of 19kW/m^2 or self-extinguish at exposures of 3 minutes or less.

This also implies that for screening for sustained smouldering combustion purposes samples at least 38mm thick should be considered.

The residual mass results from the 38mm thick sample tests performed at an irradiance of 19kW/m^2 clearly differentiated the increased tendency for sustained smouldering combustion with the copper-based treatments. The results at an irradiance of 50kW/m^2 were less clearly defined because a greater proportion of the timber is consumed during the 30-minute exposure but nevertheless the test protocol could differentiate the untreated specimens identified as F from the treated specimens identified as A and C. The X-series samples were thicker and had a higher density than the F1 untreated control which explains the higher residual mass of the AX specimens. Notwithstanding this and variations in density between the F1 groups, the protocol still demonstrated a difference between sustained smouldering combustion behaviour of specimens AX and CX which had similar densities. This further justified the selection of treatment C as the default treatment for the large-scale test series since it has the greatest tendency for sustained smouldering combustion.

For routine screening / comparison of treatments test series should be carried out at approximately 19kW/m^2 and 50kW/m^2 irradiances using radiata pine specimens at least 38mm thick. Tests in each series should be performed with exposure periods of 3, 5, 10 and 30 minutes after flaming ignition using the protocol in attachment 3 with the updates in attachment 4 of Appendix 1.

Fire properties of preservative treated timber

Time to piloted ignition

For the thin test specimens (nominally 12mm thick) cone calorimeter tests were performed at irradiance levels of 15, 19 and 29kW/m^2 and the back temperature measurements at the time of ignition show that the specimens at 15kW/m^2 and 19kW/m^2 did not approximate to the definition of thermally thick and therefore correlations such as Janssens' (Janssens 1991) that assume thermally thick elements were not applied. Further, if a surface temperature at ignition of approximately 350°C is assumed, the specimens also do not approximate to the definition of thermally thin. Therefore, general estimates of ignition times were based directly on the experimental data.

The typical time to ignition when exposed to an incident heat flux of 15kW/m^2 for specimens conditioned under standard conditions and at 35°C and 25% relative humidity exceeded 6 minutes and at lower irradiance levels approaching a critical heat flux of 12.5kW/m^2 the time to ignition would be expected to increase exponentially until ignition is no longer possible at heat fluxes below the critical heat flux.

This indicates that there is a low probability of piloted ignition with exposures to heat fluxes below 15kW/m^2 for less than 6 minutes. Thus, it would be unlikely for the treated pine to be ignited if located within a BAL−12.5 zone and substantial part of the BAL−19 zone by radiant heat from fire front and a small ignition source, unless there is an additional heat source from for example collections of burning debris, embers, or vegetation in either direct contact or very close proximity to a timber element.

At 19kW/m^2 exposure there was a large reduction in the time to ignition (average of 84s for the specimens conditioned at 35°C and 25% relative humidity). This period is at the upper end of the range of flame residency periods expected at bushfire fronts which approximates to the period of exposure to maximum heat flux directly from the fire front. This is less than the 2-minute maximum exposure period required by AS 1530.8.1 which is intended to include safety factors to account for some limitations associated with the test method such as the use of standard conditioning requirements for specimens. The time to ignition of specimens exposed to 19kW/m^2 after standard conditioning was significantly beyond 2-minutes.

These results are therefore consistent with the expected performance and use of exposed radiata timber elements forming the external walls of a house within BAL−12.5 and BAL−19 exposures as defined in AS 3959.

At exposures of 29kW/m^2 the average time to ignition under standard pre-test conditioning was 68s which reduced to 36s for specimens conditioned at 35°C and 25% relative humidity. These results indicate that at BAL−29 exposures there is a higher risk of ignition of buildings if clad with preservative treated radiata pine, although the timbers could still provide resistance to ignition for fuel types with lower flame residency periods such as some grassland fires provided the walls are protected against the build-up of debris. The results also highlight the potential beneficial effects of pre-wetting treated radiata pine prior to exposure to bushfire attack.

For the thicker specimens the specimens tended to behave as thermally thick elements at the time of ignition and therefore the Janssens method was used to determine relationships between the time to ignition and imposed heat flux. Relationships were derived for treated radiata pine after standard conditioning at 23°C and 50% relative humidity and after conditioning at 35°C and 25% relative humidity and are plotted against time in Figure 10.

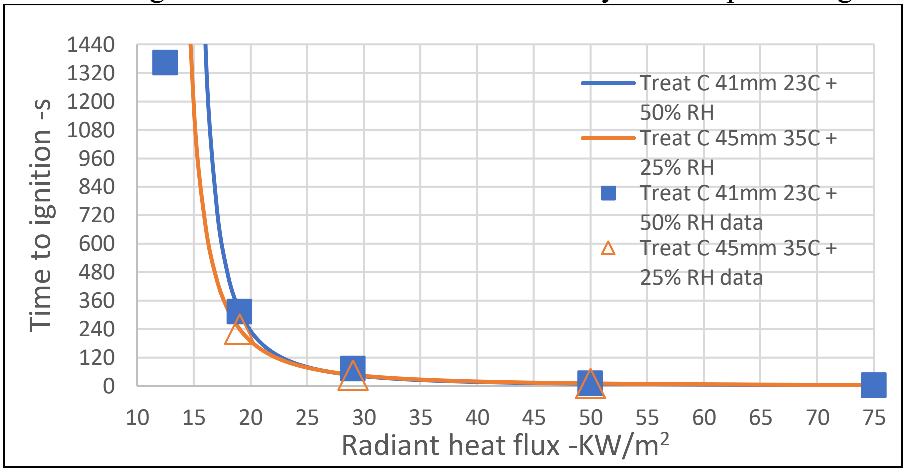


Figure 10 Plots of time to ignition for Radiata Pine with preservative treatment C(H4) based on Janssens method

The experimental results are closely aligned with the correlations except for the specimens exposed to 12.5kW/m^2 which were very close to the critical heat flux.

The results confirm the finding that if the heating is only provided directly from the fire front and the imposed heating conditions do not exceed the BAL−19 requirements of AS 3959, piloted ignition of waterborne copper-based preservative treated timber would be unlikely since exposures greater than four minutes at a heat flux of 19kW/m^2 are required for ignition. This finding is dependent on there being no additional heat source from burning debris, embers or other burning materials and is consistent with the construction requirements in AS 3959.

A series of tests on 12mm thick specimens at an irradiance of 19kW/m^2 were undertaken to evaluate the impact of density on the time to ignition but the results were inconclusive.

The following correlation derived by Babrauskas (Babrauskas 2003) was therefore used to provide a semi-quantitative estimate of the time to ignition based on incident heat flux and density:

$$t_{ig} = 130\rho^{0.73} / (q''_e - 11.0)^{1.82}$$

where ;
ρ = density (kg/m^3),
q''_e = irradiance (kW/m^2), and
t_{ig} = ignition time (s).

The correlation was used to generate plots of the time to ignition for variations in density, within the range typical of radiata pine at irradiance levels of 19, 25, 29, and 50kW/m^2. Data points at the same irradiance levels were then plotted based on representative tests undertaken under stages 1 and 2 of this project. The results indicate that if the dimensions of specimens and irradiance levels ensure the specimen behaviour will approximate to that of a thermally thick specimen and the irradiances are not less than 25kW/m^2, Babrauskas's correlation will provide a reasonable indication of the variation of the time to piloted ignition as a function of density for untreated and preservative treated radiata pine. The correlation is less reliable at irradiances below 25kW/m^2 and when the specimen does not behave as a thermally thick element due to the combination of specimen dimensions and irradiance. In these cases, reliance may have to be based directly on relevant experimental data.

Heat Release Rate Data for Radiata Pine treated with preservative C.

The comparative testing confirmed that similar fire properties were obtained from tests on waterborne copper-based preservative treated radiata pine and untreated radiata pine with respect to piloted ignition and flaming combustion with significant variations limited to sustained smouldering combustion. During investigations into sustained smouldering combustion a significant amount of data relating to the flaming combustion of radiata pine with preservative treatment C was recorded.

The magnitude and time of occurrence of the first heat release rate (HRR) peak, and the average HRR for 180s after ignition are commonly used parameters for the characterisation of the burning behaviour of timber and have been summarised in Table 22. Generally, there were at least 3 samples to provide a mean value for each cell except for the results obtained at an irradiance of 12.5kW/m^2 where one of the three specimens did not ignite since the irradiance was close to the critical flux. Whilst the general behaviour was similar, there are differences between the performance of timber specimens that can be regarded as thermally thin and those that exhibit thermally thick characteristics. The thinner specimens exhibited two HRR peaks, the first peak occurring shortly after ignition and then decaying as a protective char layer develops. The second peak occurs about the time the smouldering combustion front reaches the back face of the specimen. For thicker specimens only one peak occurred during the test duration. These behaviours are demonstrated in Figure 11 and Figure 12.

Table 22 Summary of Heat Release Rate Data for Radiata Pine treated with a water-borne copper-based preservative derived from the Stage 1 and 2 Cone Calorimeter tests

Pre-test conditioning (°C / %)	Property when tested using cone calorimeter	12mm paling samples			41 mm framing samples				
		Irradiance -kW/m^2			Irradiance -kW/m^2				
		15	19	29	12.5	19	29	50	75
Standard 23/50	Time to Peak HRR	345	336	82	1390	332	90	37	34
	Peak HRR	104	107	127	76	110	126	156	207
	Av HRR - 180s after ignition	75	73	87	62	73	86	115	161
35/25	Time to Peak HRR	398	117	58		270	60	31	
	Peak HRR	127	136	142		135	149	184	
	Av HRR - 180 s after ignition	103	108	102		76	89	119	

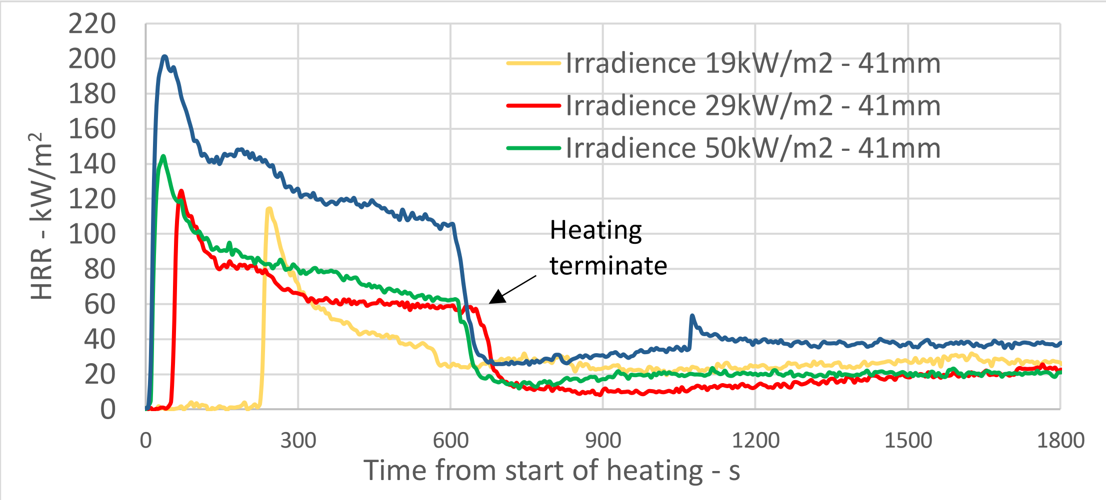


Figure 11 HRR from fire cone calorimeter tests on radiata pine, nominally 41mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

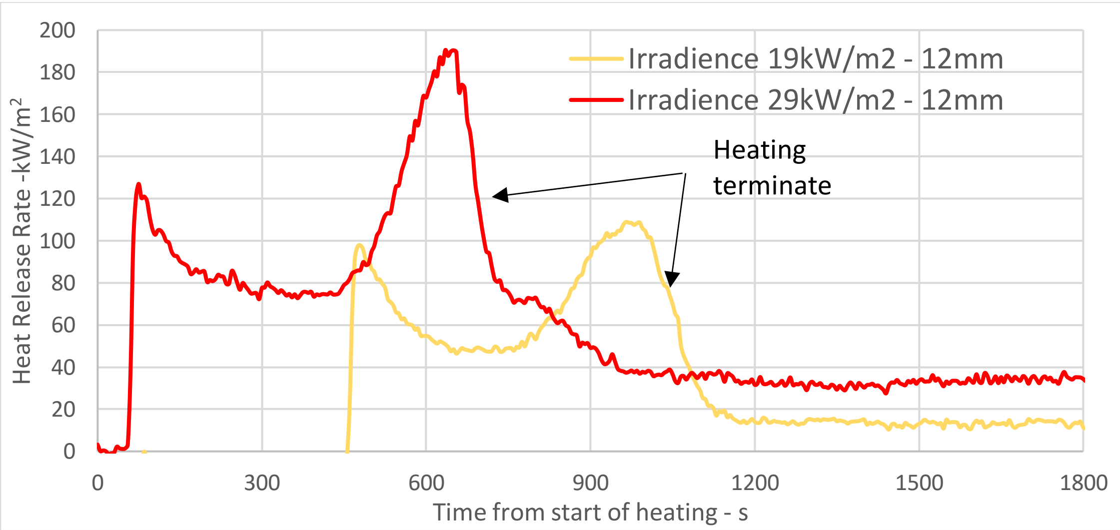


Figure 12 HRR from fire cone calorimeter tests on radiata pine, nominally 12 mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

Sustained smouldering combustion

Thin radiata pine elements (e.g., 12mm thick) were found likely to be fully consumed if ignition occurs, and the flaming combustion becomes established irrespective of whether the radiata pine is preservative treated or untreated. However, for short exposures (say less than 2 minutes) it is possible for treated pine to self-extinguish in some applications.

A useful design / maintenance strategy for thin radiata pine elements is therefore to avoid combustible materials, vegetation and mulch collecting against timber fences since, if these materials ignite, they may provide sufficient heat for flaming combustion to become established. Details such as non-combustible plinths as specified in AS 3959 for the walls to houses may achieve this purpose.

Results from tests performed on the thick (38mm – 46mm) specimens show that at irradiances of 19kW/m^2 and 29kW/m^2 and exposure periods of 3 and 5 minutes after ignition, self-extinguishment occurred with specimens conditioned prior to testing at 23°C/50% RH and 35°C/25% RH.

At an irradiance of 50kW/m^2, the results were marginal with a significant mass remaining but substantially below the mass remaining after tests at 19 and 29kW/m^2.

The specimens tested at an irradiance of 12.5kW/m^2 and 75kW/m^2 preconditioned at 23°C/50% RH and exposure periods of 3 and 5 minutes after ignition also exhibited self-extinguishing behaviour.

Analysis of internal temperature data indicated for thermally thick specimens that there may be a critical threshold for the 250°C contour at a depth of approximately 10mm for self-extinguishment to occur for radiata pine treated with waterborne copper-based preservatives but more work is required to confirm this hypothesis over a broad range of heating profiles.

Effects of pre-wetting preservative treated pine

Timber samples were conditioned at 35°C and 25% relative humidity then pre-wet increasing their moisture content. The samples were then conditioned at 35°C and 25% for periods of 2, 3, 4 and 24 hours before the moisture content was checked and a cone calorimeter test performed at an irradiance of 19kW/m^2. Moisture measurements were obtained using a moisture meter and are indicative values for comparison.

The moisture content data from both the thin and thick samples was consistent with expectations with the smaller (thinner) specimens drying quicker.

The cone calorimeter results for the thick specimens were consistent with the expected results but there were some inconsistencies in the cone calorimeter test results for the thin specimens. These may have been caused by specimen deflections modifying heating conditions, the proximity of the igniter to the specimen varying and the effect of testing timber specimens below irradiances of 25kW/m^2 where other modes of ignition may be introduced. This resulted in unrealistic results for specimens S1, S3 and S4. Repeat tests were undertaken yielding results that still had some inconsistencies (identified as S1A, S3A, S6A, S1B, S4B and S6B).

Table 23 Summary of pre-wetting test results with addition of Moghtaderi time to ignition data for thin specimens

Time relative to pre-wetting	Thick (36mm+)		Thin (12mm)			
	MC %	t_{ig} -s	Test-run	MC %	t_{ig} -s	t_{ig} Moghtaderi cone data[2]
Before	7	267	S1 S1A S1B	7,7,7 (7)[1]	102,209,407 (239)[1]	229
<15min	31	647	S2	30	471,	543
2h	29	631	S3 S3A	17,23 (20)[1]	76,429 (253)[1]	373
3h	23	457	S4 S4B	15,19 (17)[1]	290,564 (427)[1]	334
4h	23	495	S5	12	520	277
24h	11	306	S6 S6A S6B	8,8,9 (8)[1]	456,77,296 (276)[1]	238

Note 1 Value in brackets mean of replicate results

Note 2 Time to ignition calculated based on moisture content results using correlation derived from (Moghtaderi, Novozhilov et al. 1997) data.

The results from Stage 2 indicated that at irradiances below 25kW/m^2 pre-wetting can extend the time to ignition substantially and a greater effect can be expected with larger timber members.

Chapter 6 Large-scale tests adapted from AS 1530.8.1

Large-scale test methods and procedures

Overview of the development of test procedures

The focus of the large-scale test program is to investigate the potential impact of timber fences and sleeper walls on buildings constructed in Bushfire Prone Areas under bushfire attack conditions.

The primary test method in Australia for evaluation of the reaction of elements of construction to bushfire attack is AS 1530.8.1:2018 (Standards_Australia 2018). Bushfire provisions for landscaping features such as fences and sleeper walls are not currently included in AS 3959 (Standards_Australia 2018) and hence test procedures and associated performance criteria specific to these elements are not provided in AS 1530.8.1.

Test procedures were therefore developed to adapt AS 1530.8.1 and incorporate relevant performance criteria. The procedures and performance criteria were subsequently agreed with the test laboratory prior to undertaking the tests so that critical parameters and performance criteria were clearly documented prior to the tests being undertaken. (ATL report reference 20231201-FRT230047-TRO1.0)

Adaption of AS 1530.8.1 for evaluation of fences

Test method AS 1530.8.1 does not include specific provisions for fences and sleeper walls because, amongst other things, fencing and sleeper walls lie outside the scope of AS 3959 (Standards_Australia 2018) because they do not form part of a building envelope, and in many cases are not directly attached to a building.

Notwithstanding these limitations AS 1530.8.1 includes an informative Appendix A Guidelines for application of tests under similar circumstances which states:

"*The test method specified in this standard may be applied to miscellaneous attachments and building services such as air conditioning units, plastic pipes penetrating walls, verandas, and carports etc. When testing these elements, the assessment criteria should be applied to the building envelope, if the attachment serves a non-critical role during a fire emergency, and not the attachment. For example, the impact of an attached veranda should be assessed by exposing a representative section of the building envelope (wall and eaves) with a representative section of the veranda to the test conditions appropriate to the particular application (e.g. BAL:A19).*

The acceptance criteria would then be applied to the building envelope. If combustibles are likely to be stored under a veranda the risk of secondary fires should be assessed separately."

Applying these principles to the fencing and sleeper walls means that the performance criteria of AS 1530.8.1 should not be applied directly to a fence or sleeper wall, but to a combination of the fence or sleeper wall and a building envelope.

Therefore, the performance criteria were based on the exposure of a simulated (reference) building to the heating conditions prescribed by AS 1530.8.1 for wall systems including timber cribs placed at re-entrant details. The imposed heat load was measured by heat flux meters, plate thermometers and embedded thermocouples between the plasterboard and cement sheet cover. Calibration runs were undertaken to quantify the maximum exposure that the façade of a building is expected to withstand when exposed to BAL−12.5, BAL−19, and BAL−29 conditions. Tests were then undertaken to determine if the imposed heat loads determined in the calibration runs were not exceeded with the fence or sleeper wall in place.

AS 3959:2018 introduced the use of a Class AA crib for evaluation of elements such as walls which was adopted for this program. The Class AA crib uses 9mm x 9mm x 100mm sticks arranged in 6 rows each with 5 sticks of Tasmanian oak having a total mass of 0.152±0.03kg. This crib was adopted for this test series and the calibrations of the reference building since in conjunction with the imposed radiant heat profile it defines the current expectations of the resistance of buildings designed to AS 3959 requirements.

Prior to 2018 a Class A crib was commonly adopted which uses 20mm x 20mm x 100mm sticks of radiata pine arranged in 3 rows of four sticks having a total mass of 0.25±0.05kg which burns for a longer duration than the AA crib. The Class A crib was included in the BAL−19 calibration run for comparison with the AA crib.

Test Program

The large-scale test program comprised.

Three calibration tests on a simulated building (reference building) to derive performance criteria for buildings designed to satisfy AS3959 requirements for buildings located on a site or part of a site classified as BAL−12.5, BAL−19 and BAL−29 which will be identified as tests:

CAL 1 (ATL report reference 20231130-FRT230047 R1.0)
CAL 2 (ATL report reference 20231130-FRT230048 R1.0)
CAL 3 (ATL report reference 20231130-FRT230049 R1.0)

Two lapped paling fence tests.

Test 1: A test on a fence exposed to AS 1530.8.1 BAL−29 heating profiles and cribs. (ATL report reference 20231201-FRT230047 R2.0)

Test 2: A test on a l fence exposed to AS 1530.8.1 BAL−12.5 heating profiles and cribs. (ATL report reference 20231201-FRT230047 R2.0)

Two Sleeper wall tests:

Test 3: A sleeper wall above ground level simulating a wall supporting a garden bed facing the north face of the reference building. The west face of the building was exposed to the AS 1530.8.1 BAL−29 profile (peak at centre of reference building wall 29kW/m^2) and the west edge of the wall exposed to a peak greater than 29kW/m^2 but reducing as the wall runs perpendicular to and away from the heating source parallel to the north face of the reference building. (ATL report reference 20231201-FRT230050 R1.0)

Test 4: A sleeper wall below ground level simulating a retaining wall running in front of the west and north sides of the building with exposed sleepers facing the heat source and subjected to the AS 1530.8.1 BAL−29 heating profiles and cribs. (ATL report reference 20231201-FRT230050 R1.0)

General Test Configurations

Moving Platform and specimen mounting

The basic concept comprised a moveable platform on which the reference building could be constructed. Test specimens including footings could be constructed separately and conditioned and then mounted on the platform as shown in Figure 13.

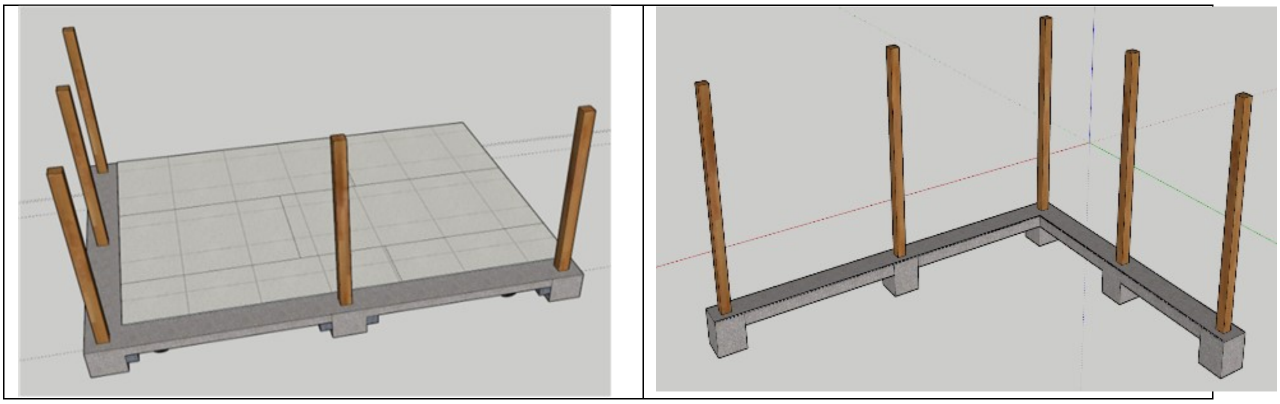


Figure 13 Schematic of test platform and pre-prepared footing assembly prior to mounting on platform

Reference Building Calibration Configuration

A plan schematic view of the configuration for the calibration of the reference building is shown in Figure 14. The crib can be applied to either corner. For the comparison of Class AA and Class A cribs, a crib was applied to each corner as shown.

Views of the reference building during a calibration run are shown in Figure 15

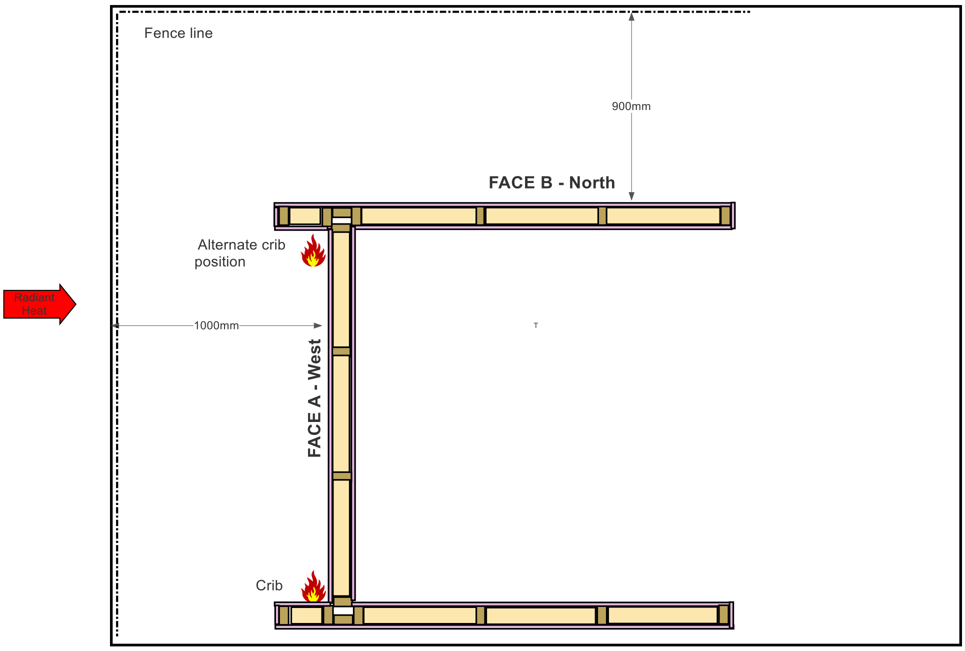


Figure 14 General layout showing reference building on moving platform and general arrangement for calibration

		
View from North	View from South during calibration	West face

Figure 15 Views of reference building before and during calibration run

Test configurations for Fences.

A combined front and side exposure fire test configuration was adopted for fences. The configuration is shown in Figure 16 to Figure 18. This is typical of the rear of houses that face a bushfire hazard except that the 1m separation is substantially less than most typical scenarios representing a very conservative (severe) test condition. The fencing wraps around the instrumented simulated building façade with a separation distance of 900mm at the side of the house simulating the minimum permitted separation distance of a building from a boundary with unprotected openings permitted by the NCC.

If the fire does not spread along the fencing down the side of the house, provision has been made for a second crib to be ignited simulating ember / mulch or debris ignition in an area shielded from radiant heat.

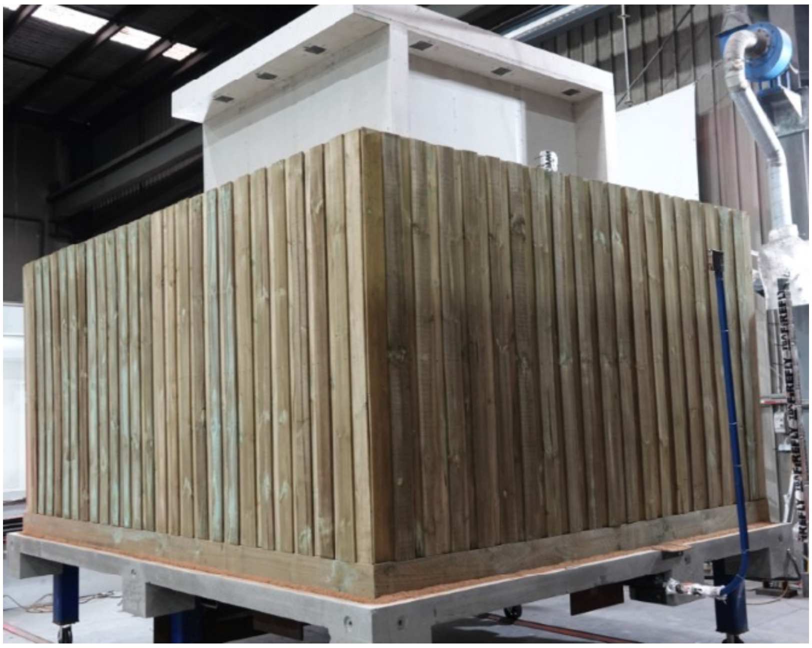


Figure 16 General view of test configuration for fencing tests

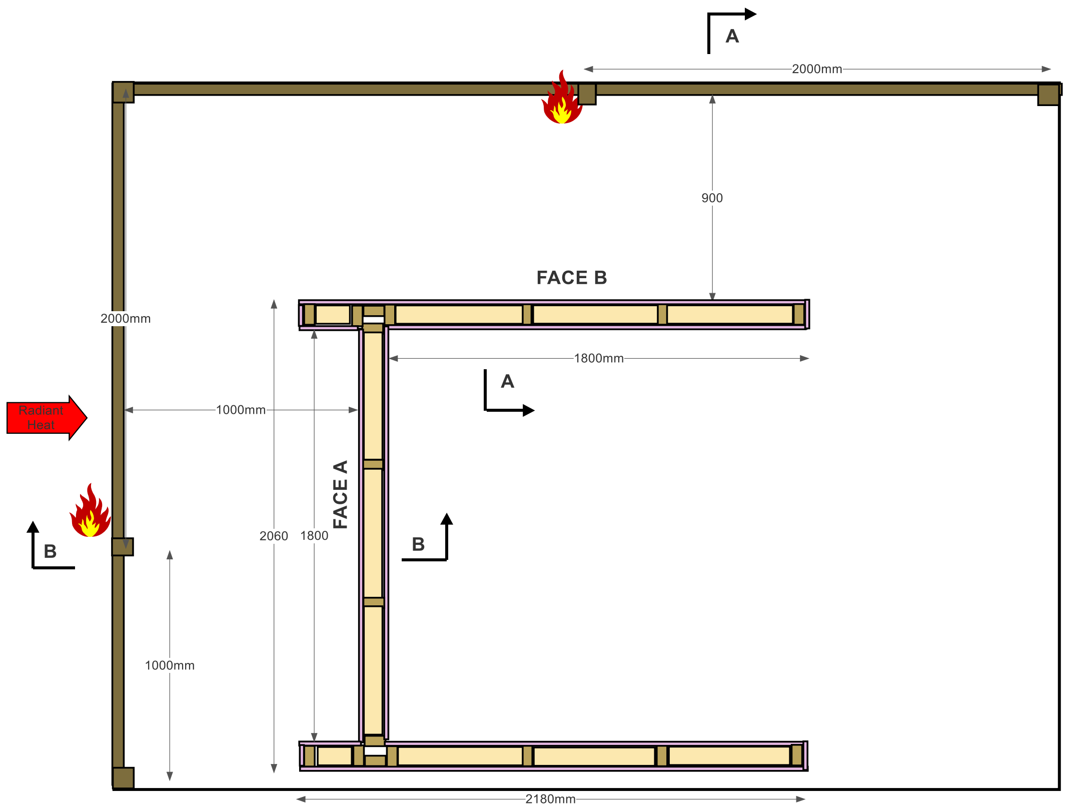


Figure 17 Fence facing bushfire hazard 1m from face of reference building with return running perpendicular to bushfire hazard 900mm from the building

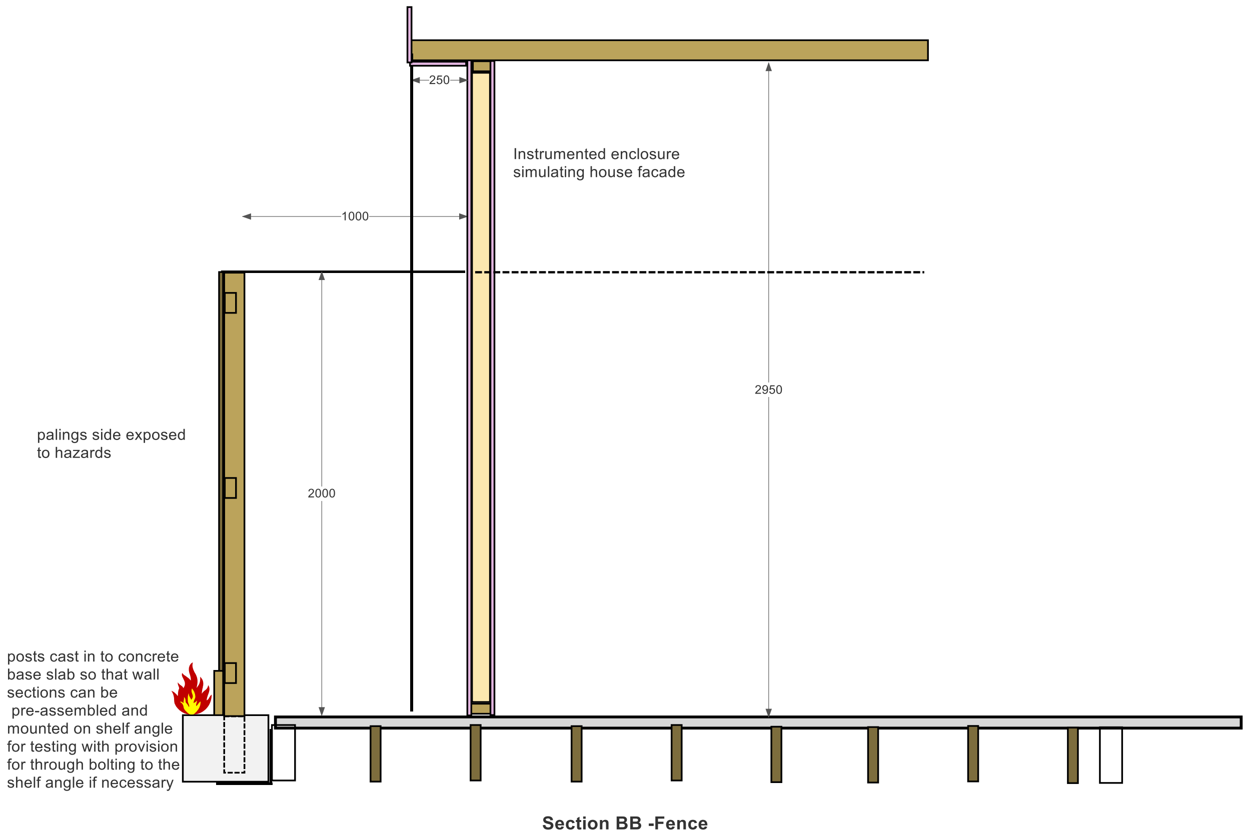


Figure 18 Longitudinal section B-B through fencing and reference building

Test configurations for Garden Sleeper Walls

Two configurations were evaluated. One with a wall supporting a pathway around a house and the other with a wall directly facing the reference building simulating a garden wall supporting a garden bed.

The configuration supporting the pathway includes a sleeper wall located 1m in front of the building, directly facing a simulated bushfire as shown in Figure 19 to Figure 21. In this configuration the exposed face will be ignited and the heat flux on the front of the building from the flames and simulated bushfire front will need to be evaluated.

Figure 19 General view of test configuration for sleepers supporting a pathway around a house

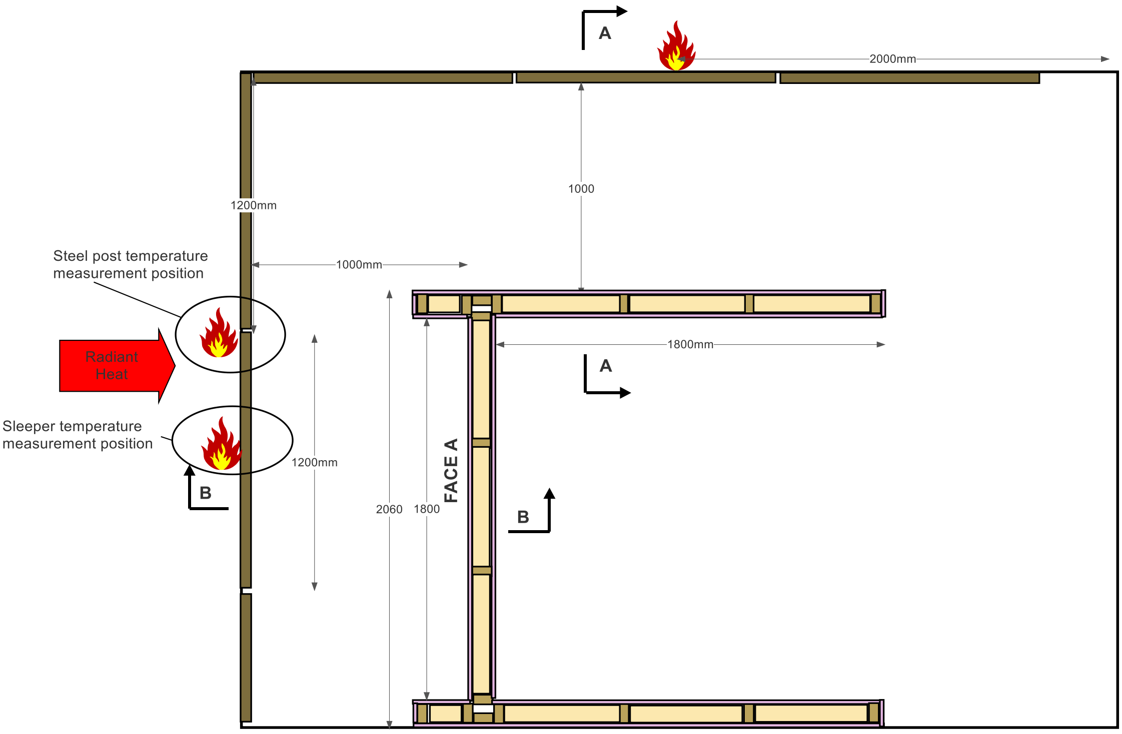


Figure 20 Sleeper wall below house level and 1 m in front of the house façade facing bushfire front.

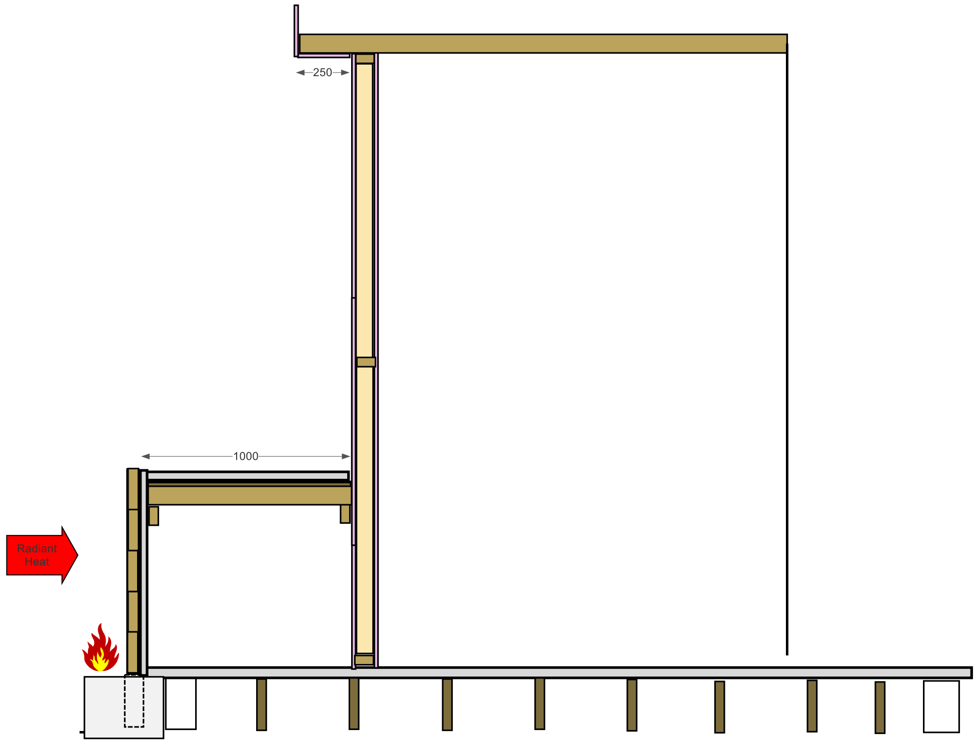


Figure 21 Section BB Retaining wall below house level 1 m in front of façade facing bushfire

The second configuration applies to cases where a garden bed is retained above a pathway providing access to the house with the sleeper wall directly facing the house facade. In this application radiant heat is applied perpendicular to face of the sleeper wall and side of the simulated house as shown in Figure 23 and Figure 24.

	
Test configuration viewed from west (simulated bushfire attack face)	Test configuration viewed from north. Face of sleeper wall covered simulating backfilling of wall to form garden bed

Figure 22 Garden bed configuration with sleepers facing the reference building

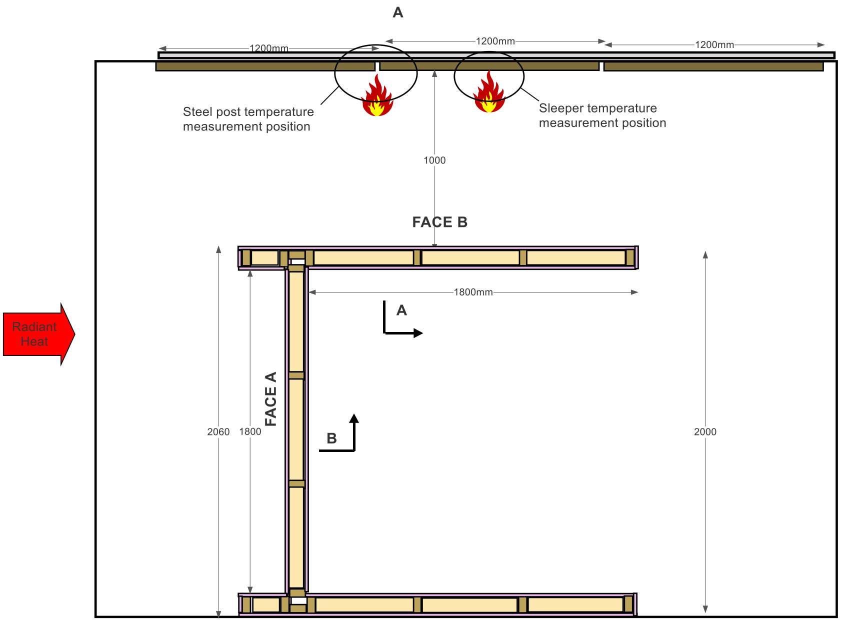


Figure 23 Garden bed retained above path with wall facing reference building - radiant heat perpendicular to face of sleeper wall,

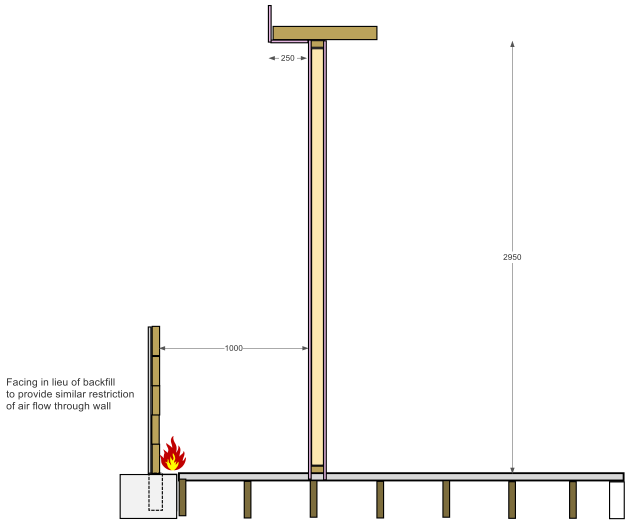


Figure 24 Section AA Garden bed retained above path with wall facing reference building - radiant heat perpendicular to face of the sleeper wall

Instrumentation

Construction and instrumentation of reference building

Generally, the form of construction for the simulated building included a timber-frame with non-combustible insulation, faced with plasterboard with an additional face layer of 6mm thick cement sheet board on the exterior face.

The layouts for the west and north faces are shown in Figure 25 and Figure 27 respectively. Figure 26 shows typical sections of the wall highlighting instrumentation details at typical locations on the west face. The positioning and fitting of instrumentation at other locations on the north and west faces were similar.

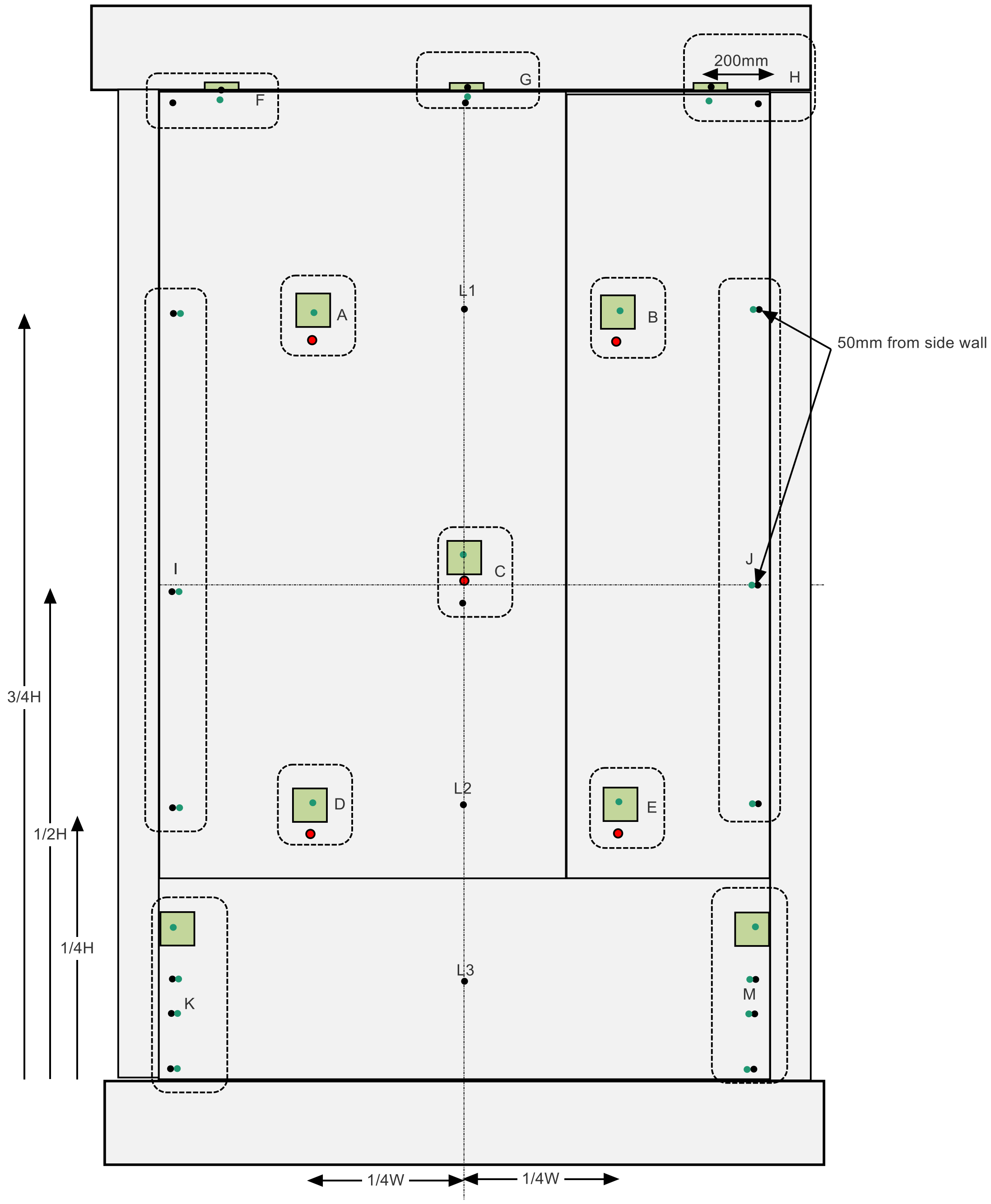


Figure 25 Elevation of west wall of reference building showing instrumentation of building facing the simulated fire source.

The fibre cement sheet was replaced as necessary if damaged either in small areas or an entire face with minimal disruption of the instrumentation.

The west face of the reference building faced the radiant heat source Test specimens were mounted in front of the west and/or north faces of the simulated buildings and both these faces were instrumented extensively with heat flux meters, plate thermometers, sheathed thermocouples and interface thermocouples which were designed to be re-used throughout the test program.

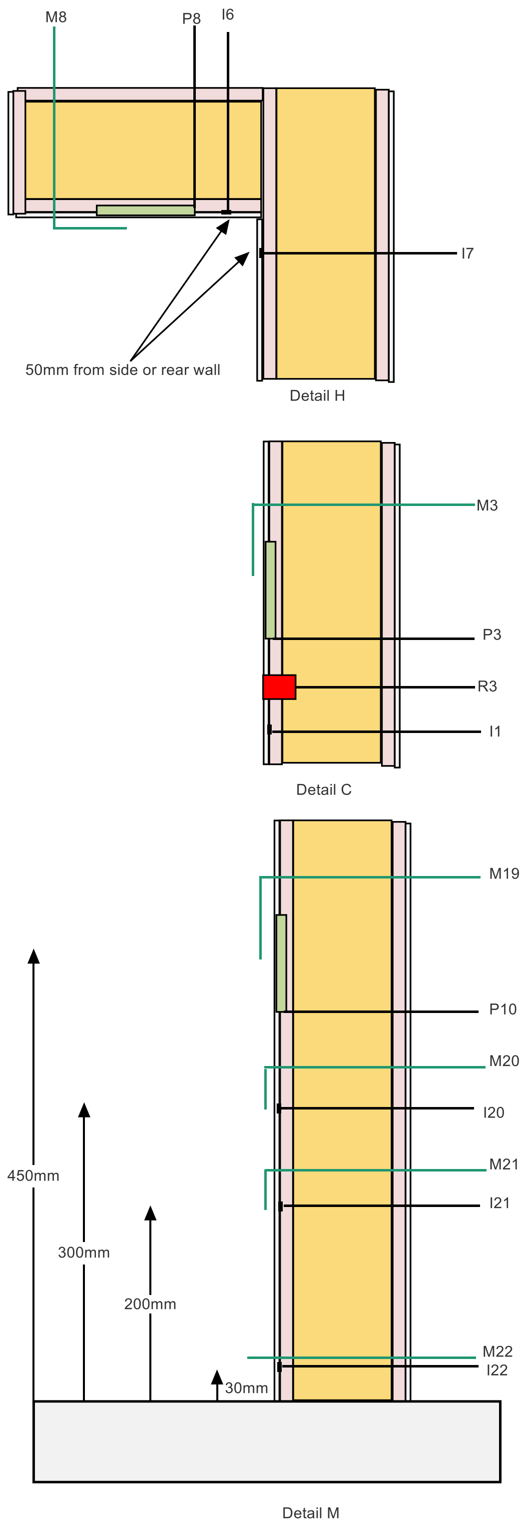


Figure 26 Section showing typical instrumentation details for the west face

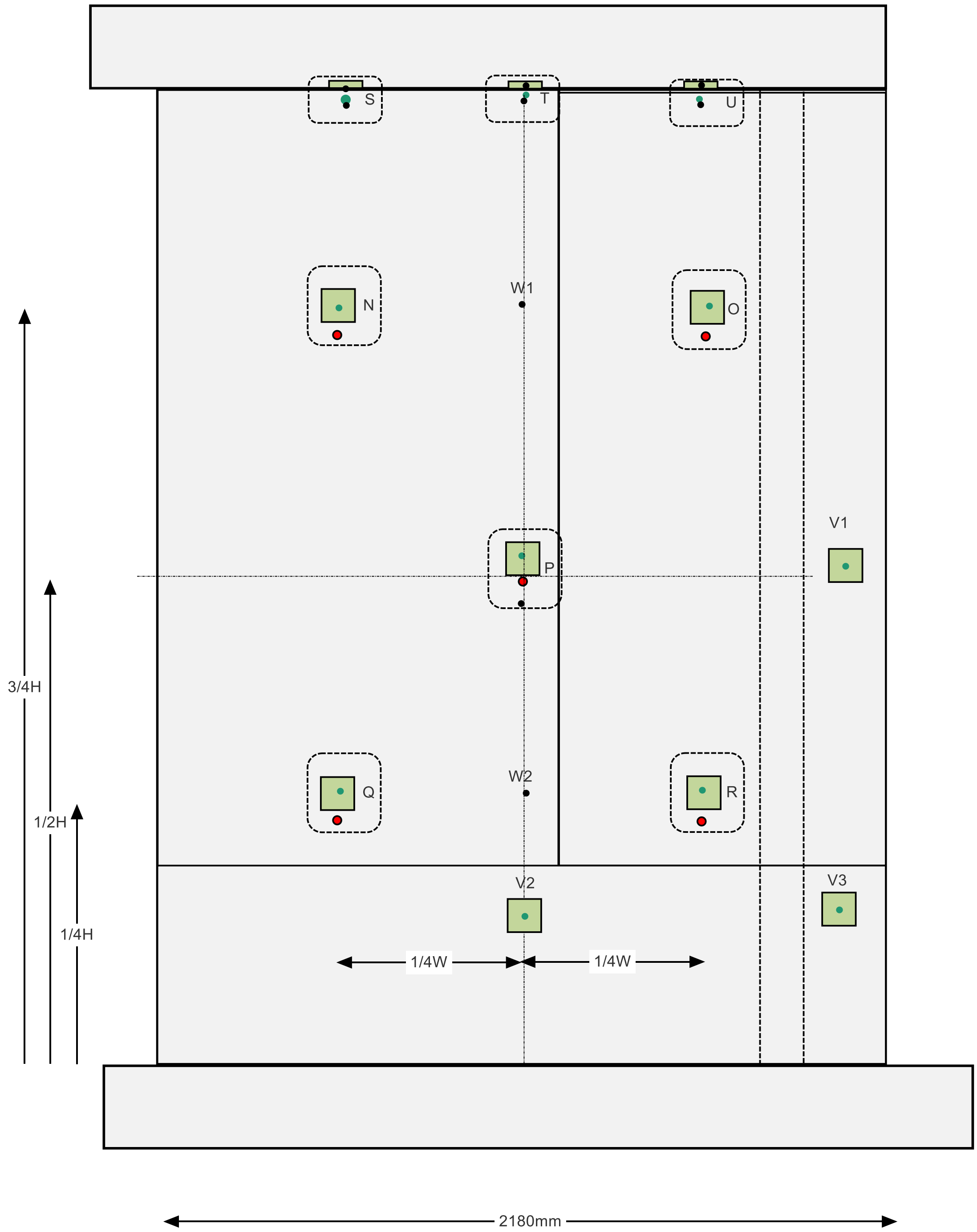


Figure 27 Elevation of north wall showing instrumentation of building perpendicular to the simulated fire source

Supplementary Instrumentation

Additional measurements were taken to supplement the data from the reference building to provide information of the behaviour of the fences and walls under test and also facilitate the extension of the results.

The additional instrumentation included:

- heat flux meters and plate thermometers fitted to stands to take measurements at intermediate locations between the heat source and fence / wall or between the fence / wall and reference building
- specimen thermocouples to measure internal and surface specimen temperatures of selected elements.

Test Procedures

Calibrations

AS 1530.8.1 describes how the following exposure conditions are addressed to evaluate the performance of specimens that may be used in Bushfire Prone Areas. The explanation is summarised in the following dot points.

- Exposure to individual burning embers impinging on vertical surfaces and the underside of exposed horizontal surfaces is simulated by application of a small gas flame to volatiles released from combustible materials.
- Exposure to burning debris and the collection of burning embers on the upper surface of horizontal and near-horizontal surfaces is simulated by pre-ignited timber cribs. AS 3959:2018 introduced the use of a Class AA crib for evaluation of elements such as walls which was adopted for this program. The class AA crib uses 9mm x 9mm x 100mm sticks arranged in 6 rows each with 5 sticks of Tasmanian oak having a total mass of 0.152±0.03kg. This crib was adopted for this test series and the calibrations of the reference building since, in conjunction with the imposed radiant heat profile, it defines the current expectations of the resistance of buildings designed to AS 3959 requirements.
- Exposure to a radiant heat profile under controlled conditions simulating the passage of the fire front adjacent to the structure.

AS 1530.8.1 includes the following note:

> *"It is recognised that the radiant heat profiles will vary from one bushfire to the next as will the extent and nature of attack from burning embers and debris. The radiant heat exposure conditions specified in this Standard have been selected to represent a rapidly approaching bushfire to maximise the potential for thermal shock, a constant peak radiant heat flux maintained for a period of 2 min and a slow reduction in radiant heat to maximize the total applied heat load. The specified profiles are expected to be conservative for most bushfire exposures except some glazed elements, which may be susceptible to thermal shock during the cooling phase."*

The AS 1530.8.1 radiant heat profiles are summarised in Table 24

Table 24 AS 1530.8.1 Heat flux exposure conditions

BAL	Specified Peak HF - kW/m^2	Time from start of test -s									
		0-20	20-140	140-180	180-240	240-300	300-360	360-420	420-480	480-540	540-600
		Maximum heat flux at centre of specimen kW/m^2									
BAL−12.5	12.5	6.25	12.5	10	8	6	5	4	3	3	3
BAL 19	19	9.5	19	15	11	8	7	5	4	3	3
BAL 29	29	14.5	29	21	14	11	8	6.5	5	3.5	3
BAL 40	40	20	40	24	16	12	8.5	7	5	4	3

AS 1530.8.1 requires the average heat flux for each nominated duration shall be not less than the specified value in Table 24 and not exceed the specified value by 20%. During the calibration runs, the heat fluxes at the centre of the simulated building were generally within the nominated values but other areas of the exposed wall were subjected to significantly higher heat fluxes. It was therefore necessary to use the measured maximum heat fluxes from the calibration runs rather than the specified values in the standard to define the maximum values for the performance criteria. A consequence of this is that the calibration runs will only apply to the specific furnace / heat source and simulated building configuration and any changes may necessitate additional calibrations.

The basic procedures for calibration of the reference building are summarised below.

- the mobile flat-bed assembly supporting the simulated (reference) building was positioned on tracks so that the short edge is parallel to the radiant heat source and that the alignment of the reference building and platform will be similar for all calibrations and test runs.
- a heat flux gauge was positioned at the fence location for the calibration run to record the heat flux at the fence line.
- Timber cribs were lit in accordance with the procedure outlined in AS 1530.8.1:2018.
- The following three calibrations will be performed.
  − BAL−12.5 using a class AA crib
  − BAL−19 using a class AA and a class A crib located at each internal corner on the west face of the reference building
  − BAL−29 using a class AA crib
- Calibrations runs were conducted over the 10-minute exposure period prescribed by AS 1530.8.1:2018 and data acquisition was undertaken for a further 50 minutes (total duration 60 minutes).

Performance Criteria

To provide a robust assessment, the performance criteria were based on measurements of heat flux, plate thermometers and embedded thermocouples as detailed below:

The maximum heat flux floating average over a 2-minute period calculated from 1 minute before to one-minute after the selected time must not exceed the maximum heat flux determined in the calibration test plus 20%.

The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 on a heat flux v time plot from a garden sleeper wall or fence test shall not exceed the area between the measured heat flux and the critical threshold of 9.6 kW/m^2 determined in the calibration run plus 20 %

The 9.6 kW/m^2 threshold was selected since it provides an approximate value at which plate glass would be likely to have cracked but be unlikely to become dislodged and is also less than the critical heat flux for ignition of commonly used combustible materials such as radiata pine. (i.e. ignition is unlikely after a long time).

The limiting plate thermometer temperature performance criteria was derived from measurements taken on the west face of the simulated building during calibration runs with no intervening fences or sleeper walls.

The mean plate thermometer temperature performance criterion was determined as the average of measurements taken at approximately the centre and centre of each quarter section during the calibration run plus a margin to allow for typical variations between fire tests.

The maximum plate thermometer temperature performance criterion was determined as the maximum plate thermometer temperatures measured on the west face from plate thermometers plus a margin to allow for typical variations between fire tests.

The maximum embedded thermocouple temperature performance criteria was based on the maximum measurements recorded by the embedded thermocouple temperatures measured on the west face plus a margin to allow for typical variations between fire tests.

Table 25 summarises the performance criteria derived from the calibration runs which were applied to determine the potential impact of fences and garden walls on a building:

Table 25 Performance Criteria Derived from Calibration runs at 12.5, 19 and 29 kW/m²

Performance criteria	**Description**	**Determined threshold values for ref building BAL−12.5**	**Determined threshold values for ref building BAL−19**	**Determined threshold values for ref building BAL−29**
Heat flux	The maximum heat flux floating average over a two-minute period calculated from one minute before to one minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m2	≤ 26.0 kW/m2	≤ 38.6 kW/m2
	The area between the measured heat flux and a critical threshold of 9.6 kW/m2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m2.	≤ 26.8 kW/m2.min	≤ 54.2 kW/m2.min	≤ 105.1 kW/m2.min
Plate thermometer absolute temperature	Average absolute temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C
	Maximum absolute temperature during the entire test period.	≤ 350 °C	≤ 400 °C	≤ 500°C
Embedded thermocouple temperature	Maximum absolute temperature after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C
Crib class	Class AA			

During the calibrations, the heat flux distributions over the west face of the reference building were recorded and the radiant heat flux at a height of 1.5m in the plane of the fence or wall that will be subsequently tested was also recorded. The results are shown in Figure 28 and indicate that whilst compliance with the AS 1530.8.1 heating profile was achieved there was a significant variation over the west face of the reference building and the heat fluxes that the fences and walls in a plane 1m in front of the reference building would be exposed to would be significantly higher.

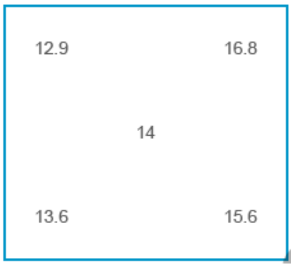
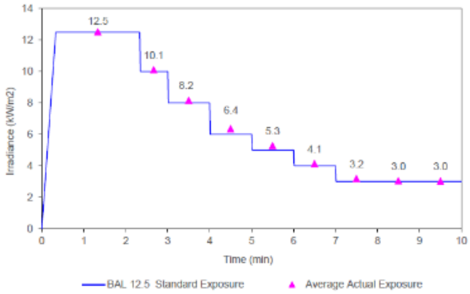
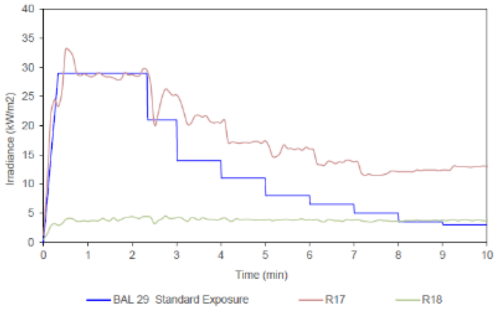
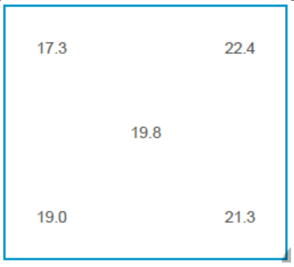
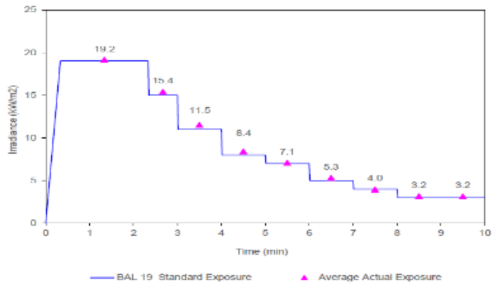
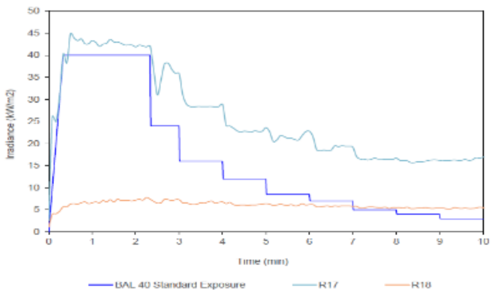
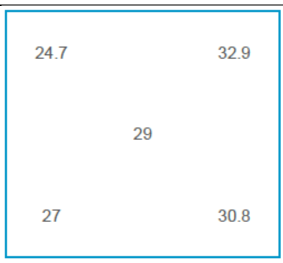
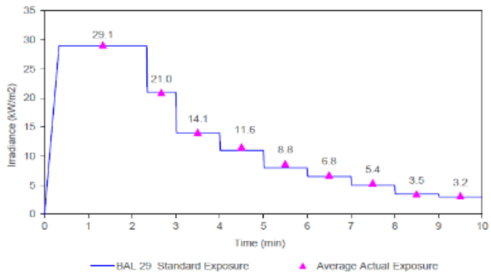
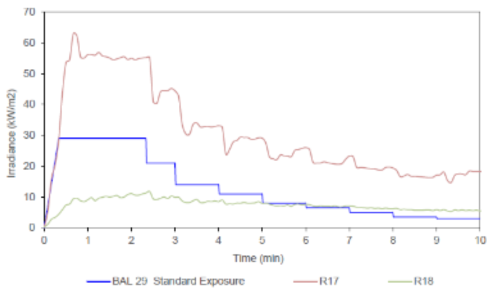
CAL 1 BAL–12.5 calibration		Right, BAL–12.5 calibration averaged irradiance levels - centre west face of reference building	
	Above, Variation of radiance heat flux at reference building centre and centre of each quarter section BAL–12.5	Right, Irradiance 1.5m high in plane of fence/sleeper compared to the BAL–29 exposure profile Note: R17 facing heat source	
CAL 2 BAL–19 calibration		Right, BAL–19 calibration averaged irradiance levels - centre west face of reference building	
	Above, variation of radiance heat flux at reference building centre and centre of each quarter section BAL–19	Right, Irradiance 1.5m high in plane of fence/sleeper compared to the BAL–40 exposure profile Note: R17 facing heat source	
CAL3 BAL– 29 calibration		Right, BAL–29 calibration averaged irradiance levels - centre west face of reference building	
	Above, variation of radiance heat flux at reference building centre and centre of each quarter section BAL–29	Right, Irradiance 1.5m high in plane of fence/sleeper compared to the BAL–29 exposure profile Note: R17 facing heat source	

Figure 28 Radiant heat flux at reference building and plane of fence or wall 1m in front of reference building during calibrations (graphs adapted from Warringtonfire test reports)

Fence test procedures (Tests 1 and 2)

The procedures for testing fences are summarised below:

- The mobile flat-bed assembly supporting the simulated (reference) building was positioned on tracks so that the short edge is parallel to the radiant heat source and that the alignment of the reference building and platform will be similar to the previous calibration runs.
- The pre-constructed fence / footing assembly was moved into position in front of the mobile flat-bed assembly and bolted to the front of it with the return fence line running along the north side.
- A mobile heat flux gauge was positioned mid-way between the fence assembly (specimen) and the reference building (west side).
- A mobile heat flux gauge was placed midway between the north fence and the reference building.
- Class AA timber cribs were lit at the appropriate time in accordance with the procedures of AS 1530.8.1:2018 and placed against the fence specimens. One was located on the exposed/fire side of the west fence and the other was located on the unexposed side of the north fence after 70 minutes if there is no flame spread of the fence observed.
- The specimen was exposed to radiant heat as per the exposure profile defined in AS 1530.8.1:2018 for the respective BAL being evaluated over a 10-minute period.
- A pilot ignition source as defined in AS 1530.8.1:2018 was applied to volatiles released during the test period.
- The mobile heat flux gauge between the north fence and reference building could be relocated along the north fence where the most severe specimen behaviour (maximum flaming/combustion) is observed, if safe to do so.
- After completion of the exposure period, all the instrumentation remained connected and data acquisition continued for a further 3 hours (180 minutes). The specimen was not extinguished or moved during this time.
- After completion of the post exposure monitoring with data acquisition (180 minutes), the fence specimen assembly may be detached from the mobile flat-bed assembly and set aside to continue to char and combust without intervention or left in place.
- The specimen was allowed to continue to combust or self-extinguish overnight for a min. period of 12 hours and then extinguished at 9am the following morning (if a min of 12 hours has elapsed). Otherwise, the specimen would be extinguished at exactly 12 hours (15 hours and 10 minutes from the commencement of the test). A video camera was positioned to record the specimen's behaviour during this time.
- During this period, no extinguishing material was applied to the specimen and only visual observations made with a camera positioned in front to capture the specimen behaviour.
- At the completion of the entire monitoring period, any residual combustion was extinguished, and the specimen allowed to cool.
- The simulated building was then inspected for any damage, and any areas damaged or impacted by heat will be replaced prior to the commencement of the next test.

Procedures for sleeper walls – wall supporting garden bed with exposed face facing the building (Test 3 wall above ground level).

- The constructed sleeper wall assembly will be moved into position along the north side of the mobile flat-bed assembly and bolted to the north side.
- A mobile heat flux gauge will be positioned on the north side of the sleeper wall at the mid length of the sleeper wall, facing the radiant heat source to provide an indication of the incident heat flux.
- Two class AA cribs will be lit in accordance with the procedure outlined in AS 1530.8.1:2018 and placed against the sleeper wall at the following locations:
  - On the side of the sleeper wall facing the north side of the instrumented building, mid-width of the most central sleeper.
  - On the side of the sleeper wall facing the north side of the instrumented building, at the base of the most central post.
- The specimens were then exposed to radiant heat as per the exposure profile defined in AS 1530.8.1:2018 for the respective BAL being evaluated over a 10-minute period.
- A pilot ignition source as defined in AS 1530.8.1:2018 was applied to volatiles evolved during the test period.
- A mobile heat flux gauge was available to be placed midway between the sleeper wall and the simulated building where the most severe specimen behaviour is observed. (maximum flaming / combustion).
- After completion of the exposure period, data acquisition continued for a further 3 hours (180 minutes). The specimen was not to be extinguished or moved during this time.
- After completion of the post exposure monitoring with data acquisition (180 minutes), the sleeper wall specimen assembly may be detached from the mobile flat bed assembly and set aside to continue to char and combust at its own pace or left in position.
- The specimen was allowed to stand overnight for a min. period of 12 hours without intervention and then extinguished (if a min of 12 hours has elapsed). A video camera was positioned to record the specimen behaviour during this time.
- At the completion of the entire monitoring period, any residual combustion was extinguished, and the specimen allowed to cool.
- The simulated building will then be inspected for any damage, and any areas damaged or impacted by heat will be replaced prior to the commencement of the next test.

Procedures for sleeper walls – wall supporting path around a building (Test 4 wall below ground level).

- The constructed sleeper wall assembly was moved into position in front of the mobile flat-bed assembly and bolted to the front of it with the return sleeper wall running along the north side only.
- A mobile heat flux gauge was positioned mid-way between the sleeper wall assembly and the simulated building (west side).
- A mobile heat flux gauge stand was placed midway between the north sleeper wall and the simulated building.
- Three class AA cribs will be applied after being ignited in accordance with the procedure outlined in AS 1530.8.1:2018 and placed against the sleeper wall at the following locations:
  - On the fire exposed side of the west sleeper wall, mid-width of the most central sleeper at the start of the test.

    - On the fire exposed side of the west sleeper wall, at the base of the most central post at the start of the test.
    - On the side facing the instrumented building along the north sleeper wall, mid-width of the central most sleeper if there is no flame spread of the specimen after 70 minutes of test.
- The specimen was exposed to radiant heat as per the exposure profile defined in AS 1530.8.1:2018 for the respective BAL being evaluated over a 10-minute period.
- A pilot ignition source as defined in AS 1530.8.1:2018 will be applied to volatiles evolved during the test period.
- The mobile heat flux gauge along the north fence may be relocated to where the most sever specimen behaviour is observed if safe to do so. (maximum flaming / combustion).
- After completion of the exposure period, data acquisition continued for a further 3 hours (180 minutes). The specimen was not to be extinguished or moved during this time.
- After completion of the post exposure monitoring with data acquisition (180 minutes), the sleeper wall specimen assembly may be detached from the mobile flatbed assembly and set aside to continue to char and combust at its own pace or left in position.
- The specimen was allowed to stand overnight for a min. period of 12 hours without intervention and then extinguished (if a min of 12 hours has elapsed). A video camera will be positioned to record the specimen behaviour during this time.
- At the completion of the entire monitoring period, any residual combustion was extinguished, and the specimen allowed to cool.
- The simulated building will then be inspected for any damage, and any areas damaged or impacted by heat will be replaced prior to the commencement of the next test.

Large-scale test materials

The density, moisture content and preservative retention ratios of samples of the treated radiata pine members used to prepare the specimens for the large-scale fire tests are summarised in Table 26. All the treated pine members were treated with a waterborne copper-based preservative treatment identified as Treatment C. A hazard class as defined in AS 1604.1 (Standards_Australia 2021) was specified for the treatment (either H3 and H4). Samples were tested at an accredited test laboratory (ATL) to compare the actual concentration and the required concentration for specified hazard class. The retention ratio is the ratio of the actual preservative concentration to the concentration of preservative required by AS 1604.1.

Details of other materials and products used to construct the test specimens and reference buildings are included in the formal test reports.

ATL report reference 20231201-FRT230047 R2.0 BAL exposure 29kW/m^2 at fence
ATL report reference 20231201-FRT230048 R2.0 BAL exposure 29kW/m^2 at fence
ATL report reference 20231201-FRT230050 R1.0 Sleeper wall below ground level
ATL report reference 20231201-FRT230051 R1.0 Sleeper wall above ground level

Table 26 Summary of radiata pine test sample properties

Test no	Component	Dimensions	Treatment		Density kg/m³	Moisture Content %
			Specified Hazard Class	Retention Ratio (mean)		
1	Corner Post	90mm x90mm	H4	0.89	474	9.2
	Intermediate Post	90mm x 70mm	H4	1.13	493	9.2
	Rails	75mm x 50mm	H3	0.33	407	9.2
	Paling	100x12mm	H3	1.11	487	9.7
	Paling	150mm x 12mm	H3	0.47	410	9.7
	Plinth Board	150mm x 25mm	H4	0.57	455	8.9
2	Corner Post	90mm x90mm	H4	0.89	474	9.2
	Intermediate Post	90mm x 70mm	H4	1.13	493	9.2
	Rails	75mm x 50mm	H3	0.33	407	9.1
	Paling	100x12mm	H3	1.11	487	9.7
	Paling	150mm x 12mm	H3	0.47	410	9.7
	Plinth Board	150mm x 25mm	H4	0.57	455	8.9
3	Sleeper	200mm x 50mm	H4	0.52	426	9.9
4	Sleeper	200mm x 50mm	H4	0.52	426	9.9

Results and Discussion

Radiant heat source sizes effect on radiant heat contours

The test configuration comprised a 3m x 3m heated steel panel located approximately 3m from the west face of the reference building. With this configuration a fence or wall 1m in front of the west face of the building could be subjected to over twice the heat flux at the building based on the changes to the configuration factor. This was observed during the calibration runs where a supplementary radiant heat flux measurement was taken at the proposed fence location indicating that with a radiant heat flux of 12.5kW/m² at the building, the heat flux at the proposed fence line could be over 29kW/m². Similar proportionate increases were obtained in the other calibrations - refer Figure 28 for comparative data.

AS 3959 assumes a 100m fire front with an average effective temperature of 1090K over the entire fire front maintained for two minutes to cover a large range of potential fire scenarios. With fire sources larger than the test source (3m x 3m) the reduction of heat flux with distance will tend to be less and this is reflected in the calculated separation distances in the Tables provided in AS 3959:2018 as shown in the extracted values presented in Table 27.

Table 27 Typical separation distances from AS 3959:2018

Veg Class	FDI	Slope	BAL–29	BAL–19	BAL–12.5
Grassland	40	0°	5 to <8	8 to <12	12 to < 50
Grassland	40	15-20°	9 to <15	15 to <22	22 to < 50
Grassland	100	0°	9 to <13	13 to <19	19 to < 50
Grassland	100	15-20°	15 to <23	23 to <32	32 to < 50
Forest	100	0°	25 to <35	35 to <48	48 to < 100
Forest	100	15-20°	61 to <78	78 to <98	98 to < 100

Based on the AS 3959 separation distances in Table 27 for the incident radiant heat flux to drop from 29 to 12.5kW/m² separation distances would need to be increased by between 7m (grassland, no slope FDI 40) and 37m (forest 15-20° slope FDI 100) whereas this reduction occurs within 1m when performing tests to AS1530.8.1. The impact of the heat flux gradient will be considered in the following discussion.

Tests 1 and 2 Lapped timber fences

Tests 1 and 2 were based on the same lapped timber fence design but in test 1 the west section of the fence was exposed to the AS 1530.8.1 BAL−29 heating profile which corresponds to the BAL−12.5 heating profile at the west face of the reference building if no fence had been present. The fence in test 2 was exposed to a BAL−12.5 heating profile.

Test 1 Lapped paling fence exposed to a heating profile based on AS 1530.8.1 BAL-29 profile.

Observations from test 1 are provided in Figure 29 through Figure 36.

		
View of northwest corner of fence in front of reference building	West face of reference building and fence	North face of reference building and fence

Figure 29 Test 1 Fence and reference building before test

				
t=10sTest started crib applied and volatiles released as exposed to radiant heat source	t=25s flames at top of wall flaming area width approx. 300mm	t=100s flame spread over most of west face	t=150s flame intensity on west side reducing	t=5mins flame intensity reducing

Figure 30 Test observations from first 5 minutes of test 1

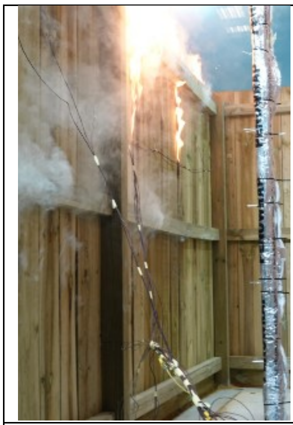
<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>t=5min 30s flames penetrating west fence</td><td>t= 6min Internal surface of southwest corner of fence</td><td>t=6min 5s flaming substantially reduced on west fence external surface</td><td>t=10mins flaming on inner face of west fence</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td>t=10mins flaming on inner face of west fence viewed from southwest corner</td><td>t=11min 40s external face of west fence</td><td colspan="2">t=13min 05s external face of fence showing little damage to north section but palings on west section mostly consumed</td></tr>
<tr><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="2">t=22min 22s showing most continuing glowing combustion of upper parts of framing and flaming from base of fence</td><td>t=22 min collection of burning debris at base of timber fence</td><td>t=30 min rails and posts still in place on western side, flaming embers at base substantially reduced</td></tr>
</table>

Figure 31 Test observations from 5-30 minutes from test 1

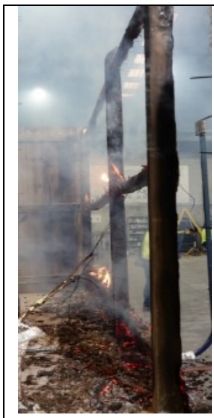
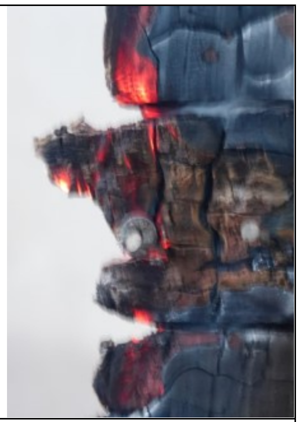
		
t=30 view heavily charred and smouldering west frame. Discolouration of north wall at corner post	t=31min 52s mid rail falls away from main section of west wall – no damage to reference building or north fence other than associated with NW corner post	t=33min 30s Smouldering combustion of NW corner post showing minor spread to palings
		
t=37min top rail falling away from northwest post	t=41 min frame members fell away no damage to west face of reference building. NW corner post in place but smouldering. No significant spread to north fence	t=41 min frame members SW corner
	t=85 min Right transition to flaming combustion at base of NW post. Left Flaming combustion from post spreading to palings	

Figure 32 Test observations from 30-85 minutes from test 1

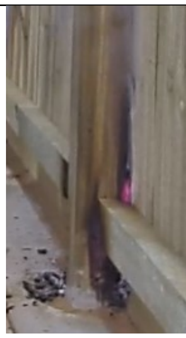
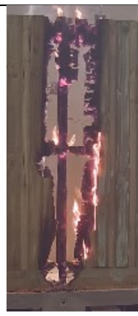
<table>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>t=93min timber crib applied to central post of north fence, igniting post and lower rail</td><td colspan="2">t=97min flaming reduced to lower rail and embers from crib</td><td>t=102min flaming of bottom rail stopped. Glowing embers from crib still visible</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>t=122 mins glowing combustion at interface between post and plinth</td><td>t=268mins traces of smouldering combustion around centre post</td><td>glowing at interface between post rail and palings</td><td>transition to flaming combustion on inner face of fence</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>t=290mins burn through and flaming combustion on external surface of fence</td><td colspan="2">t=313 mins palings consumed and / or fallen way around centre post 313</td><td>t=331 mins central post north wall</td></tr>
</table>

Figure 33 Timber crib test applied to central stud of north wall after approximately 90 minutes of test

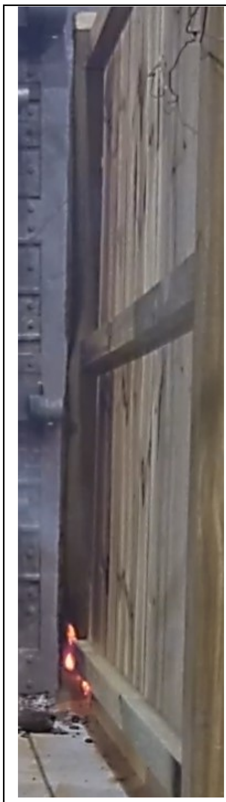
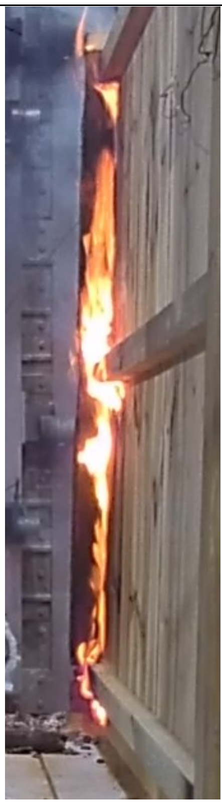
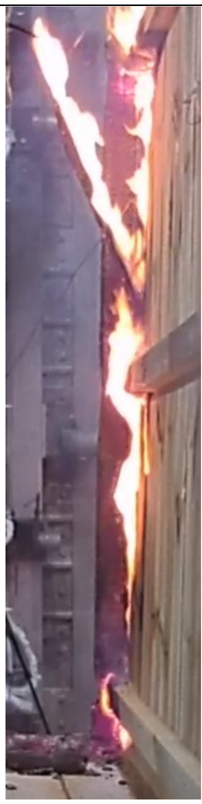
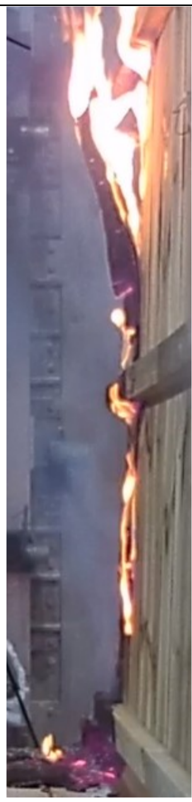
				
t=142 mins flaming ignition of NW post on internal face of north fence	t=148mins flame spread to palings around NW post	t=158 mins paling falling away adjacent to NW post	t=171 mins NW post falling	t=190 mins flaming combustion stopped at NW corner

Figure 34 Collapse of NW post and localised flaming combustion from 142 minutes to 190 minutes

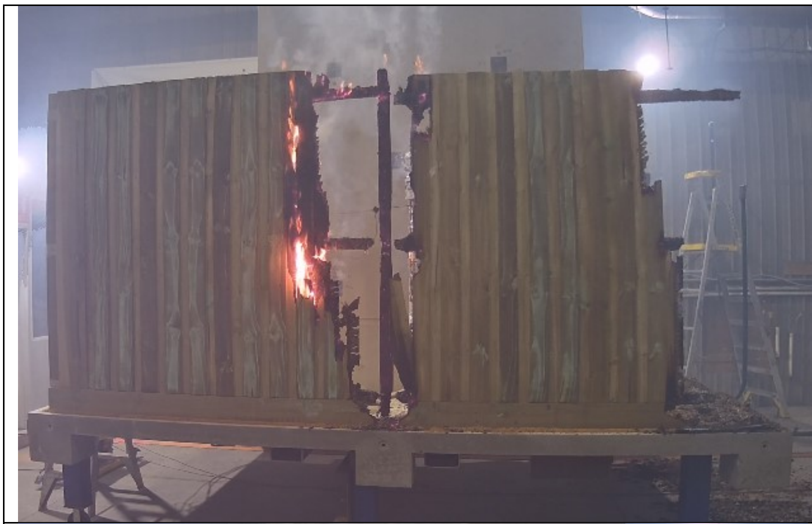
	
	t=361 mins west end of north wall falls towards the reference building
	
	t=390 mins flaming combustion stopped without manual intervention

Figure 35 Section of North wall falling towards building after 361 minutes

Figure 36 North wall 15.5 hours after commencement with no evidence of ongoing combustion

The west fence was substantially consumed, a section of the north fence adjacent to the west fence was consumed and another section of the north fence was consumed by the central post where a crib was applied 90 minutes after the start of the test.

Despite these areas of fencing being consumed the performance criteria for BAL 19 and BAL 29 buildings were not exceeded and the performance criteria for a BAL 12.5 building were also not exceeded except the area limit above the 9.6 kW/m^2 threshold of the heat flux v time graph recorded by heat flux gauge R5 located at the lower south quarter point on the west face of the reference building was exceeded after 15 minutes 30 seconds.

The results are summarised in Table 28.

In most applications if a fence is constructed within 1m of a AS 3959 compliant building and the fence is in an area classified as BAL 29 the building would be likely to have been required to have complied with the BAL 29 construction requirements of AS 3959. In an extreme case where the fence is at the interface with a BAL 19 classification, an adjacent building could be required to be constructed to BAL 19. Since the performance criteria were satisfied for both BAL 19 and BAL 29 it is reasonable to expect that the fire load imposed by radiata pine fences, similar to those subjected to test treated with waterborne copper-based preservatives, would be unlikely to exceed that design capacity for a BAL−19 or BAL−29 building.

During the test fire spread along the fencing was shown to be limited if there is no external fire exposure other than from the burning fence.

The failure of the supporting posts did occur, some 4.5 hours following placement of the timber crib adjacent to the central posts of the north face, and a section of fence fell onto the reference building but did not cause significant damage.

If buildings adjacent to fences are vulnerable to minor impacts consideration could be given to increasing the distance between the fence and the building so that it is equal or greater than the height of the fence

Table 28 Results summary for test 1 Lapped paling fence Bushfire attack level (BAL) exposure: 12.5 kW/m2 at the reference building and approx. 29 kW/m² at the fence

Performance criteria	Description	Determined threshold values for BAL-12.5	Determined threshold values for BAL-19	Determined threshold values for BAL-29	Result BAL-12.5 @ building BAL 29 @ fence
Heat flux	The maximum heat flux floating average over a two minute period calculated from one minute before to one- minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m²	≤ 26.0 kW/m²	≤ 38.6 kW/m²	16.0 kW/m²
	The area between the measured heat flux and a critical threshold of 9.6 kW/m² shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m².	≤ 26.8 kW/m². min	≤ 54.2 kW/m². min	≤ 105.1 kW/m². min	34.1 kW/m². min
Plate thermometer absolute temperature	Average absolute temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	228 °C
	Maximum absolute temp during the entire test period.	≤ 350 °C	≤ 400 °C	≤ 500°C	274 °C
Internal thermocouple absolute temperature	Maximum absolute temp after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	165 °C

Test 2 Lapped paling fence exposed to a heating profile based on AS 1530.8.1 BAL-12.5 profile.

As noted above a second test was undertaken with the fence exposed to a peak irradiance of 12.5kW/m² following the AS 1530.8.1 profile. At the end of the test the north side fence assembly was intact, with no signs of char nor flame spread except minor surface damage at the location of crib application.

The west side fence assembly charred, and an opening formed in the centre area. Some palings were heavily burnt but the plinth, centre post and rails were only charred, and still standing in their original position. Smouldering combustion continued until the remaining smouldering area at the southwest edge was extinguished by a test operator after 18 hours without intervention.

Observations from test 2 are provided in Figure 37 through Figure 43.

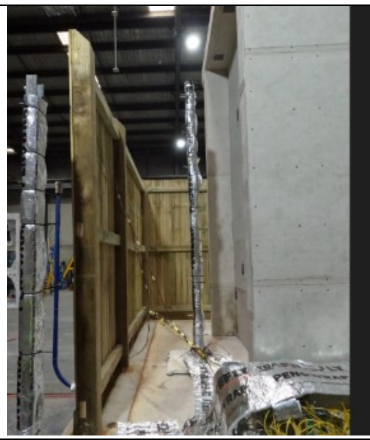
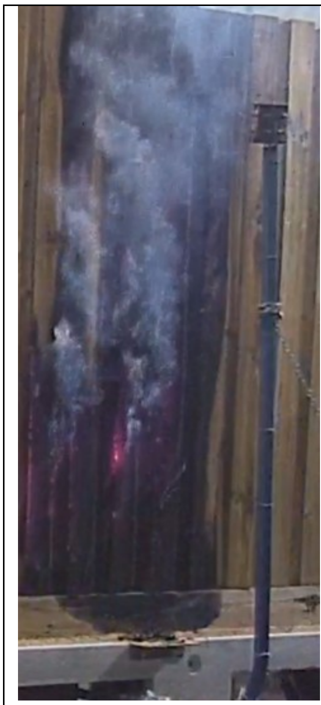
		
View of northwest corner of fence in front of reference building	North face of reference building and fence	West face of reference building and fence

Figure 37 Fence and Reference building before test

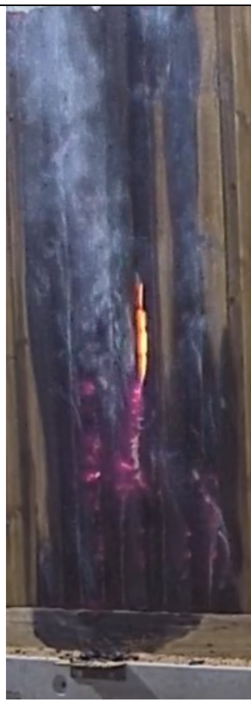
		
t=60s specimen exposed to radiant heat and crib	t=90s flames close to top of fence	t=140s flames extending above fence above crib
		
t=6min flaming reducing	t=8min small area of flaming	t=10min increased flaming

Figure 38 Fire initiation and spread under AS 1630.8.1 BAL 12.8.1 heating profile

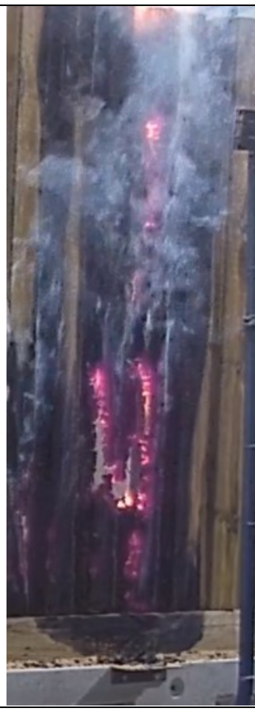


t=12min no flaming

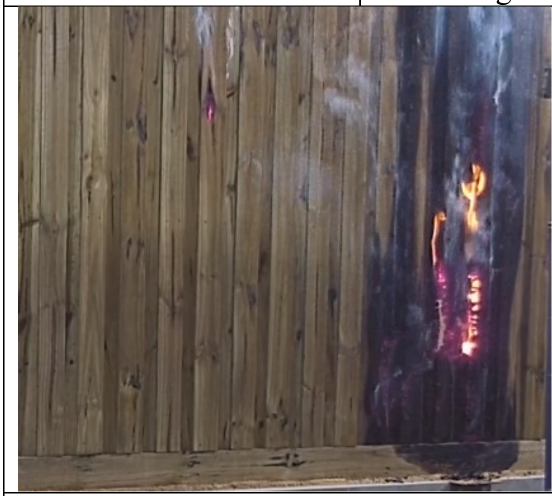
t=18min smouldering continuing



t=25min flaming combustion recommenced



t=30 min areas burning through



t=27min small area to left of main zone glowing and transitioning to intermittent flaming

t=40mins small area and large area continuing to burn with intermittent flaming

t=60min

t=80min

Figure 39 Localised continuing combustion to 80 minutes

	
t=90min	t=120min
	
t=183min upper part of central post falling away	t=600min smouldering continuing at low level in central area

Figure 40 Continuing low level smouldering combustion in central area.

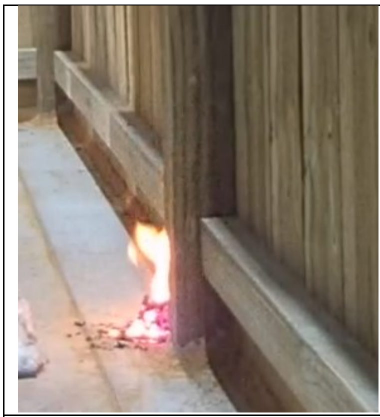
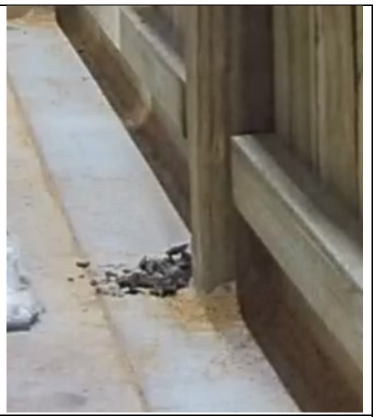
		
t=72min 20s crib applied	t=78 mins flaming stopped glowing embers present	t=84 mins no glowing embers visible

Figure 41Application of crib to northern fence

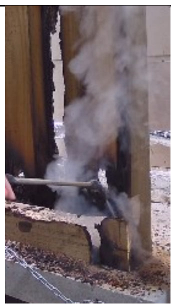
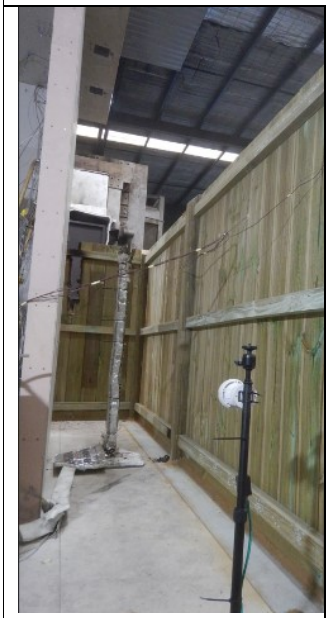
		
t=18 hours (1080mins) test terminated. smouldering at base of the SW post continues	Suppression of remaining combustion	SW post and remaining combustion suppressed

Figure 42 Termination of test 2

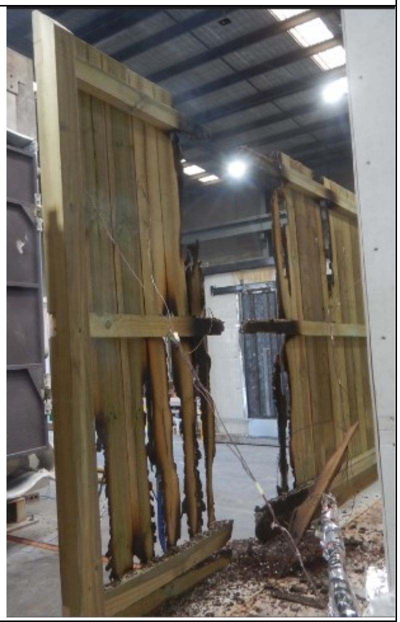
West face of fence after test

North face of fence after test



Inner face of north fence showing no damage

Elevated view from southwest corner showing no visible deterioration of west face



Inner face of north fence showing burn-through at central section

Figure 43 View of specimen after test.

The results are summarised in Table 29. The performance criteria for BAL−12.5 buildings were not exceeded and there was a large margin of safety. Therefore, it is reasonable to expect that the fire load imposed by radiata pine fences similar to those subjected to the test treated with waterborne copper-based preservatives would be unlikely to exceed the design capacity for a BAL−12.5 building if the fence is located within an area classified as BAL−12.5 or less.

The observations highlight the differences between exposure to BAL−12.5 and BAL−29 heating profiles with fire spread being relatively localised and slow for BAL−12.5 exposures and the severity of sustained smouldering combustion appears to be reduced but not necessarily prevented.

Table 29 Results summary for test 2 Lapped paling fence Bushfire attack level (BAL) exposure: 12.5 kW/m2 at the fence

Performance criteria	Description	Determined threshold values for BAL-12.5	Determined threshold values for BAL-19	Determined threshold values for BAL-29	Result BAL-12.5 at the fence
Heat flux	The maximum heat flux floating average over a two minute period calculated from one minute before to one-minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m^2	≤ 26.0 kW/m^2	≤ 38.6 kW/m^2	4.5 kW/m^2
	The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m^2.	≤ 26.8 kW/m^2.min	≤ 54.2 kW/m^2.min	≤ 105.1 kW/m^2.min	0.0 kW/m^2.min (9.6kW/m^2 threshold not exceeded during the test)
Plate thermometer absolute temperature	Average absolute temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	228 °C
	Maximum absolute temperature during the entire test period.	≤ 350 °C	≤ 400 °C	≤ 500°C	274 °C
Internal thermocouple absolute temperature	Maximum absolute temperature after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	165 °C

Tests 3 and 4 Sleeper garden walls with steel supports

Tests 3 and 4 were based on the same sleeper garden wall design comprising sleepers nominally 50mm x 200mm supported within steel channel section posts design.

In test 3 a garden wall detail was tested running perpendicular to the simulated fire front along the north side of the reference building with the west side of the reference building exposed to the BAL 29 heating profile as shown in Figure 22 through Figure 24. In this configuration exposed sleepers were directly facing the reference building simulating a garden wall supporting a garden bed.

In test 4 a configuration was tested simulating a pathway around the house supported by a retaining wall located 1m in front of the building and on the west side directly facing the radiant heat source, as shown in Figure 19 to Figure 21. In this configuration the exposed sleepers will be ignited and the heat flux on the front of the building could potentially be affected.

Test 3 Sleeper wall running perpendicular to the fire source.

The general sleeper wall configuration before test is shown in Figure 44 and Figure 45 and the test configuration during exposure to the radiant heat profile is shown in Figure 45. In this configuration the west face of the subject building was fully exposed to the radiant heat source and the west face would be expected to exceed the performance criteria for BAL−12.5

and BAL−19 buildings but meet the performance criteria for a BAL−29 building. This was confirmed in the data recorded during the test and results summarised in Table 30. The primary objective of this test was to determine the potential for ignition and spread of fire along the sleeper wall or ignition by a small pile of debris and, if ignition occurs, determine the exposure of the north face of the reference building which directly faced the wall.

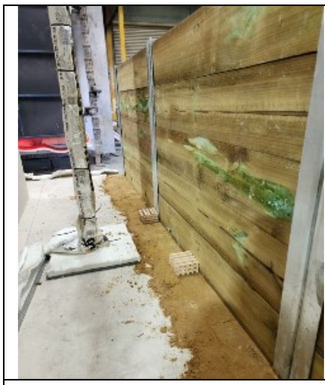
		
Sleeper wall viewed from east end looking towards simulated fire source	Wall viewed from north. Plasterboard cover in place simulating back filled part of garden bed raised above ground level. Exposed sleepers were facing the north face of the subject building.	Sleeper wall viewed from west looking away from the simulated fire source with west face of reference building visible to the right.

Figure 44 Wall configuration before test

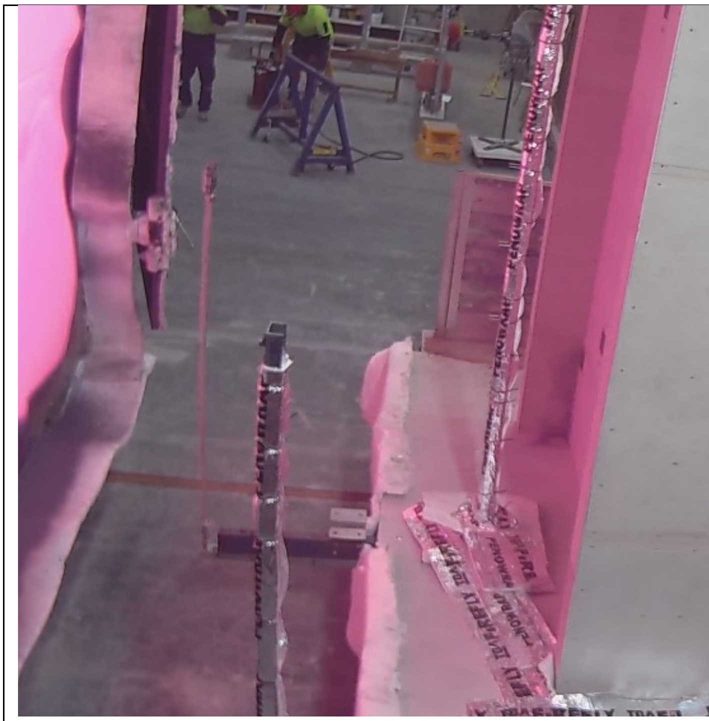
	
Test configuration viewed from south with the subject building on the right and test wall on the right extending past the subject building. On the left is the heat source	Test configuration viewed from the north showing the back face of the specimen with backfill conditions simulated by coverings. The uncovered sleepers directly faced the north face of the reference building

Figure 45 Test configuration during exposure of test assembly to radiant heat source.

The application of the timber cribs and exposure to the perpendicular heat source are shown in Figure 46.

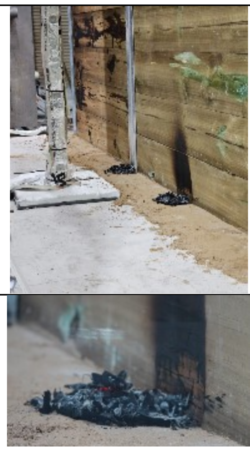
		
Application of burning cribs with radiant heat source in the background	Sleeper wall with radiant heat and cribs applied simulating attack from piles of burning embers or debris	Sleeper wall after exposure to radiant heat profile and embers showing minor charring only

Figure 46 Crib tests applied to sleeper wall.

Table 30 Results summary for test 3 Sleeper wall running perpendicular to the fire source - west face of the reference building exposed to 29kW/m²

Performance criteria	Description	Determined threshold values for BAL 12.5 buildings	Determined threshold values for BAL 19 buildings	Determined threshold values for BAL29 buildings	Result BAL 29 on west face of reference building
Heat flux	The maximum heat flux floating average over a two-minute period calculated from one minute before to one minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m^2	≤ 26.0 kW/m^2	≤ 38.6 kW/m^2	34.0 kW/m^2
	The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m^2.	≤ 26.8 kW/m^2.min	≤ 54.2 kW/m^2.min	≤ 105.1 kW/m^2.min	89.8 kW/m^2.min
Plate thermometer absolute temperature	Average absolute temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	380 °C
	Maximum absolute temperature during the entire test period.	≤ 350 °C	≤ 400 °C	≤ 500°C	453 °C
Internal thermocouple absolute temperature	Maximum absolute temperature after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	129 °C

Sustained smouldering or flaming combustion and subsequent fire development over the surface of the wall did not occur and the performance criteria for BAL−12.5, 19 and 29 buildings were therefore not exceeded on the north face of the reference building. This result indicates that larger imposed heat loads would be required to initiate and maintain sustained combustion and subsequent spread in this configuration to present a direct risk to buildings 1m or more away from the sleeper wall. Since sustained flaming ignition did not occur across the sleeper wall it was not possible to quantify the impact from a flaming wall on the north side of the building directly from these test results, but the test indicated that spread along sleeper walls would be unlikely unless a continuous secondary fire source such as mulch or vegetation runs along the base of the wall

Test 4 Sleeper wall below a house and 1m away supporting a walkway

The general test configuration is shown in Figure 19 through Figure 21 and simulates a garden wall of maximum height 1m located 1m in front of a building directly facing the fire front. In the test configuration the sleeper wall runs in front of the west face of the reference building which faces the radiant heat source and along the northern side of the reference building to investigate the potential for fire spread perpendicular to the heat source.

The sleeper wall was exposed to peak radiation of approximately 29kW/m^2 and the heating profile was based on that specified in AS 1530.8.1. The corresponding exposure of the west face of the reference building 1m back from the sleeper wall was estimated to be BAL−12.5 based on the calibration results.

Figure 47 shows visual observations during exposure to the AS 1530.8.1 profile during the first 10-minutes of the test.

Two pre-ignited cribs were applied to the base of the sleeper wall and then the specimen was exposed to conditions similar to or more severe than the AS 1530.8.1 BAL 29 profile. Within 60s, flaming had spread over the surface of the majority of the central bay and continued burning at a relatively high intensity and spread across the whole of the west facing wall whilst the peak incident radiant heat was maintained at 29kW/m^2 at the wall position between 20s and 140s of the test. The estimated height of the flames above the wall at this stage was approximately 500mm. As the incident radiant heat was reduced to follow the AS 1530.8.1 profile, and a char layer developed on the face of the sleepers, the intensity of flames decreased with only a few small, isolated flames visible 370s after the start of the test.

After 12 mins 20s flaming from the west wall had stopped with little visible change at 60 minutes as shown in Figure 48. During the period between 12 minutes and 60 minutes there were traces of smoke released from the central bay indicating the likelihood of sustained smouldering combustion occurring.

An additional burning crib was applied to the north wall 72 minutes after the start of the test to simulate burning embers collecting at the bottom of the wall and potentially igniting the wall. Details of the crib test and reaction of the wall are shown in Figure 49. The sleeper wall self-extinguished after the crib had been fully consumed approximately 10 to 20 minutes after initial application of the crib.

The specimen was monitored for more than 18 hours after the test. Images are provided in Figure 50 which show sustained smouldering combustion occurring in the central bay on the west wall throughout the 18-hour monitoring period. Re-ignition of flaming combustion occurred at the northern end of middle bay of the west wall after approximately 160 minutes. An image taken after 161minutes is provided in Figure 50 showing the flaming remaining localised. The flaming persisted for over 20 minutes before transitioning to glowing / smouldering combustion. The outer bays on the west wall and the north wall all self-extinguished during the monitoring period. This is consistent with the findings of the cone calorimeter program in that a critical heat load / extent of damage is required to initiate sustained smouldering combustion without a continuing external heat source.

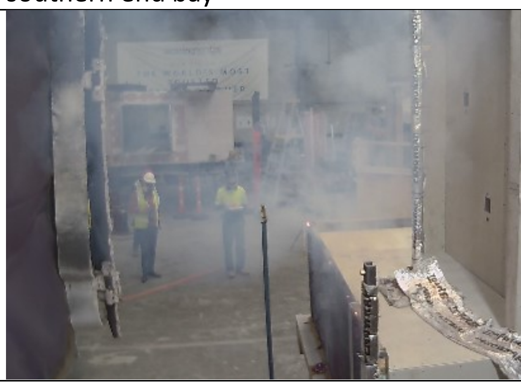
	
t=10s test commenced. Radiant heat exposure and cribs applied	t=60s Flame spread over surface of central bay of sleeper wall
	
t=90s full involvement of west face of sleeper wall (maximum intensity)	t=140s at end of peak irradiance
	
t=150s flaming beginning to diminish	t=190s Flaming reducing no involvement of southern end bay
	
t=370s further reduction in flaming combustion reduced to small, isolated flames	t=460s flaming reduced to small flames on top surface of sleeper wall

Figure 47 Western sleeper wall exposed to BAL 29 radiant heating profile of AS 1530.8.1

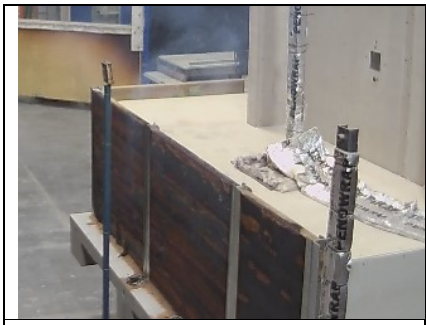
		
t=12 min 20s flaming stopped	t=30 min No flaming visible. Small amounts of smoke from west face indicative of smouldering combustion	t=60 min no appreciable change from 30 minutes

Figure 48 Sleeper wall test 4 from 12 to 60 minutes after heating

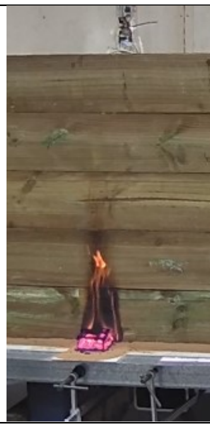
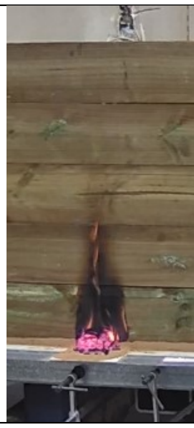
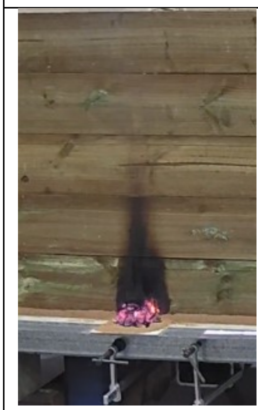
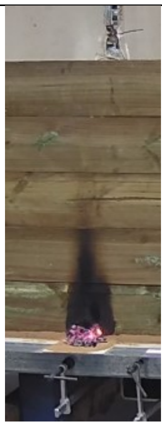
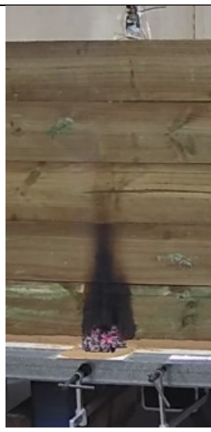
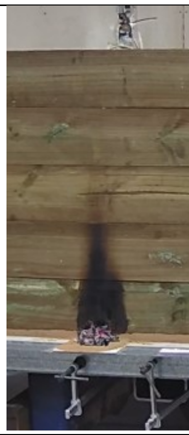
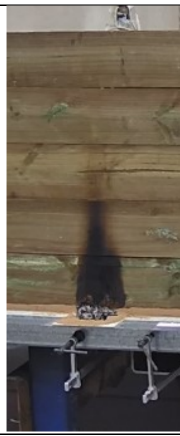
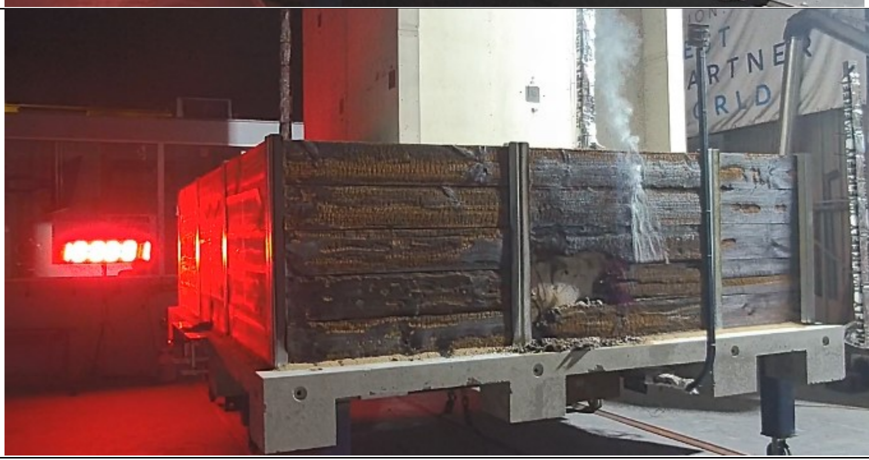
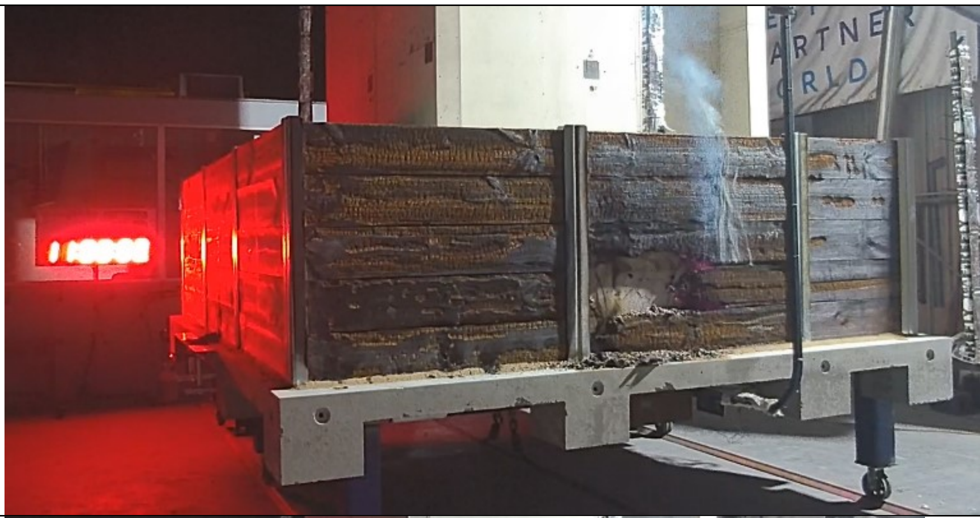
				
t=72min crib applied to north wall central bay. Smoke release visible from central bay of west wall indicative of smouldering combustion.		t=73min Crib 1minute after application to north centre bay	t=74min, 2 min after application	t=75min, 3 min after application
				
t=76min, 4min after application	t=78min, 6min after application	t=80min, 8min after application	t=82min 10min after application	t=92min, 20min after application

Figure 49 Timber crib test observations from application to northern sleeper wall.

t=1hour – west sleeper fence with charred face.		
t=2hour Smouldering combustion (no flaming combustion)		
t=2h 40min Smouldering and glowing combustion (no flaming combustion)		
t=2h 41min flaming combustion re-established on surface near source of smoke		

t=3 hour	
t=4 hour	
t=5 hours	
t=6 hours	

t=7 hour	
t=8 hour	
t=9 hours	
t=10 hours	

t=11 hour	
t=12 hour	
t=13 hours	
t=14 hours	

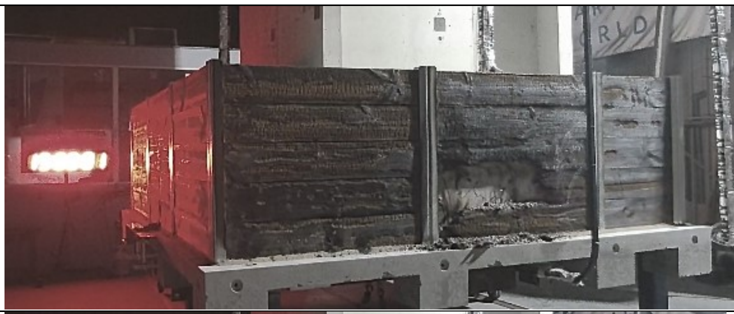
t=15 hour	
t=16 hour	
t=17 hours	
t=18 hours	
t=18 hours 13min. Showing consumption of the 2nd sleeper and parts of the 1st sleeper & 3rd sleeper at the north end of the central bay.	

Figure 50 West wall between 1 and 18 hours after the start of the test showing the progressive smouldering combustion of sleepers in the middle bay.

	
West face showing impact of sustained smouldering combustion occurring in the central bay	North face showing self-extinguishment after application of a burning crib

Figure 51 Sleeper walls approximately 19 hours after start of test

The measurements from the reference building showed that the performance criteria for BAL−12.5, 19 and 29 buildings were not exceeded during the test and monitoring period which indicates that the configuration with a sleeper wall 1m in front of the building did not significantly increase the fire exposure to the reference building.

Table 31 Results summary for test 4 West sleeper wall facing fire source and exposed to 29kW/m^2; exposure of reference building 12.5kW/m^2

Performance criteria	Description	Determined threshold values for BAL-12.5 buildings	Determined threshold values for BAL-19 buildings	Determined threshold values for BAL-29 buildings	Result BAL-29 at the sleeper
Heat flux	The maximum heat flux floating average over a two-minute period calculated from one minute before to one minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m^2	≤ 26.0 kW/m^2	≤ 38.6 kW/m^2	14.4 kW/m^2
	The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m^2.	≤ 26.8 kW/m^2.min	≤ 54.2 kW/m^2.min	≤ 105.1 kW/m^2.min	13.5 kW/m^2.min
Plate thermometer absolute temperature	Average absolute temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	129 °C
	Maximum absolute temperature during the entire test period.	≤ 350 °C	≤ 400 °C	≤ 500°C	276 °C
Internal thermocouple absolute temperature	Maximum absolute temperature after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	104 °C

Chapter 7 Large-Scale Tests of Paling Fences exposed to ember and wind attack.

Background

Following post-fire inspections that were conducted in the US, it was postulated that wood fencing assemblies were vulnerable to ignition from ember attack during bushfires but it was observed that there had never been any experimental verification of the ignition mechanisms (Suzuki, Johnsson et al. 2016). To address this knowledge gap, a series of experiments were conducted by Suzuki et al to examine ignition of Western Red Cedar and Redwood fencing assemblies subjected to continuous, wind-driven firebrand (ember) showers generated by the NIST full-scale Continuous Feed Firebrand Generator installed in the Fire Research Wind Tunnel Facility at the Building Research Institute in Japan. Specimens were subjected to a wind speed of 8m/s (28.8km/h). The results of these tests were reviewed in Chapter 3 but the outcomes are summarised again as part of the background to the proposed test program.

Dried shredded hardwood mulch beds were placed adjacent to some of the fencing assemblies. The fencing assemblies were varied in length and in orientation to the applied wind field to simulate a range of configurations that may be encountered in realistic situations. Both flat and corner sections of fencing assemblies were used in these experiments.

All configurations considered resulted in flaming ignition of the mulch beds, and subsequent flaming ignition of the wood fencing assemblies. The time to flaming ignition of the fencing after the flaming ignition of the mulch bed is provided in Table 32.

Table 32 Time to flaming ignition of fencing after the flaming ignition of the mulch bed derived from (Suzuki, Johnsson et al. 2016)

Configuration	**Material**	**Time to flaming ignition of fencing assembly after flaming ignition of mulch beds (s)**
0.91 m wide flat wall assembly	Cedar	14
Inside corner assembly	Cedar	25
Inside corner assembly	Redwood	23
Outside corner assembly	Cedar	29
1.83 m wide flat wall assembly	Cedar	9

Experiments were also undertaken to determine if wind-driven firebrand showers could produce ignition of fencing assemblies without the presence of fine fuels such as mulch adjacent to the fence sections. The results are summarised in Table 33. Ignitions occurred within 20 minutes of commencement of the simulated ember shower

Table 33 Summary of ignition results of the fencing assemblies without mulch beds by ember showers derived from (Suzuki, Johnsson et al. 2016)

Configuration	**Ignition at the bottom**	**Ignition at the joints**
0.91 m wide flat wall assembly	Ignited but not sustained	Ignited and sustained
Inside corner assembly	Ignited but not sustained	Not applicable
V-corner assembly	Ignited but not sustained	Ignited and sustained

It was observed that there were two potential ignition vulnerabilities, the base (see Figure 9), and the joints of the rails and fencing boards. The inside corner assembly and V-corner assembly had both of these vulnerabilities, whereas the 0.91 m wide flat assembly had only one potential ignition point, the base on the outside face (exposed to the shower) because the rails were fitted to the inside face.

It was found that embers accumulated at the base of the fencing assemblies initiating smouldering ignition and that these ignitions were not sustained because holes were formed at the base of the assemblies allowing embers to pass through the fence rather than accumulating.

The ignition of the fencing assembly at the joints of the rails and palings was observed due to embers accumulating at the joint. Smouldering ignition occurred which transitioned to flaming combustion intermittently.

The effects of wind speed and angle on fire spread along privacy fences were examined (Johnsson and Maranghides 2016), All the specimens had mulch applied at the base except for specimen 4 which was not ignited at wind speeds of 18, 13.5 and 9 m/s.

Table 34 Fire spread rates derived from experiments which burned from the ignition point to the end of the fence under the specified conditions derived from (Johnsson and Maranghides 2016) .

Test No.	Type of Material	Wind Angle (°)	Nominal Wind Speed (m/s)	Flow Straightener (Y/N)	Fastest Horizontal Fire Spread Rate (m/min)
18	Cedar	90	0	Y	
1	Cedar	90	9	N	0.07
17	Cedar	90	9	Y	
5	Cedar	45	9	Y	1.16
6	Cedar	45	9	Y	1.1
7	Cedar	45	13½	Y	0.57
8	Cedar	45	13½	Y	0.28
4	**Cedar- no mulch at base**	**0**	**18, 13½, 9**	**Y**	**No spread**
2	Cedar	0	9	N	0.08
3	Cedar	0	9	Y	0.44
9	Cedar	0	13½	Y	1.32
14	Cedar	0	13½	Y	0.47
15	Cedar	0	13½	Y	0.67
13	Cedar/P res.	0	13½	Y	0.61
11	Redwood	0	13½	Y	1.15
12	Redwood/ Pres.	0	13½	Y	1.44
10	Cedar	0	18	Y	1.01

The tests and further work highlighted that the mulch was needed to cause ignition and facilitate the spread along fences ((Suzuki and Manzello 2019)

A series of 187 field experiments was conducted to examine the effects on fire spread toward a structure for combustible fences and mulch under simulated conditions that may be encountered in a wildland-urban interface (WUI) fire (Butler, Johnsson et al. 2022). Since these experiments were published after completion of the review of previous studies in Chapter 3, extracted data is provided below.

The general test configuration adopted by Buttler et al is shown in Figure 52

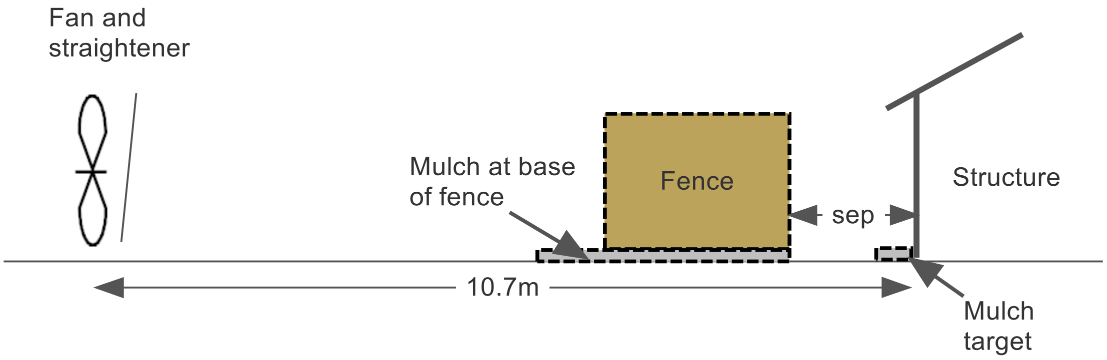


Figure 52 Typical test configuration for wind-driven fire spread to a structure from fences and mulch used in Nist experiments by (Butler, Johnsson et al. 2022)

Series 1 was performed using a combustible wall of the structure as the target.
Series 2 was performed with a non-combustible facing applied to the wall with a mulch bed as a target at the base of the structure as a surrogate for the combustible target wall.
Series 3 comprised a few tests without the structure in place to examine the potential distances travelled by embers.

The ignition mechanisms of the fence due to bushfire attack from embers and /or radiant heat was not examined in the test series. Instead, the fencing and / or mulch was ignited and flaming combustion established by propane burners at the end of the mulch and /or fence furthest from the structure or mulch target that was used as a surrogate for structure.

A small structure was located between 0 m and 1.83 downwind of the fence as a target for flames and firebrands in series 1 experiments. The 460mm wide target mulch bed at the base of the structure tested the ability of firebrands produced by the burning fence and mulch bed to ignite spot fires that could threatened a structure that was not hardened against ember and burning debris / mulch attack and mulch was present at the base of the wall during a bushfire attack (series 2). This meant that a mulch bed was continuous between the fence and structure for separation distances less than 460mm and the separation distance between the fence and surrogate mulch target was reduced by 460mm from the quoted building separation distances of 900mm and 1.8m. The corresponding separation distances of the mulch target in series 2 are compared to the approximate separation distance of the structure wall in Table 35

Table 35 Approx distance from end of fence or mulch to structure wall (series 1) or front of mulch bed (series 2)

Approx distance from end of fence or mulch (mm)	
To structure wall	To front edge of mulch target[1]
0	0
300	0
900	440
1800	1340

Note 1 Separation distances may have been further reduced by the thickness of protective coverings applied to the structure wall.

Four main types of mulch and fence tests were performed:

- Mulch only (approx. 25%)
- Fence only
- Fence plus mulch (approx. 50%)
- Parallel fences

Three nominal wind speeds were used;

- Low – 6m/s (22km/h)
- Medium 10m/s (36km/h)
- High 14m/s (50km/h)

Fence materials included western red cedar, California redwood, pine, vinyl, and wood-plastic composites, and fence styles included privacy, lattice, and good neighbour (board on board).

The following information has been extracted as having the greatest relevance to this study:

Series 1 tests (combustible structure wall as a target)

The mulch only tests performed in Series 1 indicated that with separation distances of 300mm or more, spread occurred to the end of the mulch bed but not to the structure. With no separation of the mulch, spread occurred to the combustible wall of the structure at medium and high wind speeds.

The fence only tests in Series 1 with western red cedar privacy fences showed that there was little spread along the fencing and no spread to the combustible wall of the structure at medium and high wind speeds.

The fence plus mulch tests performed in Series 1 indicated that with separation distances of 300mm or more, spread occurred to the end of the mulch bed but not to the structure. With no separation of the fence and mulch, spread occurred to the combustible wall of the structure at low, medium and high wind speeds.

Series 2 tests (non-combustible wall facing with 460mm wide mulch bed as target at base of the wall as a surrogate for a combustible wall)

Pine bark mulch was found to pose the highest risk of fire spread with shredded hardwood mulch providing similar results at medium and high wind levels. Observations will be based on these mulches at medium and high wind levels

The mulch bed at the base of the structure was ignited at medium and high wind levels with the source mulch bed continuous to the base of the wall or ending 440mm or 1340mm from the front of the mulch bed (900mm or 1.8m from the structure wall) in the mulch only tests.

In the fence only test with western red cedar privacy fences at medium wind speeds there was little spread but at higher wind speeds spread to the mulch bed target was more likely to be ignited due to embers produced by the fence.

The fence plus mulch tests performed in Series 2 indicated that the fire spread to the mulch bed target at the base of the structure occurred at low medium and high wind levels up to a maximum separation of 1.8m from the target structure.

Parallel fences (back-to-back) performed substantially worse than standard privacy fences due to the parallel fence configuration facilitating rapid fire growth and spread due to radiative feedback amongst other things. Parallel fences are unusual in Australia and are not recommended.

Series 3 potential travel distances for embers.

The fire sources used included a double (parallel) lattice fence and mulch beds. The double lattice fence would be expected to produce significant volumes of embers. The results indicated that the double lattice fence and mulch fires were capable of igniting spot fires in combustible material located at least 47.6 m from the burning item under high wind conditions and over a paved surface.

Applicability of previous studies and scope of supplementary tests

These recent studies relating to fencing (and mulch) provided useful insights into the threat posed to housing by embers and mulch during bushfires, that have been observed in post incident studies over many years. The focus of the studies has tended to be on demonstration and to some extent quantification of hazards associated with existing fence configurations and the increased hazards associated with mulch located against the base of fences; but work on modification of fence designs to minimise the risk of ignition and spread is limited and only a limited number of investigations into waterborne copper-based preservative treated radiata pine fencing has been undertaken.

Post incident studies led, amongst other things, to requirements in the original editions of AS 3959 (Standards_Australia 1991) for ember protection of openings and the protection of the lower parts of combustible external walls of residential buildings in bushfire prone areas in Australia. These requirements have been progressively refined in subsequent editions and in the AS 1530.8.1 fire test standard (Standards_Australia 2018).

The current approach for housing in bushfire prone areas in Australia is to specify construction requirements that are resistant to ember attack and ignition of burning debris that can collect around a building during a bushfire in addition to radiant heat from the fire front for Bushfire Attack Levels (BALs) up to BAL−40. The radiant heat applied is dependent on the BAL determined for the site. More stringent requirements apply to buildings in Flame Zone (BAL−FZ) which lie outside the scope of this study.

Advice to residents is provided regarding preparation of their properties prior to days of high bushfire risk including removal of debris / leaf litter and avoidance of use of mulch in close proximity to buildings. It is therefore reasonable to expected that the equivalent of 50mm deep mulch beds will not be located around the perimeter of most houses if owners have taken precautions to address the risk from bushfires. Notwithstanding this, buildings complying with AS 3959 are expected to be resistant to collections of burning embers and mulch that may collect around the building perimeter assuming reasonable levels of maintenance.

The large-scale test program described in Chapter 6 incorporated two tests on typical lapped radiata pine timber fences treated with waterborne copper-based preservatives and demonstrated partial shielding of buildings during the early stages. The potential for fences to impose an increased heat flux at certain times during a test / fire scenario and the occurrence of sustained smouldering combustion and re-ignition of flaming combustion was evaluated using an instrumented building and monitoring the behaviour of the fencing for an extended period after exposure.

The fences were of typical Australian construction except that for the arrangement of palings which were configured so that they minimised cavities for embers to collect between the palings and rails. The tests indicated that sustained smouldering combustion does not significantly increase the fire exposure of an adjacent building but could lead eventually to failure of fence posts and rails.

Additional large scale tests of fencing exposed to ember and wind

Supplementary large-scale experiments were undertaken to evaluate the performance of treated radiata pine fences when exposed simultaneously to wind and ember attack. Enhancements to the standard fence construction to reduce the risk of ignition were evaluated including

- Addition of wedge-sections to the tops of rails to shed embers and reduce radiant heat transfer between the rails, palings and posts.
- Protection of the base of the fence posts using non-combustible boards.
- Protection of the base of the palings by use of non-combustible plinth boards.
- Configuring paling boards to prevent embers accumulating in pockets and potentially igniting the fence

The potential ignition of the fence directly from embers and indirectly via mulch ignited by embers under imposed airflows simulating wind was evaluated with supplementary observation of the potential for localised ignition from the Type AA cribs prescribed by AS 1530.8.1, also under simulated air flow conditions.

The supplementary test program comprised three tests with test 3 incorporating two phases:

- Test 1 Waterborne copper-based preservative treated radiata pine with lapped palings detailed to avoid forming pockets and ember shedding sections with hardwood mulch at base
- Test 2 Design as test 1 with additional protection against ignition from burning hardwood mulch
- Test 3 Phase 1 as test 1 but without mulch
- Test 3 Phase 2 (if sustained smouldering or flaming ignition did not occur with ember and wind attack only) test 3 Phase 2 was undertaken. Phase 2 comprised the application of two AS 1530.8.1 Type AA timber cribs whilst exposed to the simulated wind.

Tests 1 and 2 were included based predominantly on in-kind contributions from Warringtonfire and the researchers and test 3 was sponsored by FWPA. Permission has been provided for the data to be used in this study).

Supplementary test method and procedures for fencing exposed to ember and wind attack

Test procedures

The test procedures for these supplementary tests were developed by Warringtonfire Australia, in conjunction with the researchers. Bushfire provisions for landscaping features such as fences and sleeper walls are not specifically included in AS 3959:2018 and hence specific test procedures and associated performance criteria specific to these elements are not provided in AS 1530.8.1:2018. The procedures described in Chapter 6 were based on the AS 1530.8.1 but did not include specific procedure for physically subjecting test specimens to ember attack to investigate potential ignition of mulch or ignition of combustible elements and subsequent fire spread if embers become lodged in joints. Instead, AS 1530.8.1:2018 evaluates elements forming the building envelope against ember attack by limiting any gaps developed during testing through which a 3 mm diameter probe can penetrate from the fire exposed face to the non-fire exposed face of the element at any time during the test, applying cribs at locations where significant quantities of embers and debris can collect and applying a piloted ignition source at positions where embers may impact on the element.

In order to consider the risk of ignition by embers in conjunction with an airflow, supplementary tests were undertaken using a purpose-built ember generator designed by Warringtonfire. The apparatus generates and lofts embers towards a specimen whilst at the same time the specimen can be subjected to an airflow. The ember generator comprised of a 2.5 m high × 300 mm diameter duct section with a 90° elbow at the discharge point. A continuous feed hopper enables a steady and constant supply of wood chips into the ember generator. Two 50 mm propane burners were used to ignite the chips for 30 seconds to allow the initial load of mulch to burn after which they were turned off. An electric fan was used to force air through the duct and loft the glowing embers towards the specimen. Another variation to AS 1530.8.1 procedures was that the specimens will not be simultaneously subjected to radiant heat.

Approximate wind measurements were recorded to provide indicative wind velocity data. The target range for airflows was between 2 and 3 m/s (7 to 11km/h). Figure 53 shows the ember generator during operation and fan applying the airflow.

Figure 53 Ember generator and fan during test 1

The proposed test apparatus also included an instrumented enclosure with a wall/eave system simulating an existing building structure as used for the large scale test program described in Chapter 6.

General Test Configuration

The general test configuration is shown in Figure 54.

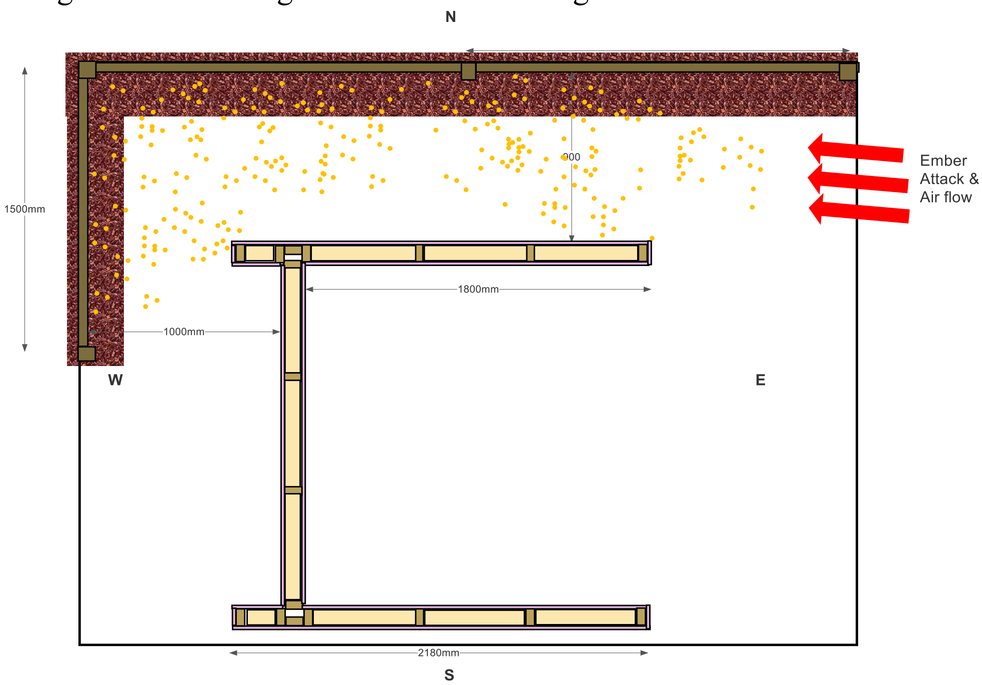


Figure 54 General Test configuration

Two 1950 mm high treated pine lapped paling fences were constructed along the west and north faces of the simulated building structure and located 1000 mm and 900 mm from the respective faces.

Instrumentation
The instrumentation of the reference building was as described in Chapter 6.

Additional measurements were taken to supplement the data from the reference building to provide information of the behaviour of the fences and walls under test and also facilitate the extension of the results.

The additional instrumentation included:

- heat flux meters and plate thermometers fitted to standard to take measurements at intermediate locations between the fence and walls of the reference building
- specimen thermocouples to measure internal and surface specimen temperatures of selected elements

Test materials and specimen construction

The basic fence construction (tests 1 and 3) comprised;

- 12 mm lapped vertical palings fixed to 70 × 45 treated pine rails which were notched to suit 90 × 90 treated pine corner posts and 90 × 70 intermediate posts.
- 150 mm wide palings (item 14) were butt joined onto the exposed side of the rails and secured to each rail using a single fencing nail located at the centre of the palings into each rail.
- 100 mm narrow palings were installed on the exposed side of the 150 mm wide palings and overlapped the butt joints of the 150 mm wide palings
- The 100 mm narrow palings were secured to each rail using two fencing nails located 25 mm from the edge of the palings, through the 150 mm palings, into each rail.
- The top of each rail was capped with an additional 45° chamfered section constructed from the same treated timber to enhance ember shedding and reduce radiant heat interchanges between timber surfaces should ignition occur.
- 150 × 25 mm treated pine plinths were fitted along the bottom edge of the paling fence for the basic construction.
- The corner and intermediate posts were cast into concrete piles to provide representative construction details.

Test 2 evaluated an enhanced construction with the following variations from the basic construction.

- replacement of the 150 × 25 mm treated pine plinths for a non-combustible plinth comprising of a 200 × 24 mm compressed fibre cement sheet.
- 12 mm thick cement sheet was applied along the underside and front face of all the bottom rails and also applied to the bottom 200 mm of all the posts.

Results and Discussion

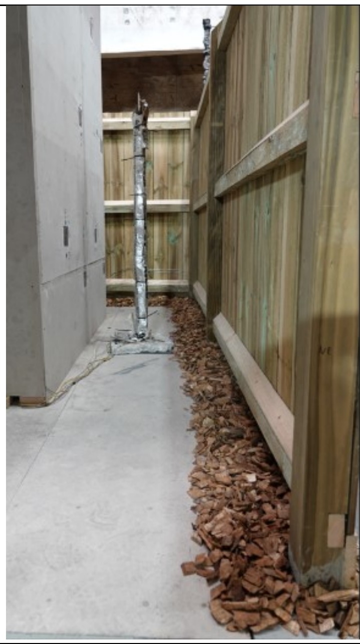
Test 1 Waterborne copper-based preservative treated radiata pine with lapped palings and ember shedding sections – mulch bed at the base of the wall.

Overview of test

The general arrangement before testing is shown in Figure 55.

External view of fence and ember generator

View from south showing NW corner o



View from East between north face of the reference building and fence and mulch

Figure 55 General Arrangement of test 1 paling fence before test

The average air velocity measured over a 2 minute period prior to commencement of the test was approximately 2.1-2.4m/s with a peak value of 2.6m/s. The direction of flow was east to west. The ember attack was maintained for the first 30 minutes of the test with the airflow maintained throughout the first 30 minutes and further 20 minutes. The test specimen was then monitored for a further 12 minutes with no imposed air flow before the test was terminated after a total of approximately 62 minutes.

Visual Observations of fire development

Figure 56 shows the early stages of ember attack and establishment of flaming ignition at two positions prior to 15 minutes exposure. Figure 57 through Figure 59 show progressive fire spread along the fence and consumption initiated by the burning mulch until the test was terminated.

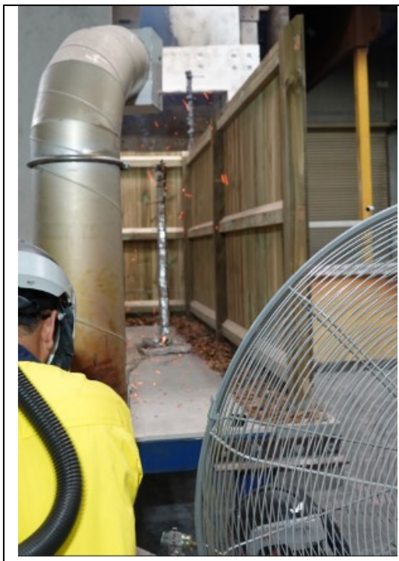
	
t=4.5 mins. View from east end showing release of embers from ember generator	t=5 mins. View of NW corner from the south showing embers interacting with mulch
	
t=10min Mulch at west section of fencing ignited	t=14.5 mulch at mid post north section of fencing ignited

Figure 56 Test observations 4.5 mins to 14.5 mins

t=17.5 mins – background; involvement in flaming combustion of bottom rail of west fence section and right: involvement in flaming combustion of mid post and adjacent rail up to bottom rail

t=21min-fire spread beyond lower rail at NW corner post and central north intermediate post.

Figure 57 Fire spread from mulch to fencing

t=25 min Fire development above lower rail west of the central northern fence section post. East of the central northern post there was minimal spread above lower rail

t=25 min Fire spread to outside face of fencing at NW corner

t=26.5 min Fire spread to outside face of fencing at NW corner increasing

t=30 min fire spread over outer surface of face NW corner. Ember generation stopped.

t=31 min Opening developing in lower half of west part of fence

Figure 58 Fire test 1 observations 25-31 minutes

t=34 min fire spread and opening up of west end of north fence with minor burn through by central post

t=50min air flow terminated - palings on west fence and western end of north fence consumed and central rail at western end of north fence fallen away.

t=62min test terminated (note northwest corner post and top and bottom rails on north face of specimen collapsed after approximately 58- 60 minutes exposure

Figure 59 Fire Test 1 Observations 34min to 50 min

Temperatures at interface between mulch and fencing

Temperatures were measured on the lower levels of the fence assembly in the proximity of the north-western corner post to provide an indication of exposure of the fencing from the burning mulch and interactions between the mulch and fencing.

The surface temperatures (refer Figure 60) measured on the corner post indicated that the post was ignited by the burning mulch after approximately 20 minutes which is consistent with the visual observations. This is also consistent with the temperatures measured approximately 100mm from the corner post on the plinth and lower rail (refer Figure 61). The temperatures measured 500mm from the corner post shown in Figure 62 are also consistent with the visual observations (refer Figure 57) confirming spread to the corner post from the south.

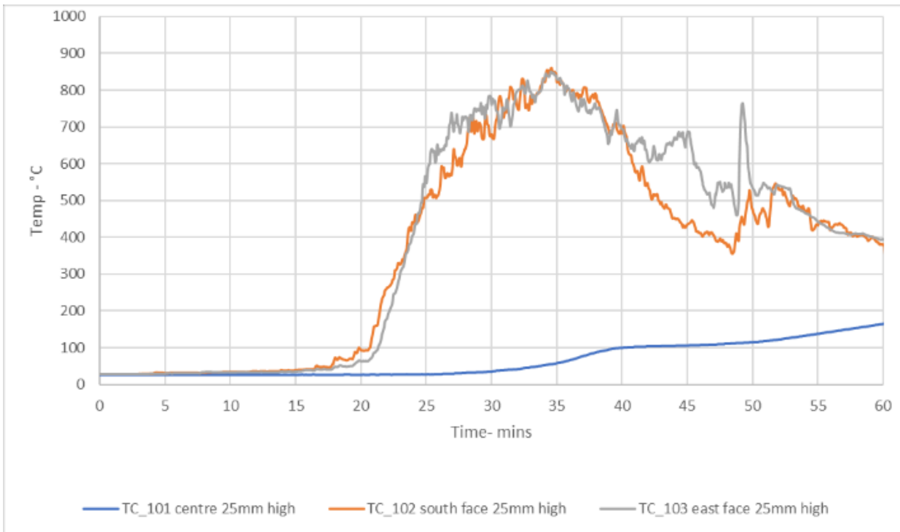


Figure 60 Corner post temperatures for ember test 1: Lapped paling fence with mulch at base of exposed to ember attack with applied airflow

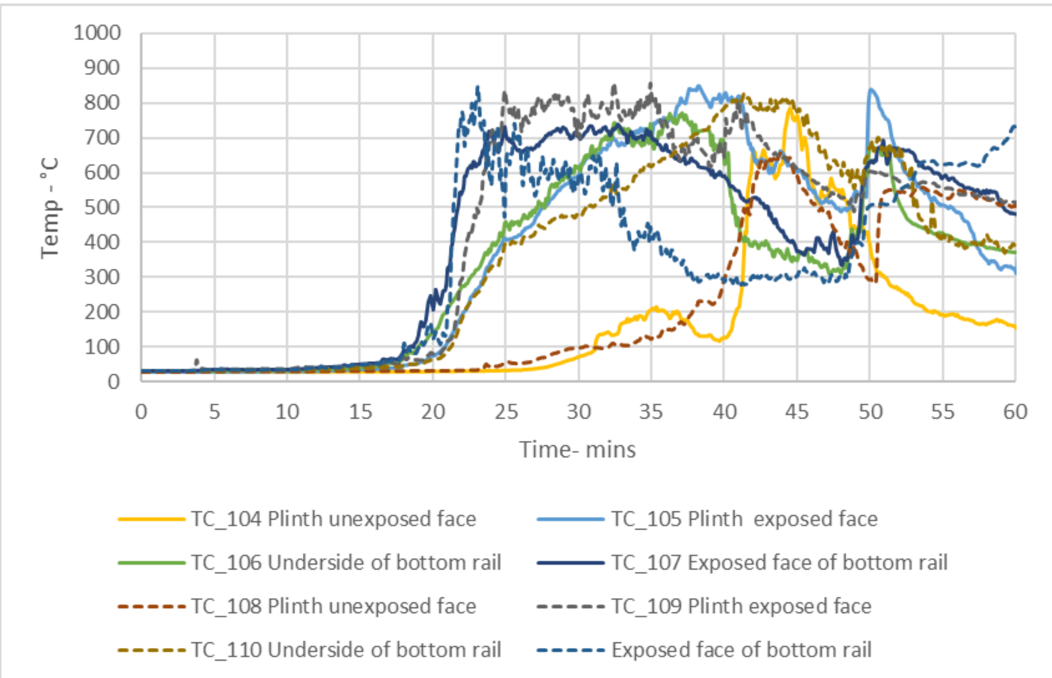


Figure 61 Plinth temperatures at a height of 25mm and bottom rail temperatures 100mm away from corner post; Solid lines are south of the corner post and dashed lines are east of the corner post

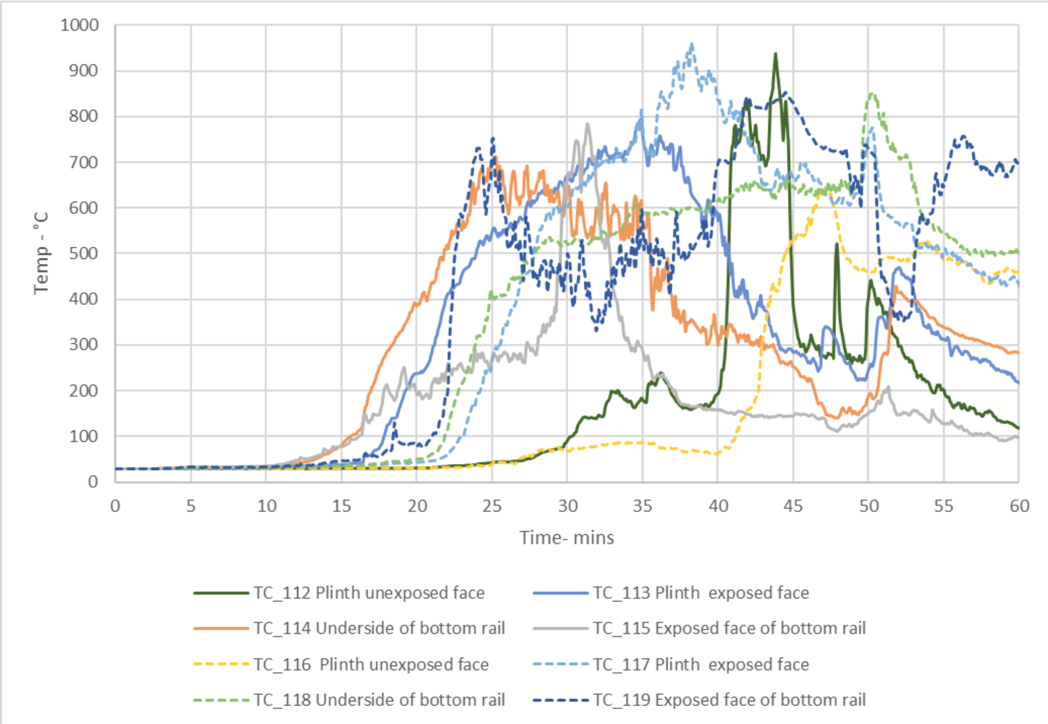


Figure 62 Plinth temperatures at a height of 25mm and bottom rail temperatures 500mm away from corner post; Solid lines are south of the corner post and dashed lines are east of the corner post

The temperature data also indicated that high interface temperatures of the order of 800°C can be generated by flaming combustion of mulch which can compromise the loadbearing capacity of loadbearing elements.

Potential exposure of adjacent structures

The potential exposure of adjacent structures was measured using the instrumented simulated building described in Chapter 6 which had been pre-calibrated for bushfire Attack Level (BAL) 12.5, 19 and 29 based on AS 1530.8.1 exposure criteria. Positions of the measurement points are shown in Figure 25 and Figure 27 of Chapter 6.

Table 36 shows the results obtained from ember test 1 compared to the calibration outcomes. In line with expectations the accelerated spread and growth resulting from the continuous mulch bed at the base of the wall led to the BAL−12.5 threshold being exceeded with a separation distance of 900mm between the fence and north face of the building under several criteria highlighted in a bold font in Table 36. In addition, the performance criteria limits based on the area between the measured heat flux and a critical threshold of 9.6 kW/m^2 were exceeded for BAL−12.5, 19 and 29 with a separation distance of 900mm.

The individual heat flux measurements from the insulated building are plotted in Figure 63 and Figure 64 and plate thermometer temperatures are plotted in Figure 65 and Figure 66. The greatest heat transfer to the building occurred over the lower western quarter of the north face near position R measured by heat flux meter R10 and plate thermometer P15 and position V3 measured by plate thermometer P21. The earlier peak for P21 (377°C after 36 minutes) occurred because it was closer to the NW corner where the initial fire growth was greatest. The threshold limits in Table 36 were not exceeded at other positions. The images of the specimen shown in Figure 67 show areas where the intensity of flaming combustion was greatest and are consistent with the measured temperatures and heat flux measurements

Table 36 Results for exposure of adjacent structures summary for ember test 1: Lapped paling fence with mulch at base exposed to ember attack with applied airflow

Performance criteria	Description	Determined threshold values for BAL-12.5	Determined threshold values for BAL-19	Determined threshold values for BAL-29	West face	North face
Heat flux	The maximum heat flux floating average over a two minute period calculated from one minute before to one- minute after the selected time must not exceed the specified maximum heat flux plus 20%.	**≤ 19.8 kW/m²**	≤ 26.0 kW/m²	≤ 38.6 kW/m²	6.3 kW/m² recorded by heat flux gauge R4 at 34 minutes	22.6 kW/m² recorded by heat flux gauge R10 at 39 mins
	The area between the measured heat flux and a critical threshold of 9.6 kW/m² shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m².	**≤ 26.8 kW/m². min**	**≤ 54.2 kW/m². min**	**≤ 105.1 kW/m². min**	0.0 kW/m2.min (the critical threshold of 9.6 kW/m² was not reached)	176 kW/m2.min (max.) recorded by heat flux gauge R10 at 50 mins)
Plate thermometer absolute temperature	Highest average temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	110 °C (max.) at 36 minutes	243 °C (max.) at 41 minutes
	Maximum temp during the entire test period.	**≤ 350 °C**	≤ 400 °C	≤ 500°C	172 °C recorded by TC 009 (P4) at 36 minutes	379 °C recorded by TC 064 (P15) at 40 minutes
Internal thermocouple absolute temperature	Maximum temp after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	91 °C recorded by TC 017 (I10) at 40 minutes	198 °C recorded by TC 072 (I31) at 49 minutes

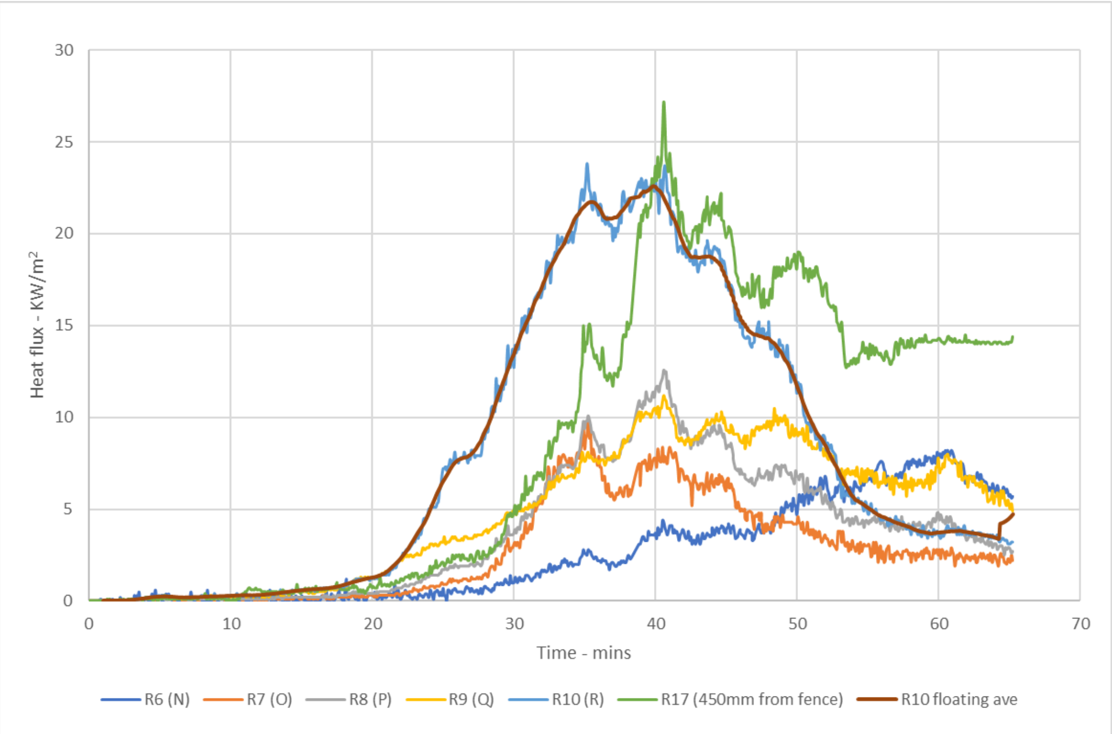


Figure 63 Ember test 1Heatflux measured on north face of structure and 450mm from fence

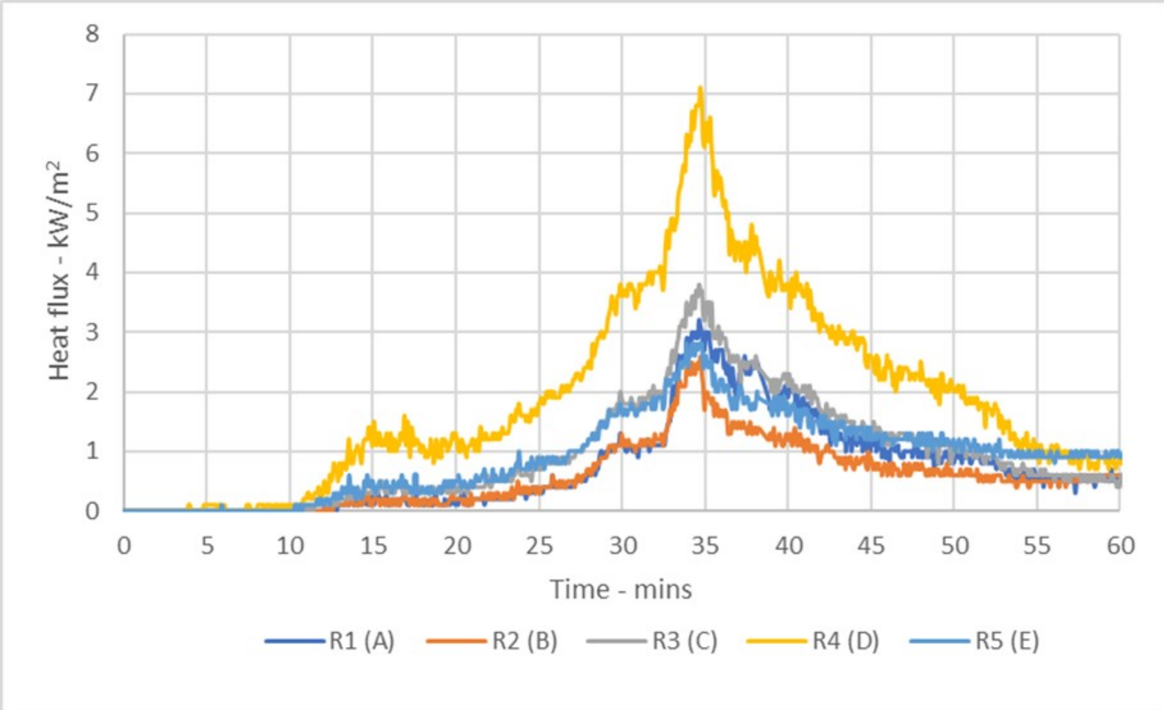


Figure 64 Ember test 1 Heat flux measured on west face of structure

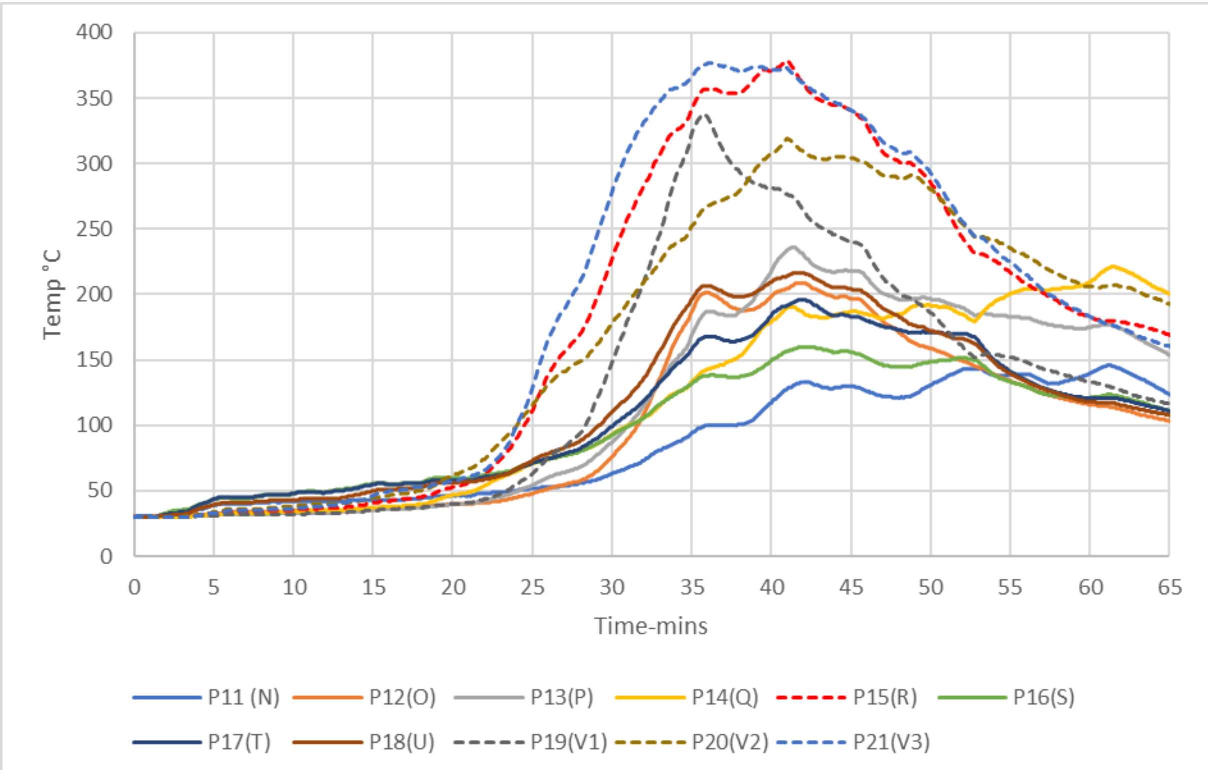


Figure 65 Plate thermometer measurements on the north face of simulated building

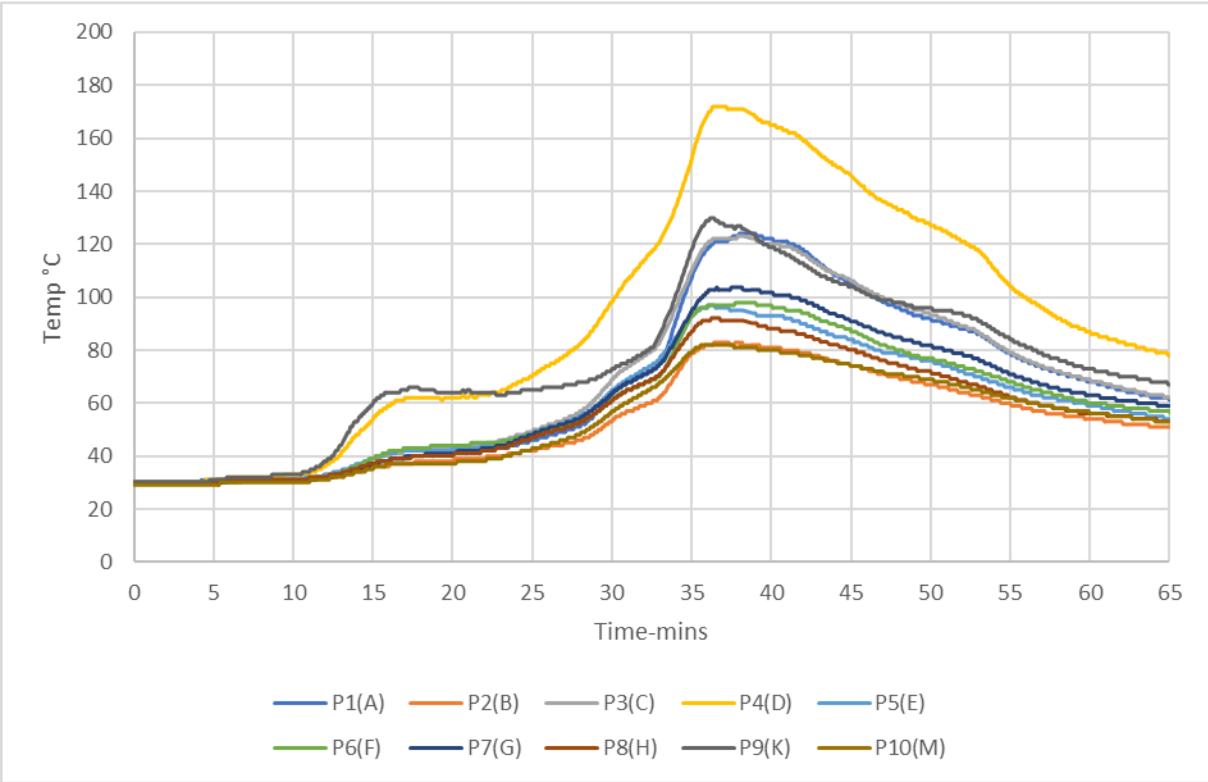


Figure 66 Plate thermometer measurements on the north face of simulated building

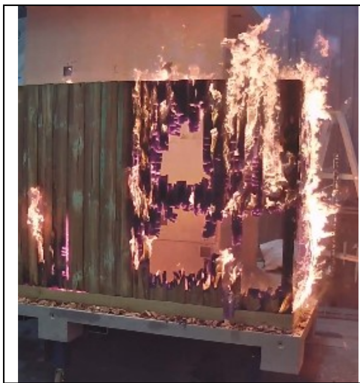
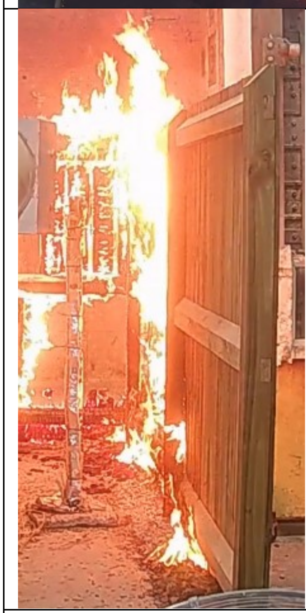
		External side of fence
		Internal side of fence facing instrumented structure
35 mins	40mins	

Figure 67 Fence at times corresponding to peak heat fluxes on simulated building.

The behaviour of the fence was quite complex with the mulch being ignited at a number of locations and either self-extinguishing or spreading to ignite the fence at localised locations. Sustained flaming or smouldering combustion was not initiated directly on the surface of the fence indicating that the ember shedding details were effective. Ignition without mulch acting as a large flaming ignition source was examined further in test three and a method of protecting the base of the wall to prevent ignition from mulch was evaluated in test 2.

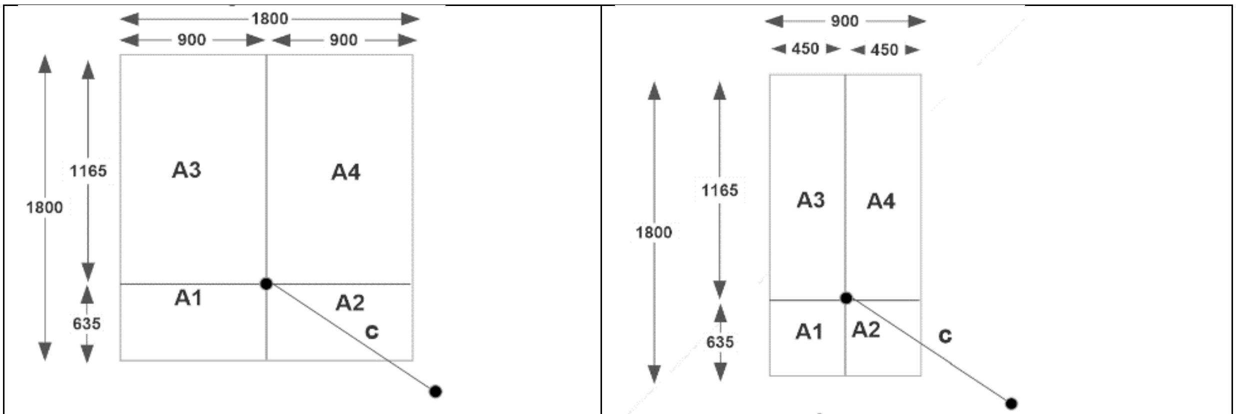
The initial sustained flaming ignition of the fence occurred on the side of the fence facing the simulated building at the short length of fence at the west end and at the post close to the middle of the north section of the wall. Fire growth was initially greatest at the west end and flaming combustion spread to the northwest corner and then along the northern fence and mulch towards the centre post in the north wall.

Before flames spread to the upper part of the fence, burn through occurred allowing fire spread through the fence to the outer face at some locations. Between 25 and 45 minutes substantial involvement of the northwest corner involving all the western section of the fence and the north section to approximately the centre post with sections of the palings being consumed forming holes through the fence.

At 50 minutes the palings had been consumed over more than 50 % of the fence with palings only remaining in the northern fence east of the centre post.

To calculate safe separation distances between the fence and the simulated building an area of the fence was assumed to impose a constant uniform heat flux on the building. To account for the variable exposure two configurations were assumed to bracket the impact of a range of exposures. Configuration 1 assumed a uniform radiant heat source 1.8m wide x 1.8 high at the original fence position (0.9m from the building) centred opposite heat flux meter R10 and Configuration 2 assumed a uniform radiant heat source 0.9m wide x 1.8 high at the original fence position (0.9m from the building) centred opposite heat flux meter R10.

Configuration factors were calculated for these cases with separation distances increased from 0.9m to 1.5m (a common separation specified for timber fences in the United States) and 1.8m (a separation distance similar to the fence height to minimise the risk if a section of fence falls towards a building). Maximum incident heat fluxes were estimated at the simulated building, assuming these extended separation distances. Schematics of the configurations analysed are shown in Figure 68.



(a) Configuration 1 1800mm x 1800 source	(b) Configuration 2 1800mm x 900mm source

Figure 68 Assumed heat sources for checking separation distances.

Test configuration

Table 37 Configuration factors based on assumed area of simultaneous involvement of a fence directly opposite a sensor at a height of 635mm representing the position of heat flux meter R10

Configuration	a	b	c	$\Phi^{1,2}$
1 Test (A1&A2)	635	900	900	0.115
1 Test (A3&A4)	1165	900	900	0.153
1 Test (Sum A1-A4)	1800	1800	900	**0.535**
1 -1.5m (A1&A2)	635	900	1500	0.060
1 -1.5m (A3&A4)	1165	900	1500	0.091
1 -1.5m (Sum A1-A4)	1800	1800	1500	**0.302**
1 -1.5m (A1&A2)	635	900	1800	0.045
1 -1.5m (A3&A4)	1165	900	1800	0.072
1 -1.5m (Sum A1-A4)	1800	1800	1800	**0.234**
2 Test (A1&A2)	635	450	900	0.076
2 Test (A3&A4)	1165	450	900	0.098
2 Test (Sum A1-A4)	1800	900	900	**0.348**
2 -1.5m (A1&A2)	635	450	1500	0.034
2 -1.5m (A3&A4)	1165	450	1500	0.052
2 -1.5m (Sum A1-A4)	1800	900	1500	**0.173**
2 -1.5m (A1&A2)	635	450	1800	0.025
2 -1.5m (A3&A4)	1165	450	1800	0.040
2 -1.5m (Sum A1-A4)	1800	900	1800	**0.129**

Note 1 the configuration factors simulating a section of fence burning simultaneously are shown in a bold font and are the sum of ϕ_{A1}, ϕ_{A2} , ϕ_{A3} and ϕ_{A4} for that specific configuration.
Note 2 values of configuration factors have been rounded to 3 decimal places. The total configuration factors were rounded after calculation and therefore vary slightly from the sum of φA_1 to φA_4 using the rounded values in the table.

The maximum heat flux floating average over a two minute period calculated from one minute before to one- minute after the selected time was 22.6kW/m^2 recorded by sensor R10 after 39 minutes. Assuming a uniform heat source this equates to a source radiant heat flux of 42kW/m^2 for configuration 1 and 65kW/m^2 for configuration 2. These values are comparable to peak heat fluxes measured from 2.4m high plywood specimens with low applied external heat fluxes (Delichatsios, Wu et al. 1994) where maximum heat fluxes (including convection and radiation) varied from 38 to 50kW/m^2. It is therefore considered that the assumed radiant heat source sizes are reasonable for evaluating the impact of changes to the separation distances. The estimated heat fluxes at distances of 1.5m and 1.8m from the fence are provided in Table 38.

Table 38 Estimated heat fluxes at varying separation distances from a 1.8m high paling fence ignited by continuous mulch bed

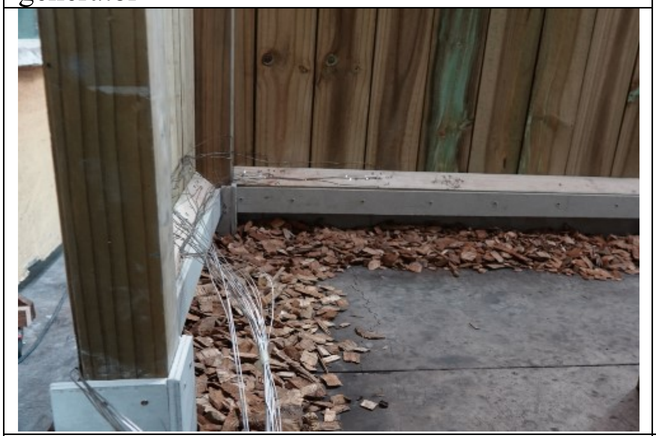
Configurations	Maximum heat flux at varying separation distances (kW/m^2)		
	0.9m - test result	1.5m	1.8m
1	22.6	12.8	11.2
2	22.6	9.9	8.4

Test 2 Design as Test 1 with additional protection against ignition from combustible mulch at base of wall

Overview of test

The general arrangement before testing is shown in Figure 69

External view of fence showing ember generator



View from south showing NW corner of fence and mulch

View from East between north face of the reference building and fence and mulch

Figure 69 General Arrangement of test 2 paling fence before test with additional protection at base

The average air velocity measured prior to commencement of the test was approximately 2.2-2.4m/s. The direction of flow was east to west. The ember attack was maintained for 30 minutes of the test with the airflow maintained throughout the first 30 minutes and for a monitoring period in excess of 14 hours.

After approximately 60 minutes a piloted ignition source was applied to the mulch at the northwest corner of test assembly with sustained flaming combustion established after 63 minutes .

Visual Observations of fire development

Figure 70 shows ember attack and establishment of flaming ignition at two positions during the 30 minutes exposure. The mulch was progressively consumed as fire front in the mulch bed moved in an easterly direction against prevailing air flow. Figure 71 shows the piloted ignition of the mulch close to the north-east corner post after approximately 62 minutes, and subsequent establishment. Progressive spread in an easterly direction from the initial point of sustained flaming combustion to the eastern end of the fence after 93 minutes is also shown.

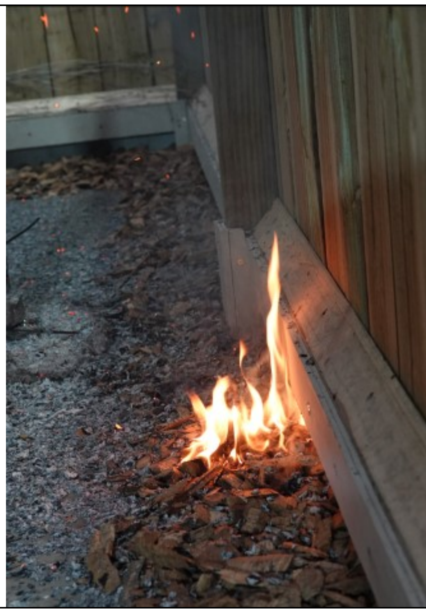
	
t=22.5 Initial ignitions	t= 26.7 min burning mulch
	t=30 Established flaming ignitions of mulch – ember generator stopped
	t=44min Mulch being progressively consumed as fire front moves against prevailing air flow but no evidence of sustained combustion of the fence.

Figure 70 Ignition and development of burning mulch fire,

		t=62 mins mulch manually ignited near the north-west corner of fence - burning of mulch west of the central post has self-extinguished therefore mulch ignited to investigate performance if the burning mulch fire had spread.
		t=68 mins Mulch fire in north-west corner (background) established and fire in foreground continues spreading along the base of the north fence towards the east end post
		t=73 min Mulch fire in NW corner
		t=93 min mulch fire front spread to east post along base of north wall

Figure 71 Observations from 62 minutes to 93 minutes after start of test

Figure 72 Shows the northwest corner after approximately 112 minutes of test with the fire spreading east and south from the corner without ignition of the fencing

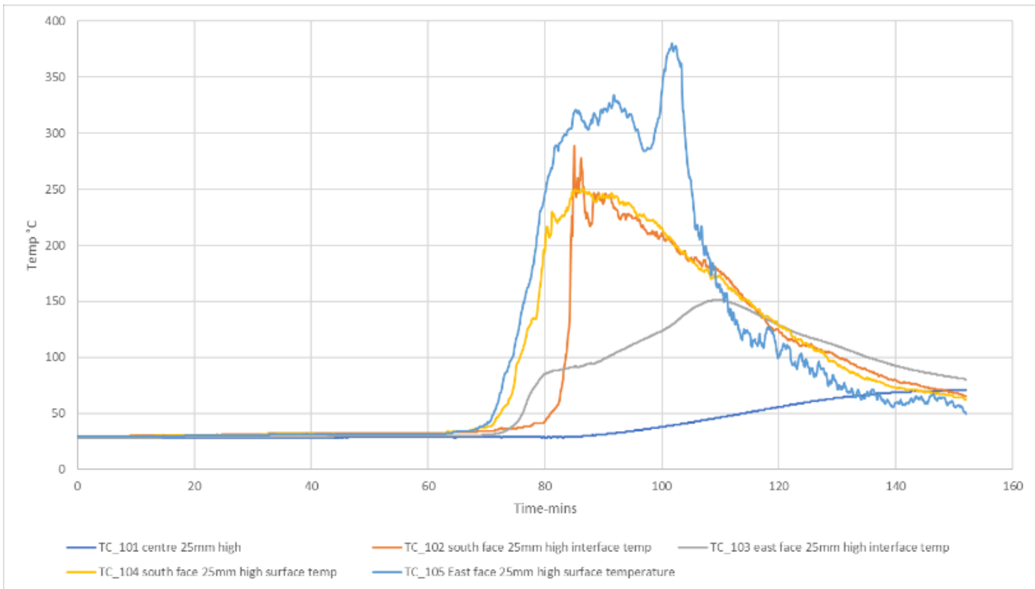
Figure 72 t=112min fire spread from NW Corner along west and north fences approximately 1m with no ignition of timber fencing.

Figure 73 shows the fence after test and monitoring for a total of 14 hours. There was minimal damage to the fence timber elements.

Temperatures at the base of the fence and close to the north-west corner post are presented in Figure 74 to Figure 78 and show that the protection system at the base prevented ignition of the fence and significant loss of strength of the timber posts. The maximum temperatures measured on the non-exposed face of the plinth were approximately 100°C or less limiting heat transfer to combustibles on the non-fire exposed face of the fence by conduction.

<table>
<tr><td></td><td>North -west corner with residual ash from embers and mulch after test</td></tr>
<tr><td></td><td>End of western fence section with residual ash from embers and mulch and minimal damage to timber post</td></tr>
<tr><td></td><td>Post at centre of north fence with protective coverings to face of lower rail and post in the foreground removed showing minimal impact on timber post and rail.</td></tr>
<tr><td></td><td>Eastern end of north fence with protection to face of lower rail and left hand post removed showing minimal damage to timber</td></tr>
<tr><td></td><td>Face of fencing that faced the simulated building with protection removed showing minimal damage to timber.</td></tr>
</table>

Figure 73 Fence 14h after test . Mulch had burnout without igniting the fence



Note TC-102 temperature is similar to exposed surface temperature and may have malfunctioned

Figure 74 Corner post temperatures for ember test 2: Lapped paling fence with ground level protection

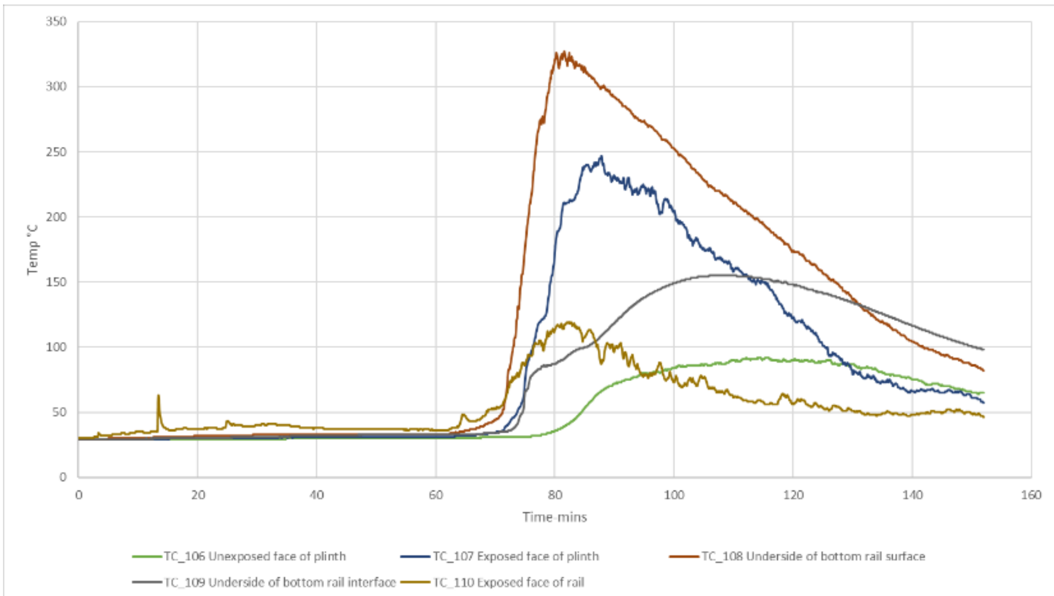


Figure 75 Temperatures measured at base of fence 100mm from south face of corner post

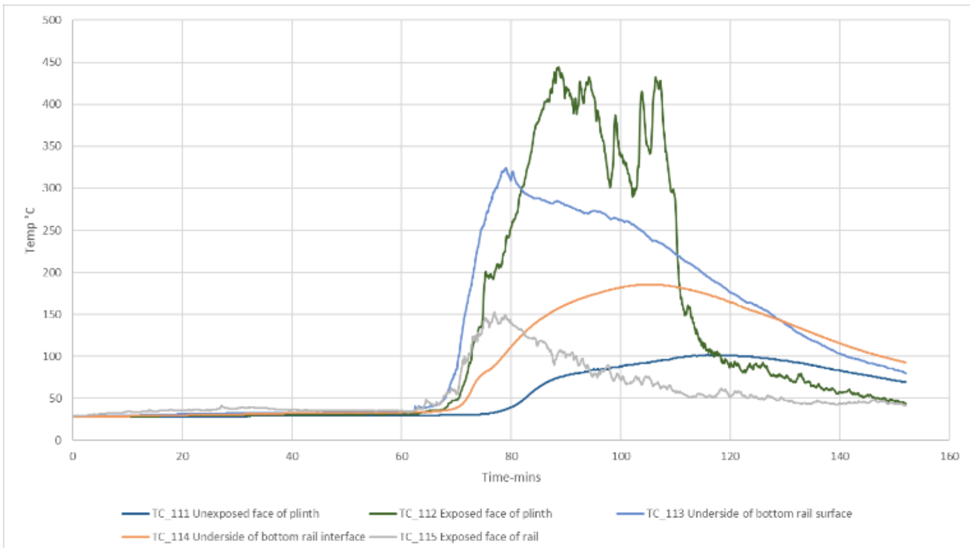


Figure 76 Temperatures measured at base of fence 100mm from east face of corner post

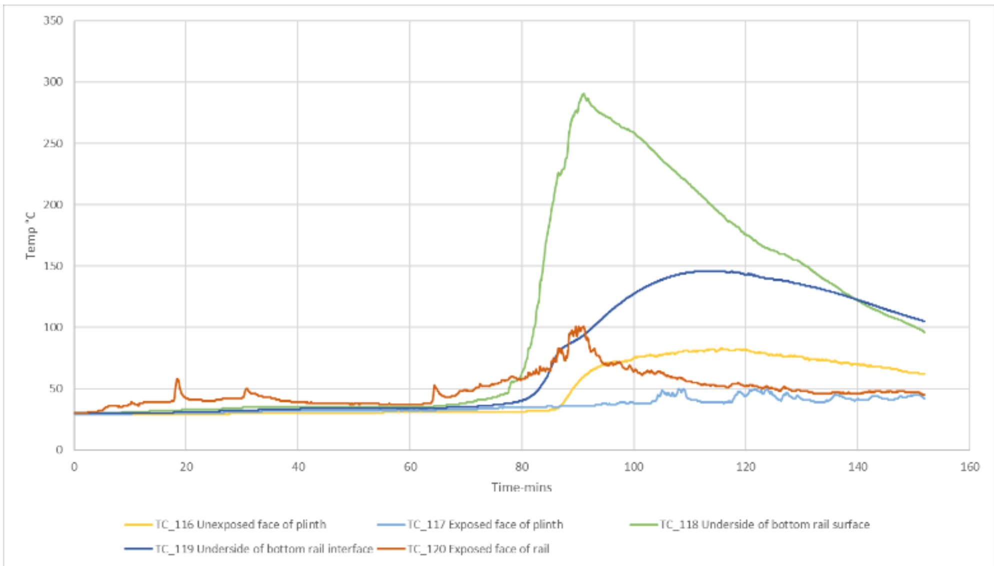


Figure 77 Temperatures measured at base of fence 500mm from south face of corner post

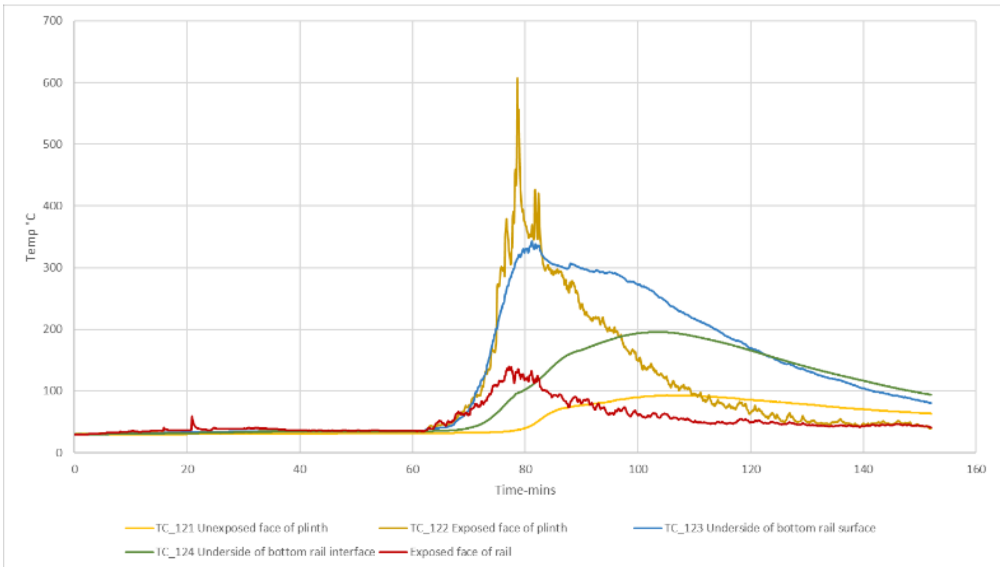


Figure 78 Temperatures measured at base of fence 100mm from east face of corner post

Potential exposure of adjacent structures

The potential exposure of adjacent structures was measured using the instrumented simulated building described in Chapter 6 which had been pre-calibrated for bushfire Attack Level (BAL) 12.5, 19 and 29 based on AS 1530.8.1 exposure criteria. Positions of the measurement points are shown in Figure 25 and Figure 27 of Chapter 6.

Table 39 shows the results obtained from ember test 2 compared to the calibration outcomes. Since there was no contribution to the building exposure from the fence and the only exposure to the building was from the burning mulch positioned at the base of the fence and ember shower, the threshold values for BAL−12.5 or greater were not exceeded and there was a very large margin of safety,

Table 39 Results for exposure of adjacent structures summary for ember test 2: Lapped paling fence with protected base and mulch at base exposed to ember attack with applied airflow

Performance criteria	Description	Determined threshold values for BAL 12.5	Determined threshold values for BAL 19	Determined threshold values for BAL29	West face	North face
Heat flux	The maximum heat flux floating average over a two minute period calculated from one minute before to one-minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m^2	≤ 26.0 kW/m^2	≤ 38.6 kW/m^2	0.6 kW/m^2 recorded by heat flux gauge R4 at 127 minutes	1.4 kW/m^2 (max.) recorded by heat flux gauge R9 at 31 minutes
	The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m^2.	≤ 26.8 kW/m^2. min	≤ 54.2 kW/m^2. min	≤ 105.1 kW/m^2. min	0.0 kW/m^2.min (the critical threshold of 9.6 kW/m^2 was not reached)	0.0 kW/m^2.min (the critical threshold of 9.6 kW/m^2 was not reached)
Plate thermometer absolute temperature	Highest average temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	38 °C (max.) at 126 minutes	61 °C (max.) at 31 minutes
	Maximum temp during the entire test period.	**≤ 350 °C**	≤ 400 °C	≤ 500°C	46 °C recorded by TC 025 (P9) at 122 minutes	96 °C recorded by TC 076 (P16) at 31 minutes
Internal thermocouple absolute temperature	Maximum temp after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	42 °C recorded by TC 027 (I14) at 125 minutes	68 °C recorded by TC 079 (I24) at 51 minutes

Test 3 Design as Test 1 without mulch – phase 1 ember / wind attach only; phase 2 AS1530.8.1 Type AA cribs applied simulating ignition of collections of debris

Overview of test

The general arrangement before testing is shown in Figure 79.

The average air velocity measured prior to commencement of the test was approximately 2.4-2.6m/s. The direction of flow was east to west.

The airflow was maintained throughout the 30 minute ember attack (phase 1) and continued throughout phase 2 of the test.

Ember attack commenced 160 seconds after commencement of data logging and was terminated at 32 minutes 40 seconds after commencement of data logging with no evidence of sustained smouldering or flaming combustion. The test then progressed to phase 2 with the application of a AS 1530.8.1 Type AA timber crib at the base of the central post on the north face 37 minutes 15 seconds after commencement of logging and at the northwest corner post 40 minutes 19 seconds after commencement of logging.

The test was terminated 120 minutes after commencement of data logging and the specimen was then extinguished.

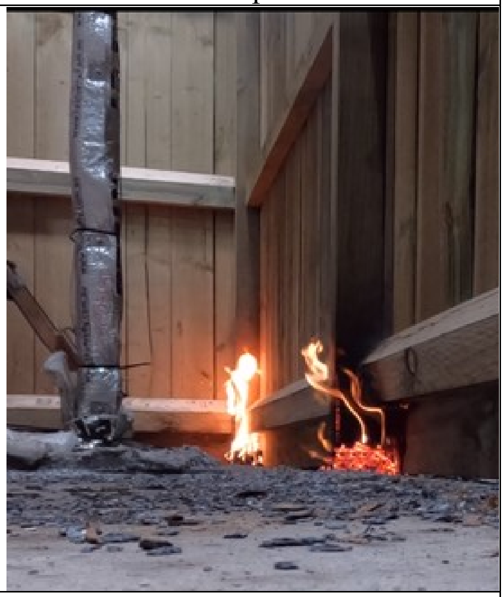
	
External view of fence before test	View from East showing reference building and fence prior to commencement of phase 1
	
North face before test showing ember generator to left before test	Phase 2 timber cribs applied at base of posts during phase 2 approx. 41 minutes after commencement of data logging

Figure 79 General Arrangement of test 3 paling fence before test.

Visual Observations of fire development

Figure 80 shows phase 1 of test 3 which indicates that ignition of a fence with the ember shedding details is unlikely if it is attacked by embers without the presence of mulch or other collections of combustible materials which can act as an accelerant / kindling to cause ignition particularly if the fence is not exposed to high external radiant heat levels.

	t = 1 minute ember attack showing embers deflected away from fence rails by 45° section fitted to rails and collecting on the floor
	t = 5 minute ember attack
	t=34 min specimen after phase 1 ember and wind exposure showing no evidence of sustained smouldering or flaming combustion

Figure 80 Test 3 Phase 1 Ember and Wind exposure – no mulch

Since ignition did not occur during phase 1, the test progressed to phase 2 with the induced air flow being maintained but the ember shower was stopped and AS 1530.8 Type AA timber cribs were applied as shown in Figure 81.

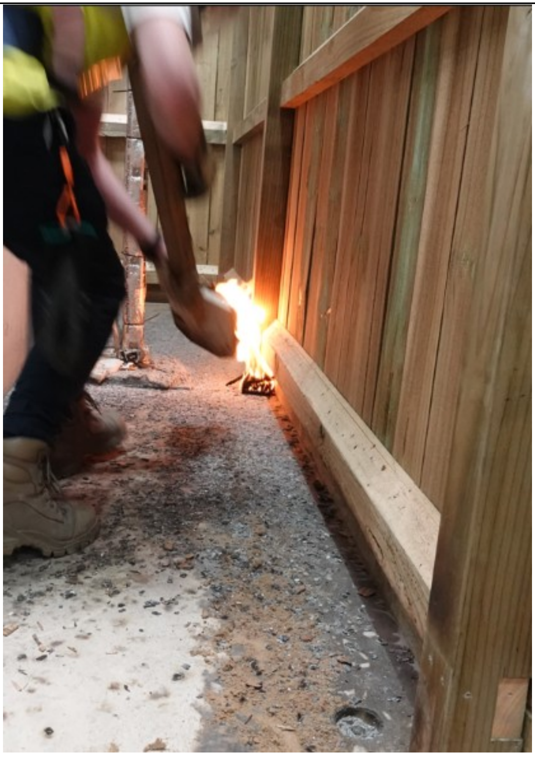
	
Crib 1 applied at the base of central post on the north face 37 minutes and 15secs after commencement of data logging	Crib 2 applied at base of northwest corner post 40 minutes and 19 seconds after commencement of data logging – flaming combustion of crib 1 in the foreground reducing

Figure 81 Placement of timber cribs.

After application of the flaming cribs, the flames lapped the lower rail as shown in Figure 81 but as the timber cribs were consumed, they tended to transition to smouldering combustion and also initiated smouldering combustion of the posts and palings as shown in Figure 82.

Flaming combustion developed more rapidly on the outer face than the inner face between 82 minutes and 106 minutes (refer Figure 83) but fire spread slowed with the burning areas remaining localised until the end of the test after 120 minutes and subsequent suppression. Suppression required only a light water spray. The specimen after test and after suppression is shown in Figure 84.

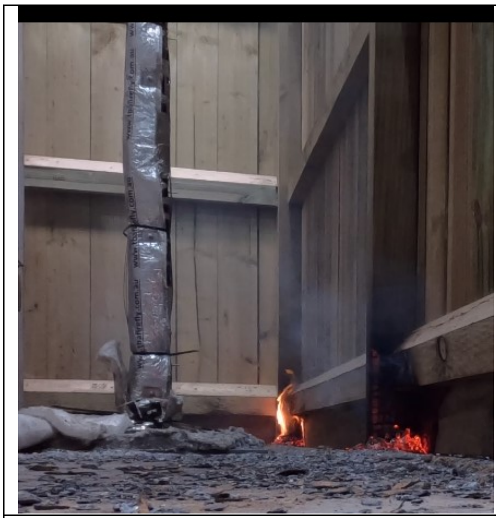
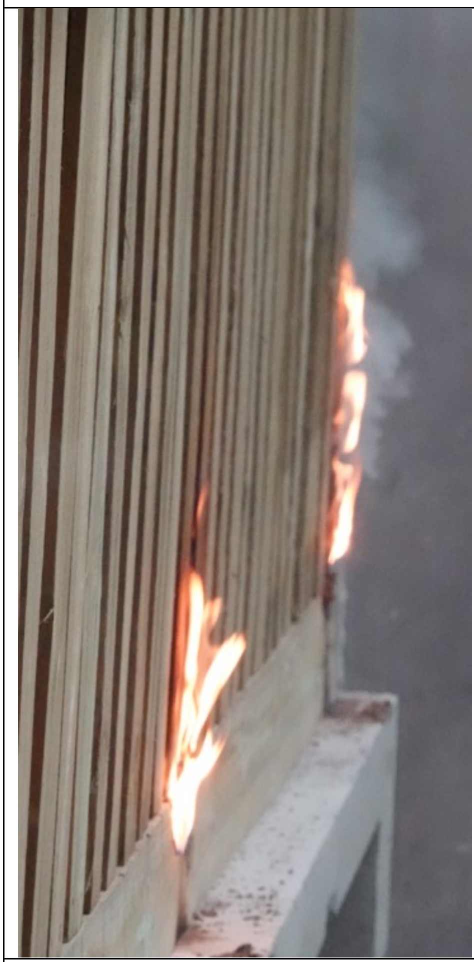
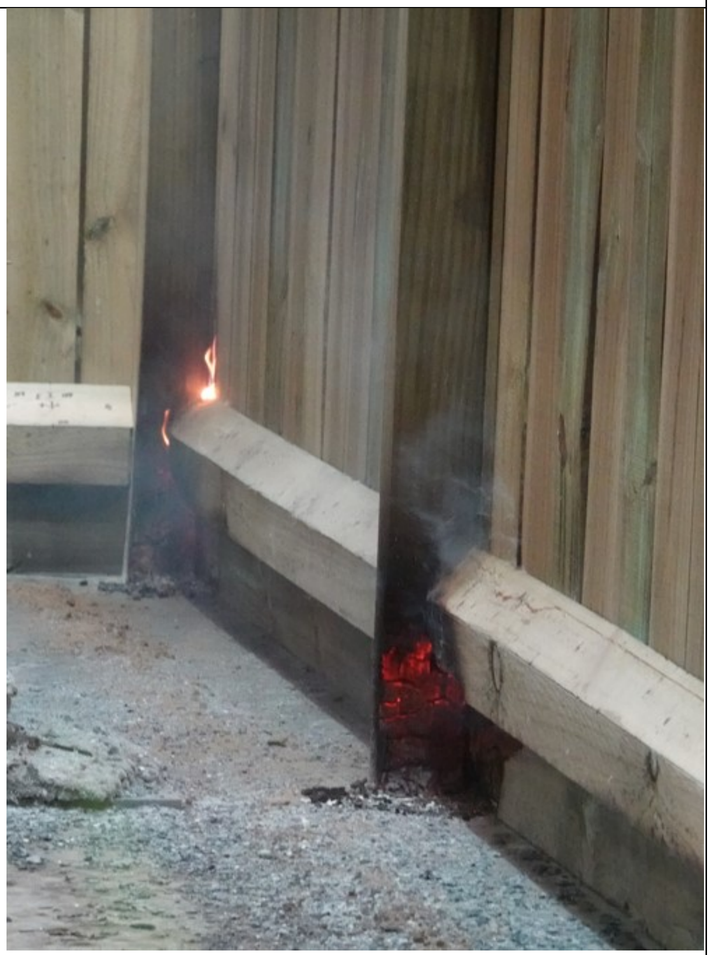
	
Crib 1 transitioning from flaming to smouldering combustion 42 minutes 50s after commencement of data logging - slight evidence of smouldering combustion from fence post. Flaming of crib 2 continuing at a reduced level	Smouldering combustion of cribs and posts 51minutes after commencement of data logging
	
Flames breaking through to outer face of fence after 82mins 30seconds	Flaming and smouldering combustion at base of columns after 83mins

Figure 82 Transition to smouldering combustion of the crib and fencing materials in close proximity to the crib and later transition to flaming combustion of fencing materials

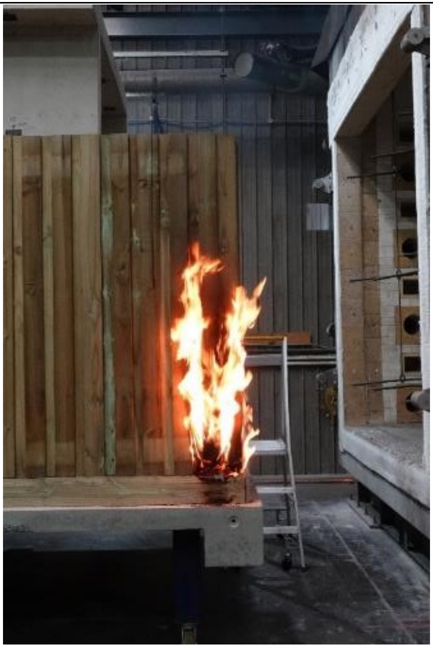
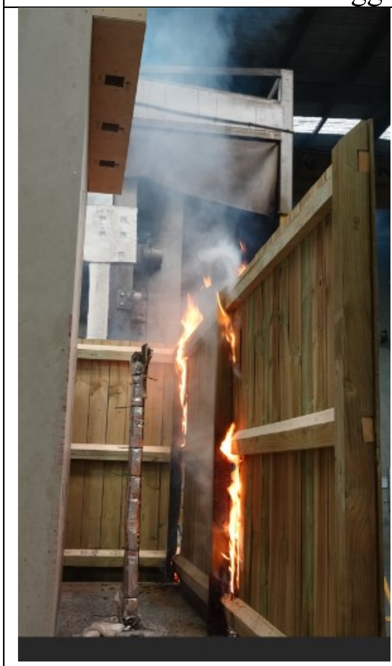
	
Flaming on outer face of northwest corner approximately 86 minutes 30 seconds after commencement of data logging	Transition to flaming of posts at interface with palings on side facing simulated building, approximately 87 minutes after commencement of data logging
	
Flaming on side of fence facing the simulated building approx. 106 minutes after commencement of data logging	Flaming on outer face of fence approx. 106 minutes after commencement of data logging

Figure 83 Growth of flaming combustion of the fencings

	
Outer face of fence after 120 minutes – test terminated	Fence facing simulated building at end of 120 minute test.
	
Outer face of fence after extinguishing residual combustion	Fence facing simulated building after extinguishing residual combustion

Figure 84 Fencing at the end of test and after suppression after test was completed.

Potential exposure of adjacent structures

The potential exposure of adjacent structures was measured using the instrumented simulated building described in Chapter 6 which had been pre-calibrated for Bushfire Attack Level (BAL) 12.5, 19 and 29 based on AS 1530.8.1 exposure criteria. Positions of the measurement points are shown in Figure 25 and Figure 27 of Chapter 6.

Table 40 shows the results obtained from ember test 3 compared to the calibration outcomes. Since there was only a small contribution to the building exposure from the fence and ember shower, the threshold values for BAL−12.5 or greater were not exceeded and there was a very large margin of safety.

Table 40 Results for exposure of adjacent structures summary for ember test 3: Lapped paling fence without mulch at base exposed to ember attack with applied airflow

Performance criteria	Description	Determined threshold values for BAL 12.5	Determined threshold values for BAL 19	Determined threshold values for BAL29	West face	North face
Heat flux	The maximum heat flux floating average over a two minute period calculated from one minute before to one-minute after the selected time must not exceed the specified maximum heat flux plus 20%.	≤ 19.8 kW/m^2	≤ 26.0 kW/m^2	≤ 38.6 kW/m^2	0.8 kW/m^2 recorded by heat flux gauge R2 at 91 minutes	1.9 kW/m^2 (max.) recorded by heat flux gauge R7 at 111 minutes
	The area between the measured heat flux and a critical threshold of 9.6 kW/m^2 shall not exceed the area between the specified heat flux plus 20% and the critical threshold of 9.6 kW/m^2.	≤ 26.8 kW/m^2. min	≤ 54.2 kW/m^2. min	≤ 105.1 kW/m^2. min	0.0 kW/m^2.min (the critical threshold of 9.6 kW/m^2 was not reached)	0.0 kW/m^2.min (the critical threshold of 9.6 kW/m^2 was not reached)
Plate thermometer absolute temperature	Highest average temperature during the entire test period.	≤ 300 °C	≤ 350 °C	≤ 450 °C	31 °C (max.) at 114minutes	54 °C (max.) at 115 minutes
	Maximum temp during the entire test period.	**≤ 350 °C**	≤ 400 °C	≤ 500°C	37 °C recorded by TC 009 (P4) at 114 minutes	65 °C recorded by TC 063 (P14) at 115 minutes
Internal thermocouple absolute temperature	Maximum temp after 20 minutes from the commencement of the test.	≤ 250 °C	≤ 250 °C	≤ 250 °C	32 °C recorded by TC 041 I18) at 118 minutes	62 °C recorded by TC 072 (I31) at 119 minutes

Chapter 8 Discussion & Conclusions

Stage 1

The Stage 1 literature review found that there are significant inconsistencies in the application of AS 3959 across Australia with additional requirements being introduced at State and Territory level and also at municipal government levels.

Various guides are provided to assist residents maintain vegetation around properties in a manner that does not encourage fire spread. Terms such as ‘defendable space’ are adopted and despite the focus on vegetation, recommendations for the use of non-combustible fencing and sleeper walls within prescribed distances up to 10m and beyond are included in some guides and reference materials.

The Australian fire brigades’ views were obtained, and the potential hazards identified that are associated with timber fencing and sleeper walls related primarily to combustibility. The information provided by the fire brigades was used to inform the hazard assessment process.

Estimates of the current bushfire risk based on reported fire losses, which includes a large proportion of buildings pre-dating current building standards, were derived to quantify the current risk and potential for risk reductions if additional controls are applied. This study highlighted that the majority of losses (human and property) associated with dwellings occurring close to the interface with bushland (generally within 50m) where severe exposure to flame and /or high levels of radiation may occur. This work was extended during stage 2 of this project to include cost estimates for losses at various distances from the predominant vegetation to provide a context for controls placed on fences and retaining walls in bushfire prone areas.

Statistical analysis of post fire surveys were reviewed and it was found that, based on these, residential fencing and sleeper walls were not identified as major contributors to bushfire losses; however anecdotal evidence based on recent surveys does identify scenarios where it is postulated that fencing and/or sleeper walls present significant risks and this information appears to have been used as justification for restrictions in the use of timber fences and sleeper walls.

Published experimental studies relating to fencing exposed to simulated bushfire attack were identified, and the information that is accessible was reviewed providing a resource that can be used to complement the current project. Some key issues that were identified from the studies were:

- potential failures and ignition points at joints and ground level
- the risk of fire spread along fencing particularly if mulch is present
- the risk of collapse of fencing on to buildings which can be influenced by sustained smouldering combustion (afterglow), and
- observations that specimens need to be conditioned to low moisture contents prior to standard fire tests.

Stage 1 included a test program to complement the literature review which demonstrated that the cone calorimeter can be used in conjunction with the proposed test protocol to differentiate treated timber that has a propensity for sustained smouldering without an externally applied heat source (commonly referred to as afterglow) and identified three treated timber combinations that were prone to sustained smouldering combustion. A protocol was developed that describes modifications to standard procedures that can be used to evaluate the potential for sustained smouldering combustion.

Generally, other than for the material designated ‘E’ (non-waterborne, copper-based preservative), the burning behaviours were similar for all the remaining treatments and untreated radiata pine whilst undergoing flaming combustion. This means that for applications where sustained smouldering combustion is not a critical factor, test results from one type of waterborne copper-based preservative treated radiata pine may be able to be applied to other similar treatments or untreated radiata pine if appropriate comparative data from a cone calorimeter or other suitable test method is available.

Stage 2

Investigations and additional experimental work to address questions raised relating to the comparative performance of radiata pine with treatments A and C under the proposed test protocol were undertaken in stage 2. The investigations included:

- Commissioning of independent testing of samples from the Stage 1 tests to determine more accurately retention rates and undertake penetration spot tests.
- Further comparative testing of samples with treatments A and C under different heat fluxes, time of exposure, proportions of sapwood and specimen thicknesses.
- Additional research into available information of the catalytic effects of waterborne copper-based preservatives and a comparison of constituents of treatments complying with AS/NZS 1604.1.

The outcomes did not change the recommendation to adopt treatment C for full scale tests, but the additional tests and analysis provide further confidence in the protocols. It was noted that the retention rates of treatments B and D tested under stage 1 on the thicker specimen were significantly below the requirements for H4 treatment levels specified in AS/NZS 1604.1.

Further development of the protocol was undertaken in stage 2 to incorporate exposure levels consistent with AS 3959 BAL classification levels, variations in the time of exposure, internal temperature measurements within the specimens to track the progress of the char front and smouldering combustion. This was combined with a project to obtain test data to determine the fire properties of waterborne copper-based preservative treated radiata pine including the impact of variations to moisture content, irradiance levels and duration and specimen thickness. The results showed similar properties to untreated radiata pine except in relation to sustained smouldering combustion.

The cone series was also extended to demonstrate the impact of pre-wetting timber elements prior to the passage of the fire front to inform the development of guidance documents and provide a proof of concept.

Additional review and analysis was undertaken of relevant existing test data, in lieu of undertaking additional small or intermediate scale testing, since the information identified in the literature review and additional documentation accessed since Stage 1 provided adequate information. This enabled resources to be diverted to the additional development work of the test protocol for the cone calorimeter and investigations into Stage 1 testing as well as the main Stage 3 project.

The detailed findings from the cone calorimeter series to investigate sustained smouldering combustion have been provided in Appendix 1. This provides a standalone document defining the fire properties of waterborne copper-based preservative treatments. Since the information has applications beyond residential fences and garden walls in bushfire prone areas, this approach facilitates technology transfer for broader use by industry and researchers.

Stage 3.

A large scale test program was undertaken to quantify the impact of waterborne copper-based preservative treated radiata pine garden sleeper walls (sleeper walls) and fences.

In order to quantify the impact of sleeper walls and fences on buildings in bushfire prone areas, it was necessary to quantify the potential fire exposure (actions) imposed on buildings directly from a fire front and the ability of buildings /elements of construction to resist these actions and then determine how these actions are modified by sleeper walls and fences.

AS 3959 provides a classification system for buildings in bushfire prone areas using the Bushfire Attack Level (BAL) framework which classifies the bushfire risk (except within the flame zone close to the fire front) based on the maximum imposed heat-flux from the fire front using conservative assumptions and assuming all properties in Bushfire Prone Areas that are classified as BAL−12.5, and above will be subjected to ember attack.

It was decided to maintain as far as practicable consistency within the National Construction Code (NCC) and relevant referenced standards and therefore, peak radiant heat levels of 12.5, 19 and 29kW/m^2 that correspond with BAL−12.5, 19 and 29 were adopted for the test program on the basis that treated timbers are most suited to these levels and the BAL range covers the majority of the market.

Since fire exposure is not just dependent upon the maximum imposed heat flux but also the duration of heating test, profiles were developed for AS 1530.8.1 to reflect the passage of a fire front generally incorporating conservative assumptions relating to heating durations. To maintain compatibility with NCC code requirements, and for the purposes of repeatability, the relevant AS 1530.8.1 radiant heat profiles and the class AA crib size specified by AS 3959 and detailed in AS 1530.8.1 were also adopted.

Standardised test procedures for evaluation of fencing and sleeper walls were not provided in AS 1530.8.1 since fences and sleeper walls in bushfire prone areas are not regulated nationally at the time this study was undertaken. Therefore, procedures were developed specifically for the project to extend the AS 1530.8.1 approaches by;

- defining a reference building that was extensively instrumented
- undertaking calibration runs for BAL−12.5, 19 and 29 fire exposures with no sleeper walls and fences in place
- deriving performance criteria based on the calibrations.

Innovative features incorporated in the reference building to supplement radiation measurements and thermocouple temperature measurements included, embedded plate thermometers in the facings and internal thermocouples between a fibre cement facing and plasterboard of the reference building. These features provided a comprehensive set of performance parameters that have relevance to the performance of building façade options commonly used in domestic buildings.

The calibration runs identified that there are significant variations in the incident heat flux over the surface of the reference building and the centre measurement was not necessarily the maximum value. This finding has significance for the general design of systems for AS 1530.8.1 testing as well as identifying the impact of fences and walls. The performance criteria were derived to take account of these variations.

The calibrations also highlighted that the change in heat flux with distance from the fire source was considerably greater in the lab scale experiments (3m x 3m source) compared to actual fire front scales (flame-height by 100m width assumed in AS 3959). This was due to variations in configuration factors and can become significant when testing 3-dimentional specimens rather than 2-dimesional specimens. The combination of the reference building and intervening wall provides a 3D configuration and therefore the impact of changes in configuration factors was considered when analysing the results.

Following the calibrations, a series of four tests were performed:

- two on lapped paling fences with incident peak heat fluxes at the fence position of 12.5kW/m^2 and 29kW/m^2
- a sleeper wall detail running perpendicular to the simulated fire front along the north side of the reference building with the west side of the reference building exposed to the BAL−29 heating profile. In this configuration exposed sleepers were directly facing the reference building simulating a sleeper wall supporting a garden bed.
- A sleeper wall 1m high and 1m in front of the reference building and on the west side directly facing the radiant heat source. In this configuration the sleeper wall on the west side was exposed to a heat flux of approximately 29kW/m^2. In this configuration exposed sleepers were directly facing the radiant heat source simulating a sleeper wall below the referenced building.

All tests were monitored after heating for extended periods to observe sustained smouldering combustion and re-ignition of flaming combustion.

The test series successfully demonstrated partial shielding of buildings during the early stages of test, the potential for some exposures for fences and walls to impose an increased heat flux at certain times during a test / fire scenario. The occurrence of sustained smouldering combustion and transition to flaming combustion were also noted in some cases.

The tests indicated that in many situations sustained smouldering combustion does not significantly increase the fire exposure of a building but could lead to failure of structural elements. Applications such as sleeper walls limited to 1m high and fences more than the fence height from vulnerable features on an external wall are examples that could be considered provided alternate paths of travel to exit the building are available.

The above tests showed that, for the configurations tested, the net thermal impact of introducing waterborne copper-based preservative treated radiata pine was relatively minor and the performance criteria for the corresponding building BAL were not exceeded (refer specific results). However, due to sustained smouldering combustion structural failure of the timber posts and rails did occur for the fence exposed to BAL 29 conditions. If a building is susceptible to damage this can be addressed by extending the separation distance to the fence height.

In addition to the results obtained, additional benefits from Stage 3 include the development of test procedures for fences and sleeper walls based on AS 1530.8.1 and the development of a capability to perform tests on fences and sleeper walls.

A well-known limitation of test methods generally is that the impact of wind is not considered. An extension of the initial literature review was undertaken, and supplementary large-scale tests of paling fences exposed to ember and wind attack were undertaken using an ember generator, and fan generated air flows to provide additional information as described in Chapter 7.

The following configurations were evaluated at a large scale whilst exposed to ember attack and imposed air flows. In all cases, the fencing comprised lapped paling fences constructed from radiata pine with a water borne copper-based preservative treatment and ember shedding details comprising paling configurations to avoid pockets for embers and debris to collect and 45° timber ember shedding sections ("wedges") fitted to the rails

Supplementary Test 1 – treated radiata pine with lapped palings and ember shedding details with a mulch bed at the base of the fence. In this test the mulch bed acted as an accelerant and facilitated the spread along the fencing causing the highest imposed heat flux from all the large scale tests on the simulated building 900mm from the fence. Exposure limits for BAL 12.5, 19 and 29 buildings were exceeded.

The test data was used to calculate radiant heat fluxes on a building if located 1500mm and 1800mm from the fence. The calculated maximum heat flux was below 12.5kW/m^2 if the fence was located 1800mm from the building and this separation distance will also reduce the risk of damage to a building if structural failure of the fence occurred.

This test highlighted the importance of restricting the use of mulch close to buildings and fences but provided data from which a safe separation distance of 1.8m was derived for a treated pine paling fence, if mulch is located at the base of the fence.

However, it should be noted that if mulch is placed or collects at the base of a fence close to a building, mulch is also likely to collect around the base of the building and provide a direct threat to the building.

Supplementary Test 2 – as Supplementary Test 1 with increased protection against ignition from combustible mulch at base of fence.

The increased protection comprised a fibre cement sheet plinth board 25mm thick in lieu of a treated pine plinth board and fibre cement sheet, 12mm thick applied to be base of the posts, underside of the bottom rail and face of the bottom rail. In this test there was no ignition of the fence, but the mulch was ignited by the embers, and the fire spread along the mulch at the base of the fence. This test provides a proof of concept that with ember shedding details and detailing of the base of the fence ignition of water borne copper- based preservative treated pine fencing due to ember attack can be avoided even if combustible mulch is present at the base of the fence. Alternative hybrid solutions other than protecting the base of the fence or solutions including raising the base of the fence could be developed to reduce the risk associated from mulch or other combustibles at the base of fences.

Supplementary Test 3a – as Supplementary test 1 but without the mulch at the base of the fence.

No ignition of the fence occurred during the 30-minute ember test and the test demonstrated the efficacy of the ember shedding details and substantially lower risk of ignition at the base of fences if the use of mulch is not permitted at the base of fences.

Supplementary test 3b – was a continuation of test 3a without ember attack but with AS 1530.8.1 Type AA cribs applied at a corner post and intermediate post detail simulating an accumulation of debris. The cribs were placed approximately 37 and 40 minutes after the commencement of test 3a

In this case the cribs instigated smouldering combustion of the post and adjacent palings and rail which transitioned to flaming combustion approximately 40 minutes after the cribs were first applied.

The test was terminated after a total of 120 minutes (i.e. approximately 80 minutes after placement of the cribs after sections of the palings nominally 300mm wide had been consumed. The rate of spread was relatively slow compared to the tests based on AS 1530.8.1 exposures since no external radiant heat was applied. The remaining combustion was easily extinguished with a light water spray.

The exposure from the fence 900mm from the simulated building was substantially below the thresholds for a BAL–12.5 building.

This test demonstrated that localised collection of debris, if ignited by embers, could cause ignition of fencing and was consistent with the results of the series of tests based on AS 1530.8.1 without applied air flows. This highlights the importance of good housekeeping around buildings. Also, this test highlighted the potential effectiveness of manual suppression if occupants are present which is consistent with observations after bushfires that indicate substantially lower house losses occur if occupants are present.

Recommendations

1) Residential fencing and sleeper walls were not identified as major contributors to bushfire losses based on the reviewed statistical analyses, however, experimental studies particularly from the US identify scenarios where it is postulated that fencing and/or sleeper walls present significant risks where mulch and other combustible debris collects around the base of walls. The results of this study confirm that mulch collecting at the base of a fence (or other elements of construction) impose a high heat flux on an element such as a fence and can act as an accelerant. Without mulch accelerating fire spread fencing and sleeper walls were shown not to increase the net exposure of an element if located at least 900mm to 1000mm away from a building when exposed to AS 1530.8.1 exposures between BAL 12.5 and BAL 29 with the Class AA cribs applied simulating localised collections of debris. It is therefore recommended that rather than applying regulatory restrictions to fencing and garden walls voluntary "good practice guidelines" are produced suggesting appropriate detailing and separation distances.

2) If further regulation is deemed necessary over and above AS 3959 current requirements to address fire spread from combustible materials consideration

should be given to restricting the use of combustible mulches and provision of garden beds close to buildings in bushfire prone areas but again the provision of "good practice guidelines" for occupants and designers may be an effective option.

3) An adaptation of the cone calorimeter test method was successfully developed to screen and measure the impact of water-borne copper-based preservative treatments on the sustained smouldering combustion characteristics of treated and untreated pine. The increased tendency for sustained smouldering combustion to be promoted by water-borne copper-based preservative treatments was clearly demonstrated using the bench scale cone calorimeter test.
The bench scale test method is a useful tool to develop fire retardant treatments and / or preservative treatments that do not promote sustained smouldering combustion. A potential alternative area of research is to focus on treatments that interfere with the catalytic effects of the copper based compounds on the combustion process in addition to conventional types of fire retardant treatments.

4) The effect of sustained smouldering combustion during large scale tests was clearly demonstrated by the failure of the post and rails leading to collapse of sections of fencing and the slow consumption of sleepers over a period of several hours. Guidance should be issued indicating that if a building or part of a building is susceptible to damage from a falling fence the separation distance should not be less than the fence height. The guidance should also indicate the need to quickly reinstate garden walls after fires where sleepers have been consumed.

5) Further research should be undertaken to address the risk of structural failure of posts, rails and sleepers to avoid the need for separation distances greater than 900mm to 1000mm to address structural failures. Options include;

   a. Hybrid systems using timbers with the required durability for posts and rails, that are more likely to self-extinguish than undergo sustained smouldering combustion
   b. Hybrid systems using non-combustible posts and rails that have the necessary fire resistance to prevent collapse of large sections of fencing
   c. Use of fire retardants
   d. Protection of vulnerable details and elements close to horizontal surfaces- i.e. mulch resistant detailing and ember shedding details

6) The results of the bench scale tests showed that the results of the time to ignition are affected by the moisture content of the timber element particularly when exposed to heat fluxes below 20kW/m^2. Prewetting was also demonstrated to have an impact up to several hours after application of water. These results indicate that prewetting of timber elements may be an effective use of fire-fighting water applied either manually or automatically prior to the passage of the fire front. This could be a useful area of further research for all types of exposed wood products.

References

(2020). Bushfire Resilient Building Guidance for Queensland Homes. Queensland, Queensland_Government
CSIRO.
(2020). Ministerial Building Standard MBS 008. Designated bushfire prone areas - additional requirements. South Australia, Department Planning Transport and Infrastructure South Australia.
(2021). Guidelines for Planning in Bushfire Prone Areas. Western Australia, Western Australia Planning Commission.
(2022). Landscaping for bushfire. Garden Design and Plant Selection. Victoria, CFA.
ABCB (2020). "National Construction Code 2019 Volume One Amendment 1."
ABCB (2020). "National Construction Code 2019 Volume Two Amendment 1."
Babrauskas, V. (2003). "Ignition Handbook."
Bartlett, A. I. (2018). Auto-extinction of engineered timber. Doctor of Philosophy, Edinburgh.
Bell, N. (2021). National desktop review of bushfire building regulations, Forest and Wood Products Australia.
Blanchi R, Leonard J, Haynes K, Opie K, K. M. James M, Dimer de Oliveira F and V. d. H. R (2012). Life and house loss database description and analysis -report to the Attorney-General's Department. CSIRO EP-129645, CSIRO and Bushfire CRC.
Blanchi, R. and J. Leonard (2005). Investigation of bushfire attack mechanisms resulting in house loss in the ACT bushfire 2003, Bushfire Cooperative Research Centre.
Boura, J. (2016). Wye River & Separation Creek BAL Assessment Report. Victoria, Terramatrix.
Butler, K., E. L. Johnsson, A. Maranghides, S. Nazare, M. G. Fernandez, R. McIntyre, W. Saar, M. Zarzecki, W. Tang and E. Auth (2022). "Wind-Driven Fire Spread to a Structure from Fences and Mulch."
Butler, K. M., E. L. Johnsson and W. Tang (2020). "Structure vulnerability to firebrands from fences and mulch." In: Hood, Sharon M.; Drury, Stacy; Steelman, Toddi; Steffens, Ron,[eds.]. Proceedings of the Fire Continuum-Preparing for the future of wildland fire; 2018 May 21-24; Missoula, MT. Proceedings RMRS-P-78. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 31-43. **78**: 31-43.
Chow, V. and P. England (2010). Bushfire Research Report - Evaluation of Cost Effective Forms of Construction for Buildings in Bushfire Prone Areas. Melbourne, Exova Warringtonfire**:** 158.
Crielaard, R., J.-W. van de Kuilen, K. Terwel, G. Ravenshorst and P. Steenbakkers (2019). "Self-extinguishment of cross-laminated timber." Fire Safety Journal **105**: 244-260.
Delichatsios, M., P. Wu, M. Delichatsios, G. Lougheed, G. Crampton, C. Qian, H. Ishida and K. Saito (1994). Effect of external radiant heat flux on upward fire spread: measurements on plywood and numerical predictions. Fire Safety Science—Proceedings of the Fourth International Symposium.
Evans, P. D., P. Beutel, R. B. Cunningham and C. F. Donnelly (1994). "Fire resistance of preservative-treated slash pine fence posts." Forest products journal **44**(9): 37.
Gardner, W. D. and J. A. White (2009). Assessing the ability of a large-scale fire test to predict the performance of wood poles exposed to severe bushfires. Australia, FWPA.
Harper, J. (2018). Bushfire Hazard Advisory Note No 06 - 2018, Tasmanian Fire Service.
ISO (2015). ISO 5660-1:2015 Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement), ISO. **ISO5660-1:2015**.
ISO (2017). ISO 13943:2017 Fire Safety Vocabulary. Switzerland, ISO. **ISO 13943:2017**.

Janssens, M. (1991). "A thermal model for piloted ignition of wood including variable thermophysical properties." Fire Safety Science **3**: 167-176.
Johnsson, E. L. and A. Maranghides (2016). Effects of wind speed and angle on fire spread along privacy fences, US Department of Commerce, National Institute of Standards and Technology.
Leonard, J., R. Blanchi, N. White, A. Bicknell, A. Sargeant, F. Reisen, M. Cheng and K. Honavar (2006). "Research and investigation into the performance of residential boundary fencing systems in bush fires." CMIT and BlueScope Steel Limited, Clayton South, Victoria, Australia.
Leonard, J., K. Opie, R. Blanchi, G. Newnham and M. Holland (2016). Wye River/Separation Creek Post-bushfire building survey findings, CSIRO.
Manzello, S. L. (2014). "Enabling the investigation of structure vulnerabilities to wind-driven firebrand showers in wildland-urban interface (WUI) fires." Fire Safety Science **11**: 83-96.
Moghtaderi, B., V. Novozhilov, D. Fletcher and J. Kent (1997). "A new correlation for bench-scale piloted ignition data of wood." Fire safety journal **29**(1): 41-59.
NSW_Rural_Fire_Service (2019). Planning for Bush Fire Protection. NSW, Rural Fire Service.
Penman, T., C. Eriksen, R. Blanchi, M. Chladil, A. M. Gill, K. Haynes, J. Leonard, J. McLennan and R. A. Bradstock (2013). "Defining adequate means of residents to prepare property for protection from wildfire." International Journal of Disaster Risk Reduction **6**: 67-77.
Ramsay, G. C., N. A. McArthur and V. Dowling (1996). Building in a fire-prone environment: Research on building survival in two major bushfires. Proceedings Linnean Society of New South Wales, Linnean Society of New South Wales.
Standards_Australia (1991). AS 3959 Construction of Buildings in Bushfire-Prone Areas. Sydney, Standards_Australia. **AS 3959-1991**.
Standards_Australia (1998). AS/NZS 3837:1998 Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter. Sydney, Standards Australia.
Standards_Australia (2007). AS 1530.8.1-2007 Methods for fire tests on building materials, components and structures - Tests on elements of construction for buildings exposed to simulated bushfire attack - Radiant heat and small flaming sources. Sydney. **AS 1530.8.1-2007**.
Standards_Australia (2014). AS 1530.4 Methods for fire tests on building materials, components and structures Part 4: Fire-resistance tests for elements of construction. Sydney, Standards Australia. **AS 1530.4:2014**.
Standards_Australia (2018). AS 1530.8.1-2018 Methods for fire tests on building materials, components and structures - Part 8.1 Tests on elements of construction for buildings exposed to simulated bushfire attack - Radiant heat and small flaming sources. Sydney. **AS 1530.8.1-2018**.
Standards_Australia (2018). AS 1530.8.2-2018 Methods for fire tests on building materials, components and structures - Part 8.2: Tests on elements of construction for buildings exposed to simulated bushfire attack—Large flaming sources. Sydney. **AS 1530.8.2-2018**.
Standards_Australia (2018). AS 3959 Construction of Buildings in Bushfire-Prone Areas. Sydney, Standards_Australia. **AS 3959:2018**.
Standards_Australia (2021). AS/NZS 1604.1:2021 Preservative-treated wood-based products Part 1:Products and treatment. Australia, Standards_Australia. **AS/NZS 1604.1:2021**.
Suzuki, S., E. Johnsson, A. Maranghides and S. L. Manzello (2016). "Ignition of Wood Fencing Assemblies Exposed to Continuous Wind-Driven Firebrand Showers." Fire Technology **52**(4): 1051-1067.
Suzuki, S. and S. L. Manzello (2019). "Understanding structure ignition vulnerabilities using mock-up sections of attached wood fencing assemblies." Fire and materials **43**(6): 675-684.

Timber_Queensland (2014). Technical Data Sheet 20 Residential Timber Fences. Queensland, Timber Queensland.
Timber_Queensland (2017). Woodsolutions Technical Design Guide 41 Timber Garden Retaining Walls.
Victorian_Government (2018). Building Regulations 2018 (Victoria). Victorian_Government. Australia.
Wu, W., J. Hidalgo, J. Morrell and F. Wiesner (2021). Experimental study on smouldering of CCA treated timber.

Acknowledgements

Wood Products Victoria and in particular Boris Iskra for sourcing and distribution of the test specimens and reviews of the project reports.

The industry participants in the project for supply of materials and treatment of timbers and advice relating to industry practices

The tests for this study were undertaken by the following accredited test laboratories that provided substantial assist throughout the project

- Australian Wool and Textile Association – Undertaking the majority of the cone calorimeter test programmes except for weathering tests and cone calorimeter testing of weathered samples. A number of additional test runs were carried out to refine the test procedures

- BRANZ - Undertaking weathering tests and cone calorimeter testing of weathered samples

- IVS Labs Ltd, - Undertaking preservative treatment tests including advice on establishing the test program

- WarringtonFire Australia Undertaking the Large Scale Fire Tests including construction of specialised test rigs and significant inkind contribution for the ember fire tests

Investigation of Preservative Treated Plantation Timber Fencing and Sleeper Markets in Bushfire Prone Areas

Stage 3 Final Report
Appendix 1

Fire properties of waterborne copper-based preservative treated radiata pine

Prepared for

Forest & Wood Products Australia

by

Paul England

April 24

Publication: Timber Fencing and Sleeper Walls Appendix 1 - Fire properties of waterborne copper-based preservative treated radiata pine and untreated radiata pine

Project No: NIF144-2122 [NV054]

IMPORTANT NOTICE

This work is supported by funding provided to FWPA by the Department of Agriculture and Water Resources (DAWR).

ISBN: New number (this is provided by FWPA upon publication)

Paul England
EFT Consulting

Final report received by FWPA in April, 2024

Forest & Wood Products Australia Limited
Level 11, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

Table of Contents

Appendix 1 Fire Properties of Preservative Treated and Untreated Radiata-Pine

Abstract

Numerous chemical preservative treatments are available to enhance the durability of timber species with low natural durability. These treatments may modify the fire properties of timber. An experimental program has been undertaken using the cone calorimeter to investigation the fire properties of waterborne copper-based preservative treated radiata pine as part of a larger program identifying applications, material fire properties and design details for preservative treated timber fencing and sleeper products in Bushfire Prone Areas (BPAs).

Enhanced cone calorimeter test protocols were developed requiring measurement of back face temperatures, extended monitoring after termination of heating, measuring internal temperatures and varying heating durations to investigate the effects of water borne copper based preservative treatments on sustained smouldering combustion of radiata pine.
.
The enhanced cone calorimeter test protocols successfully differentiated the performance of different treatments or radiata pine and untreated radiata pine and identified critical heating durations and irradiance level combinations below which the likelihood of the occurrence of sustained smouldering combustion is substantially reduced.

The outcomes were consistent with other findings in that water borne copper-based preservative treatments do not substantially modify other fire properties of radiata pine such as the time to ignition and heat release rates. The times to ignition and HRR data under a range of exposure conditions for water borne copper-based preservative treated radiata pine is provided. The impact of accelerated weathering was also quantified.

A preliminary study to determine the impact of pre-wetting preservative treated radiata pine on its fire properties was included. The study demonstrated that there was significant potential to increase the time to ignition at irradiance levels at irradiance levels of 19kW/m^2 but the impact would be less at higher irradiance levels.

Introduction

Objective

The objective of this research program is to demonstrate the fire performance of preservative treated radiata pine fencing and sleeper garden walls in bushfire prone areas. The performance of the fences and sleeper walls is to be evaluated when exposed to radiant heat flux levels and exposure durations comparable to the AS 3959 (Standards_Australia 2018) Bushfire Attack Levels (BALs) and associated AS 1530.8.1 (Standards_Australia 2018) test methods.

The required treatment levels and compositions for commonly used waterborne copper-based preservative treatments available in Australia are provided in AS/NZS 1604.1 (Standards_Australia 2021).

The program focussed on the following waterborne copper-based treatments that are defined in AS/NZS 1604.1. The treatments have been identified as treatments A to D throughout this report since the outcomes are intended to apply equally to all the treatments.

- Micronized Copper Azole (MCuAz)
- Alkaline Copper Quaternary (ACQ)
- Copper Azole (CuAz)
- Copper-Chromium-Arsenic (CCA)

The objectives of this part of the research program were to

- undertake comparative screening tests to select a critical treatment for more detailed investigation and full-scale testing and compare the performance of the treated radiata pine with untreated radiata pine.
- quantify critical fire properties of waterborne copper-based preservative treated radiata pine and compare the results to the fire properties of untreated radiata pine.

Data obtained relating to the fire properties of preservative treated radiata pine may have broader applications to other elements of construction in bushfire prone areas and to fire exposures other than those associated with bushfires including internal structural fires. Therefore, the fire properties of waterborne copper-based preservative treated Radiata Pine with an emphasis on the properties that can impact on ignition and fire spread have been reported separately in this Appendix.

Some fire properties of wood products are sensitive to the density of timber and moisture content and when considering the impact of preservative treatments, issues such as the proportion of sapwood, retention rates and penetration of the treatment are also relevant.

To address the inherent variability the test program sought to use representative samples and as appropriate, identify the potential impact of variations in material properties.

Background

This Appendix focuses on the following critical fire properties:

- Time to ignition
- Heat Release Rate (HRR)
- Mass Loss
- Potential for sustained smouldering combustion

The cone calorimeter /oxygen consumption calorimetry was selected because it can measure a broad range of parameters with a bench scale apparatus in a reasonably cost effective manner and facilities are readily available and commonly used for both research and to provide evidence of suitability with the National Construction Code (NCC) (ABCB 2020) and AS 3959:2018 (Standards_Australia 2018).

The first three critical parameters are standard outputs from cone calorimeters.

There are other advantages in adopting methods based on cone calorimeter data. For example, there is a large pre-existing source of data available which can be used to make meaningful comparisons with existing research on other species and some available correlations can be adopted. To this end, commonly used irradiance exposures of 25kW/m^2 and 50kW/m^2 were adopted for the Stage 1 comparisons which were then expanded in Stage 2 to include exposures to the maximum radiant heat fluxes associated with AS3959 Bushfire Attack Level classifications (i.e. 12.5kW/m^2, 19kW/m^2, 29kW/m^2, 40kW/m^2). A limited amount of work was undertaken at heat fluxes of 15kW/m^2 and 75kW/m^2

Untreated timber of sufficient cross-section can exhibit self-extinguishing behaviour if there is no external heat source and there are sufficient heat losses from the timber element boundaries. Sustained smouldering combustion tends to occur with untreated timber in configurations where thermal feedback occurs between adjacent surfaces or there is some other external heat flux applied and /or there are limited heat losses from the timber element surfaces. Conditions under which timber can self-extinguish have been investigated by numerous researchers including (Crielaard, van de Kuilen et al. 2019).

A greater tendency for sustained smouldering combustion of preservative treated timber (commonly described as ‘afterglow’) has been observed, which can result in the total destruction of some preservative treated fence posts after bushfires. This behaviour was also demonstrated in fire tests. (Evans, Beutel et al. 1994, Gardner and White 2009).

In order to evaluate the potential for sustained smouldering or self-extinguishing behaviour, supplementary procedures incorporating the determination of mass loss over the 24-hour period following the test were developed and refined during the project.

Radiata pine treated with waterborne copper-based preservative treatments

General details and material properties of the main constituents of radiata pine treated with waterborne copper-based preservative treatments that have been evaluated in this program are described below:

Common copper-based preservative treatments used in Australia.

Studies described in Attachment 1 identified that the quantity of copper (typically in the form of copper oxides) in a timber treatment significantly increases the propensity for sustained smouldering combustion. Additional constituents of a treatment, such as other metal oxides can further increase afterglow whilst other constituents may react with copper and other metal oxides if present; reducing the tendency for sustained smouldering combustion.

With respect to CCA, the chromium content may further increase the tendency for sustained smouldering combustion but if the arsenic reacts with the Copper and/or Chromium compounds, the tendency for sustained smouldering combustion may be reduced. The outcome appears to be sensitive to the heating rate and extent and timing of volatilisation of the arsenic prior to the reaction with the copper or chromium compounds.

The minimum copper quantities required for copper-based timber preservatives in Australia are specified in AS / NZS 1604.1 (Standards_Australia 2021). The standard also nominates permitted ranges for other key constituents of the preservatives. These are summarised in Table 1 for hazard classes H3 and H4 (which generally apply to components used in timber fencing and sleeper walls above ground and inground respectively). The typical copper and chromium contents are derived for comparison assuming mid-range values for the proportions of key constituents permitted by AS / NZS 1604.1. The total of Cu and combination of Cu and Cr for CCA preservatives have been calculated and compared with the Cu content for other preservatives in Table 1.

Table 1 Comparison of constituents of common copper-based preservative treatments for application to softwoods

Hazard Class	Treatment	Mid-range		Typical % of oven dry weight of timber			
		Cu (%)	Cr (%)	Preservative (minimum)	Cu	Cr	Cu+Cr
H3	Copper Chrome Arsenic - CCA	24	41.5	0.38	0.091	0.158	0.249
H3	Alkaline Copper Quaternary - ACQ	61.5	-	0.35	0.215	-	0.215
H3	Copper Azole -CA	96.2	-	0.229	0.220	-	0.220
H3	Micronized Copper Azole - MCA	96.2	-	0.229	0.220	-	0.220
H4	Copper Chrome Arsenic -CCA	24	41.5	0.63	0.151	0.261	0.412
H4	Alkaline Copper Quaternary - ACQ	61.5	-	0.89	0.547	-	0.547
H4	Copper Azole -CA	96.2	-	0.416	0.400	-	0.400
H4	Micronized Copper Azole - MCA	96.2	-	0.416	0.400	-	0.400

The total metal content (Cu and Cr) for Hazard Classes H3 and H4 are within approximately 13% and 3% for CCA and Copper Azole preservatives respectively with ACQ potentially requiring a higher concentration of Cu for the H4 hazard Class. The fire properties of radiata pine with common waterborne copper-based preservative treatments were compared based on an experimental study described in "Stage 1 Initial comparative evaluation of waterborne copper based preservative treated and untreated radiata pine"(Page 8)

Density Distribution for Australian radiata pine

Densities of timber can vary with climate, soil conditions, genetics, and forestry practices. Some fire properties of timber vary with density and timber densities have been recorded during the program to confirm they are representative. The distribution shown in Figure 1 has been derived from a large sample of structural radiata pine from Australian plantations. A normal distribution has been assumed with a mean value of approximately 463 kg/m^3 and a Standard deviation of approximately 66kg/m^3.

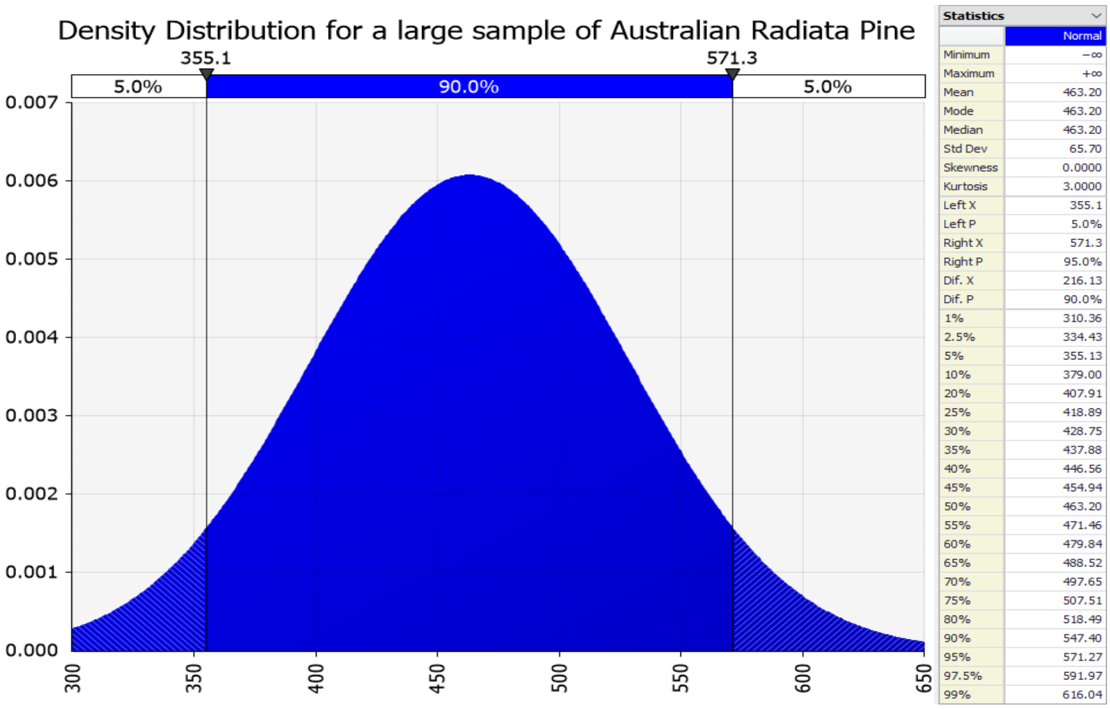


Figure 1 Density Distribution from a large sample of Australian Radiata Pine (Morrell 2022)

The distributions for the cone calorimeter samples for paling and fence framing / sleepers are shown in Figure 2. These are broadly similar to the distribution obtain from Australian plantations but with a mean densities of approximately 492kg/m^3 (an increase of approximately 6.3% from the plantation survey and a reduction in the standard deviation to 50-53 kg/m^3).

The density value for radiata pine of 550kg/m^3, at a moisture content of 12%, quoted in AS 1720.1 (Standards_Australia 2010) is for use only in computing dead load due to mass of timber. It represents an approximate 90 percentile value based on the plantation distributions above which is consistent with the need for a conservative high value for estimating the dead load associated with a structure.

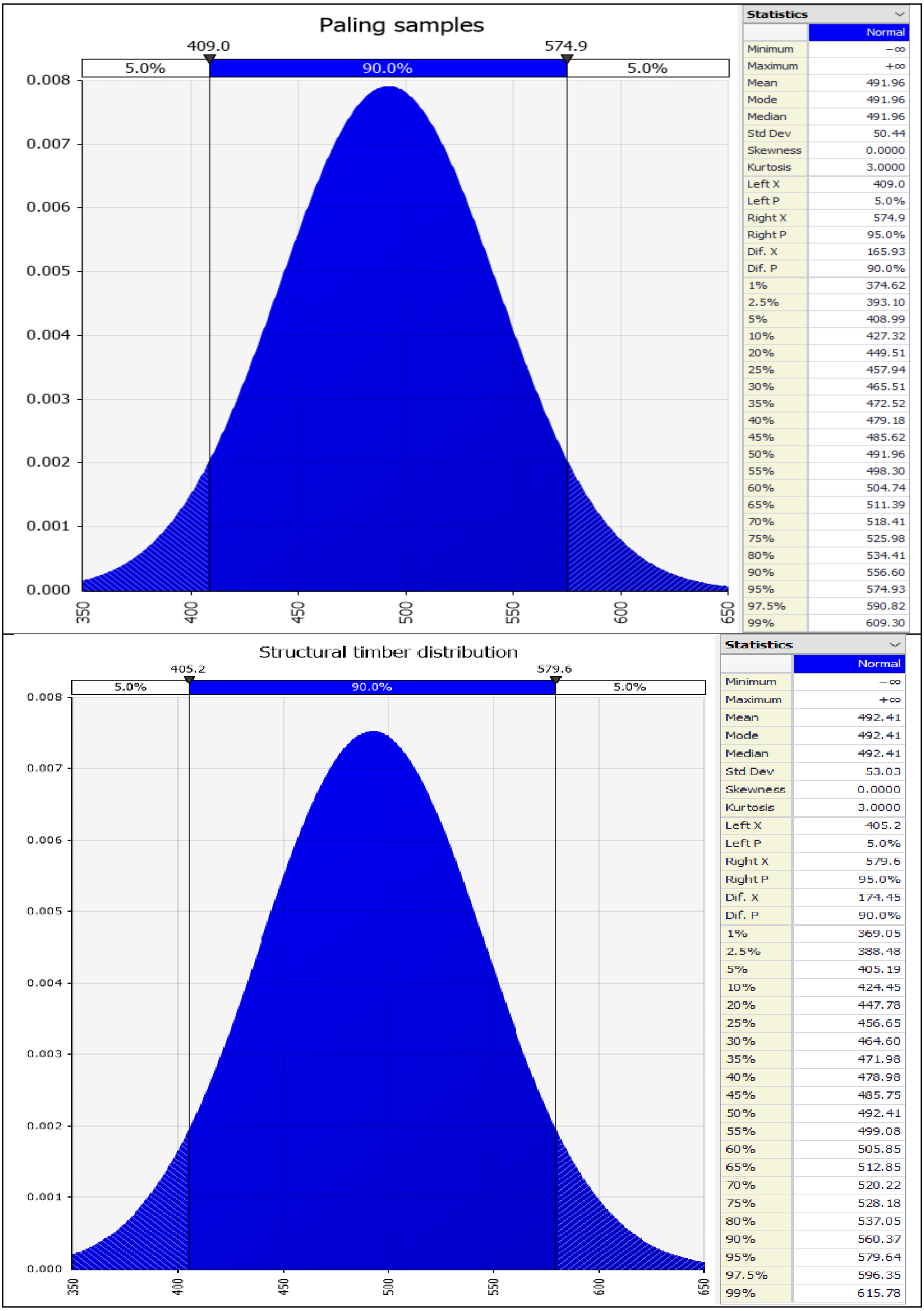


Figure 2 Distribution of densities for samples of Radiata Pine subjected to Cone calorimeter tests

Surface finish of timber

Structural timbers used included timber sections that were not sanded with rough unfinished surfaces typical of fence posts and sleepers (Stick references S1-S9)

Dressed timber samples were also incorporated in the test series (Stick references S10 to S20). Surface finishes / imperfections can cause variations in the time to ignition particularly at lower heat fluxes. Samples exposed to accelerated weathering tests were also included in the program which can also impact on surface finishes

Stage 1 Initial comparative evaluation of waterborne copper based preservative treated and untreated radiata pine

Methodology for comparative evaluation of treated timbers and untreated timber

Fencing components and sleeper wall components can be grouped as:

(i) thicker timber members used for posts and the main framing of fences and sleepers for garden and retaining walls; or
(ii) thinner timbers members for palings and other members which may be of the order of 12mm thick.

The cone calorimeter test procedures need to cover both these applications and therefore test protocols were prepared nominating two material thicknesses and corresponding irradiance levels and test durations. Copies of the protocols initially issued to the laboratories are included as Attachments 2 and 3.

The protocols also address issues such as specimen mounting and orientation and requirements for monitoring the behaviour of the specimen after exposure to the heat source. This includes mass loss measurements at 15-minute intervals for 1-hour after termination of heating and at 24-hours after termination of heating to determine the extent of sustained smouldering combustion.

Typical samples of the treated and untreated radiata pine were also subjected to accelerated weathering using the procedures defined in Appendix F of AS 3959. These procedures require exposure to ASTM D2898 Method B (ASTM 2010) regime with the water flow rate modified to be the same as ASTM D2898 Method A. The specimens were then conditioned and tested in accordance with ISO 5660.1 (ISO 2015).

The tests were performed by Accredited Testing Laboratories.

Materials

The test series included four waterborne copper-based preservative treatments applied to radiata pine and untreated radiata pine controls. Samples of painted radiata pine and a treatment that was not copper based were also included but lie outside the scope of this report.

A matrix of the relevant tests undertaken during the initial study is provided in Table 2. A minimum of three replicate samples were tested as required by ISO 5660.1. The preservative treated samples will be referenced throughout this report using the code references from Table 2.

Table 2 Matrix of test undertaken

Treatment	Standard Conditioning		Accelerated weathering and Standard Conditioning	
	≥ 38mm	≈12mm	≥ 38mm	≈12mm
A	A1	A2	WA1	WA2
B	B1	B2	WB1	
C	C1	C2	WC1	WC2
D	D1	D2	WD1	
F Control	F1	F2	WF1	WF2

Further details of the properties of the tested samples are summarised in Table 3. All specimens were conditioned to constant mass at a temperature of 23 ± 2°C and relative humidity of 50 ± 5%. Specimens with the W prefix were subjected to accelerated weathering prior to conditioning to constant mass.

Table 3 Summary of cone calorimeter specimen properties

Treatment Ref	Accelerated. Weathering	Thickness (mm)	Density (kg/m³)	Moisture Content (%)
A1	N	40	469	11.2
B1	N	41	488	10.8
C1	N	40	433	10.5
D1	N	39	469	11.2
E1	N	40	573	9.6
F1 (Control)	N	40	503	10.9
A2	N	12	473	10.6
B2	N	13	467	10.4
C2	N	10	422	10.6
D2	N	12	516	10.4
F2 (Control)	N	12	432	10
WA1	Y	38	466	10.1
WB1	Y	41	439	12.2
WC1	Y	40	475	12.2
WD1	Y	39	435	11.9
WE1	Y	40	526	15.0
WF1 (Control)	Y	40	531	12.1
WA2	Y	12	580	11.5
WC2	Y	13	559	11.8
WF2 (Control)	Y	11	559	11.5

Samples were taken from the batches treated with preservatives and forwarded to an independent accredited test laboratory for assessment of the preservative penetration and determination of retention rates.

Figure 3 below shows how test samples were cut from nominal 800mm long sticks for testing in the cone calorimeter. A length of at least 50mm is removed from each end to reduce end effects where the end grain is exposed. Samples nominally 100mm x 100mm were then cut from the remainder of the stick avoiding as far as practical major flaws such as large knots.

Additional sticks were prepared as part of the original test series in Stage 1. These were not exposed to accelerated weathering. Two additional sticks for each thickness and treatment were used to determine retention rates which were calculated from specimens taken from positions 1 and 2. A sample closest to exposed end grain and a maximum distance away from the end grain were selected thus being representative of the expected range of retention rates and treatment penetrations that may occur with the treated samples.

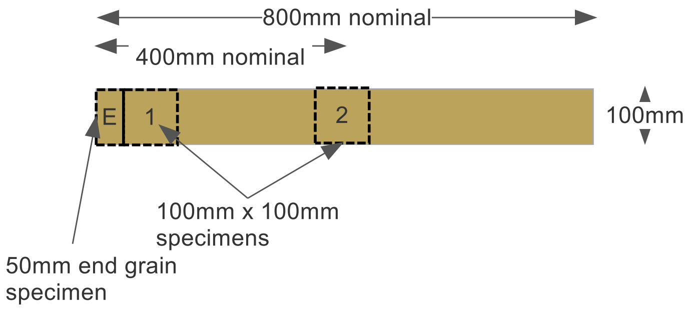


Figure 3 Sampling for determination of retention rates and compliance with penetration criteria

The ratio of the estimated actual retention rate over the prescribed rate was calculated for the copper-based materials. A value greater than 1 indicated the retention rate was estimated to be above the minimum prescribed retention rate specified in AS /NZS 1604.1 (Standards_Australia 2021).

The results are summarised in Table 4 with mean retention ratios being greater than 1 for all the nominally 12mm thick samples and treatment A1 and C1 for the 40mm samples. Samples with treatment A exhibited the highest retention ratios followed by those with treatment C. The penetration spot test results are expressed as the number of samples passing over the number of samples evaluated. There were no failed penetration tests for the thinner samples or for sample A with a nominal thickness of 40mm. The penetration results for samples B and C were 2 passes from 4 tests and for Specimen D no passes from 4 tests.

Table 4 Retention Ratios and Penetration pass rate for the four samples of each copper based preservative treatment

Treatment Ref	Thick-ness (mm)	Retention Ratios based on AS/NZS 1604.1 requirements			Penetration (Pass rate)
		Mean	Max	Min	
A1	40	1.45	1.98	1.02	4/4
B1	41	0.36	0.4	0.29	2/4
C1	40	1.01	1.42	0.72	2/4
D1	39	0.71	0.99	0.53	0/4
A2	12	1.54	1.71	1.37	4/4
B2	13	1.22	1.71	0.68	4/4
C2	10	1.52	1.70	1.35	4/4
D2	12	1.31	1.79	1.05	4/4

The accelerated weathering test samples for penetration and retention testing were derived from off-cuts and excess samples as shown in Figure 4.

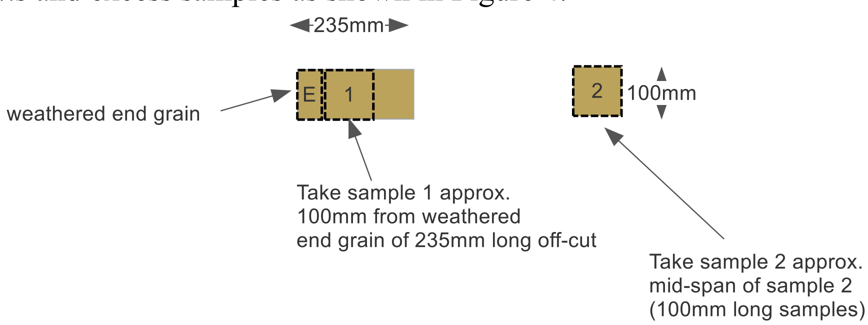


Figure 4 Samplings for determination of retention rates and compliance with penetration criteria after accelerated weathering in accordance with the requirements of AS 3959.

Since only a single stick of each treatment was subjected to accelerated weathering two samples were available to provide an indication of the variation in retention ratios and penetration spot test results. The results are summarised in Table 5.

Table 5 Retention Ratios and Penetration pass rate for the four samples of each copper based preservative treatment after accelerated weathering

Treatment Ref	Nominal thickness (mm)	Retention Ratios based on AS/NZS 1604.1 requirements			Penetration (Pass rate)
		Mean	Max	Min	
WA1	40	1.12	1.22	1.02	2/2
WB1	40	0.57	0.59	0.55	2/2
WC1	40	0.92	0.94	0.89	2/2
WD1	40	0.79	0.99	0.58	0/2
WA2	12	0.66	0.71	0.61	2/2
WC2	12	0.67	0.77	0.59	2/2

The mean retention ratios for treatments A and C were 1.12 and 0.92 respectively for the 40mm nominal thickness samples and 0.66 and 0.67 respectively for the 12mm nominal thickness samples.

Mean retention ratios for treatments B and D were 0.57 and 0.79 respectively for the 40mm thick samples. Penetration spot test results indicated 100% pass rates for all samples except for treatment D where there were no passes from two tests for a nominal 40mm thick sample.

Results and Discussion

Post-test mass loss measurements for determination of sustained smouldering combustion.

Mass loss measurements were taken at 15 minute intervals for a period of one hour after heating was terminated followed by an additional measurement 24-hours after termination of heating to investigate sustained smouldering combustion of the samples.

The method effectively identified sustained smouldering behaviour and differentiated the relative performance of the preservative treated timbers and the control sample when applied to the nominally 41mm thick samples at an irradiance of $50kW/m^2$.

The mass data at the termination of exposure and 1-hour and 24-hours after termination are presented in Table 6 and the mass loss between 1 and 24-hours after termination of heating is shown in Table 7.

Some specimens showed a minor increase in weight during this later period which is likely to be the result of absorption of moisture by the residue; under these circumstances a zero value is recorded. Specimen types A, C and D (after weathering) showed clear evidence of sustained smouldering combustion which is most evident in Table 7.

The thinner palings specimens (nominally 12mm thick) were substantially consumed within the 10-minute heating period making resolution of sustained smouldering behaviour difficult.

Table 6 Cone Calorimeter specimen mass after termination of heating

Specimen Ref	Sample masses (g)						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean
At end of exposure							
A1	74.6	74.9	75.7				75.1
WA1	53.2	41.7	46.8				47.2
B1	70.3	80.3	84.5				78.4
WB1	52.3	50.3	52.4				51.7
C1	57.0	60.2	47.6	54.3	60.2	68.7	58.0
WC1	42.4	47.0	47.8				45.7
D1	71.6	69.4	69.4				70.2
WD1	37.2	37.8	37.3				37.4
F1 (Control)	72.0	77.7	70.5	76.8			74.3
WF1 (Control)	84.8	78.3	86.5				83.2
1h after exposure	1	2	3	4	5	6	Mean
A1	34.4	33.7	35.4				34.5
WA1	41.9	33.1	21.2				32.1
B1	31.5	37.3	40.7				36.5
WB1	42.7	41.6	48.2				44.2
C1	19.2	23.1	18.0	23.9	26.5	32.4	23.9
WC1	15.1	21.7	43.5				26.8
D1	31.2	31.8	31.1				31.4
WD1	36.2	35.3	22.8				31.4
F1 (Control)	32.5	33.9	31.6	33.6			32.9
WF1 (Control)	83.8	76.9	85.1				81.9
24h after exposure	1	2	3	4	5	6	mean
A1	4.4	30.5	34.8				23.2
WA1	31.2	4.9	5.0				13.7
B1	30.4	36.5	39.8				35.6
WB1	42.7	41.6	48.2				44.2
C1	4.4	6.0	3.1	3.0	2.8	2.8	3.7
WC1	3.3	2.9	2.6				2.9
D1	30.5	30.2	22.5				27.7
WD1	3.8	26.7	13.1				14.5
F1 (Control)	31.6	34.5	32.4	32.5			32.8
WF1 (Control)	85.0	78.1	86.4				83.2

Table 7 Cone Calorimeter specimen mass loss between 1 and 24-hours after termination of heating

Specimen Reference	Mass loss between 1 and 24-h after termination of heating (g)						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean
A1	30.0	3.2	0.6				11.3
WA1	10.7	28.2	16.2				18.4
B1	1.1	0.8	0.9				0.9
WB1	0.0	0.0	0.0				0.0
C1	14.8	17.1	14.9	20.9	23.7	29.6	20.2
WC1	11.8	18.8	40.9				23.8
D1	0.7	1.6	8.6				3.6
WD1	32.4	8.6	9.7				16.9
F1 (Control)	0.9	0	0	1.1			0.7
WF1 (Control)	0	0	0				0

From Table 7 Specimen references A, C and D showed susceptibility to sustained smouldering combustion and treatment C was proposed to be used for the following testing programs where sustained smouldering combustion (afterglow) needs to be evaluated on the basis that the results could be conservatively applied to all four of the evaluated treatments.

The data obtained from the cone calorimeter tests reflected the stochastic nature of self-extinguishment where minor variations will impact the timing and probability of a sample self-extinguishing as will external factors such as minor variations in airflow.

Time to ignition and HRR Comparisons

There are a number of parameters that can be used to compare the fire properties of timber; including the time to ignition, peak heat release rate, time averaged heat release rates after ignition and the maximum average rate of heat emission (MARHE).

These results together with key physical properties of the samples are summarised in the following Tables and Figures.

The results for the nominal, 41mm samples are presented in Table 8 (with additional data from an untreated radiata pine specimen with applied acrylic paint. The results are reasonably consistent with, for example, the maximum and minimum MARHE values varying from the mean of all treatments by less than 5.1% and 6.1% respectively.

Table 8 Summary of cone calorimeter time to ignition and heat release rate data for specimens of nominal 41mm thickness excluding treated timber E results, exposed to 50kW/m² irradiance

Specimen	T_{ig} (s)	Peak HRR (kW/m²)	HRR_{120} (kW/m²)	HRR_{300} (kW/m²)	HRR_{600} (kW/m²)	MARHE (kW/m²)	Density (kg/m³)
A1	13	163	126	107	90	114.6	469
WA1	19	168	130	110	94	111.3	466
B1	14	169	121	109	95	107.6	488
WB1	11	173	127	108	94	116.6	439
C1	12	167	126	109	93	112.7	433
WC1	21	179	137	118	102	117.4	475
D1	15	173	123	104	91	108.1	469
WD1	19	175	139	117	101	120.5	435
F1 (Control)	16	168	137	117	100	119.7	503
WF1 (Control)	25	178	139	120	102	114.6	531
G1 (Acrylic P)	12	184	129	114	102	117	557
Mean	16	172	130	112	97	114.6	479
Max	25	184	139	120	102	120.5	557
Min	11	163	121	104	90	107.6	433
S.D	4.2	6	6	5	4	4.1	38

T_{ig} – Time to ignition, HRR-Heat Release Rate, HRR_n – HHR averaged over n seconds after ignition, MARHE – maximum average rate of heat of emission, SD standard deviation

Figure 5 Comparison of HRR data for all specimens of nominal 41mm thickness, exposed to 50kW/m² irradiance

The paling specimen results from tests on nominally 12mm thick samples at an irradiance of 25kW/m^2 are shown in Table 9 and Figure 6. There was a significant variance between the three specimens tested before and after weathering (designated A, C and F) where F was the untreated control. In all these cases, the HRR was significantly higher for the samples that were subjected to accelerated weathering. For example, the maximum MARHE value from the three weathered materials was over 20% above the mean for all the materials. This was inconsistent with the thicker specimen results where there were only small variations in HRR.

Table 9 Summary of cone calorimeter time to ignition and heat release rate data for all specimens of nominal 12mm thickness, exposed to 25kW/m^2 irradiance

Specimen	T_{ig} (s)	Peak HRR (kW/m^2)	HRR_{120} (kW/m^2)	HRR_{300} (kW/m^2)	HRR_{600} (kW/m^2)	MARHE (kW/m^2)	Density (kg/m^3)
A2	99	126	94	77	87	75.2	473
WA2	140	188	107	90	113	91.5	580
B2	90	120	81	66	79	68.2	467
C2	82	118	75	68	69	66.7	422
WC2	119	180	97	78	97	81.1	559
D2	102	130	89	71	73	66.4	516
F2 (Control)	101	128	84	70	83	72.4	432
WF2 (Control)	121	200	91	78	103	86.4	559
G2 (Acrylic P)	78	100	87	66	83	73.55	495
Mean	104	143	89	74	87	75.7	500.3
Maximum	140	200	107	90	113	91.5	580
Minimum	78	100	75	66	69	66.4	422
SD	18.9	33.9	8.8	7.3	13.5	8.4	53.9

T_{ig} – Time to ignition, HRR-Heat Release Rate, HRR_n – HHR averaged over n seconds after ignition, MARHE – maximum average rate of heat of emission, SD standard deviation

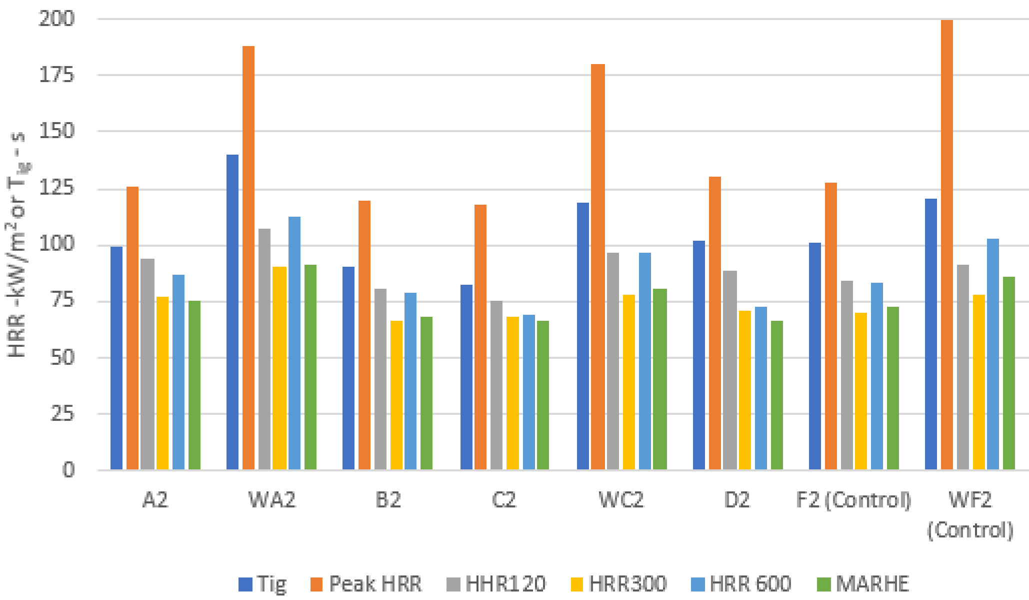


Figure 6 Comparison of HRR data and piloted ignition time for specimens of nominal 12mm thickness, exposed to 25kW/m^2 irradiance

The variation can be explained by the distribution of densities which ranged from 422 to 580kg/m^3 with the weathered samples having substantially higher densities than the rest of the group. Higher density samples will tend to have longer times to ignition because additional time is required to heat the additional mass of material sufficiently to increase the pyrolysis rate to a level where the concentration of volatiles released exceeds the lower flammability limit . This then tends to increase the pre-heating of the specimen prior to ignition which can result in a higher HRR peak immediately after ignition. The delay in ignition time for the higher density specimens is clearly shown in Figure 6. If the high density samples WA2, WC2 and WF2 are compared in isolation the heat release rate (HRR) results were consistent.

Conclusions from Stage 1 Preliminary Experiments

The test program demonstrated that the cone calorimeter can be used to differentiate treated timber that has a propensity for sustained smouldering.

With 41mm nominal thickness specimens at an irradiance of 50kW/m^2 for 30 minutes and subsequent monitoring period of 24 hours using the protocol in Attachment 2, it was possible to identify three treated timber combinations (A, C and D) that were clearly prone to sustained smouldering combustion with treatment B being borderline at the treatment levels tested.

Testing of retention rates and penetration spot tests on representative samples indicated that the retention rates for treatment B was very low (mean retention rate ratios of 0.36 to 0.57 of the retention rate required by AS / NZS 1604:1:2021) and for treatment D was low (0.71-0.79 of the required retention rate). It was also noted that the penetration was below requirements for all samples tested for treatment B. These variations may explain at least in part the lower tendencies for sustained smouldering combustion for treatments B and D.

The mean retention rate ratios for treatment A were 1.12 and 1.45 of the retention rate required by AS /NZS 1604:1 with all the spot tested samples passing the AS /NZS 1604:1 criteria whilst mean retention rates for treatment C were 0.92 and 1.01 for the accelerated weathered and unweathered specimens respectively and half of the unweathered samples did not pass the penetration spot test.

Based on the post exposure mass loss results, treatment C exhibited the greatest tendency to promote sustained smouldering combustion despite treatment C test samples having lower retention rate ratios compared to treatment A. Therefore, if sustained smouldering combustion is a critical part of an evaluation, treated pine with treatment C will be selected to provide results for general application.

With thinner specimens (e.g. 12mm thick) at an irradiance of 25kW/m^2 for 10 minutes, the entire cross-section of the specimen was substantially pre-heated through to the rear face of the specimen such that the majority of the specimen had been consumed at the end of the heating period or shortly after.

For thinner materials, some adjustment to the protocol in Attachment 2 would be required to successfully identify treatments that promote sustained smouldering behaviour. Modifications that could be evaluated include testing at an increased thickness or reducing the period of exposure below 10 minutes. However, thinner materials if ignited are likely to be consumed during flaming combustion and sustained smouldering combustion may not be significant when materials nominally 12mm thick or less are used.

In the context of bushfire protection, sustained smouldering combustion is most significant for larger elements of construction that could potentially self-extinguish, if preservative treatments do not promote sustained smouldering combustion. How critical smouldering combustion is depends on the specific applications and potential risks to people and property.

Therefore, the protocol defined in Attachment 3 applied to timber samples of a minimum thickness of 35mm can be used to identify and evaluate wood-based materials with a potential for sustained smouldering combustion. Generally excluding differences relating to sustained smouldering combustion the fire properties were similar for all the remaining treatments and untreated radiata pine. This means that for applications where sustained smouldering combustion is not a critical factor, fire properties such as the time to ignition and heat release rate data during flaming combustion for any one of the four types of waterborne copper-based treated radiata pine or untreated pine may be applied. For other treatments appropriate comparative data should be obtained before making this assumption. The protocols and data derived from this study may be useful for the comparative testing

It was identified that sustained smouldering combustion is potentially sensitive to heating rates, duration of heating, boundary conditions and density and thickness of the timber element in addition to preservative and fire retardant treatments. Some further comparative testing was therefore undertaken comparing treatments A and C and untreated controls under a range of irradiance levels, exposure times to further evaluate the sensitivity to these variables during Stage 2. This work was integrated into a broader experimental program investigating the fire properties of treated timber over a range of exposure conditions including determination of key fire properties of timber exposed to the peak heat flux levels specified in AS 3959 as part of the bushfire attack level (BAL) classification system (i.e. 12.5, 19, 29 and 40kW/m^2) for different time periods.

Stage 2 Investigation of fire properties of waterborne copper-based preservative treated radiata pine

Introduction

The cone calorimeter protocols from Stage 1 were enhanced for Stage 2 to investigate the fire properties of preservative treated timbers including sensitivity to sustained combustion under a range of exposure conditions including:

- time of exposure to peak radiant heat (varying from 3 to 30 minutes)
- peak incident imposed radiant heat varying from 12.5kW/m^2 to 75kW/m^2
- specimens conditioned to constant mass when exposed to temperature and relative humidity of approximately 23°C and 50% or 35°C and 25% relative humidity
- piloted and unpiloted ignition

Specimens also incorporated typical variations in material properties including

- variations of radiata pine
- variations in treatment levels.
- proportion of sapwood

In addition, the protocols were expanded to incorporate an option to monitor internal temperatures when testing thicker specimens which can provide data relating to char rates and sustained smouldering combustion during and after exposure to heating.

Further details are provided in Attachment 4

Extension of Stage 1 Comparative Program and preliminary evaluation of enhancements to the test protocols

The updated test protocols for stage 2 were also adopted to provide additional confidence in the selection of the treatment to be used in Stage 2 and Stage 3 testing.

Paling tests

Methodology

The extension of the initial comparative test program for palings was limited to a comparison between an untreated control (treatment F) and specimens with preservative treatments A and C, the two treatments that promote sustained smouldering combustion the most at an irradiance of 19kW/m^2 rather than the 25kW/m^2 adopted in the Stage 1 tests. The tests on each treatment were undertaken on three samples, nominally 12mm thick, after conditioning at 23°C and 50% relative humidity in accordance with ISO 5660-1 (ISO 2015). The irradiance periods after ignition for each treatment were 3, 5 or10 minutes for the three samples of each treatment

Materials

One set of specimens (identified as treatment F) was an untreated control, and the other two specimen sets (identified as treatments A and C) were water-borne copper-based preservative treatments to an intended hazard class of H3. The specimens were cut from a nominally 800mm long sticks identified as P1, P2 and P9 and a sample from each stick was tested by an accredited test laboratory to determine retention rates, percentage sapwood and to undertake a spot penetration test. The results are summarised in Table 10.

Table 10 Material Properties for Radiata Pine Paling Samples for a comparative study when exposed to an irradiance of 19kW/m2 for time periods of 3, 5 and 10 minutes after ignition.

Treat-ment Ref	Stick ID	Thick-ness (mm)	Retention Ratio based on AS/NZS 1604.1 H3 requirements	Penetration Test results	Sapwood %
A	P1	13	0.97	Pass	30%
C	P2	13	0.92	Fail	45%
F	P9	12			

Results and Discussion

The results of the paling test series extension are summarised in Table 11. It can be observed that the times to sustained flaming ignition, peak heat release rates (first peak) and average heat release rate are similar for the treated and untreated specimens exposed to an irradiance of 19kW/m^2.

Table 11 Summary of results from a comparative study of Radiata Pine Paling when exposed to an irradiance of 19kW/m2 for time periods between 3,5 and 10 minutes after ignition

Treatment -specimen ID	Density (kg/m^3)	mc %	t_{ig}[1] (s)	Exp. after ig[2] (min)	Peak HRR (kW/m^2)	HRR_{180} (kW/m^2)	Specimen mass after exposure (g)			
							EoE[3]	EoE[3] +30 min	EoE[3] +60 min	EoE[3] +24 h
F-P9-2	427	9.0	396	3	98	70	33.6	33.7	33.6	35.5
F-P9-3	439	9.3	403	5	106	74	15.9	3.6	3.4	1.7
F-P9-4	438	9.1	402	10	91	64	11.6	2.5	1.9	2.1
A-P1-2	478	8.2	342	3	115	76	43.6	43.4	43.2	44.3
A-P1-3	488	7.3	356	5	113	69	39.9	39.6	39.8	40.2
A-P1-4	472	9.0	407	10	90	60	22.7	7.3	1.8	2.7
C-P1-2	479	10.4	393	3	113	76	38.7	38.2	38.2	39.8
C-P1-3	459	10.1	410	5	115	71	28.6	4.8	1.6	1.9
C-P1-4	473	10.1	455	10	98	67	17.0	3.1	1.4	2.2

1 t_{ig} is the time to flaming ignition after commencement of exposure in seconds
2 Exp after ig" refers to the time of exposure to the nominated irradiance after flaming ignition
3 EoE refers to the mass at end of exposure to the nominated irradiance and EoE +30min refers to the mass 30 minutes after exposure to the nominated irradiance was terminated

The HRR plots for specimens exposed to 19kW/m^2 prior to ignition and for a further 10 minutes after ignition are shown in Figure 7. All the plots follow similar trends with a second peek occurring as the rear face of the specimen becomes involved in combustion. The exposure of the specimen was sufficient to lead to the effective consumption of the specimens leaving minimal residual material. With this level of exposure there were no significant differences between the behaviour of the copper-based water borne preservative treated and untreated radiata pine samples.

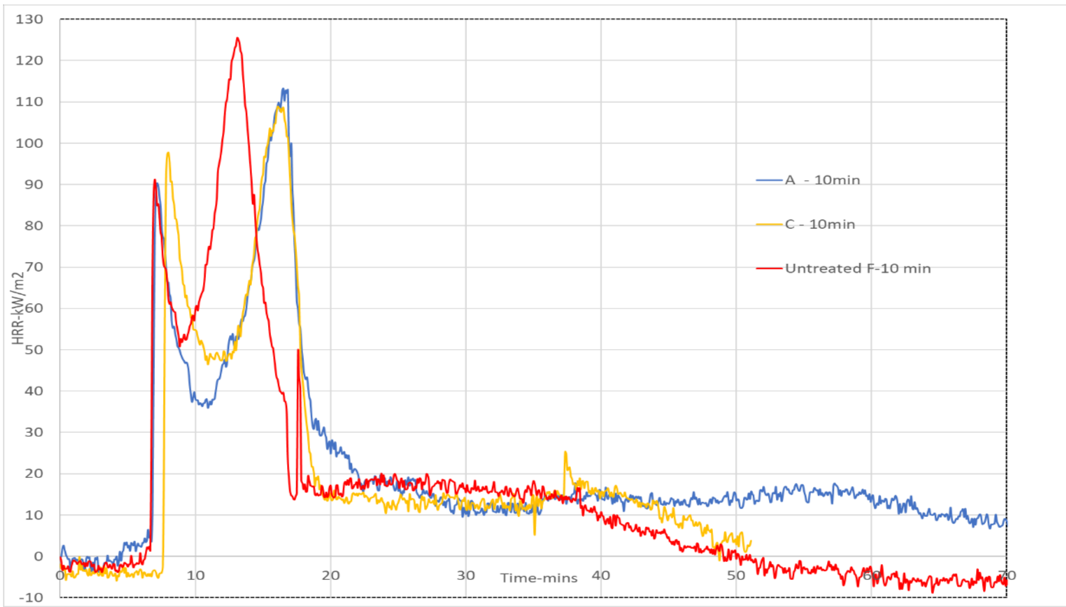


Figure 7 Heat Release Rate for 12mm palings with treatments A and C and untreated exposed to an irradiance of 19kW/m² before ignition and a further 10 minutes

The HRR plots for specimens exposed to 19kW/m² prior to ignition and for a further 3 minutes after ignition shown in Figure 8. All the plots follow similar trends but at this level of exposure no second peaks occur, and all the specimens self-extinguish.

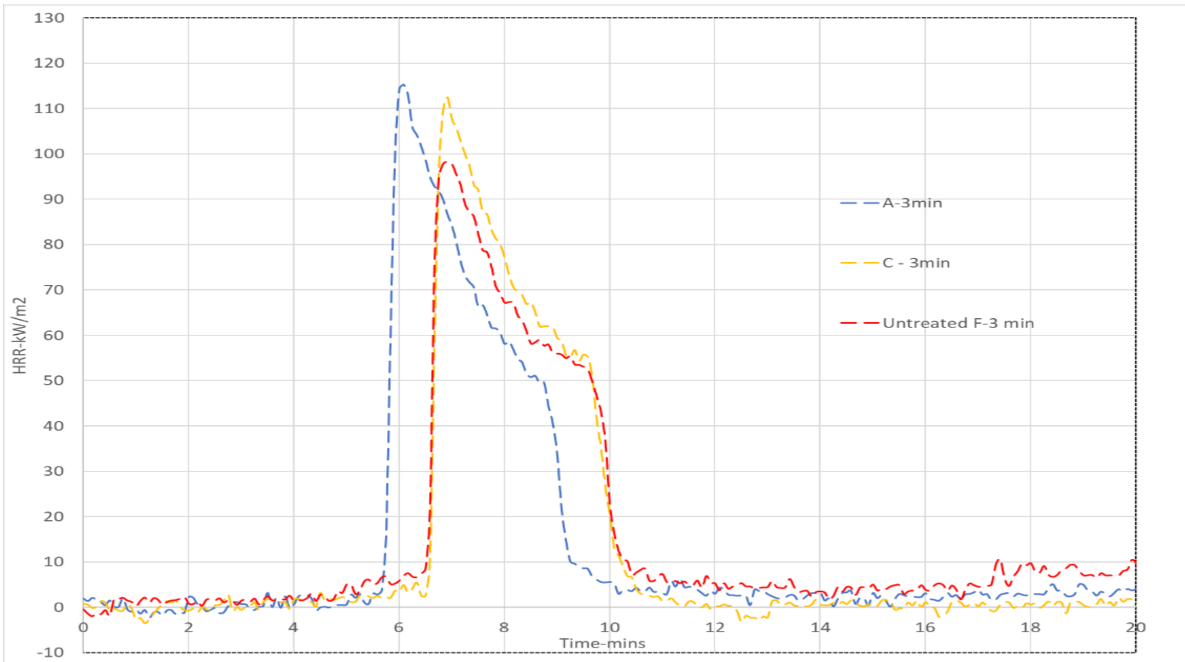


Figure 8 Heat Release Rate for 12mm palings with treatments A and C and untreated exposed to an irradiance of 19kW/m2 before ignition and a further 3 minutes

Figure 9 shows the HRR plots for specimens exposed to 19kW/m² until ignition occurs and for a further five minutes. The untreated specimen and specimen with treatment C both showed evidence of secondary peaks and within 60 minutes of the termination of exposure the specimens had been effectively consumed whilst the specimen with treatment A self-extinguished shortly after the heat source was removed.

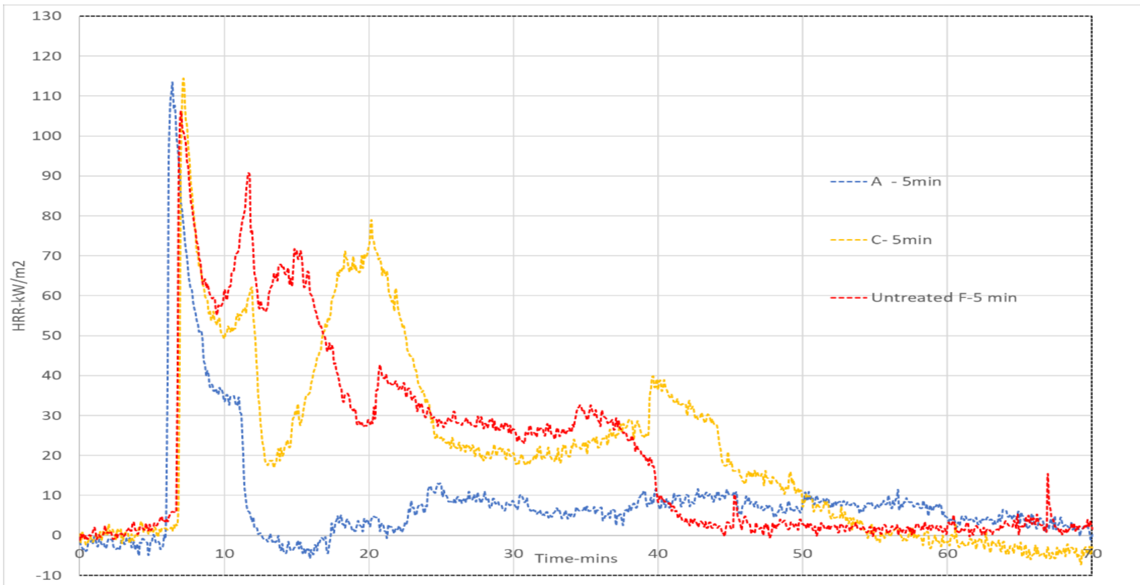


Figure 9 Heat Release Rate for 12mm palings with treatments A and C and untreated exposed to an irradiance of 19kW/m² before ignition and a further 5 minutes

The above behaviour was confirmed by the temperatures measured on the back face of the specimens which are plotted in Figure 10 and the specimen masses reported in Table 11. A transition between the two modes of performance (full consumption within 60 minutes or self-extinguishment) occurs if exposure to an irradiance of 19 kW/m^2 is terminated before 3minutes after ignition (i.e. typical total exposure time of 8 minutes including the pre-ignition time).

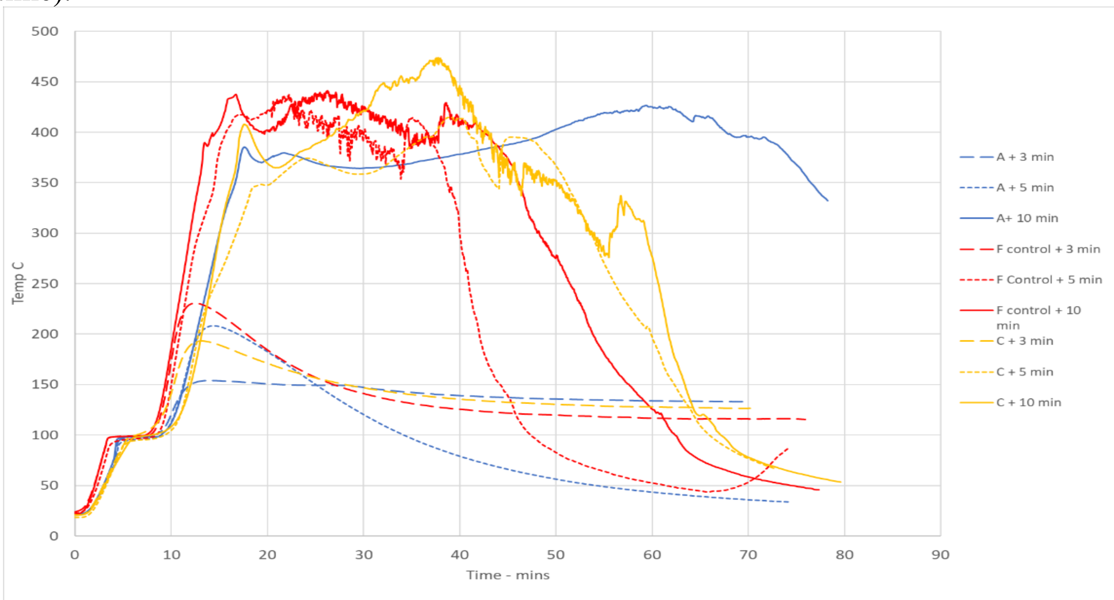


Figure 10 Temperature of back face of 12mm palings with treatments A and C and untreated, exposed to an irradiance of 19kW/m² before ignition and for 3, 5 and 10 minutes after ignition.

Conclusions

Based on the above analysis of the results it was concluded that developing screening tests to identify sustained smouldering behaviour of smaller cross section components such as palings is not necessary because either early self-extinguishment or full consumption can be assumed as a likely outcome depending upon the exposure conditions.

The focus of the screening tests will therefore be on larger cross-section components such as sleepers, posts, and rails.

The results of the above tests are significant in that, provided the exposure of treated and untreated radiata pine to the incident radiant heat flux of $19kW/m^2$ is 3 minutes or less after ignition (or a total of typically 8 minutes if the pre-ignition time is included), self-extinguishment of elements nominally 12mm thick or greater is likely. For exposures above 3 minutes after ignition the specimens are expected to burn until effectively fully consumed in most cases.

Larger cross-section component comparative tests

Methodology

The protocol for larger cross-section components provided in Attachment 3 successfully identified variations in the potential for preservative treatments to promote sustained smouldering combustion in radiata pine elements with larger cross-sections. Notwithstanding this a number of refinements to the protocol were made in this extension of the Stage 1 program to evaluate the fire properties of preservative treated radiata pine and the sensitivity of the protocol to variations in heat flux and exposure duration using irradiance levels of $50kW/m^2$ and $19kW/m^2$.

Materials

Tests on each treatment were undertaken on nominally 40 to 45mm thick specimens after conditioning at 23°C and 50% relative humidity in accordance with ISO 5660-1 (ISO 2015).

One set of specimens of each group was an untreated control and identified as treatment F or UX, and the other two sets of specimens were identified as treatments A or AX and C or CX protected to an intended hazard class of H4.

The X-series specimens were pre-cut to nominally 100 x 100mm and individually prepared / treated. Each specimen was stated to have been pre-cut to size and only specimens with 100% sapwood, similar densities and that were free from significant defects were selected. The end grain was then sealed and specimens that were to be preservative treated were treated individually. These were identified by the codes UX (untreated controls), AX (treated with preservative A) and CX (treated with preservative C) and are shown shaded in Table 12. The densities of these samples were greater than $550kg/m^3$ and were therefore representative of the upper end of the density distribution of radiata pine.

The remaining specimens identified in Table 12, were prepared in a similar manner to other specimens for the cone experiments. They were cut from a nominally 800mm long sticks identified as S15, S5, S8 and S10.

A specimen from each group of pre-prepared and pre-treated specimens (AX and CX) was selected at random and tested by an accredited test laboratory to determine retention rates, confirm the percentage sapwood and to undertake a spot penetration.

For the preservative treated specimens prepared in a similar manner to the rest of the program a sample from each 800mm stick was tested by an accredited test laboratory to determine retention rates, percentage sapwood and to undertake spot penetration tests. The results of the preservative tests are summarised in Table 13.

Table 12 Summary of supplementary comparative test program for protocol development

Specimen treatment	Stick ref.	Irradiance (kW/ m^2)	Irradiance duration after ignition (min) for samples						
			S2 (UX1)	S3	S4(UX2)	S5(UX3)	S5 (A-CX)	S6 (A-CX)	S6
F (untreated control)	UX[2]	19	3	-	10	30	-	-	-
A	S15/AX[2]	19	3	5	10	30	30[2]	30[2]	30[1]
A	S5/ AX[2]	50	3	5	10	30	30[2]	30[2]	30[1]
C	S10/CX[2]	19	3	5	10	30	30[2]	30[2]	30[1]
C	S8/ CX[2]	50	3	5	10	30	30[2]	30[2]	30[1]

Note 1 Internal thermocouples fitted.

Note 2 Pre-prepared samples cut to size and sealed before treatment (cells shaded in blue).

Table 13 Material Properties for Radiata Pine specimens nominally 40mm thick for comparative testing at radiant heat fluxes of 19 and 50kW/m^2.

Treatment Ref	Stick ID	Retention Ratio based on AS/NZS 1604.1 requirements for H4	Penetration results	Sapwood %
A	S15	1.14	Pass	85
	S5	1.1	Pass	90
	AX	0.97	Pass	100
C	S8	1.13	Pass	95
	S10	0.87	Pass	100
	CX	0.87	Pass	100
F	UX1			
	F1			

Results and Discussion

The cone calorimeter comparative test results are summarised in Table 14 for the X-series specimens and in Table 15 for the specimens cut from pre-treated sticks. It can be observed that the peak heat release rates and average heat release rate over 180s after ignition are similar for both the treated samples but higher for the untreated sample exposed to 19kW/m^2. If data from untreated radiata pine is applied to radiata pine with treatments A or C when exposed to an irradiance of 19kW/m^2 the peak HRR and HRR_{180} will yield conservative results. There was some variability with respect to the times to ignition particularly at an irradiance of 19kW/m^2. Large variations in ignition times can occur at low irradiance levels where the ignition times are longer. Suspect outliers have been identified with "**" in Table 14. In addition, specimens F1-Sap-A-6/50 and F1-Sap-C-6/50 were fitted with internal thermocouples and were subjected to low level heating whilst the thermocouples were set up, pre-heating the surface and this is likely to have reduced the time to ignition and increased the peak HRR and therefore data from these tests was excluded from the average values shown in Figure 11.

Table 14 Summary of results from a comparative study of Radiata Pine Sapwood only members, nominally 45mm thick, when exposed to irradiance of 19kW/m² or 50 kW/m² for time periods of 3, 10 or 30 minutes after ignition

Treatment -specimen ID	Density (kg/m³)	mc %	t_{ig}[1] (s)	Exp. after ig[2] (min)	Peak HRR (kW/m²)	HRR180 (kW/m²)	Specimen mass after exposure (g)			
							EoE[3]	EoE[3] +30 min	EoE[3] +60 min	EoE[3] +24 h
F-UX-1/19	552	7.6	301	3	134	103	221.1	220.8	220.6	220.3
F-UX-2/19	572	11.5	379	10	125	81.9	*211.5	*210.8	*210.4	207.4
F-UX-3/19	563	19.0	741**	30	134	105.7	186.8	164.9	*164.1	152.3
A-AX-2/19	556	-	318	30	104	70.7	175.6	151.5	128.4	102.1
A-AX-3/19	570	12.9	193**	30	110	67.7	185.9	161.3	138.4	116.2
A-AX-4/50	616	13.0	24	30	168	122	158.2	128.4	102.6	82.8
A-AX-5/50	558	12.1	10	30	130	111	142.9	116.7	91.0	59.6
C-CX-4/19	580	14.5	440	30	106	71.9	188.5	158.1	125.4	10.3
C-CX-5/19	619	14.9	406	30	112	80.4	201.4	172.2	141.1	32.1
C-CX-2/50	582	13.4	21	30	161	140	146.7	116.8	90.6	55.5
C-CX-3/50	573	13.0	23	30	169	133	140.6	103.6	71.7	4.4

1 t_{ig} is the time to flaming ignition after commencement of exposure in seconds
2 Exp after ig" refers to the time of exposure to the nominated irradiance after ignition
3 EoE refers to the mass at end of exposure to the nominated irradiance and EoE +30min refers to the mass 30 minutes after exposure
* Mass reading may have been affected due to contact of the specimen with the closed shutter
**Inconsistent results

Table 15 Summary of results from a comparative study of Radiata Pine nominally 40mm thick, when exposed to irradiance of 50 kW/m² for time periods of 3,5, 10 or 30 minutes after ignition

Treatment - specimen ID	Density (kg/m³)	mc %	t_{ig}[1] (s)	Exp. after ig[2] (min)	Peak HRR (kW/m²)	HRR180 (kW/m²)	Specimen mass after exposure (g)			
							EoE[3]	EoE[3] +30 min	EoE[3] +60 min	EoE[3] +24 h
F1-1/50	509.1	-	15	30	172	132	72.0	39.5	32.5	31.6
F1-2/50	499.2	-	16	30	165	126	77.7	40.7	33.9	34.5
F1-3/50	492.6	-	10	30	160	124	70.5	38.1	31.6	32.4
F1Sap-A-2/50	536.1	11.9	18	3	145.5	113.6	180.7	140.9	102.5	82.9
F1Sap-A-3/50	538.2	12.1	23	5	160.5	115.1	179.0	137.0	95.5	30.6
F1-Sap-A4/50	535.1	11.6	15	10	150.5	114.9	164.0	126.6	92.9	60.8
F1Sap-A-5/50	551.3	12.0	17	30	147.38	117.7	101.8	66.4	47.8	7.8
F1Sap-A-6/50	568.5	10.4	10	30	175.33	130.2	120.2	75.9	63.7	18.0
FSap1-C-2/50	386.1	11.7	10	3	152.7	108.9	136.3	100.8	50.4	3.6
F1Sap-C-3/50	389.8	11.5	8	5	155.37	103.5	129.0	92.4	52.2	10.5
F1Sap-C-4/50	421.2	11.7	9	10	160.02	109.6	123.6	86.6	46.4	4
F1Sap-C-5/50	378	12.8	17	30	163.47	107.9	47.4	21.8	14.4	4.8
F1-SapC-6/50	368	11.3	7	30	182.72	98.4	44.3	15.2	2.4	2.7

1 t_{ig} is the time to flaming ignition after commencement of exposure in seconds
2 Exp after ig" refers to the time of exposure to the nominated irradiance after ignition
3 EoE refers to the mass at end of exposure to the nominated irradiance and EoE +30min refers to the mass 30 minutes after exposure to the nominated irradiance was terminated

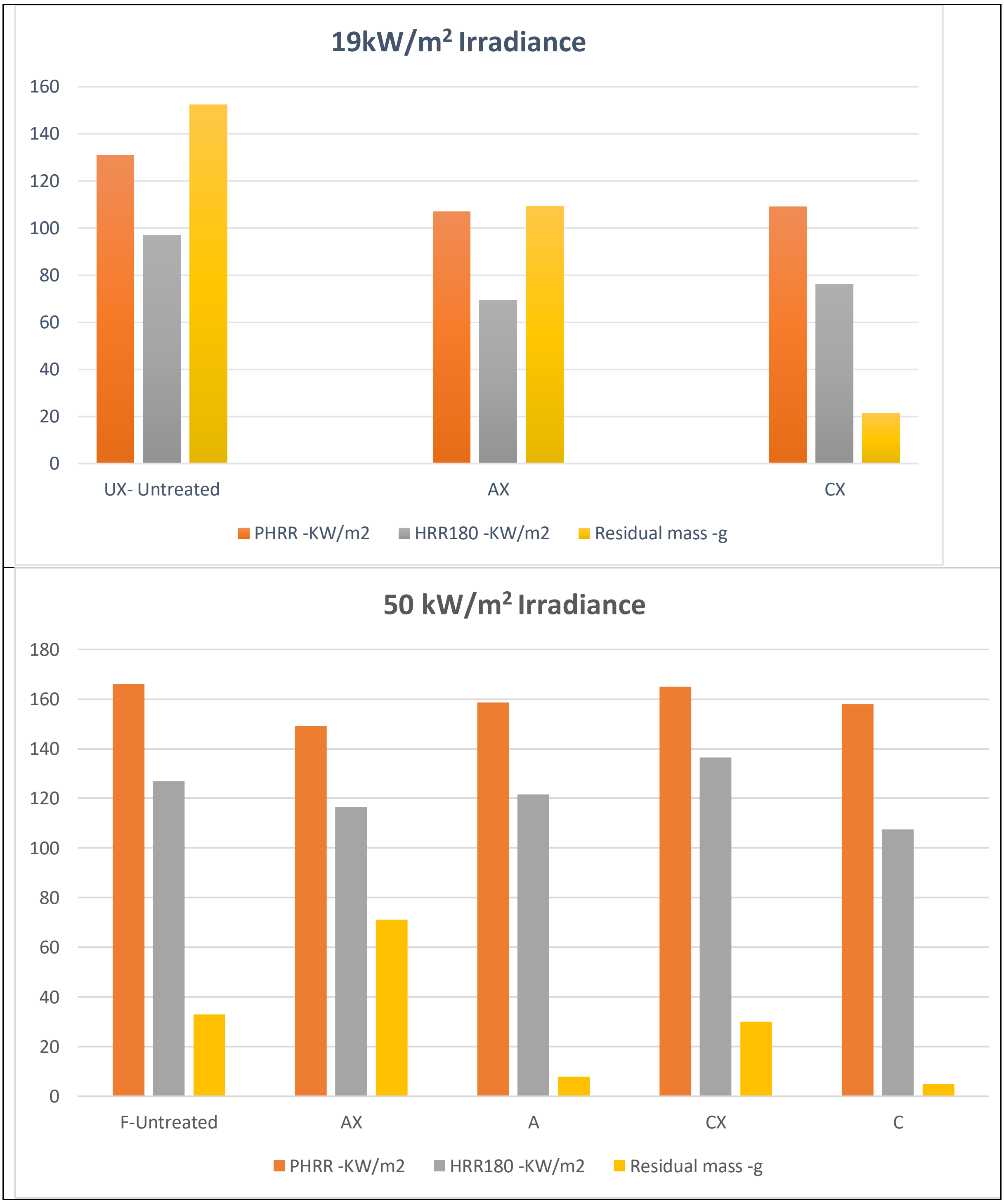


Figure 11 Peak HRR, Average HRR over 180s after flaming ignition and mass loss 24-hours after end of 30-minute exposure times .for comparative tests performed at irradiance levels of 19kW/m^2 and 50kW/m^2 on treated and untreated radiata pine specimens

The residual mass results from the tests performed at an irradiance of 19kW/m^2 clearly differentiate the increased tendency for sustained smouldering combustion with the copper based treatments. The results at an irradiance of 50kW/m^2 are less clearly defined because a greater proportion of the timber is consumed during the 30 minute exposure but nevertheless the test protocol could differentiate the untreated specimens identified as F from the treated specimens identified as A and C. The X-series samples were thicker and had a higher density than the F1 untreated control which explains the higher residual mass of the AX specimens. Notwithstanding this and variations in density between the F1 groups the protocol still demonstrated a difference between sustained smouldering combustion behaviour of specimens AX and CX which had similar densities. This further justifies the selection of treatment C as the default treatment for the large scale test series since it has the greatest tendency for sustained smouldering combustion.

Standardised Bushfire Exposures

AS 3959 (Standards_Australia 2018) classifies building bushfire exposures in terms of Bushfire Attack Levels (BALs) which are based on calculated incident heat from an assumed credible severe bushfire front by making simplifying assumptions and ignoring shielding except in very limited cases.

To facilitate practical classification of building systems the continuous distribution of peak exposures is broken down to:

BAL 12.5 for buildings potentially exposed to incident heat fluxes between 0 and 12.5kW/m^2

BAL 19 for buildings potentially exposed to incident heat fluxes between 12.5 and 19kW/m^2

BAL 29 for buildings potentially exposed to incident heat fluxes between 19 and 29kW/m^2

BAL 40 for buildings potentially exposed to incident heat fluxes between 29 and 40 kW/m^2

BAL FZ for buildings potentially exposed to direct flame impingement from the fire front.

The duration of exposure to these maximum heat fluxes is relatively brief and generally is expected to be similar to the flame residency period. The flame residency period is relatively short for example, Wotton (Wotton, Gould et al. 2012) found average flame-front residence time for dry eucalypt forest fires to be 37 s. For evaluation of building elements the test method specified by AS 3959 (Standards_Australia 2018), AS 1530.8.1 (Standards_Australia 2018) nominates heating profiles maintaining the peak intensity for approximately 2 minutes as shown in Figure 12.

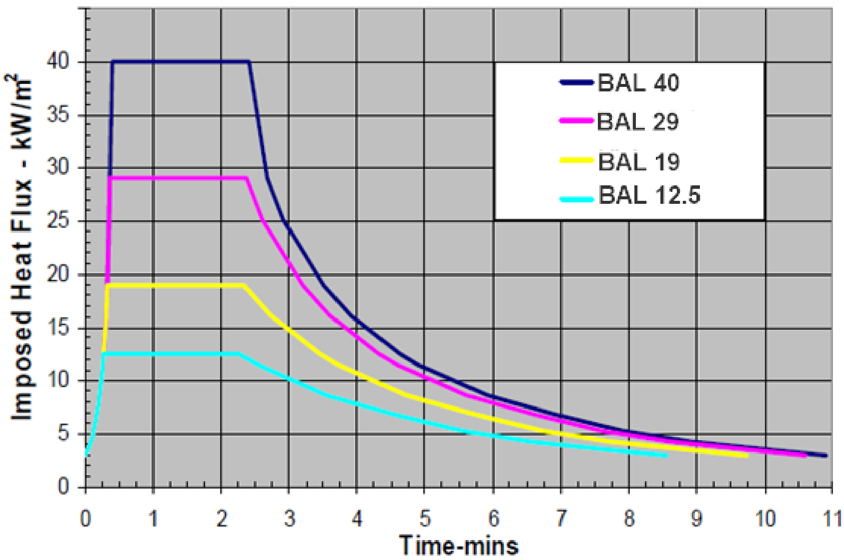


Figure 12 AS1530.8.1 Radiant Heat Profiles based on AS 1530.8.1

AS 1530.8.1 also requires timber cribs to be applied where collections of debris and / or embers could form and expose a building element to higher heat fluxes for longer durations in localised areas.

General Methodology and Materials

Tests were performed following the test protocols described in Attachments 2 and 3 with the modifications described in Attachment 4 to maximise the data that could be obtained from the cone calorimeter test program included in Stages 1 and 2.

Palings and framing timber elements were tested and evaluated separately because thin members (12mm or less) were not expected to behave as thermally thick materials when tested at lower heat fluxes whereas fence posts and general framing members would be expected to behave as thermally thick members for a larger range of irradiance levels.

The tests were performed on specimens conditioned to standard temperature and relative humidity conditions of 23°C and 50% respectively and after conditioning at 35°C and 25% which is considered more representative of conditions immediately preceding a severe bushfire.

The thin specimens were tested in groups of at least three at irradiance levels of 15, 19 and 29kW/m^2. Exposures above 29kW/m^2 are expected to result in the rapid consumption of thin members and therefore testing at higher heat fluxes was focussed on thicker sections.

The thick specimens were tested in groups of 4 at irradiance levels of 19, 29, 50kW/m^2. At least one specimen of each group was exposed to heating until 3,5,10 or 30 minutes had elapsed after ignition. Internal thermocouples were generally fitted to at least one specimen in each group that was exposed for 30 minutes. The specimens with internal thermocouples may have been subjected to pre-heating whilst the thermocouples were connected by low level radiation from the shielding plate particularly for tests at higher irradiance levels. Therefore specimens with internal thermocouples were not used to provide data relating to the time f ignition.

Single thick specimens were tested at 40kW/m^2 irradiance after conditioning at 23°C and 50% and 35°C and 25% prior to testing.

Additional thick specimens were tested at an irradiance of 12.5kW/m^2 and 75kW/m^2 after conditioning at 23°C and 50% to check the approximate critical flux for piloted ignition and investigate the performance of timbers at high heat fluxes.

After exposure the specimens were monitored for mass loss for 60 minutes and checked 24-hours after termination of heating to determine the extent of sustained smouldering combustion.

Details of the irradiance levels and exposure conditions are summarised in Table 16 and Table 17 together with the physical properties of the timber specimens.

The relevant results obtained from the Stage 2 cone calorimeter tests are summarised in Table 18 and Table 19.

Further details of the methodologies for deriving specific fire properties are provided in the following sections together with the results and discussion relating to each of the properties

Table 16 Materials and Exposure Conditions for evaluation of fire properties of thin treated radiata pine specimens

Group	Spec. ID (stick /num)	Conditioning T °C/RH %	Thick. mm	Initial mass (g)	Density kg/m³	MC %	Retention ratio %	Irrad. kw/m²	Irad. Dur post ig -min
P1	P2-S2	23 / 50	12.5	58.3	479	10.4	0.92	19	3
	P2-S3	23 / 50	12.9	58.2	458	10.1	0.92	19	5
	P2-S4	23 / 50	12.9	61.2	473	10.1	0.92	19	10
P2	P8-S2	23 / 50	10.7	45.5	429	10	1.57	15	3
	P8-S3	23 / 50	10.6	46.2	440	10	1.57	15	5
	P8-S4	23 / 50	10.8	55.2	516	10	1.57	15	10
	P10-S2	23 / 50	13.2	66.4	510	13.3	1.48	29	3
	P10-S3	23 / 50	13.3	67.2	513	12.3	1.48	29	5
	P10-S4	23 / 50	13.3	72.7	547	12.3	1.48	29	10
P5	P6 -S2	23 / 50	13.1	55.7	427	9.6	1.75	19	10
	P11-S2	23 / 50	11.7	62	530	9.6	0.83	19	10
	P7 -S2	23 / 50	12.9	72.7	570	9.6	1.27	19	10
	P5 -S2	23 / 50	12	67.1	564	9.6	1	19	10
	P6 -S5	23 / 50	12.9	52.1	407	9.6	1.75	19	10
	P11-S5	23 / 50	11.5	52.1	454	9.6	0.83	19	10
	P7 - S5	23 / 50	13.2	73.9	569	9.6	1.27	19	10
	P5 -S5	23 / 50	11.5	62.1	542	9.6	1	19	10
P3	P8-S5	35 / 25	10.4	45.9	443.3	10	1.57	15	3
	P8-S6	35 / 25	10.1	44.5	446.6	10	1.57	15	5
	P8-S7	35 / 25	9.7	42.7	441.7	10	1.57	15	10
	P11-S4	35 / 25	10.8	54.9	521.8	9.6	0.83	19	3
	P11-S6	35 / 25	10.8	58.1	544	9.6	0.83	19	5
	P11-S7	35 / 25	10.5	61.4	597.9	9.6	0.83	19	10
	P10-S5	35 / 25	12.9	66.8	532.7	7.2	1.48	29	3
	P10-S6	35 / 25	13	58.5	471.5	7.2	1.48	29	5
	P10-S7	35 / 25	12.5	58.3	478.1	7.2	1.48	29	10

Table 17 Materials and Exposure Conditions for evaluation of fire properties of thick treated radiata pine specimens

Group	Specimen ID (stick /num)	Conditioning T °C / RH %	Thick. mm	Initial mass (g)	Density (kg/m³)	MC %	Retention ratio %	Irrad. kw/m²	Irad. Dur post ig -min
F2	S1/S2	23 / 50	39.1	173.8	457.8	10.3	0.94	12.5	48(Note1)
	S1/S3	23 / 50	39	170.3	455.2	10.3	0.94	12.5	3
	S1/S4	23 / 50	39.1	170.7	455.1	10.3	0.94	12.5	5
	S7/S2	23 / 50	38.1	174.8	460	11.4	0.91	19	3
	S7/S3	23 / 50	37.9	175.6	466	11.4	0.91	19	5
	S7/S4	23 / 50	39.2	189.3	487	11.4	0.91	19	10
	S7/S5	23 / 50	39.5	184.4	473	11.4	0.91	19	30
	S2/S2	23 / 50	41.4	204.6	509	12	0.89	29	3
	S2/S3	23 / 50	41.4	199.8	499	12	0.89	29	5
	S2/S4	23 / 50	41.2	190.4	481.9	12	0.89	29	10
	S2/S5	23 / 50	40.5	200.5	487	12	0.89	29	30
	S1/S6	23 / 50	39.1	169.8	451	10.7	0.94	40	30
	S4/S2	23 / 50	39.8	197.6	502.2	10	0.87	50	3
	S4/S3	23 / 50	39.8	205.7	527.9	10	0.87	50	5
	S4/S4	23 / 50	39.5	189.7	487.1	10	0.87	50	10
	S4/S5	23 / 50	39.2	181.8	483.5	10	0.87	50	30
	S12/S2	23 / 50	46.1	230	506	9.7	0.99	75	3
	S12/S3	23 / 50	45.8	223.8	505.2	9.7	0.99	75	5
	S12/S4	23 / 50	46	234.1	506.9	9.7	0.99	75	10
	S12/S5	23 / 50	46.1	248.1	547.5	9.7	0.99	75	30
F3	S14	35 / 25	45	204.6	471.6	7.1	0.89	19	3
	S14	35 / 25	44.7	203.2	470.6	7.1	0.89	19	5
	S14	35 / 25	44.8	198.2	458	7.1	0.89	19	10
	S14	35 / 25	45	204.2	468.8	7.1	0.89	19	30
	S13/S2	35 / 25	44.8	200.1	463.3	7.3	0.99	29	3
	S13/S3	35 / 25	45.2	233.5	539.1	7.3	0.99	29	5
	S13/S5	35 / 25	44.8	201.2	460.6	7.3	0.99	29	10
	S13/S4	35 / 25	45.3	207.6	472.9	7.3	0.99	29	30
	S14/S6	35 / 25	45.8	209.2	473.2	8	0.89	40	30
	S18/S2	35 / 25	44.1	194.8	459.6	7.1	0.75	50	3
	S18/S3	35 / 25	44.1	203.3	478.1	7.1	0.75	50	5
	S18/S4	35 / 25	44.2	194	476.4	7.1	0.75	50	10
	S18/S5	35 / 25	44.2	195.5	462	7.1	0.75	50	30

Table 18 Results summary from evaluation of fire properties of thin treated radiata pine specimens

Group	Cond. T °C / RH %	Density kg/m³	Reten-tion ratio %	Irrad. kw/m²	Dura. tion post ig -min	t_{ig} -s	Back-T @ig -°C	HRR Peak kW/m²	Back-T @ peak -°C	Time to peak -s	Av HRR_{180} kW/m²	Av HRR_{300} kW/m²	Av HRR_{600} kW/m²	Back Temp end exp °C	Initial mass (g)	Mass at end of exposure - +0min	+30min	+60min	+24h
P1	23 / 50	479	0.92	19	3	393	101	112.5	102	415	75.8	50.1	25.11	129	58.3	40.6	38.2	38.2	39.8
	23 / 50	458	0.92	19	5	410	95	114.5	95	430	71.1	64.3	47.6	153	58.2	33	4.8	1.6	1.9
	23 / 50	473	0.92	19	10	455	100	97.8	100	480	67.1	59.6	70.8	408	61.2	17	3.1	1.4	2.2
P2	23 / 50	429	1.57	15	3	410	104	105.1	109	435	72	56.2	57.14	218	45.5	11.8	3	0	2.6
	23 / 50	440	1.57	15	5	386	93	105.1	95	405	73.1	77.6	64.9	294	46.2	11.4	3.2	0	1.5
	23 / 50	516	1.57	15	10	148	63	102.2	89	195	79.6	73.7	93.19	409	55.2	17.6	4.2	1	2.3
P2	23 / 50	510	1.48	29	3	60	34	125.4	37	70	80.8	50.61	23.6	98	66.4	48.3	47.7	47.9	48.5
	23 / 50	513	1.48	29	5	86	32	130.1	35	100	86.7	80.55	43.7	111	67.2	42.2	42	42.1	44
	23 / 50	547	1.48	29	10	57	28	127	29	75	94.4	87.5	102.1	294	72.7	29.2	10.3	5.8	3.6
P5	23 / 50	427	1.75	19	10	252	94	102.6	94	265	59.8	54.4	73.4	377	55.7	16.6	7.7	1.7	1.2
	23 / 50	530	0.83	19	10	119	37	102.4	44	150	76.9	69.7	91.3	309	62	19.9	5.3	1.7	3.3
	23 / 50	570	1.27	19	10	392	99	121.7	99	410	88.6	78.2	95	392	72.7	21.9	7.4	2.7	1.5
	23 / 50	564	1	19	10	424	100	107.9	100	440	84.3	84.7	100.1	468	67.1	14.7	3.6	0.5	1.3
	23 / 50	407	1.75	19	10	259	96	79.9	97	270	46.7	40.1	61.7	435	52.1	13.5	8	1.2	1.7
	23 / 50	454	0.83	19	10	253	99	126.9	101	270	75.4	68.3	83.4	385	52.1	12.9	10.1	10.1	10.4
	23 / 50	569	1.27	19	10	419	137	111.8	96	435	83.6	75.8	98.4	359	73.9	20.7	12.5	3.8	1.7
	23 / 50	542	1	19	10	93	35	95.1	58	135	75.1	69.9	100.3	404	62.1	16.2	8.5	1.7	1.2
P3	35 / 25	443.3	1.57	15	3	388	142	129.1	154	415	101.12	88.45	71.19	278	45.9	21.3	3.1	1.3	1.1
	35 / 25	446.6	1.57	15	5	368	151	118.2	162	390	94.32	103.89	64.86	402	44.5	17.1	5	2.3	1.9
	35 / 25	441.7	1.57	15	10	367	147	135.0	158	390	112.34	118.99	87.77	359	42.7	8.2	1.4	1.6	1.3
P3	35 / 25	521.8	0.83	19	3	74	35	137.5	49	105	114.53	81.39	46.26	128	54.9	41.6	39.7	39.7	41.2
	35 / 25	544	0.83	19	5	97	49	130.5	64	125	98.56	93.3	93.88	241	58.1	38.4	7.3	3	4.7
	35 / 25	597.9	0.83	19	10	81	41	138.8	55	120	111.88	106.76	133.36	430	61.4	16.4	6.4	4.3	3.6
P3	35 / 25	532.7	1.48	29	3	38	30	135.8	32	55	104.58	70.17	39.3	107	66.8	52.3	15.2	4.4	3.2
	35 / 25	471.5	1.48	29	5	42	31	152.5	33	65	104.45	94.29	85.51	168	58.5	37.1	7.3	3.8	1.3
	35 / 25	478.1	1.48	29	10	30	27	137.0	29	55	98.65	91.07	111.27	437	58.3	15.2	4.6	3.3	1.8

Table 19 Results summary from evaluation of fire properties of thick treated radiata pine specimens

Grp	Cond. T °C / RH %	Dens-ity kg/m³	Reten-tion ratio %	Irrad. kw/m²	Irrad. Dur Post Ig. -min	t_{ig} -s	Back-T @ ig -°C	HRR Peak kW/m²	Back-T @ peak -°C	Time to peak -s	Av HRR_{180} kW/m²	Av HRR_{300} kW/m²	Av HRR_{600} kW/m²	Back T end exp °C	Initial mass (g)	Mass end of exposure-g			
																+0 min	+30 min	+60 min	+24h
	23 / 50	457.8	0.94	12.5	48(Note1)	sm>1080[1]	-	-	-	-	-	-	-	100	173.8	100.6	73.2	54.6	19.0
	23 / 50	455.2	0.94	12.5	3	1356	60.7	80.46	62.6	1390	66.8	49.1	28.4	70	170.3	150.5	147.3	147.3	148.1
F2	23 / 50	455.1	0.94	12.5	5	1366	63.2	71.63	65.3	1390	57.6	47.9	28.4	83	170.7	146.2	143.2	143.2	143.4
	23 / 50	460	0.91	19	3	384	21.0	102.1	21	400	67.2	45.0	22.9	26	174.8	159.5	156.8	156.3	158.6
	23 / 50	466	0.91	19	5	329	21.0	103.3	20	345	64.1	57.3	31.9	28	175.6	156.1	153.5	153	153.1
	23 / 50	487	0.91	19	10	228	20.0	114.5	21	245	68.6	57.6	42.9	42	189.3	160.7	135.4	101	68.1
	23 / 50	473	0.91	19	30	191	26.0	111.9	27	210	70.7	60.5	48.9	108	184.4	111.3	80.2	61.8	26.9
	23 / 50	509	0.89	29	3	83	19.9	119.62	20	100	84.1	55.2	26.9	21	204.6	189.2	187.5	184.3	185.1
	23 / 50	499	0.89	29	5	81	19.7	134.81	19.9	100	86.8	76.9	41.4	22	199.8	178.1	173.8	159.8	135.1
	23 / 50	481.9	0.89	29	10	50	22.5	124.66	22.7	70	88.3	80.1	69.8	37	190.4	155.5	126.8	88.9	8.0
	23 / 50	487	0.89	29	30	6	26.7	180.22	26.3	30	135.0	125.5	106.9	196	200.5	48.1	21.9	15.4	16.2
	23 / 50	451	0.94	40	30	11	23.8	140.7	24	30	98.2	91.9	77.4	191	169.8	84.8	51.1	37.4	16.9
	23 / 50	502.2	0.87	50	3	8	25.0	160.45	25.2	25	117.4	88.1	59.7	27	197.6	180.6	143.5	98.0	20.7
	23 / 50	527.9	0.87	50	5	15	24.6	139.48	25.1	35	110.3	101.4	56.8	29	205.7	179.1	154.9	110.1	63.1
	23 / 50	487.1	0.87	50	10	11	25.7	144.43	26.1	35	105.4	96.2	83.1	69	189.7	145.9	106.4	60.5	5.1
	23 / 50	483.5	0.87	50	30	13	26.0	178.2	25.6	40	123.0	107.4	93.1	133	181.8	75.6	20.5	7.5	3.2
	23 / 50	506	0.99	75	3	4	24.6	204.47	25.8	25	154.5	102.9	56.0	30	230	207.8	201.9	201.7	202.8
	23 / 50	505.2	0.99	75	5	2	29.9	216.08	32.3	35	161.0	144.0	84.0	38	223.8	192.2	182.6	182.2	182.4
	23 / 50	506.9	0.99	75	10	4	20.3	200.98	21.6	35	155.1	147.8	131.0	44	234.1	172.9	125.7	79.3	4.2
	23 / 50	547.5	0.99	75	30	6	30.6	207.89	32.3	40	172.5	155.5	130.1	136	248.1	98.5	62.6	52.2	19.7
	35 / 25	471.6	0.89	19	3	185	31	150.41	30.8	205	63.75	32.89	98.42	32	204.6	188.5	188.1	187.7	190.9
F3	35 / 25	470.6	0.89	19	5	316	29	126.88	28.5	330	76.94	41.63	76.94	35	203.2	180.7	179.9	179.5	180.8
	35 / 25	458	0.89	19	10	221	28	137.74	28.6	245	82.46	69.7	69.7	49	198.2	167.3	153.6	115.0	45.8
	35 / 25	468.8	0.89	19	30	276	28	125.12	28	300	80.5	67.33	53.36	103	204.2	171.3	77	58.1	31.6
	35 / 25	463.3	0.99	29	3	42	28	133.76	28.1	55	67.06	34.36	101.94	30	200.1	186.3	183.9	182.9	181.8
	35 / 25	539.1	0.99	29	5	43	29	146.83	29.5	55	92.67	50.95	92.67	33	233.5	211.5	209.5	208.1	209.2
	35 / 25	460.6	0.99	29	10	53	34	165.82	34.7	70	107.34	94.55	94.55	51	201.2	165.4	126.6	86.2	15.3
	35 / 25	472.9	0.99	29	30	33	33	249.41	33.6	125	222.19	194.26	160.12	106	207.6	132.4	78	64.4	33.2
	35 / 25	473.2	0.89	40	30	18	39	185.98	38.9	35	130.39	114.02	93.59	118	209.2	178.7	87.9	67.8	5.7
	35 / 25	459.6	0.75	50	3	10	34	197.48	34.9	25	94.94	55.34	140.89	39	194.8	170.7	135.6	92.9	50.6
	35 / 25	478.1	0.75	50	5	11	31	184.37	31.8	40	142.96	89.97	142.96	38	203.3	171.8	137.4	96.5	69.9
	35 / 25	476.4	0.75	50	10	11	27	173.35	27.6	30	120.33	101.64	101.64	60	194	149.4	112.1	75.3	28.1
	35 / 25	462	0.75	50	30	13	32	182.67	33.1	30	116.74	97.41	72.92	206	195.5	143.6	40.4	31.9	23.0

Time to piloted ignition and estimation of critical heat flux

Methodology for piloted ignition and critical heat flux determination

Janssens method is a simplified thermal model to predict the time to piloted ignition when exposed to different irradiance levels in which the time to ignition to the power – 0.547 is plotted against the irradiance. An approximation (low estimate) of the critical irradiance is obtained from the intercept of the abscissa of a linear regression through the data. An apparent or effective kρc can be derived from the gradient of the linear regression.

Janssens method assumes

- that ignition occurs when the surface reaches a critical temperature defined as the ignition temperature.
- the material is chemically inert, has constant thermophysical properties, and is opaque
- one-dimensional heat transfer with radiant heating on the surface.
- thermally thick materials (i.e., the unexposed face temperature has not begun to increase in temperature significantly before ignition).

Further details are provided in various publications (Janssens 1991, SFPE 2002, Babrauskas 2003).

The method does not apply to thermally thin materials where there is no significant temperature drop across the section and the material can be treated as a lumped thermal mass. Many specimens fall between thermally thick and thermally thin configurations.

The SFPE guide (SFPE 2002) suggests that a material can be regarded as thermally thick if the following condition is satisfied;

$$L_o/(t_{ig}k/\rho c)^{0.5} \geq 4$$

Where;
L_o – material thickness (m)
k – thermal conductivity (W/m/K)
ρ – density (kg/m^3)
c- heat capacity (J/kg/K)
t_{ig} – time to ignition (s)

The above expression is plotted against t_{ig} in Figure 13 for thermal properties broadly similar to Radiata Pine (k=0.2 W/m/K, ρ =460kg/m^3, c=2000 J/kg/K which approximates to an effective kρc of 0.184 (kJ^{2}s^{-1}m^{-4}K^{-2}).

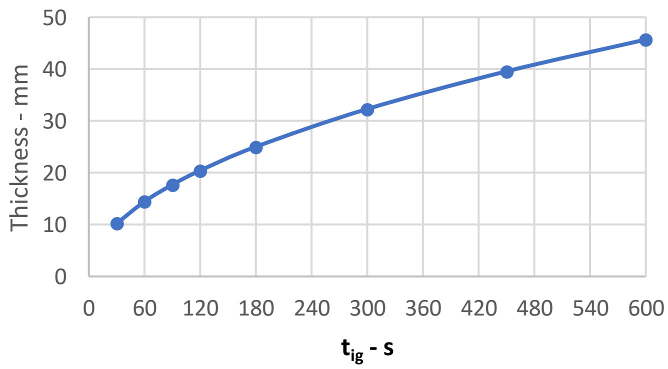


Figure 13 Bounding condition for thermally thick materials based on thickness and time to ignition

Typical paling thicknesses are 10-12mm and the sample can be regarded as thermally thick if the time for ignition does not exceed 30s.

To estimate the performance of thicker samples specimens between 38mm and 46mm were tested which implies the sample will be thermally thick if the time for ignition does not exceed approximately 420 to 600s depending on the actual thickness.

The rear face temperature of the specimens tested for the current study was measured to determine the extent of thermal penetration, amongst other things and provide a more precise indication of to what extent specimens may have deviated from thermally thick behaviour. The results from selected configurations subjected to cone calorimeter tests during this project are summarised in Table 20.

Table 20 Average rear face temperature increases from start of test exposure to piloted ignition for various specimen configurations and irradiance levels

Test Ref	Preservative treatment	MC - %	Density kg/m^3	Time to ignition (s)	Irrad-iance (kW/m^2)	Thickness (mm)	ΔT back face -°C
22-003791	F-untreated	9.5	434.7	400.3	19	12.1	75.7
22-003796	A	9.1	479.3	368.3	19	12.8	75.2
22-003794	C	10.2	470.0	419.3	19	12.8	78.7
22-004198A	C	9.6	507.9	276.4	19	12.4	70.9
21-006131	F-untreated	10.0	431.7	100.7	25	12.3	24.6
FH14526-02-1	WF-untreated	11.5	558.5	121.0	25	11.1	11.0
21-006123	A	10.6	472.5	99.0	25	12.1	10.0
FH14526-02-1	WA	11.5	580.4	140.3	25	11.5	10.8
21-006125	B	10.4	466.8	90.3	25	12.8	15.2
21-006126	C	10.6	422.2	82.3	25	10.1	27.5
FH14526-02-1	WC	11.8	528.8	119.3	25	12.8	5.6
21-006128	D	10.4	516.5	102.3	25	12.0	12.0
22-004255	C	9.6	523.3	67.7	29	13.3	2.9
22-004252	C	10.0	434.5	398.0	15	10.7	68.9
22-004656	F-untreated	10.5	562.0	340.0	19	44.6	2.5
22-004657	A	10.1	505.7	247.0	19	45.4	2.0
22-004661	C	9.5	539.4	313.9	19	45.9	2.3
22-004249	C	11.4	471.5	283.0	19	38.7	2.0
22-004259	C	10.3	455.2	1361.0	12.5	39.1	39.3

The data indicates that thermally thick behaviour could be expected at irradiances of 29kW/m^2 or greater for nominally 12mm thick radiata pine specimens that were untreated or treated with the water borne copper-based preservative treatments.

The variation from thermally thick behaviour could be expected to be relatively small at an irradiance of 25kW/m^2 for the nominally 12mm thick specimens but would be more significant at 19kW/m^2.

With specimens 38mm thick or greater thermally thick behaviour was demonstrated by the specimens exposed to irradiances of 19kW/m^2 or greater but at 12.5kW/m^2 irradiance levels (close to the critical flux) the behaviour was beginning to vary from a thermally thick due to the lengthy time to ignition (>20 minutes).

Many common applications for timber when exposed to lower heat fluxes lie in the transition zone between thermally thick and thermally thin materials. The Janssens correlation can provide reasonable estimates within the transition zone in some instances but in these instances careful verification is required.

By examining the plots of $t_{ig}^{-0.547}$ v heat flux any non-linearity at lower heat fluxes associated with deviations from thermally thick behaviour can be identified. In such cases it may be possible to restrict the general analysis to samples that approximate to thermally thick behaviours. Outside this range data points will be available with exposure to irradiance levels coinciding with the BAL level thresholds.

(Spearpoint and Quintiere 2001) observed that the mechanism for the ignition of wood at low heat fluxes close to the critical heat flux appears to be different from that at high heat fluxes. At low heat fluxes they observed small glowing regions of the wood that may increase the energy input at that point and thus lead to a localised ignition.

Figure 14 shows the HRR for one of a series of three treated radiata pine specimens nominally 39mm thick tested at an irradiance of 12.5kW/m^2 (close to the critical heat flux) in this project. One of the three specimens did not ignite, but sustained flaming occurred for the other two specimens shortly after 1300s. Figure 14 shows the HRR plot for one of the cases for which sustained flaming combustion occurred. It can be observed that heat was generated from the specimen for a considerable period prior to sustained flaming combustion commenced. Surface flashing prior to the sustained flaming ignition was observed from 1261s of the test.

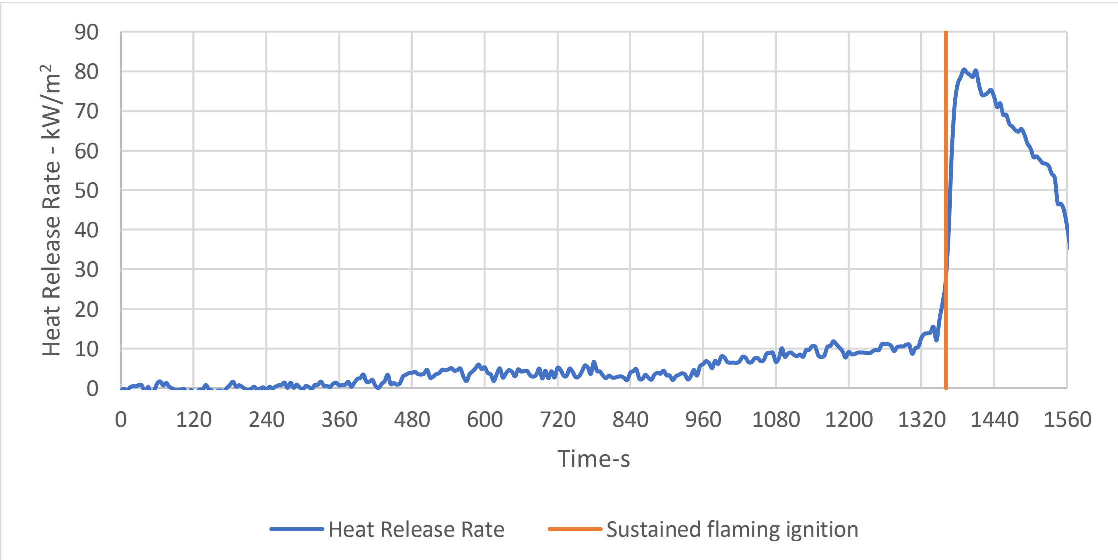


Figure 14 HRR for treated pine (preservative C) 39mm thick exposed to an Irradiance of 12.5kW/m^2

There was some variability in the time to ignition obtained, particularly at lower heat fluxes (19kW/m^2 or less) and the above behaviour is a potential cause. Other potential causes include;

- distortion of the timber specimens due to drying of the fire exposed face relative to the rear face which can cause parts of the specimen to move closer to the cone heater and igniter
- pre-heating of specimens from radiation from the shield whilst the specimen is prepared for test (this was more likely to occur whilst the internal thermocouples were connected for tests with internal temperature monitoring)

For the determination of the time to ignition a preliminary review of the data was undertaken to identify outliers prior to applying Janssens method described above.

A crude estimate of the critical heat flux can be obtained from the intercept of plots of $tig^{-0.547}$ v heat flux. The critical heat flux for the treated pine is expected to be approximately 12.5kW/m^2 and therefore three specimens were tests at an irradiance of 12.5kW/m^2. If ignition does not occur or takes a long time (>10 minutes) it was considered that the imposed heat flux will be sufficiently close to the critical flux for common applications.

Materials and Specimen Selection

Specimens with treatment C were used for the evaluation of the time to ignition analysis but were supplemented by other treatments and untreated radiata pine in some applications. The following specimen thicknesses were subjected to test after pre-conditioning using the standard conditioning requirements (23°C and 50% relative humidity) nominated in cone calorimeter test standards AS 3837 (Standards_Australia 1998) and ISO 5660-1 (ISO 2015) and after conditioning at 30°C and 25% relative humidity to evaluate the sensitivity to hotter / drier conditions:

- Thin specimens (nominally 10-12mm) conditioned at 23°C and 50% relative humidity
- Thin specimens (nominally 10-12mm) conditioned at 30°C and 25% relative humidity
- Thick specimens (nominally 38-46mm) conditioned at 23°C and 50% relative humidity
- Thick specimens (nominally 38-46mm) conditioned at 30°C and 25% relative humidity

Results and Discussion

Thin elements

Data from relevant tests on paling systems has been extracted and summarised in Table 21.

Table 21 Summary of time to ignition data for radiata pine treatment c (H3) timber palings

Conditioning 23°C and 50% relative humidity					Conditioning 23°C and 50% relative humidity				
Stick / Sample ref.	Density kg/m³	Irrad. kw/m²	t_{ig} -s	Back-T @ig -°C	Stick / Sample ref.	Density kg/m³	Irrad. kw/m²	t_{ig} -s	Back-T @ig -°C
P8-S2	429	15	410	104	P8-S5	443	15	388	142
P8-S3	440	15	386	93	P8-S6	447	15	368	151
P8-S4	516	15	148	63	P8-S7	442	15	367	147
Mean	435	15	398	99	Mean	444	15	374	147
P2-S2	479	19	393	101	P11-S4	522	19	74	35
P2-S3	458	19	410	95	P11-S6	544	19	97	49
P2-S4	473	19	455	100	P11-S7	598	19	81	41
Mean	470	19	419	99	Mean	555	19	84	42
P10-S2	510	29	60	34	P10-S5	533	29	38	32
P10-S3	513	29	86	32	P10-S6	472	29	42	33
P10-S4	547	29	57	28	P10-S7	478	29	30	30
Mean	523	29	68	31	Mean	494	29	36	32

The back temperature measurements at the time of ignition show that the specimens at $15kW/m^2$ and $19kW/m^2$ did not approximate to the definition of thermally thick and therefore the Janssens method may not be reliable. Further, if a temperature at ignition of approximately 350°C is assumed the specimens also do not approximate to the definition of thermally thin.

The typical time to ignition when exposed to an incident heat flux of $15kW/m^2$ for specimens conditioned under standard conditions and at 35°C and 25% relative humidity exceeded 6 minutes and at lower irradiance levels approaching a critical heat flux of $12.5kW/m^2$ the time to ignition would be expected to increase significantly until ignition is no longer possible at heat fluxes below the critical heat flux. There was one outlier (specimen P8-S4) with ignition at 148s which may have resulted from distortion of the test specimen, amongst other things.

This indicates that there is a low probability of piloted ignition with exposures to heat fluxes below $15kW/m^2$ for less than 6 minutes. Thus, it would be unlikely for the treated pine to be ignited if located within a BAL 12.5 zone directly from the fire front unless there is an additional heat source from for example collections of burning debris, embers or vegetation.

At $19kW/m^2$ exposure there was a large reduction in the time to ignition (average of 84s for the specimens conditioned at 30°C and 25% relative humidity). This period is at the upper end of the range of flame residency periods expected at bushfire fronts which approximates to the period of exposure to maximum heat flux directly from the fire front. This is less than the 2 minute maximum exposure period required by AS 1530.8.1 which is intended to include safety factors to account for some limitations associated with the test method such as the use of standard conditioning requirements for specimens. The time to ignition of specimens exposed to $19kW/m^2$ after standard conditioning was significantly beyond 2-minutes.

These results are consistent with the expected performance and use of exposed radiata timber elements within BAL 12.5 and BAL 19 exposures as defined in AS 3959.

At exposures of $29kW/m^2$ the average time to ignition under standard pre-test conditioning was 68s which reduced to 36s for specimens conditioned at 35°C and 25% relative humidity. These results indicate that at BAL 29 exposures there is a higher risk of ignition of buildings although the timbers could still provide resistance to ignition for fuel types with lower flame residency periods such as some grassland fires. The results also highlight the potential beneficial effects of pre-wetting treated radiata pine prior to exposure to bushfire attack.

Thick elements

Data from relevant tests on framing systems has been extracted and summarised in Table 22 and Table 23.

The back temperature measurements at the time of ignition show that all the specimens approximated to the definition of thermally thick except for the specimens subjected to an irradiance of $12.5kW/m^2$ which was close to the critical heat flux and therefore it was to be expected. Therefore, it is considered appropriate to apply the Janssens method to determine relationships between the time to ignition and imposed heat flux.

The time to ignition to the power of -0.547 ($t_{ig}^{-0.547}$) is shown plotted against the imposed irradiance and a line of best fit is determined as shown in Figure 15. The correlation was very good (R^2 values of 0.98 and 1) and the spread in results was low.

The intercepts provide an approximation of the critical heat flux which theoretically should be the same irrespective of pre-conditioning since the moisture content of the timber will eventually be reduced to zero and ignition will eventually occur if the timber is exposed to heat fluxes greater than the critical flux. Based on the intercepts the critical heat fluxes were estimated to be 13.7kW/m^2 (derived after preparation using standard conditions) or 12.1 kW/m^2 when determined after conditioning at 35°C and 25% relative humidity.

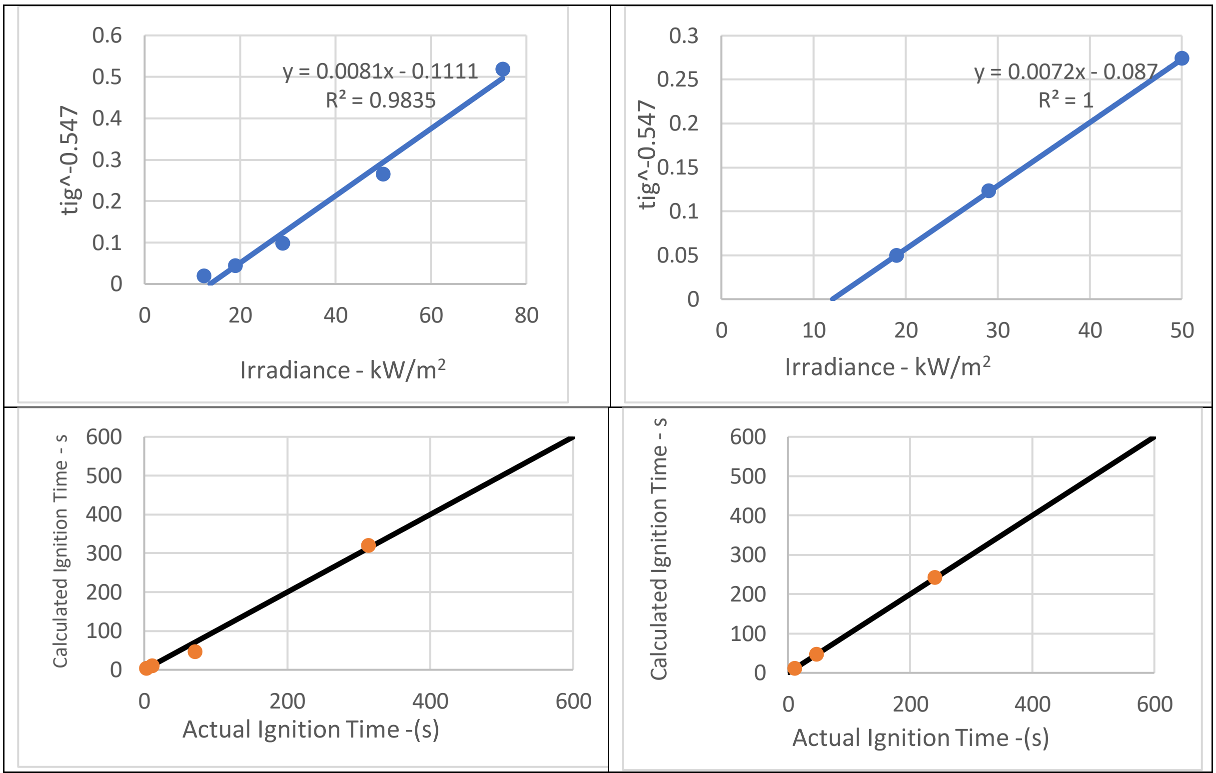
The series of tests performed at 12.5kW/m^2 indicates that the critical flux is likely to be slightly below 12.5kW/m^2.

Table 22 Summary of time to ignition data for thick radiata pine members treated with preservative C to hazard class H4 after standard conditioning at 23C and 50% relative humidity

Specimen ID (stick /num)	Thick. mm	Density (kg/m^3)	MC %	Irrad. kw/m^2	t_{ig} -s	Back-T @ig -°C
S1/S2	39.1	457.8	10.3	12.5	sm>1080[1]	-
S1/S3	39	455.2	10.3	12.5	1356	60.7
S1/S4	39.1	455.1	10.3	12.5	1366	63.2
Mean	**39.1**	**456**	**10.3**	**12.5**	**1361**	**62.0**
S7/S2	38.1	460	11.4	19	384	21.0
S7/S3	37.9	466	11.4	19	329	21.0
S7/S4	39.2	487	11.4	19	228	20.0
Mean	**38.4**	**471**	**11.4**	**19**	**314**	**20.7**
S2/S2	41.4	509	12	29	83	19.9
S2/S3	41.4	499	12	29	81	19.7
S2/S4	41.2	481.9	12	29	50	22.5
Mean	**41.3**	**497**	**12**	**29**	**71**	**20.7**
S4/S2	39.8	502.2	10	50	8	25.0
S4/S3	39.8	527.9	10	50	15	24.6
S4/S4	39.5	487.1	10	50	11	25.7
Mean	**39.7**	**506**	**10**	**50**	**11**	**25.1**
S12/S2	46.1	506	9.7	75	4	24.6
S12/S3	45.8	505.2	9.7	75	2	29.9
S12/S4	46	506.9	9.7	75	4	20.3
Mean	**46.0**	**506**	**9.7**	**75**	**3**	**24.9**

Table 23 Summary of time to ignition data for thick radiata pine members treated with preservative C to hazard class H4 after conditioning at 35C and 25% relative humidity

Specimen ID (stick /num)	Thick. mm	Density (kg/m^3)	MC %	Irrad. kw/m^2	t_{ig} -s	Back-T @ig -°C
S14	45	471.6	7.1	19	185	31
S14	44.7	470.6	7.1	19	316	29
S14	44.8	458	7.1	19	221	28
Mean	**44.8**	**467**	**7.1**	**19**	**241**	**29**
S13/S2	44.8	463.3	7.3	29	42	28
S13/S3	45.2	539.1	7.3	29	43	29
S13/S5	44.8	460.6	7.3	29	53	34
Mean	**44.9**	**488**	**7.3**	**29**	**46**	**30**
S18/S2	44.1	459.6	7.1	50	10	34
S18/S3	44.1	478.1	7.1	50	11	31
S18/S4	44.2	476.4	7.1	50	11	27
Mean	**44.1**	**471**	**7.1**	**50**	**11**	**31**



Radiata Pine with preservative treatment C(H4), 41mm thick after conditioning at 25C and 50 % RH	Radiata Pine with preservative treatment C(H4)45mm thick after conditioning at 35C and 25 % RH

Figure 15 Application of Janssens method for determination of time to ignition for thick specimens of Radiata Pine with preservative treatment C(H4)

Figure 16 shows a plot of the time to ignition for the thick timber specimens using the relationships derived by the Janssens method.

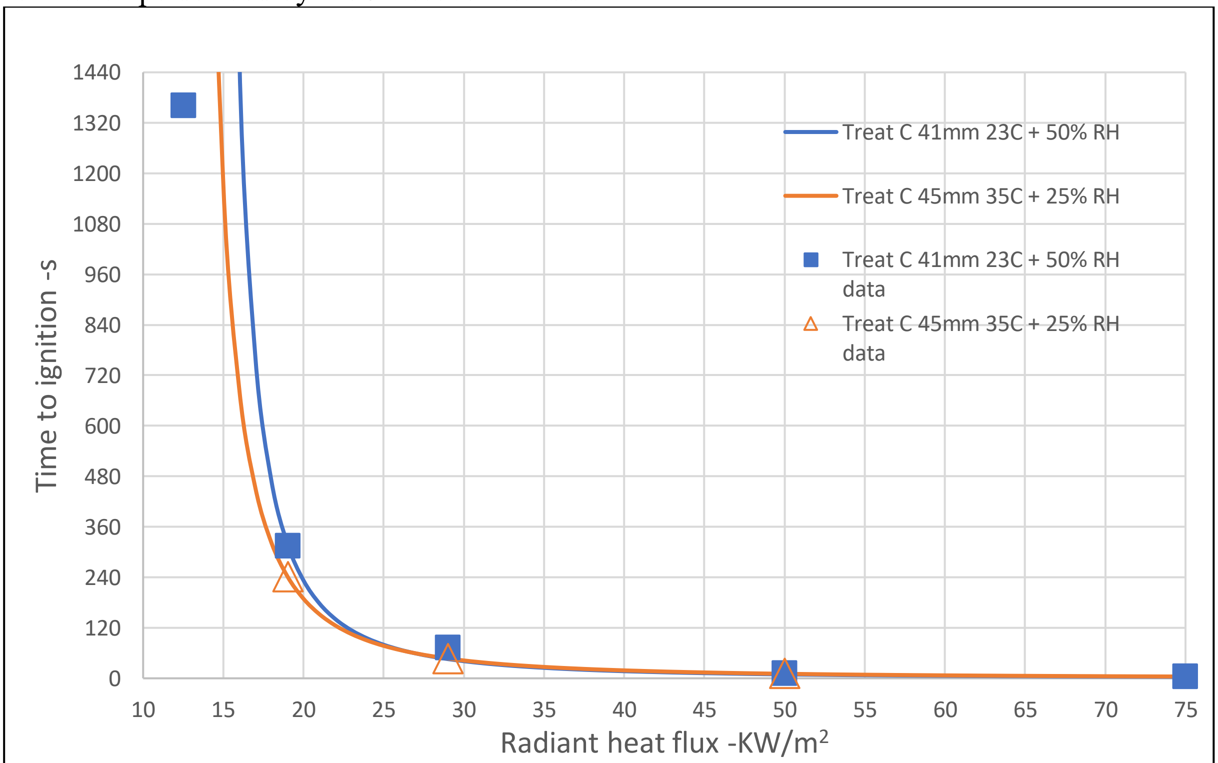


Figure 16 Plots of time to ignition for Radiata Pine with preservative treatment C(H4) based on Janssens method

The experimental results are closely aligned with the correlations except for the specimens exposed to 12.5kW/m^2. The long heating period before ignition provided time for thermal penetration to the unheated face to occur and therefore the assumption that the specimens were thermally thick was false which may account for the variance.

The results confirm the finding that if the heating is only provided directly from the fire front and the imposed heating conditions do not exceed the BAL 19 requirements of AS 3959 piloted ignition of water borne copper-based preservative treated timber would be unlikely since exposures greater than four minutes at a heat flux of 19kW/m^2 are required. This finding is dependent on there being no additional heat source from burning debris, embers or other burning materials and is consistent with the construction requirements in AS 3959.

The performance of thicker timbers was similar to that of the 12mm thick specimens with exposure to 29kW/m^2 which is to be expected because thermal penetration of the thinner members was also minimal at the time of ignition with this exposure level.

Variation of the time to ignition with density

The stage 2 series of tests included fifteen samples, approximately 12mm thick that were tested at an irradiance of 19kW/m^2. The time to ignition of 3 specimens were substantially less than the remaining twelve specimens and were therefore discarded. Potential reasons for these inconsistencies have been discussed above.

Data relating to the time to ignition for the twelve selected specimens are summarised in Table 24 and a plot of time to ignition against density is shown in Figure 17. These results do not show a significant correlation between density and time to ignition. The rear face temperature measurements indicate the samples did not behave as a thermally thick element nor were they thermally thin which may explain the inconclusive results to some extent.

Table 24 Time to ignition data for paling samples exposed to an irradiance of 19kW/m^2

Specimen (stick num)	Back-Temp @ig -°C	Treat-ment	Density (kg/m^3)	t_{ig} -s
P9-S1	99	U	427	396
P9-S2	97	U	438.7	403
P9-S3	99	U	438.4	402
P1-S2	98	A	478	342
P1-S3	95	A	488	356
P1-S4	98	A	472	407
P2-S2	101	C	479	393
P2-S3	95	C	458	410
P2-S4	100	C	473	455
P7 -S2	99	C	570	392
P5 -S2	100	C	564	424
P7 - S5	137	C	569	419

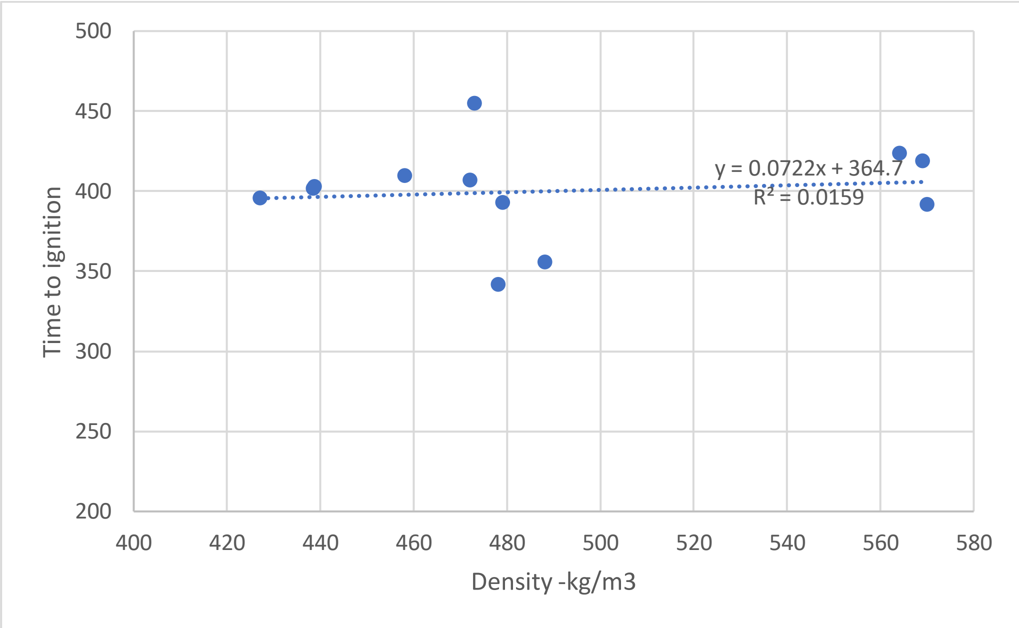


Figure 17 Time to ignition against density for 12mm paling samples at an irradiance of 19kW/m²

During Stage 1 12mm thick paling samples were tested at an irradiance of 25kW/m² and the increase in temperature of the rear face was relatively small indicating the thermal performance would be likely to approximate to a thermally thick element. The relevant results from stage 1 are summarised in Table 25 and plotted in Figure 18. Whilst a reasonable correlation can be obtained using linear regression the results should be treated as indicative only because the samples with higher densities were tested after accelerated weathering which could also have impacted the time to ignition.

Table 25 Time to ignition data for paling samples exposed to an irradiance of 25kW/m²

Specimen	Density (kg/m³)	T_{ig} (s)	ΔT back face -°C
A2	473	99	10
WA2	580	140	10.8
B2	467	90	15.2
C2	422	82	27.5
WC2	559	119	5.6
D2	516	102	12
F2 (Control)	432	101	24.6
WF2 (Control)	559	121	11

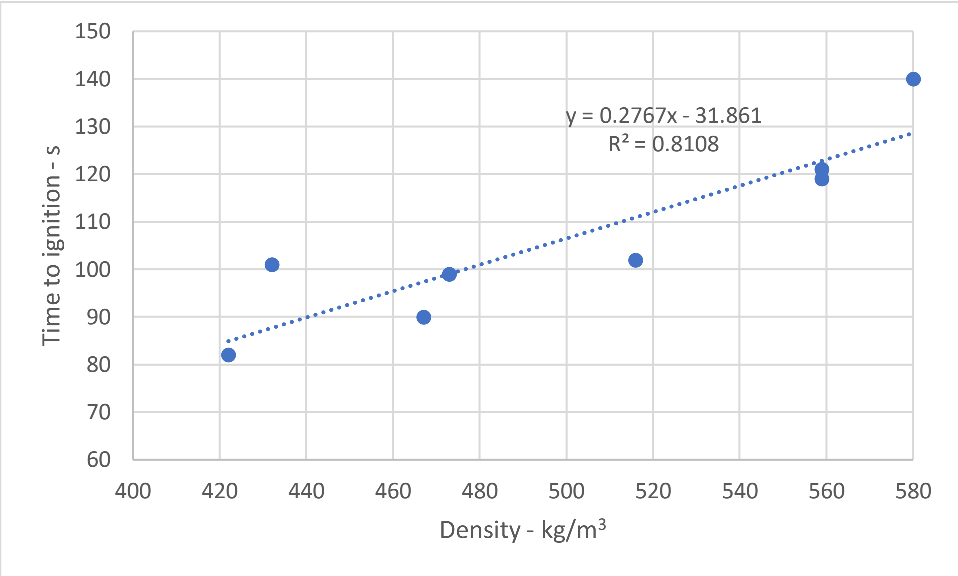


Figure 18 Time to ignition against density for 12mm paling samples at an irradiance of 25kW/m²

Babrauskas (Babrauskas 2003) derived the following general expression for estimating the time to ignition based on incident heat flux and density from an analysis of over 250 data points:

$t_{ig} = 130\rho^{0.73} / (q''_e - 11.0)^{1.82}$

where
ρ = density (kg/m^3),
q''_e = irradiance (kW/m^2), and
t_{ig} = ignition time (s).

Babrauskas indicated that the correlation should only be used semi-quantitatively. He also observed a systemic variation in results at irradiance levels below $15kW/m^2$ because the specimens no longer behaved as thermally thick elements.

The correlation was used to generate plots of the time to ignition for variations in density, within the range typical of radiata pine at irradiance levels of 19,25,29,and $50kW/m^2$ (refer Figure 19). Data points at the same irradiance levels were then plotted based on representative tests undertaken under stages 1 and 2 of this project. The results indicate that if the dimensions of specimens and irradiance levels ensure the specimen behaviour will approximate to that of a thermally thick specimen and the irradiances are not less than $25kW/m^2$ Babrauskas's correlation will provide a reasonable indication of the variation of the time to piloted ignition as a function of density for untreated and preservative treated radiata pine.

The correlation is less reliable at irradiances below $25kW/m^2$ and when the specimen does not behave as a thermally thick element due to the combination of specimen dimensions and irradiance. In these cases reliance may have to be based on relevant experimental data.

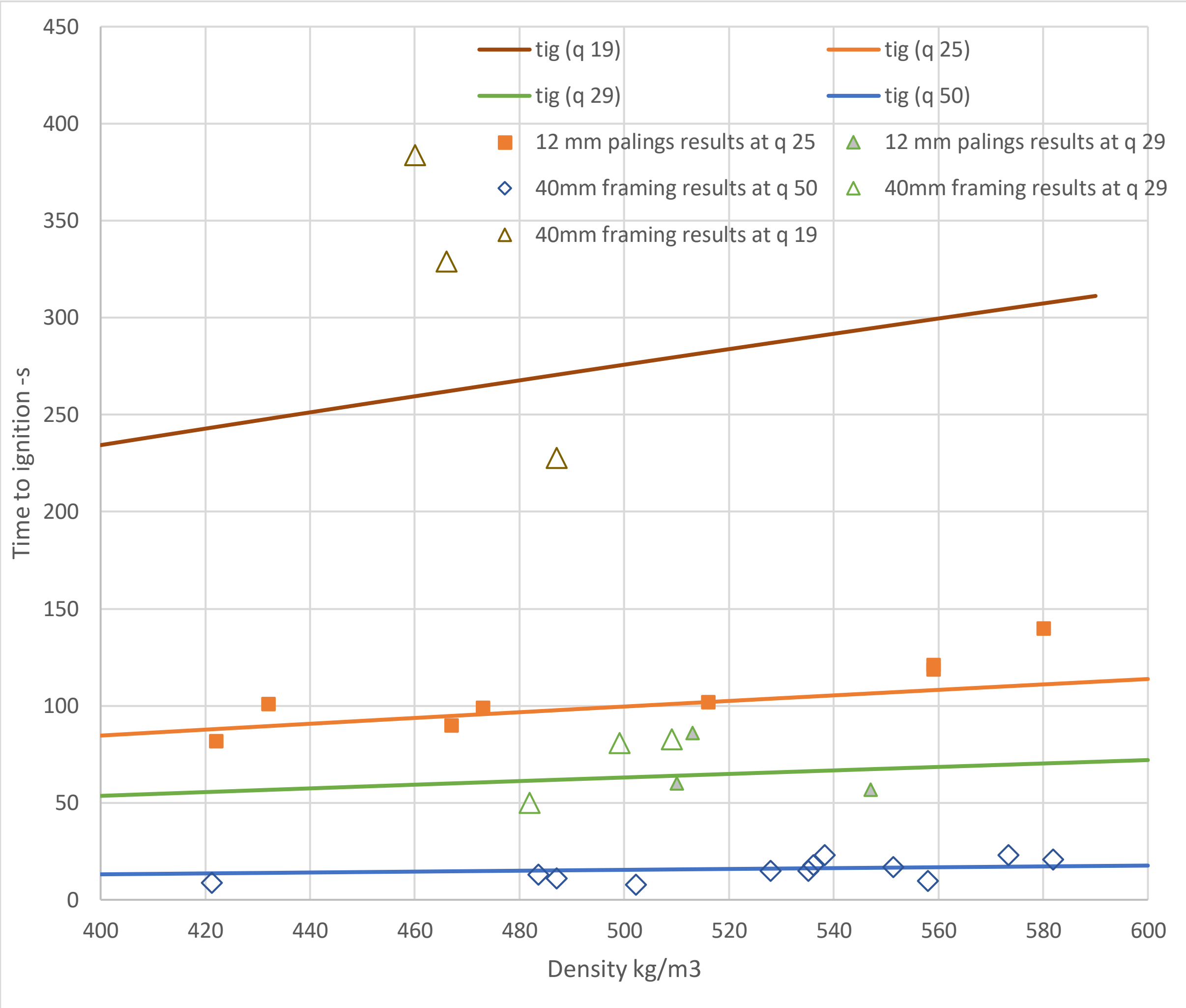


Figure 19 Comparison of Babrauskas correlation with density and typical results from Stages 1 and 2

Heat Release Rates of Preservative Treated Timbers

Methodology

The HRR data was determined using the cone calorimeter generally in accordance with the test methods defined in AS 3837 (Standards_Australia 1998) and ISO5660.1 (ISO 2015) with the adaptations described in the test protocols provided in the attachments to this appendix.

Additional instrumentation monitoring the temperature of the back face of the specimen was used to identify when thermal penetration of the test specimen had occurred, and the specimen could no longer be considered thermally thick.

Materials and Specimen Selection

Specimens with treatment C were used for the determination of the HRR data. The following specimen thicknesses were subjected to test after pre-conditioning using the standard conditioning requirements (23°C and 50% relative humidity) nominated in cone calorimeter test standards AS 3837 (Standards_Australia 1998) and ISO 5660-1 (ISO 2015) and after conditioning at 30°C and 25% relative humidity to evaluate the sensitivity to hotter / drier conditions:

- Thin specimens (nominally 10-12mm) conditioned at 23°C and 50% relative humidity
- Thin specimens (nominally 10-12mm) conditioned at 30°C and 25% relative humidity
- Thick specimens (nominally 38-46mm) conditioned at 23°C and 50% relative humidity

- Thick specimens (nominally 38-46mm) conditioned at 30°C and 25% relative humidity

The data was derived from the Stage 1 and Stage 2 Cone calorimeter data sets summarised in Table 8, Table 9 and Table 14 through Table 19. Specimens where it was identified that the time to ignition had been affected by pre-heating were omitted.

Results and Discussion

Comparative testing described earlier in this report, confirmed that similar fire properties were obtained from tests on water borne copper based preservative treated radiata pine and untreated radiata pine with respect to piloted ignition and flaming combustion. Significant variations in behaviour with respect to sustained smouldering combustion were observed, as expected. Treatment C was selected for further investigation of sustained smouldering combustion but data from these tests relating to the flaming combustion was also recorded which is summarised and discussed below.

The magnitude and time of occurrence of the first heat release rate (HRR) peak, and the average HRR for 180s after ignition are commonly used parameters for the characterisation of the burning behaviour of timber and have been selected for this analysis. The relevant results are summarised in Table 26. Generally, there were at least 3 samples to provide a mean value for each cell except for the results obtained at an irradiance of 12.5kW/m^2 where one of the three specimens did not ignite since the irradiance was close to the critical flux.

Table 26 Summary of Heat Release Rate Data for Radiata Pine treated with a water borne copper based preservative derived from the Stage 1 and 2 Cone Calorimeter tests

Pre-test conditioning (°C / %)	Property when tested using cone calorimeter	12mm paling samples			41 mm framing samples				
		Irradiance -kW/m^2			Irradiance -kW/m^2				
		15	19	29	12.5	19	29	50	75
Standard 23/50	Time to Peak HRR	345	336	82	1390	332	90	37	34
	Peak HRR	104	107	127	76	110	126	156	207
	Av HRR - 180s after ignition	75	73	87	62	73	86	115	161
35/25	Time to Peak HRR	398	117	58		270	60	31	
	Peak HRR	127	136	142		135	149	184	
	Av HRR - 180 s after ignition	103	108	102		76	89	119	

Whilst the general behaviour similar there are differences between the performance of timber specimens that can be regarded as thermally thin and those that exhibit thermally thick characteristics. Figure 20 shows typical heat release data derived from tests performed under a range of irradiances using nominally 40mm thick specimens. Corresponding data from tests performed on nominally 12mm thick specimens at irradiancies of 19 and 29kW/m^2 are plotted in Figure 21. All these tests were terminated 10 minutes after flaming ignition.
In all these cases there was sustained smouldering combustion once the external heating was removed. The thinner specimens exhibited two peaks, the first peak occurring shortly after ignition and then decaying as a protective char layer develops. The second peak occurs about the time the smouldering combustion front reaches the back face of the specimen. For thicker specimens only one peak occurred during the test duration.

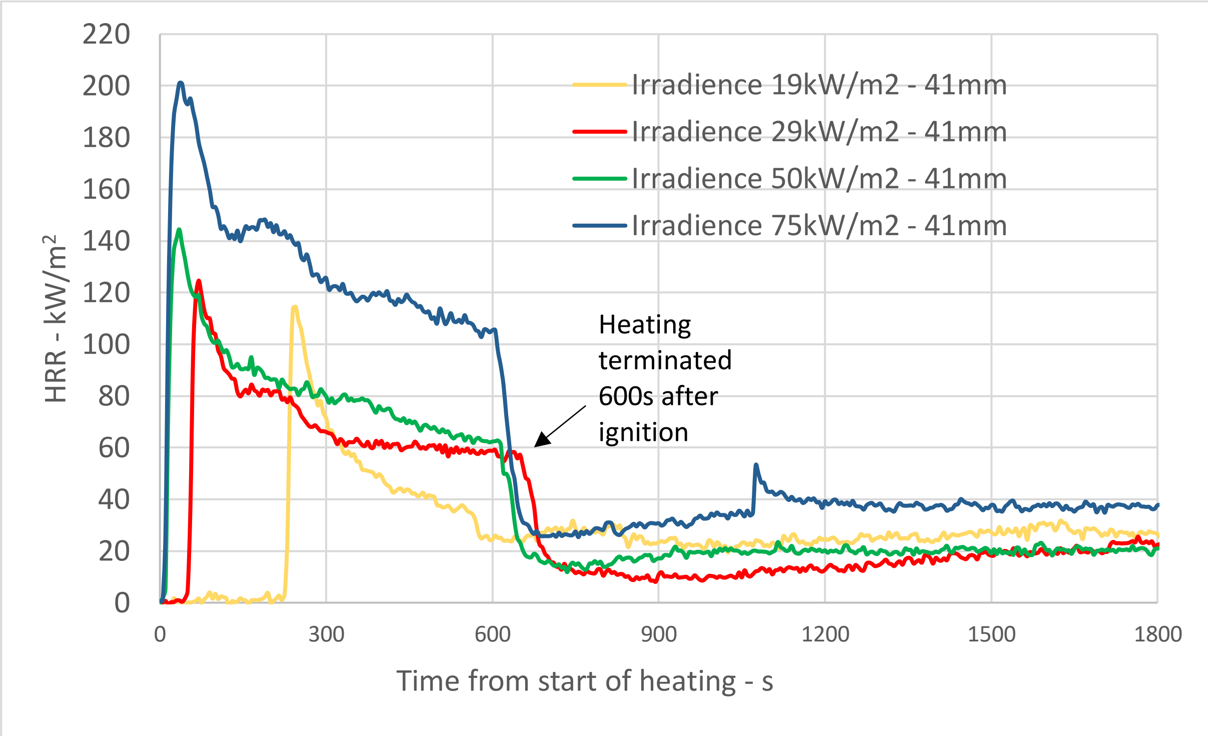


Figure 20 HRR from fire cone calorimeter tests on radiata pine, nominally 41mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

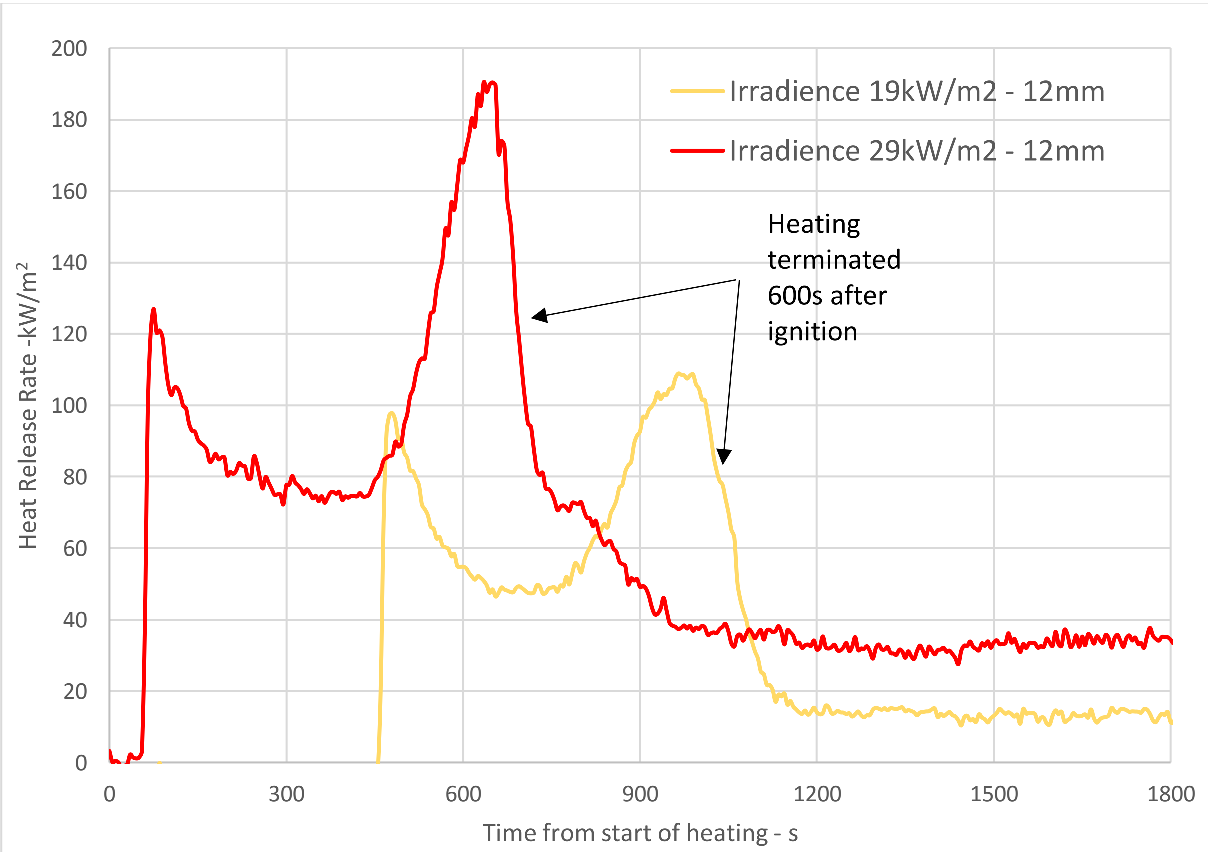


Figure 21 HRR from fire cone calorimeter tests on radiata pine, nominally 12 mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

The above results indicate that separate treatment of thermally thin and thermally thick timber elements is required as was the case for the time to ignition and thermal thickness is also important when considering sustained smouldering combustion and self-extinguishment which is discussed in the following section

Sustained Smouldering Combustion and Mass Loss after Ignition

Methodology

The occurrence of sustained smouldering combustion was determined predominately by using the cone calorimeter data from tests performed generally in accordance with AS 3837 (Standards_Australia 1998) and ISO5660.1 (ISO 2015) with the modifications described in the test protocols provided in attachments 2-4 in this appendix.

Specific enhancements to the protocols to quantify the extent of sustained smouldering and threshold values included:

- termination of exposure to the nominated irradiance levels 3, 5 and 10 minutes after flaming ignition rather than testing all three samples for the same period (e.g. 10 or 30 minutes after ignition).
- Monitoring of mass loss for 60 minutes after termination of exposure and a final check of the residual mass 24- hours after termination of exposure.
- Testing under various heat fluxes from 12.5kW/m^2 to 75 kW/m^2 including 19kW/m^2 and 29kW/m^2 to correspond to BAL thresholds in AS 3959.

The 3-minute exposure times are more representative of, although still greater than, the flame residency periods for most bushfires (especially if the pre flaming ignition time is considered. The flame residency period correspond to peak radiant heat exposures from the fire front for structures and other features that are outside the flame zone defined in AS 3959.

Using an exposure of at least 3 minutes enabled the capture of the first peak after ignition and enable comparison of results from replicates at the same irradiance levels but with irradiance durations of 5 and 10 minutes

The protocol for larger cross-section (nominally 41mm) components provided in Attachment 3 with an exposure period of 30 minutes successfully identified variations in the potential for preservative treatments to promote sustained smouldering combustion in radiata pine elements.
To provide further data relating to char rates and thresholds for sustained smouldering combustion internal thermocouples were incorporated into an additional sample in each series which was exposed to the nominated irradiance for 30 minutes exposure to provide data consistent with the Stage 1 studies and also to track the temperature profiles and char depths.

For the 12mm nominal thickness specimens a temperature measurement on the rear face were used to monitor char rates without additional internal thermocouples

When continuing tests and mounting test specimens the specimen is protected by a shutter. The standard shutter used is not fully insulated and may subject the specimens to a low background levels of radiant heat until the cone cools.

Measurements were taken with the cone set for irradiances of 19, 29 and 50 kW/m^2. With the shutter closed and cone operating the maximum irradiances with the shutter closed were 3.5,5.4 and 9.5kW/m^2 respectively(Sabatino 2023). Since there could be delays wiring the internal thermocouples prior to commencement of a test some pre-heating of the specimen is expected which could significantly impact the time to ignition, Therefore, ignition times from the specimens with internal thermocouples were not used to determine the time to flaming ignition.

At the end of heating the shutter was closed and the specimens were monitored in-situ and it is likely they were subjected to some background radiant heating from the shutter. This would tend to promote sustained smouldering combustion and the results would tend to yield conservative results (i.e. sustained smouldering combustion would tend to be over-estimated)

These effects could be reduced by using an insulated shutter for future work.

Materials and Specimen Selection

Specimens with treatment C were used for the analysis of sustained smouldering combustion The following specimen thicknesses were subjected to test after pre-conditioning using the standard conditioning requirements (23°C and 50% relative humidity) nominated in cone calorimeter test standards AS 3837 (Standards_Australia 1998) and ISO 5660-1 (ISO 2015) and after conditioning at 30°C and 25% relative humidity to evaluate the sensitivity to hotter / drier conditions:

- Thin specimens (nominally 10-12mm) conditioned at 23°C and 50% relative humidity
- Thin specimens (nominally 10-12mm) conditioned at 30°C and 25% relative humidity
- Thick specimens (nominally 38-46mm) conditioned at 23°C and 50% relative humidity
- Thick specimens (nominally 38-46mm) conditioned at 30°C and 25% relative humidity

The data was derived from Stage 2 Groups P1 to P2 and F2 and F3 Cone calorimeter data sets summarised in Table 14 through Table 19.

Results and Discussion

The general behaviour was broadly similar for the nominally 12mm and 40mm samples, in that there was a greater likelihood of the occurrence of sustained smouldering combustion after removal of the external heat source for specimens that had greater exposures to external heating (duration and or incident heat flux). However, specimens that are not thermally thick have a greater tendency for continued flaming combustion until the material has been substantially consumed because of higher specimen temperatures and potential burn through increasing the oxygen supply to the rear face.

The following discussion has therefore been split into two sections (thin elements (e.g 12mm thick materials) and thick elements (generally greater than 38mm thick). Between these values checks should be made to determine if a specimen is likely to behave as a thermally thick element or not.

Thin elements

The relevant results from a series of tests performed on 12mm thick palings that were undertaken to evaluate the potential for sustained smouldering combustion, amongst other things are summarised in *Table 27*.

Table 27 Results summary from evaluation of sustained flaming of thin treated radiata pine specimens

Spec ID Stick /num.	Cond. T °C / RH %	Dens. kg/m³	Irrad. kw/m²	Dura. tion post ig -s	t_{ig} -s	Tot exp -s	Back temperature - °C			Time back temp 250C	Initial mass (g)	Mass at end of exposure -			
							@ ignition	@ end of exp	Max			+0min	+30min	+60min	+24h
P2-S2	23 / 50	479	19	180	393	573	101	129	193	-	58.3	40.6	38.2	38.2	39.8
P2-S3	23 / 50	458	19	300	410	710	95	153	415	876	58.2	33	4.8	1.6	1.9
P2-S4	23 / 50	473	19	600	455	1055	100	408	474	848	61.2	17	3.1	1.4	2.2
P8-S2	23 / 50	429	15	180	410	590	104	218	470	619	45.5	11.8	3	0	2.6
P8-S3	23 / 50	440	15	300	386	686	93	294	398	632	46.2	11.4	3.2	0	1.5
P8-S4	23 / 50	516	15	600	148	748	63	409	488	478	55.2	17.6	4.2	1	2.3
P10-S2	23 / 50	510	29	180	60	240	34	98	175	-	66.4	48.3	47.7	47.9	48.5
P10-S3	23 / 50	513	29	300	86	386	32	111	196	-	67.2	42.2	42	42.1	44
P10-S4	23 / 50	547	29	600	57	657	28	294	446	596	72.7	29.2	10.3	5.8	3.6
P8-S5	35 / 25	443	15	180	388	568	142	278	473	541	45.9	21.3	3.1	1.3	1.1
P8-S6	35 / 25	446	15	300	368	668	151	402	508	510	44.5	17.1	5	2.3	1.9
P8-S7	35 / 25	441	15	600	367	967	147	359	512	500	42.7	8.2	1.4	1.6	1.3
P11-S4	35 / 25	521	19	180	74	254	35	128	207	-	54.9	41.6	39.7	39.7	41.2
P11-S6	35 / 25	544	19	300	97	397	49	241	484	407	58.1	38.4	7.3	3	4.7
P11-S7	35 / 25	598	19	600	81	681	41	430	528	440	61.4	16.4	6.4	4.3	3.6
P10-S5	35 / 25	533	29	180	38	218	30	107	485	683	66.8	52.3	15.2	4.4	3.2
P10-S6	35 / 25	472	29	300	42	342	31	168	476	440	58.5	37.1	7.3	3.8	1.3
P10-S7	35 / 25	478	29	600	30	630	27	437	497	420	58.3	15.2	4.6	3.3	1.8

These results include the following additional measurements for evaluation of sustained smouldering combustion:

- back face temperature of the specimen at ignition, termination of external heat exposure and the maximum value attained during the heating phase and subsequent 1-hour monitoring period.
- the time the rear face temperature attains 250°C
- specimen measurements during the heating period and for a further 60 minutes with and additional mass measurement 24-hours after termination of heating.

The back face temperatures of specimens tested at irradiances of 15 and 19kW/m² were increasing at the time of ignition and therefore the behaviour of the specimens cannot be regarding as thermally thick whereas at ignition the behaviour of the specimens exposed to an irradiance of 29kW/m² would be expected to approximate to a thermally thick specimen. However, at the time of termination of heating all back face temperatures were elevated and therefore no specimens would be likely to behave as thermally thick specimens.

For the specimens with back face temperatures over 250°C burn through of the element and / or a contribution of heat from the rear face can be expected.

There were significant residual masses after 24 hours and as expected the back face temperature did not exceed 250°C for the specimens that self-extinguished. These specimens are highlighted in blue in Table 27.

A good example of the different modes of behaviour is provided by the specimens tested at an irradiance of 19kW/m² after being conditioned at 23°C and 50% relative humidity. These are identified as specimens P2-S2 to P2-S4 and the specimens were exposed to the heat source until ignition plus 3,5, and 10 minutes respectively. The specimens heat release rates (HRR) and masses are plotted in *Figure 22* and the rear face temperatures are plotted against time in Figure 23.

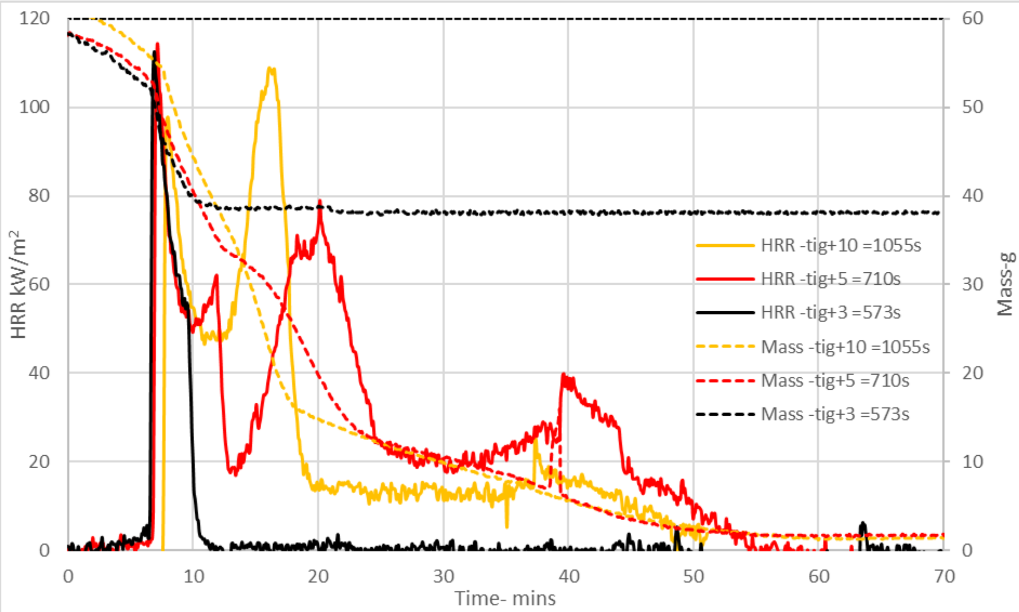


Figure 22 HHR and specimen mass for 12mm thick treated radiata pine subjected to an irradiance of 19kW/m² - black plots show specimen with heating terminated 3 minutes after flaming ignition (total exposure 573s) which self-extinguished when heat source removed; Red and yellow plots show specimens with longer exposures that continued smouldering combustion when heating continued.

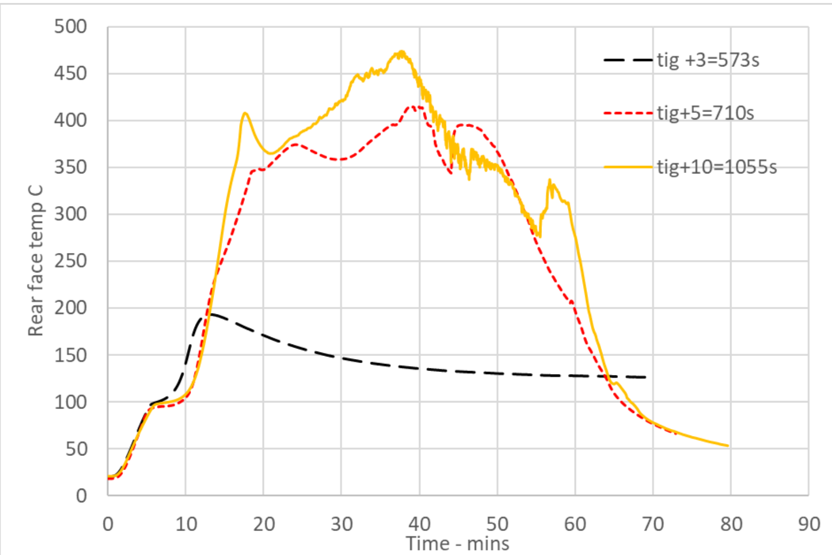


Figure 23 Rear face temperatures for 12mm thick treated radiata pine subjected to an irradiance of 19kW/m²-black long dashes show specimen with heating terminated 3 minutes after flaming ignition (total exposure 573s) which self-extinguished when heat source removed. Red and yellow plots show specimens with longer exposures that continued smouldering combustion until the timber was effectively consumed

The specimen exposed to heating for 10 minutes after ignition followed a typical mode of behaviour for thin timber elements subjected to a cone calorimeter test where there is an initial peak in the HRR after ignition followed by a second peak as additional volatiles are produced from the back face after rear face temperatures exceed 250°C and then the HRR reduces as the majority of the timber is consumed as indicated in the yellow plots.

The red plots for the specimen exposed to heating for 5 minutes after ignition show a similar behaviour until termination of heating that occurred approximately 12 minutes after the start of the test which caused a sudden drop in the heat release rate just as the HRR had begun increasing towards a second peak. This delayed the contribution of volatiles from the back face of the specimen / burn through but a weaker second peak did form and then the HRR reduced as the majority of the timber was consumed.

For both the above scenarios there was some indication of sustained smouldering combustion, but it was short lived due to the limited fuel available.

The third specimen which was subjected to external heating for 3 minutes after ignition (total exposure 573s, approximately 9.5 mins) self-extinguished because as the first peak was declining as the heating was terminated prior to burn through and a significant contribution from the rear face as shown in the black plots in *Figure 22* and *Figure 23*. Specimen P11-S4 which was conditioned prior to the test at 35°C and 25% was also tested at an irradiance of 29kW/m^2 for 3 minutes after ignition and behaved in a similar manner.

At an irradiance of 15kW/m^2 all specimens were fully consumed and at an irradiance level of 29kW/m^2 all specimens were consumed when conditioned prior to test at 35°C and 25% although two specimens self-extinguished when conditioned prior to test at 23°C and 25%.

The above results indicate that with thin elements it is likely that the timber will be fully consumed if ignition occurs, and the flaming combustion becomes established. However, for short exposures (say less than 2 minutes) it is possible for treated pine to self-extinguish in some applications.

A useful design / maintenance strategy for thin timber elements is therefore to avoid combustible materials, vegetation and mulch collecting against timber fences since if these materials ignite, they may provide sufficient heat for flaming combustion to become established. Details such as non-combustible plinths as specified in AS 3959 for the walls to houses may achieve this purpose.

Thick Elements

When thermally thick elements are exposed the effect of sustained smouldering combustion may be more pronounced because the structural performance of an element may be compromised.

The relevant results from a series of tests performed on timber specimens approximately 38mm to 46mm thick that were undertaken to evaluate the potential for sustained smouldering combustion, amongst other things are summarised in *Table 28*. This size range generally reflects the lower bound for fence framing and / garden wall applications.

The test methods and additional data generated were similar to those used for thin elements except that a full series of tests included samples where heating was terminated 3,5,10 and 30 minutes after ignition. The specimens for the 30 minute samples were additionally instrumented with internal thermocouples to enable the progression of heat transfer to be determined.

Where self-extinguishment occurred and the residual mass remaining after 24-hours was more than 60% of the initial mass the details have been shaded blue in *Table 28*.

Table 28 Results summary from evaluation of fire properties of thick treated radiata pine specimens

Spec ID Stick /num.	Cond. T °C / RH %	Dens. kg/m³	Irrad. kw/m²	Irrad Dur Post Ig. -s	t_{ig} -s	Tot exp -s	Back temp -°C			Time back temp 250C	Initial mass (g)	Mass end of exposure-g			
							@Ign-ition.	@ end of exp	Max			+ 0 min	+ 30 min	+ 60 min	+ 24h
S1/S2	23 / 50	457.8	12.5	2700[1]	1080[1]	3780	-	100	315	5274	173.8	100.6	73.2	54.6	19.0
S1/S3	23 / 50	455.2	12.5	180	1356	1536	60.7	70	89	-	170.3	150.5	147.3	147.3	148.1
S1/S4	23 / 50	455.1	12.5	300	1366	1666	63.2	83	95	-	170.7	146.2	143.2	143.2	143.4
S7/S2	23 / 50	460	19	180	384	564	21.0	26	63	-	174.8	159.5	156.8	156.3	158.6
S7/S3	23 / 50	466	19	300	329	629	21.0	28	73	-	175.6	156.1	153.5	153	153.1
S7/S4	23 / 50	487	19	600	228	828	20.0	42	150	-	189.3	160.7	135.4	101	68.1
S7/S5	23 / 50	473	19	1800	191	1991	26.0	108	192	-	184.4	111.3	80.2	61.8	26.9
S2/S2	23 / 50	509	29	180	83	263	19.9	21	75	-	204.6	189.2	187.5	184.3	185.1
S2/S3	23 / 50	499	29	300	81	381	19.7	22	95	-	199.8	178.1	173.8	159.8	135.1
S2/S4	23 / 50	481.9	29	600	50	650	22.5	37	213	-	190.4	155.5	126.8	88.9	8.0
S2/S5	23 / 50	487	29	1800	6	1806	26.7	196	365	4654	200.5	48.1	21.9	15.4	16.2
S1/S6	23 / 50	451	40	1800	11	1811	23.8	191	247	-	169.8	84.8	51.1	37.4	16.9
S4/S2	23 / 50	502.2	50	180	8	188	25.0	27	212		197.6	180.6	143.5	98.0	20.7
S4/S3	23 / 50	527.9	50	300	15	315	24.6	29	161		205.7	179.1	154.9	110.1	63.1
S4/S4	23 / 50	487.1	50	600	11	611	25.7	69	287	3981	189.7	145.9	106.4	60.5	5.1
S4/S5	23 / 50	483.5	50	1800	13	1813	26.0	133	374	2225	181.8	75.6	20.5	7.5	3.2
S12/S2	23 / 50	506	75	180	4	184	24.6	30	68		230	207.8	201.9	201.7	202.8
S12/S3	23 / 50	505.2	75	300	2	302	29.9	38	86		223.8	192.2	182.6	182.2	182.4
S12/S4	23 / 50	506.9	75	600	4	604	20.3	44	237		234.1	172.9	125.7	79.3	4.2
S12/S5	23 / 50	547.5	75	1800	6	1806	30.6	136	285	2717	248.1	98.5	62.6	52.2	19.7
S14/S2	35 / 25	471.6	19	180	185	365	31	32	61		204.6	188.5	188.1	187.7	190.9
S14/S3	35 / 25	470.6	19	300	316	616	29	35	72		203.2	180.7	179.9	179.5	180.8
S14/S4	35 / 25	458	19	600	221	821	28	49	179		198.2	167.3	153.6	115.0	45.8
S14/S5	35 / 25	468.8	19	1800	276	2076	28	103	239		204.2	171.3	77	58.1	31.6
S13/S2	35 / 25	463.3	29	180	42	222	28	30	74		200.1	186.3	183.9	182.9	181.8
S13/S3	35 / 25	539.1	29	300	43	343	29	33	87		233.5	211.5	209.5	208.1	209.2
S13/S5	35 / 25	460.6	29	600	53	653	34	51	194		201.2	165.4	126.6	86.2	15.3
S13/S4	35 / 25	472.9	29	1800	33	1833	33	106	252	5170	207.6	132.4	78	64.4	33.2
S14/S6	35 / 25	473.2	40	1800	18	1818	39	118	240		209.2	178.7	87.9	67.8	5.7
S18/S2	35 / 25	459.6	50	180	10	190	34	39	205		194.8	170.7	135.6	92.9	50.6
S18/S3	35 / 25	478.1	50	300	11	311	31	38	199		203.3	171.8	137.4	96.5	69.9
S18/S4	35 / 25	476.4	50	600	11	611	27	60	303	4121	194	149.4	112.1	75.3	28.1
S18/S5	35 / 25	462	50	1800	13	1813	32	206	318	1983	195.5	143.6	40.4	31.9	23.0

'1Flaming Ignition did not occur. Smouldering ignition occurred after approximately 18 mins (1080s) based on HR data Heating was terminated after approximately 63 minutes from start of test (45 mins after smouldering ignition)

The results show that for irradiance levels of 19kW/m^2 and 29kW/m^2 and exposure periods of 3 and 5 minutes after ignition, self-extinguishment occurred with specimens conditioned prior to testing at 23°C/50% r.h. and 35°C/25% r.h.

At an irradiance of 50kW/m^2 the results were marginal with a significant mass remaining but substantially below the mass remaining after tests at 19 and 29kW/m^2.

The specimens tested at an irradiance of 12.5kW/m^2 and 75kW/m^2 preconditioned at 23°C/50% r.h. and exposure periods of 3 and 5 minutes after ignition also exhibited self-extinguishing behaviour.

The performance during the tests performed at an irradiance of 12.5kW/m^2 varied from the tests performed at higher levels because 12.5kW/m2 is close to the critical heat flux and ignition may not occur or occurs after a long time. Two of the three specimens ignited and flaming combustion occurred after 22 minutes and the tests were continued for 3 and 5 minutes before heating was terminated and self-extinguishment occurred. Flaming combustion did not occur with the thirds specimen although smouldering combustion was estimated to have commenced at after approximately 18 minutes of heating. Heating was terminated after 63minutes and sustained smouldering combustion continued throughout the 1-hour monitoring period with minimal mass remaining 24-h later.

The graphs shown in *Figure 24* and *Figure 25* illustrate the behaviour of specimen S1/2 smouldering ignition with prolonged heating and S1/4 flaming ignition and subsequent self-extinguishment.

The rear surface of specimen S1/2 with 63 minutes heating and smouldering combustion exceeded 250°C after approximately 88 minutes indicating a char depth of approximately 39mm.

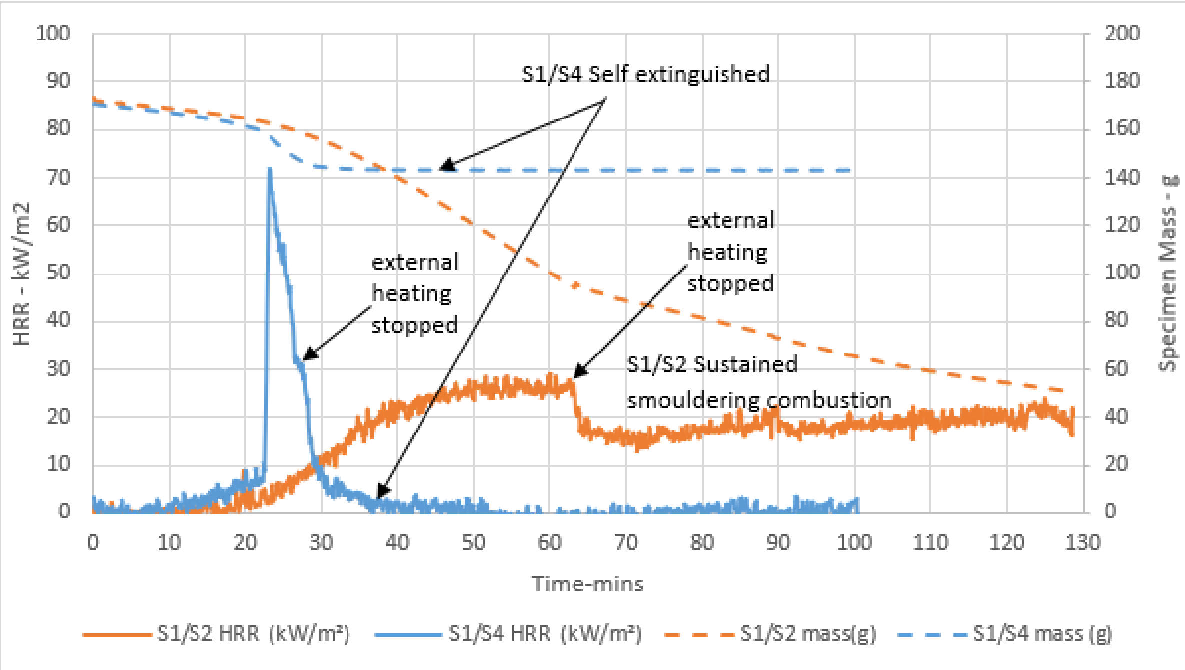


Figure 24 HHR and specimen mass for 45mm thick treated radiata pine subjected to an irradiance of 12.5kW/m^2 - blue plots show specimen with heating terminated 5 minutes after flaming ignition (total exposure 27.75mins); Brown plots show specimen that underwent smouldering ignition only with heating continued for total exposure of 63 minutes

Figure 26 shows a plot of the HRR and mass for a 45mm thick treated radiata pine specimen subjected to an irradiance of 29kW/m^2 after conditioning at 30°C/25% r.h. The solid blue line shows the HRR for a specimen subjected to heating for 10 minutes after ignition and indicates sustained smouldering combustion and the corresponding blue dashed line shows the reduction in mass of the treated pine specimen. The brown plots show the performance of a specimen that was exposed for 3 minutes after ignition and self-extinguished.

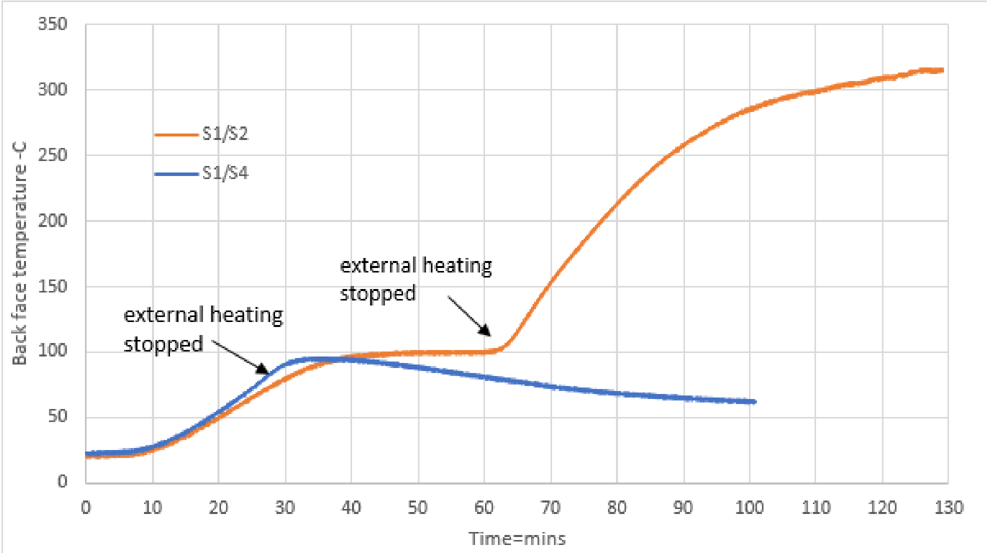


Figure 25 Rear face temperature for 45mm thick treated radiata pine subjected to an irradiance of 12.5kW/m² - blue plots show specimen with heating terminated 5 minutes after flaming ignition (total exposure 27.75mins); Brown plots show specimen that underwent smouldering ignition only with heating continued for total exposure of 63 minutes

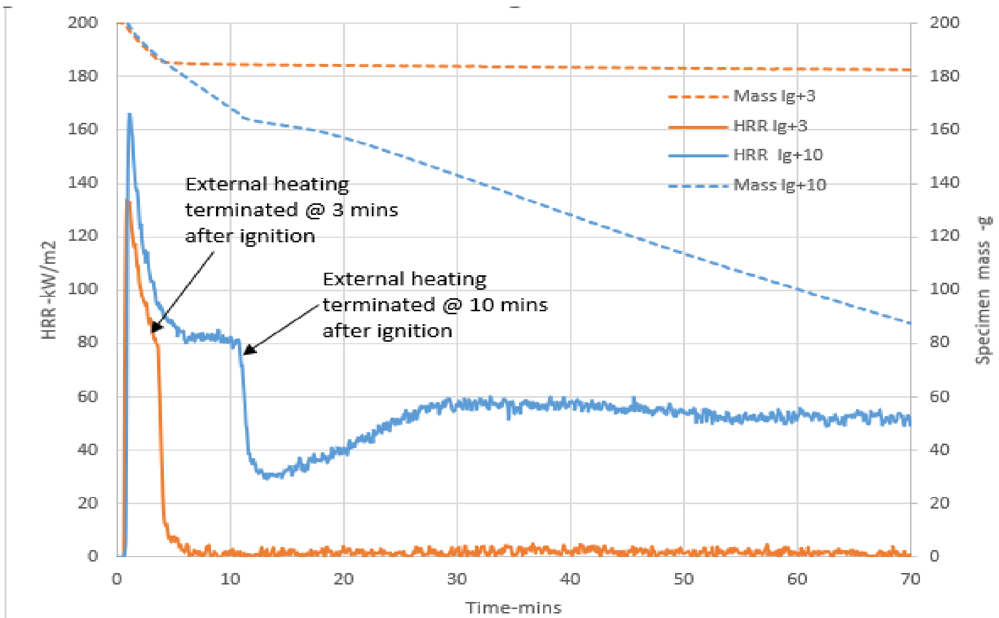


Figure 26 HRR and mass for 45mm thick treated radiata pine subjected to an irradiance of 29kW/m² after conditioning at 30°C/25% r.h.- blue plots show specimen with heating terminated 10 minutes after flaming ignition (total exposure 653s) exhibiting sustained smouldering combustion behaviour; brown plots show specimen with heating terminated 3 minutes after flaming ignition (total exposure 222s) exhibiting self-extinguishment behaviour.

A specimen similar to those that provided the results shown in Figure 26 was tested with internal thermocouples and exposed to an irradiance of 29kW/m² for 30 minutes. The results are shown in Figure 27.

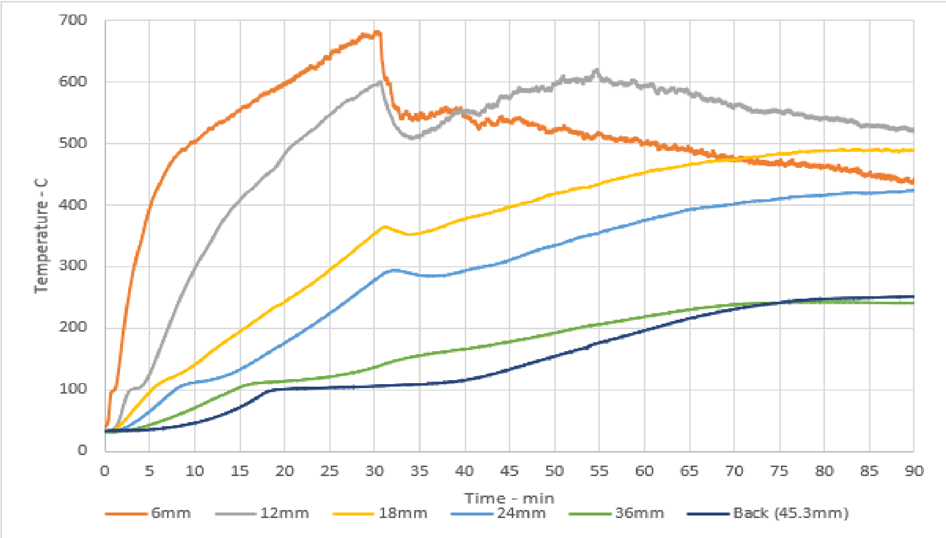


Figure 27 Internal temperatures for 45mm thick treated radiata pine subjected to an irradiance of 29kW/m² for 30 minutes after ignition and conditioning at 30°C/25% r.h.

These plots enable the temperature profiles to be determined at the time heating of specimens is terminated after 3,5 and 10 minutes. The temperature profiles shown in Figure 28 were derived for cases where self-extinguishment occurred with the specimens tested at irradiances of 19 and 29kW/m². The black lines indicate cases that were marginal and the coloured line cases were more than 60% of the initial specimen mass was retained. The results indicate for thermally thick specimens they may be a critical threshold for the 250C profile at a depth of approximately 10mm for self-extinguishment to occur for radiata pine treated with water borne copper-based preservatives but more work is required to confirm this hypothesis over a broad range of heating profiles.

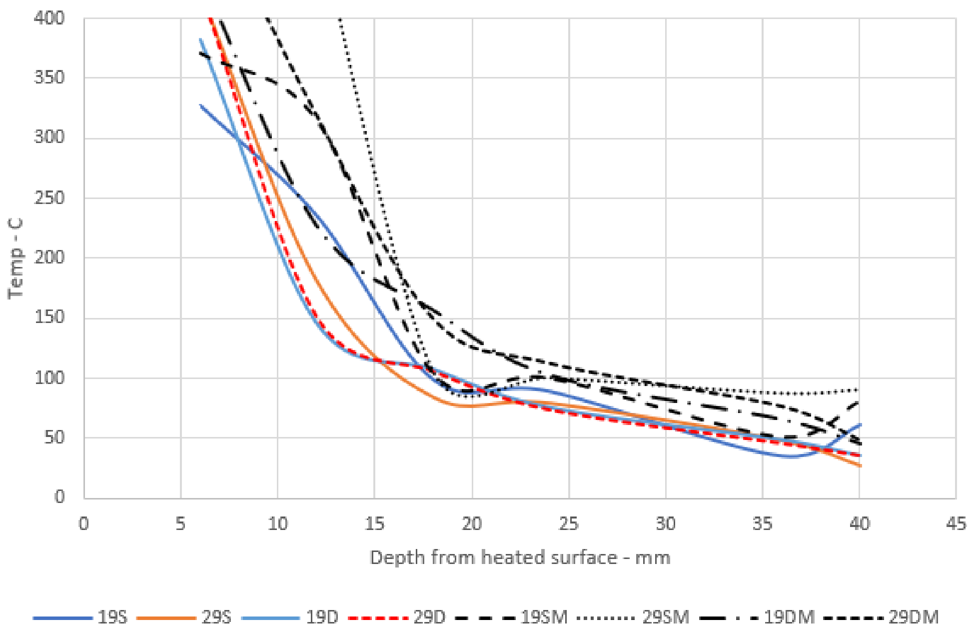


Figure 28 Temperature profiles at termination of heating for specimens subjected to irradiances of 19 and 29 kW/m². The suffix S is applied to specimens conditioned at 23°C and 50% r.h. and D to specimens conditioned at 35°C and 25% r.h. Suffix M is applied to marginal cases were there had been substantial smouldering combustion, but late self-extinguishment occurred.

Investigation of effect of prewetting waterborne copper-based preservative treated timbers

Methodology for investigation of pre-wetting

An investigation was undertaken of the potential impact of prewetting waterborne copper-based preservative treated radiata pine on the fire properties over a period of 24-hours after pre-wetting.

The fire properties were determined using a cone calorimeter at an irradiance of 19kW/m^2 to provide an indication of the change in performance of the timber elements located in areas subject to bushfire attack levels up to BAL 19.

Essentially a series of specimens were conditioned to equilibrium at 35°C and 25% RH prior to prewetting representing high ambient temperatures and low relative humidities during periods of severe bushfire risks. A control specimen prior to pre-wetting was tested. The samples were then pre-wet and one specimen was tested shortly after prewetting and the remaining samples were conditioned at 35°C and 25% RH for periods of 2h, 3h, 4h and 24h after pre-wetting to simulate progressive drying under bushfire weather conditions to determine the duration that pre-wetting may be effective.

Two series of tests were undertaken, one with thin timber specimens (12mm) and the other with thicker members (44mm) to examine the potential effectiveness of pre-wetting for different sized elements. The timing and exposure periods are summarised in Table 29 and further details of the test procedures are provided in Attachment 5

Table 29 Summary of the timing for typical specimens is shown below:

Group	Specimen thickness-mm	Exposure after Ignition (min)	T - Time relative to pre-wetting /hosing (h)					
			S1	S2	S3	S4	S5	S6
P4	12 mm	10	-1	0.25 ± 0.1	2	3	4	24
F4	44mm	30	-1	0.25 ± 0.1	2	3	4	24

Materials

Details of the samples including material properties immediately prior to cone calorimeter testing are summarised in Table 30 and Table 31. Six additional 12mm specimens were included to investigate unexpected times to ignition.

Table 30 Specimen details for pre-wetting specimens nominally 12mm thick.

Test-run	Specimen ID		Conditioning T °C / RH %	Thick. mm	Initial mass (g)	Density (kg/m³)	MC %[1]	Retention ratio %
	(stick /num)	Treatment						
S1	P3/S2	Treat C-H3	35/25% control	11.9	60.6	532.5	7	0.87
S2	P3/S3	Treat C-H3	<15min after pw	11.8	65.7	573.4	30	0.87
S3	P3/S4	Treat C-H3	35/25% for 2h after pw	12.1	58.5	495.9	17	0.87
S4	P3/S5	Treat C-H3	35/25% for 3h after pw	12.1	61.6	513.9	15	0.87
S5	P3/S6	Treat C-H3	35/25% for 4h after pw	12	60.5	518.2	12	0.87
S6	P3/S7	Treat C-H3	35/25% for 24h after pw	11.9	58.8	503.4	8	0.87
S1A	P6/S3	Treat C-H3	35/25% control	12.8	54.6	436.2	7	
S3A	P6/S6	Treat C-H3	35/25% for 2h after pw	13.3	61.1	459	23.4	
S6A	P6/S7	Treat C-H3	35/25% for 24h after pw	12.6	56.6	455.3	7.8	
S1B	P7/S3	Treat C-H3	35/25% control	12.5	68.5	567.2	7.4	
S4B	P7/S4	Treat C-H3	35/25% for 3h after pw	12.9	76.1	603.3	18.7	
S6B	P7/S5	Treat C-H3	35/25% for 24h after pw	12.7	69.8	568.3	8.8	

Note 1 moisture content measured immediately prior to cone calorimeter testing

Table 31 Specimen details for pre-wetting specimens nominally 44mm thick.

Test-run	Specimen ID (stick /num)	Treatment	Conditioning T °C / RH %	Thick. mm	Initial mass (g)	Density (kg/m³)	MC %	Retention ratio %
S1	S19/S2	Treat C-H4	35/25% control	44.1	210.5	498.2	7	0.77
S2	S19/S3	Treat C-H4	<15min after pw	44.2	226.2	528.2	31	0.77
S3	S19/S4	Treat C-H4	35/25% for 2h after pw	44.8	229.1	521.3	29	0.77
S4	S19/S5	Treat C-H4	35/25% for 3h after pw	44.9	212.6	484.2	23	0.77
S5	S19/S6	Treat C-H4	35/25% for 4h after pw	45.1	235	530.2	23	0.77
S6	S19/S7	Treat C-H4	35/25% for 24h after pw	44.4	213.1	496.9	11	0.77

Note 1 moisture content measured immediately prior to cone calorimeter testing

Results and Discussion

Thin elements

The results from the 12mm thick samples are summarised in Table 32 and confirm that significant increases in moisture content of radiata pine can be achieved by prewetting increasing the moisture from approximately 7% to 30% which then reduces over a 24hour period to 8 or 9%. This is consistent with the observations that radiata pine is very responsive to humidity changes but other timbers (e.g hardwoods) may be less responsive (Hayward 2007)

The moisture content was determined by a moisture meter and whilst correction factors were used to correct for the effect of the preservative treatment the values should be treated as indicative.

Some inconsistencies in the cone calorimeter test results were observed which may have been the result of specimen deflections modifying heating conditions, the proximity of the igniter to the specimen and the effect of testing timber specimens below irradiances of 25kW/m^2 where other modes of ignition may be introduced. This resulted in unrealistically low ignition times for specimen S1, S3 and S4. Repeat tests were undertaken yielding results that still had some inconsistencies. (identified as S1A, S3A, S6A, S1B, S4B and S6B)

Table 32 Heat Release Rate and time to ignition for pre-wet test series, 12mm thick specimens at an irradiance of 19kW/m^2

Test-run	Time after Pre-wetting	MC %	t_{ig} -s	Back Temp @ ignition °C	HRR Peak kW/m^2	Time to peak -s	Av HRR_{180} kW/m^2	Av HRR_{300} kW/m^2	Av HRR_{600} kW/m^2
S1	Before	7	102	37.1	120.74	140	95.85	92.1	114.04
S2	<15min	30	471	99.7	128.76	485	94.83	92.57	103.43
S3	2h	17	76	38.2	111.08	110	87.72	76.27	85.66
S4	3h	15	290	86.6	148.96	305	105.25	96.23	108.76
S5	4h	12	520	127.2	116.99	555	86.3	90.76	94.04
S6	24h	8	456	108.3	117.47	480	90.97	91.84	91.93
S1A	Before	7	209	103	108.36	235	69.43	64.65	78.77
S3A	2h	23	429	99	88.22	440	55.89	45.95	62.9
S6A	24h	8	77	29	110.57	115	78.17	68.14	77.98
S1B	Before	7	407	103	114.99	430	91.24	90.04	104.5
S4B	3h	19	564	99	112.64	596	82.06	73.91	93.51
S6B	24h	9	296	*	118.11	325	89.92	82.08	103.38

(Moghtaderi, Novozhilov et al. 1997) reported ignition times for radiata pine specimens nominally 9mm thick determined using the cone calorimeter obtaining the results shown in Table 33.A review of the table indicates the potential for significant increases in the time to ignition at irradiances of 20 and 30kW/m^2.

Table 33 Time to ignition for Radiata Pine, 9mm thick determined using the cone calorimeter adapted from (Moghtaderi, Novozhilov et al. 1997)

Irradiance (kW/m^2)	Time to ignition -s at nominated moisture content			
	0%	15%	22%	30%
20	179	295	420	540
30	19	52	67	93
40	9	18	30	36
50	5	11	11	19
60	3	7	9	11

The specimen mass loss results in Table 34 as expected indicate that with a 10 minute post ignition test period thin wood sections will be consumed.

Table 34 Specimen mass results for pre-wet test series, 12mm thick specimens

Test-run	Time after Pre-wetting	MC %	Initial mass (g)	Mass (x hours) after end of exposure - g				Back Temp at end of exp °C
				0	+ 0.5h	+1h	+24h	
S1	Before	7	60.6	15.5	1.6	0.8	2.2	344.5
S2	<15min	30	65.7	15.5	3.3	1.8	1.4	497.5
S3	2h	17	58.5	18.4	1.6	0	1.4	364.7
S4	3h	15	61.6	12.4	1.3	1.4	1.9	393.4
S5	4h	12	60.5	11.6	1.5	1.1	1.4	458.2
S6	24h	8	58.8	12.3	1.4	0.9	1.7	431.5
S1A	Before	7	54.6	14.7	2.9	2.0	1.1	414.1
S3A	2h	23	61.1	16.3	0	0	1.3	468.9
S6A	24h	8	56.6	18.6	3.4	1.6	1.3	352.2
S1B	Before	7	68.5	15.3	4.2	0.6	1.2	448.8
S4B	3h	19	76.1	19.8	4.4	1.1	1.2	387.5
S6B	24h	9	69.8	17.4	2.5	0.6	1.2	*

Thick elements

The results from the 44mm thick samples are summarised in Table 35 and confirm that significant increases in moisture content of radiata pine can be achieved by prewetting and increasing the moisture content from approximately 7% to 31% which then reduces over a 24-hour period to 11%. The higher moisture contents can be seen to substantial increase the time to ignition at irradiance of $19kW/m^2$.

Table 35 Heat Release Rate and time to ignition for pre-wet test series, 44mm thick specimens at an irradiance of $19kW/m^2$

Test-run	Time after Pre-wetting	MC %	t_{ig} -s	Back Temp @ ignition °C	HRR Peak kW/m^2	Time to peak -s	Av HRR_{180} kW/m^2	Av HRR_{300} kW/m^2	Av HRR_{600} kW/m^2
S1	Before	7	267	31.3	117.52	295	81.03	69.22	57.39
S2	<15min	31	647	29.5	107.55	670	69.2	58.69	48.85
S3	2h	29	631	31	105.06	655	70.46	58.65	42.74
S4	3h	23	457	32.8	104.47	485	70.32	59.38	46.01
S5	4h	23	495	33.5	104.19	520	70.69	58.5	47.08
S6	24h	11	306	27.1	114.6	325	81.15	68.65	54.25

The results of monitoring the mass of the test specimens indicate that when heating was terminated 30 minutes after ignition with the irradiance of 19kW/m^2 the residual masses were similar and there was some ongoing smouldering combustion continuing for the following hour. After 24 hours the smouldering combustion had ceased with residual masses varying from 54.7 g to 70.3g.

Table 36 Mass loss results for pre-wet test series, 44mm thick specimens

Test-run	Time after Pre-wetting	MC %	Initial mass (g)	Mass (x hours) after end of exposure - g				Back Temp at end of exp °C
				0	+ 0.5h	+1h	+24h	
S1	Before	7	210.5	133.6	105.2	81	63.3	103.1
S2	<15min	31	226.2	139.1	105.5	77.6	57.9	100.8
S3	2h	29	229.1	143.9	112.7	87.9	70.3	97
S4	3h	23	212.6	132.5	99.3	74.2	61.7	95.3
S5	4h	23	235	151.2	119.7	92.8	75.6	94.5
S6	24h	11	213.1	136.8	104.8	75.6	54.7	101.8

Results provided in preceding sections have indicated with durations of exposure after ignition reduced to 5 minutes self-extinguishment would occur substantially earlier.

These results generated in the project indicated that prewetting can substantially increase the time to ignition of timber and hence substantially reduce the risk of ignition and subsequent fire spread providing a demonstration of the concept. The drying rates did not incorporate the effects of direct exposure to the sun which would be expected to accelerate drying, but the rates did not account for shielded applications such as sub floor spaces where higher relative humidities could be maintained potentially reducing the rate of reduction in moisture contents.

Outcomes from Stage 1 and 2 studies of the fire properties of water borne copper -based preservative treated Radiata Pine.

Test protocols to determine the extent of sustained smouldering combustion

Test protocols were initially developed to identify under laboratory conditions if water borne copper-based preservative treated Radiata Pine increases the likelihood and extent of sustained smouldering combustion compared to untreated radiata pine and if so, compare the likelihood and extent of sustained smouldering combustion for different water borne copper based treatments.

The initial protocols developed are provided in attachments 2 and 3 and successfully demonstrated the increased likelihood and extent of sustained smouldering combustion with copper-based treatments and enabled the performance of the different treatments to be compared.

Key features of the protocol included

- termination of heating prior to full consumption of the timber samples
- continuous monitoring of samples for mass loss (and other criteria if appropriate) for 60 minutes after heating is terminated and measuring specimen masses 24 hours after termination of heating
- measurement of the rear face temperature of the specimens during heating and for 1-hour afterwards

- thin samples (12mm nominal thickness) were tested at an irradiance of 25kW/m^2 with 10 minutes exposure and thick samples (38mm-46mm) were tested at an irradiance of 50kW/m^2 for 30minutes prior to monitoring for sustained smouldering combustion. The irradiances were selected for compatibility with common classification criteria for timber products (50kW/m^2 for determination of NCC Group numbers for internal linings and 25kW/m^2 for evaluation of bushfire resistant timbers).

These protocols effectively differentiated the occurrence and extent of sustained smouldering combustion enabling the selection of a treatment that could provide fire test results that would be expected to be generally applicable to other waterborne copper-based treatments.

The protocol for thick samples had greater resolution because with thinner samples, even with the exposure reduced time of 10 minutes after ignition, were substantially consumed prior to termination of heating and differences in sustained combustion were therefore small.

It was identified that the extent of sustained smouldering combustion may be impacted by a number of variables including retention rates, proportion of sap wood, duration of heating, irradiance levels, density and moisture content and thickness of timber. The effect of copper compounds as a catalyst for sustained smouldering combustion may be affected by the rate of heating especially in formulations where the copper compounds may react with other chemicals such as arsenic instead of increasing the char oxidation.

The Stage 2 program was therefore modified to include further comparative testing with the following enhancements to the protocols.

For testing thin, 12mm thick and thick, 38-46mm specimens:

- Samples of the treated specimens are to be forwarded to an accredited testing laboratory for testing and comparison against AS 1604.1 (Standards_Australia 2021) specifications for preservative treatments.
- For each set of three samples the specified irradiance was applied to the three samples after 3, 5 and 10 minutes after flaming ignition rather than testing all three samples for the same period (e.g. 10 minutes after ignition). The 3-minute exposure times were considered more representative of, although still greater than, the flame residency periods for most bushfires.
- Heat flux values were varied to correspond to the radiant heat fluxes associated with the bushfire attack levels prescribed in AS 3959 with the flexibility to select other values to evaluate the sensitivity of findings to different heat fluxes. The further comparative studies were undertaken at an irradiance of 19kW/m^2.

The protocol enhancements for thick specimens also included testing a fourth sample exposed for 30 minutes after flaming ignition with additional internal thermocouples to obtain data on the progression of the char depth. The additional internal thermocouples can be viewed as a voluntary addition to the general protocol predominantly for research purposes.

The additional comparative testing on the 12mm samples at an irradiance of 19kW/m^2 indicated that the control specimen was effectively fully consumed when exposed to 19kW/m^2 for 5 and 10 minutes after ignition and treatments A,C and the untreated sample all self-extinguished when exposed to 19kW/m^2 for 3 minutes after ignition(or a total of typically 8 minutes if the pre-ignition time is included) . These results indicate that there may be little difference in the fire properties of the untreated and water borne copper-based treatment for thin sections of radiata pine (12mm or less) which are likely to be consumed if the exposure is greater than 5 minutes after ignition at an irradiance of 19kW/m^2 or self-extinguish at exposures of 3 minutes or less.

This also indicates that for screening for sustained smouldering combustion purposes samples at least 38mm thick should be considered.

The residual mass results from the tests performed at an irradiance of 19kW/m^2 clearly differentiate the increased tendency for sustained smouldering combustion with the copper based treatments. The results at an irradiance of 50kW/m^2 were less clearly defined because a greater proportion of the timber is consumed during the 30 minute exposure but nevertheless the test protocol could differentiate the untreated specimens identified as F from the treated specimens identified as A and C. The X-series samples were thicker and had a higher density than the F1 untreated control which explains the higher residual mass of the AX specimens. Notwithstanding this and variations in density between the F1 groups the protocol still demonstrated a difference between sustained smouldering combustion behaviour of specimens AX and CX which had similar densities. This further justified the selection of treatment C as the default treatment for the large scale test series since it has the greatest tendency for sustained smouldering combustion.

For routine screening / comparison of treatments test series should be carried out at approximately 19kW/m2 and 50kW/m2 irradiances using radiata pine specimens at least 38mm thick. Tests is each series should be performed with exposure periods of 3,5,10 and 30 minutes after flaming ignition using the protocol in attachment 3 with the updates in attachment 4.

Fire properties of preservative treated timber

Time to piloted ignition

For the thin test specimens (nominally 12mm thick) cone calorimeter tests were performed at irradiance levels of 15, 19 and 29kW/m^2 and the back temperature measurements at the time of ignition show that the specimens at 15kW/m^2 and 19kW/m^2 did not approximate to the definition of thermally thick and therefore methods such as Janssens' (Janssens 1991) that assume thermally thick elements were not applied. Further, if a surface temperature at ignition of approximately 350°C is assumed the specimens also do not approximate to the definition of thermally thin. Therefore, general estimates of ignition times were based directly on the experimental data.

The typical time to ignition when exposed to an incident heat flux of 15kW/m^2 for specimens conditioned under standard conditions and at 35°C and 25% relative humidity exceeded 6 minutes and at lower irradiance levels approaching a critical heat flux of 12.5kW/m^2 the time to ignition would be expected to increase exponentially until ignition is no longer possible at heat fluxes below the critical heat flux.

This indicates that there is a low probability of piloted ignition with exposures to heat fluxes below 15kW/m^2 for less than 6 minutes. Thus, it would be unlikely for the treated pine to be ignited if located within a BAL 12.5 zone and substantial part of the BAL 19 zone by radiant heat from fire front and a small ignition source, unless there is an additional heat source from for example collections of burning debris, embers or vegetation in either direct contact or very close to a timber element.

At 19kW/m^2 exposure there was a large reduction in the time to ignition (average of 84s for the specimens conditioned at 30°C and 25% relative humidity). This period is at the upper end of the range of flame residency periods expected at bushfire fronts which approximates to the period of exposure to maximum heat flux directly from the fire front. This is less than the 2 minute maximum exposure period required by AS 1530.8.1 which is intended to include safety factors to account for some limitations associated with the test method such as the use of standard conditioning requirements for specimens. The time to ignition of specimens exposed to 19kW/m^2 after standard conditioning was significantly beyond 2-minutes.

These results are therefore consistent with the expected performance and use of exposed radiata timber elements forming the external walls of a house within BAL 12.5 and BAL 19 exposures as defined in AS 3959.

At exposures of 29kW/m^2 the average time to ignition under standard pre-test conditioning was 68s which reduced to 36s for specimens conditioned at 35°C and 25% relative humidity. These results indicate that at BAL 29 exposures there is a higher risk of ignition of buildings if clad with preservative treated radiata pine, although the timbers could still provide resistance to ignition for fuel types with lower flame residency periods such as some grassland fires provided the walls are protected against the build-up of debris. The results also highlight the potential beneficial effects of pre-wetting treated radiata pine prior to exposure to bushfire attack.

For the thicker specimens the specimens tended to behave as thermally thick elements and the time of ignition and therefore the Janssens method was used to determine relationships between the time to ignition and imposed heat flux. Relationships were derived for treated radiata pine after standard conditioning at 23°C and 50% relative humidity and after conditioning at 35°C and 25% relative humidity and are plotted against time in Figure 29

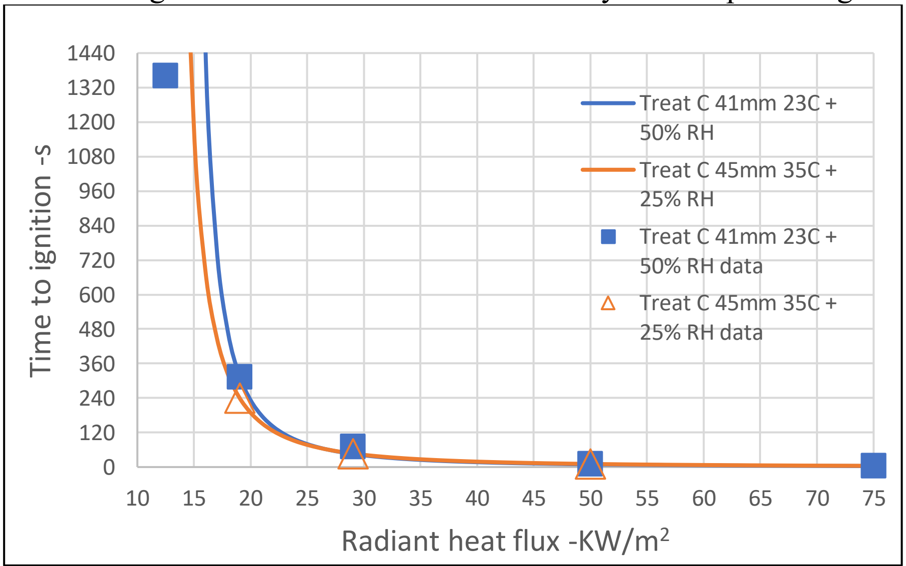


Figure 29 Plots of time to ignition for Radiata Pine with preservative treatment C(H4) based on Janssens method

The experimental results are closely aligned with the correlations except for the specimens exposed to 12.5kW/m^2 which was very close to the critical heat flux.

The results confirm the finding that if the heating is only provided directly from the fire front and the imposed heating conditions do not exceed the BAL 19 requirements of AS 3959, piloted ignition of water borne copper-based preservative treated timber would be unlikely since exposures greater than four minutes at a heat flux of 19kW/m^2 are required for ignition. This finding is dependent on there being no additional heat source from burning debris, embers or other burning materials and is consistent with the construction requirements in AS 3959.

A series of tests on 12mm thick specimens at an irradiance of 19kW/m^2 were undertaken to evaluate the impact of density on the time to ignition but the results were inconclusive.

The following correlation derived by Babrauskas (Babrauskas 2003) was therefore used to provide a semi-quantitative estimate of the time to ignition based on incident heat flux and density:

$t_{ig} = 130\rho^{0.73} / (q''_e - 11.0)^{1.82}$

where
ρ = density (kg/m^3),
q''_e = irradiance (kW/m^2), and
t_{ig} = ignition time (s).

The correlation was used to generate plots of the time to ignition for variations in density, within the range typical of radiata pine at irradiance levels of 19,25,29,and 50kW/m^2. Data points at the same irradiance levels were then plotted based on representative tests undertaken under stages 1 and 2 of this project. The results indicate that if the dimensions of specimens and irradiance levels ensure the specimen behaviour will approximate to that of a thermally thick specimen and the irradiances are not less than 25kW/m^2 Babrauskas's correlation will provide a reasonable indication of the variation of the time to piloted ignition as a function of density for untreated and preservative treated radiata pine.

The correlation is less reliable at irradiances below 25kW/m^2 and when the specimen does not behave as a thermally thick element due to the combination of specimen dimensions and irradiance. In these cases, reliance may have to be based directly on relevant experimental data.

Heat Release Rate Data for Radiata Pine treated with preservative C.

The comparative testing confirmed that similar fire properties were obtained from tests on water borne copper based preservative treated radiata pine and untreated radiata pine with respect to piloted ignition and flaming combustion with significant variations limited to sustained smouldering combustion . During investigations into sustained smouldering combustion a significant amount of data relating to the flaming combustion of radiata pine with preservative treatment C was recorded.

The magnitude and time of occurrence of the first heat release rate (HRR) peak, and the average HRR for 180s after ignition are commonly used parameters for the characterisation of the burning behaviour of timber and have been summarised in Table 37. Generally, there were at least 3 samples to provide a mean value for each cell except for the results obtained at an irradiance of 12.5kW/m^2 where one of the three specimens did not ignite since the irradiance was close to the critical flux. Whilst the general behaviour was similar there are differences between the performance of timber specimens that can be regarded as thermally thin and those that exhibit thermally thick characteristics. The thinner specimens exhibited two HRR peaks, the first peak occurring shortly after ignition and then decaying as a protective char layer develops. The second peak occurs about the time the smouldering combustion front reaches the back face of the specimen. For thicker specimens only one peak occurred during the test duration. These behaviours are demonstrated in Figure 30 and Figure 31.

Table 37 Summary of Heat Release Rate Data for Radiata Pine treated with a water borne copper based preservative derived from the Stage 1 and 2 Cone Calorimeter tests

Pre-test conditioning (°C / %)	Property when tested using cone calorimeter	12mm paling samples			41 mm framing samples				
		Irradiance -kW/m^2			Irradiance -kW/m^2				
		15	19	29	12.5	19	29	50	75
Standard 23/50	Time to Peak HRR	345	336	82	1390	332	90	37	34
	Peak HRR	104	107	127	76	110	126	156	207
	Av HRR - 180s after ignition	75	73	87	62	73	86	115	161
35/25	Time to Peak HRR	398	117	58		270	60	31	
	Peak HRR	127	136	142		135	149	184	
	Av HRR - 180 s after ignition	103	108	102		76	89	119	

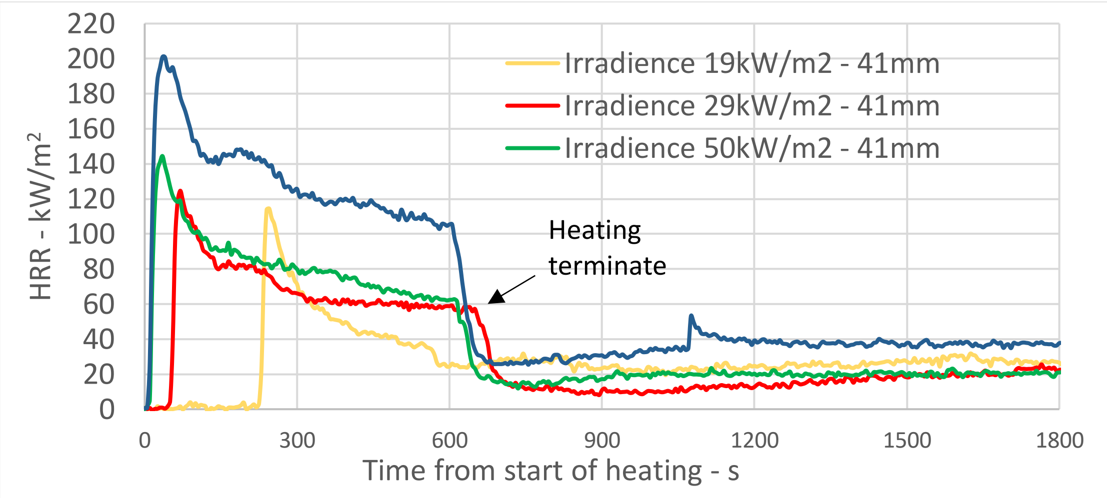


Figure 30 HRR from fire cone calorimeter tests on radiata pine, nominally 41mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

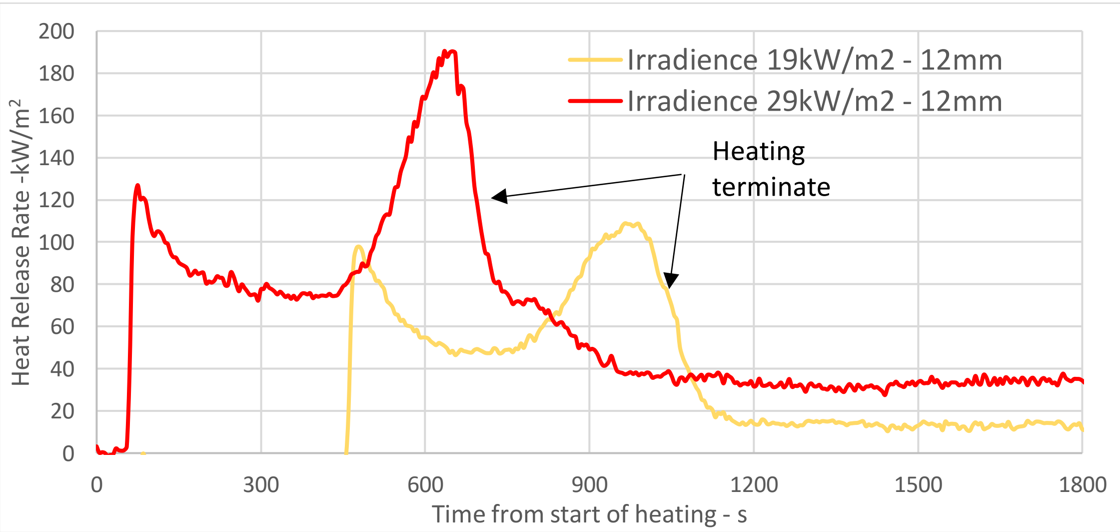


Figure 31 HRR from fire cone calorimeter tests on radiata pine, nominally 12 mm thick with preservative treatment C at varying irradiances for a heating duration of 600s after ignition – specimens conditioned at 23°C and 50% relative humidity.

Sustained smouldering combustion

Thin radiata pine elements (e.g.12mm thick) were found to likely to be fully consumed if ignition occurs, and the flaming combustion becomes established irrespective of whether the radiata pine is preservative treated or untreated . However, for short exposures (say less than 2 minutes) it is possible for treated pine to self-extinguish in some applications.

A useful design / maintenance strategy for thin radiata pine elements is therefore to avoid combustible materials, vegetation and mulch collecting against timber fences since if these materials ignite, they may provide sufficient heat for flaming combustion to become established. Details such as non-combustible plinths as specified in AS 3959 for the walls to houses may achieve this purpose.

Results from tests performed on the thick (38mm – 46mm) specimens show that at irradiances of 19kW/m^2 and 29kW/m^2 and exposure periods of 3 and 5 minutes after ignition, self-extinguishment occurred with specimens conditioned prior to testing at 23°C/50% r.h. and 35°C/25% r.h.

At an irradiance of 50kW/m^2 the results were marginal with a significant mass remaining but substantially below the mass remaining after tests at 19 and 29kW/m^2.

The specimens tested at an irradiance of 12.5kW/m^2 and 75kW/m^2 preconditioned at 23°C/50% r.h. and exposure periods of 3 and 5 minutes after ignition also exhibited self-extinguishing behaviour.

Analysis of internal temperature data indicated for thermally thick specimens that there may be a critical threshold for the 250°C contour at a depth of approximately 10mm for self-extinguishment to occur for radiata pine treated with water borne copper-based preservatives but more work is required to confirm this hypothesis over a broad range of heating profiles.

Effects of pre-wetting preservative treated pine

Timber samples were conditioned at 35°C and 25% relative humidity then pre-wet increasing their moisture content. The samples were then conditioned at 35C°C and 25% for periods of 2,3, 4 and 24 hours before the moisture content was checked and a cone calorimeter test performed at an irradiance of 19kW/m^2. Moisture measurements were obtained using a moisture meter and are indicative values for comparison.

The moisture content data from both the thin and thick samples was consistent with expectations with the smaller (thinner) specimens drying quicker.

The cone calorimeter results for the thick specimens were consistent with the expected results but there were some inconsistencies in the cone calorimeter test results for the thin specimens. These may have been caused by specimen deflections modifying heating conditions, the proximity of the igniter to the specimen varying and the effect of testing timber specimens below irradiances of 25kW/m^2 where other modes of ignition may be introduced. This resulted in unrealistic results specimens S1, S3 and S4. Repeat tests were undertaken yielding results that still had some inconsistencies. (identified as S1A, S3A, S6A, S1B, S4B and S6B)

Table 38 Summary of pre-wetting test results with addition of Moghtaderi time to ignition data for thin specimens

Time relative to pre-wetting	Thick (36mm+)		Thin (12mm)			
	MC %	t_{ig} -s	Test-run	MC %	t_{ig} -s	Tig Moghtaderi cone data[2]
Before	7	267	S1 S1A S1B	7,7,7 (7)[1]	102,209,407 (239)[1]	229
<15min	31	647	S2	30	471,	543
2h	29	631	S3 S3A	17,23 (20)[1]	76,429 (253)[1]	373
3h	23	457	S4 S4B	15,19 (17)[1]	290,564 (427)[1]	334
4h	23	495	S5	12	520	277
24h	11	306	S6 S6A S6B	8,8,9 (8)[1]	456,77,296 (276)[1]	238

Note 1 Value in brackets mean of replicate results
Note 2 Time to ignition calculated based on moisture content results using correlation derived from (Moghtaderi, Novozhilov et al. 1997) data.

The results from Stage 2 indicated that at irradiances below 25kW/m^2 pre-wetting can extended the time to ignition substantially and a greater effect can be expected with larger timber members.

Attachment 1 Previous Studies relating to fire properties of preservative treated timber

Analysis of the phenomena of afterglow was undertaken as early as the 1950s (Browne 1958) who observed that both Copper and Chromium oxides may enhance afterglow. The impact of copper oxides has been shown to increase as the concentration increases (Miyake and Morioka 2011). Thermogravimetric analysis (TGA) of the thermal decomposition of CCA treated timber waste (Kercher and Nagle 2001) provides useful background information on potential reactions between Copper and Chromium oxides and arsenic compounds in preference to oxidation of timber char.

Tame examined the products of combustion from treated timber (Tame, Kennedy and Dlugogorski 2005, Tame, Dlugogorski and Kennedy 2007) and the catalytic effect of copper(II) oxide on the oxidation of cellulose. Thermal and gas evolution was further examined (Nakayama and Miyake 2012, Nakayama and Miyake 2013).

The effect of the fire properties of solid timber and plywood treated with quaternary ammonia compounds was evaluated as part of a study that also included analysis of the impacts of fire retardants and decay resistance (Terzi, Kartal et al. 2011).

Table 39 shows the mean retention rates for cone calorimeter and fire tube test samples as required by ASTM E69 (ASTM 2002). The retention rate as a % mass ratio has been calculated assuming an oven dry density of 500kg/m^3.

Control specimens had a residual mass fraction of 0.18 for the solid pine tests in the fire tube tests. The residual mass fraction in the specimens during fire tube tests is calculated as the ratio of the final mass/initial mass. The tube specimen was heated for 3 minutes, and weight loss recorded for an additional 7 minutes. Lower average residual mass fractions of 0.16 and 0.14 were found in the solid wood specimens treated with 1 and 4% DDAC, respectively which may be indicative of sustained smouldering combustion at a greater rate than the control, but the monitoring period was insufficient to determine a significant difference in performance with reasonable confidence.

Table 39 Retention rates for ACQ treatments applied to Solid Scots pine samples assuming 500kg/m^3 oven dry density (derived from (Terzi, Kartal et al. 2011)

Treatment	Cone calorimeter tests		Fire tube tests	
	Retention rate kg/m^3	Retention rate % m/ m	Retention rate kg/m3	Retention rate % m/ m
DDAC 1%	4.5	0.9	4.7	0.94
DDAC 4%	15.9	3.18	13.1	2.62
DBF 1%	4.7	0.94	4.9	0.98
DBF 4%	18.5	3.70	17.7	3.54

Results from the cone calorimeter tests for the control and ACQ specimens are summarised in Table 40, with the mass fraction calculated in a similar manner to the tube test described above.

The results show a small reduction in the time to ignition for the treated specimens compared to the control, a modest increase in the peak and average HRRs and similar effective heats of combustion and increases in the residual mass fraction providing little evidence of afterglow behaviour.

Table 40 Cone calorimeter results for solid Scots Pine treated with ACQ including untreated control - irradiance 50kW/m² (derived from (Terzi, Kartal et al. 2011)

Specimen / treatment	Time to sustained ignition T_{ig} (s)	Peak heat release rate (kW/m²)	Average heat release rate (kW/m²)		Average effective heat of comb. (MJ /kg)	Residual mass fraction
			60s	300s		
Control	18	175	147	116	13.1	0.160
DDAC 1%	16	193	163	124	13.4	0.170
DDAC 4%	13	203	166	126	13.5	0.173
DBF 1%	15	199	165	130	13.5	0.182
DBF 4%	14	213	182	142	13.4	0.199

A compilation of Forest Products Laboratory cone calorimeter test data on wood-based decking materials cone calorimeter results (White, Dietenberger and Stark 2007) included results from untreated and preservative treated southern pine timber. An extract of relevant data is summarised in Table 41.

The sample included 19mm-and 37-mm-thick specimens treated with either:

- CCA, or
- alkaline copper quat-(ACQ), or
- ammoniacal copper citrate (CC).

The tests were performed in the horizontal orientation at an irradiance of 50 kW/m² using a spark igniter.

Table 41 A summary of cone calorimeter results extracted from untreated and preservative treated southern pine timber derived from an initial compilation of Forest Products Laboratory (FPL) cone calorimeter test data on wood-based decking materials (White, Dietenberger and Stark 2007)

Material	Density (kg/m³)	TSI (s)	PHRR (kW/m²)	tPHRR (s)	HRR60 (kW/m²)	HRR300 (kW/m²)	THR (MJ/m²)	AEHOC (MJ/kg)	RMF (%)	*N*
A1 Untreated s. pine, 37 mm	510	18.0	172	51	112	107	214	12.50	20	3
A2 Untreated s. pine, 19 mm	508	18.8	165	50	110	107	116	12.95	19	3
A3 Treated s. pine, CCA-C, 37 mm	514	19.0	185	53	117	116	190	11.42	23	3
A4 Treated s. pine, CCA-C, 19 mm	496	17.1	174	69	115	118	108	12.29	20	3
A5 Treated s. pine, ACQ-D, 38 mm	504	20.5	185	49	118	109	199	11.68	15	3
A6 Treated s. pine, ACQ-=D, 19 mm	514	15.2	186	55	115	115	114	12.35	18	3
A7 Treated s. pine, CC, 37 mm	530	21.2	183	56	119	115	214	12.07	21	3
A8 Treated s. pine, CC, 19 mm	517	18.3	175	55	115	115	111	12.39	20	3
A9 Treated s. pine, CCA, 16 mm	588	27.1	187	60	155	137	97	12.51	17	3
A10 Treated s. pine, ACQ, 24 mm	591	21.1	244	34	192	142	157	13.36	20	1

Note1 Column Description:
TSI - time for sustained ignition
PHRR - peak heat release rate,
tPHRR - time for PHRR,
HRR60 - heat release rate averaged for 60s after the observation of sustained ignition
HRR300 - heat release rate averaged for 300s after the observation of sustained ignition
THR - total heat released.
AEHOC - average effective heat of combustion rate
RMF - residual mass fraction
N Number of replicants tested

White (White, Dietenberger and Stark 2007) indicated that the test results for the CCA, ACQ, and CC treated lumber were found to be consistent with untreated southern pine timber.

Wu undertook a literature review of previous studies supplemented by an experimental study on smouldering of CCA treated timber (Wu, Hidalgo et al. 2021). The experimental studies undertaken by Wu applied similar methods and equipment to the test protocols developed by this project to compare the performance of timber elements with different preservative treatments and to evaluate the impact of preservative treatments on the fire properties of timber. The following outcomes identified by Wu (Wu, Hidalgo et al. 2021) are relevant to this study.

- The presence of CCA in treated timber did not affect flaming behaviour compared to the non-treated timber under the same experimental condition at the retentions tested.

- Critical heat fluxes for smouldering ignition and flaming ignition of CCA-treated Slash/Caribbean pine were 7.5 kW/m^2 and 10.5 kW/m^2, respectively, indicating that smouldering under lower constant heat fluxes contributes to the onset of flaming ignition by providing additional energy.

- CCA acts as catalyst to affect smouldering by lowering the activation energy so that smouldering occurs at a lower temperature.

- Less dense CCA-treated timber exhibits more severe mass loss during the self-sustained smouldering under 20 kW/m^2 heat flux.

- CCA-treated timber subjected to a high heat flux of 50 kW/m^2 with the same mass loss prior to removal of the heat supply did not sustain smouldering combustion.

- No self-sustained smouldering was observed in non-treated timber subjected to all heat fluxes with the same amount of burning time, despite its lower density.

- Preheating time appears to play a more critical role in inducing self-sustained smouldering than fire intensity (i.e. heat flux), enabling self-sustained smouldering even for higher density timber samples.

Based on the studies summarised above. sustained smouldering combustion may be less likely to occur with the CCA treatment if arsenic compounds react with metal oxides before the arsenic is volatised, and this behaviour may be sensitive to heating rates and duration of exposure.

Investigations into combinations of preservative and fire retardant treatments have been undertaken over several decades. Whilst the development and evaluation of fire retardant treatments is outside the scope of this study some findings have relevance to the behaviour of preservative treated timber.

For example, a study into the role of boron in flame-retardant treatments (LeVan and Tran 1990) indicated that Borax tends to reduce flame spread whilst boric acid suppresses smouldering but has little effect on flame spread. Therefore, these compounds are normally used together. Boron is also a preservative, protecting the borer-susceptible sapwood of some hardwood species but to be effective as a fire retardant Boron content needs to be substantially higher than that required for a preservative.

An investigation into the Fire performance of wood treated with combined fire-retardant and preservative systems was undertaken by Forest and Wood Products US (Sweet 1996). The study was undertaken in two stages. The first stage consisted of selecting several compatible combinations and undertaking small scale comparative testing using the ASTM E69 Standard Test Method for Combustible Properties of Treated Wood by the Fire-Tube Apparatus

(ASTM 1980). The fire-tube method provides a relative measurement of the combustibility of fire-retardant-treated wood specimens based on their percentage loss in weight under controlled fire exposure conditions and the following can be compared: rate of weight loss, time of flaming and afterglowing, increase in temperature, and maximum vertical flame progress.

The second stage of the Forest and Wood Products US study involved testing timber decks with a limited number of combinations of fire retardants and preservatives which is not directly relevant to this study.

Key findings included an observation that the fire tube tests showed that the fire performance of all the fire-retardant and preservative combinations were fairly similar. Materials treated with each of these fire retardant/preservative combinations was subjected to accelerated weathering procedures, and fire tests indicated that good fire performance could be achieved with weathered and unweathered specimens.

A study was subsequently undertaken in Australia with similar goals and comprised two stages. The first stage was a state of the art review (Russell, Marney et al. 2004) followed by preliminary evaluations including small scale experiments to identify viable options for a single cost effective treatment that could withstand weathering and satisfy the proposed classifications for fire retardant timbers subsequently incorporated in AS 3959 (Marney, Russell and Mann 2006). The majority of this work is not of direct relevance to this study, but it contains useful information if a combined fire retardant and preservative treatment is to be used including potential interactions between preservatives and fire retardants.

However, of direct relevance to the current project was a work package that obtained baseline properties on the fire performance of untreated and preservative treated Radiata Pine and Mountain Ash specimens using a mass loss calorimeter at an irradiance level of 25 kWm^2. The results for untreated radiata pine and radiata pine treated with the copper-based preservatives considered in this report are summarised in *Table 42*.

Table 42 Comparative data from mass loss calorimeter testing of untreated and preservative treated radiata pine samples at an irradiance of 25kW/m^2 derived from (Marney, Russell and Mann 2006)

Treatment	Time to Ignition (s)	Total Burnout Time (s)	Peak heat release rate (kWm^{-2})	Total heat release rate (MJm^{-2})
Untreated	115	315	282	70.7
CCA	110	295	250	63.1
CuAz	95	300	223	58.7
ACQ	109	306	274	70.1

The above results indicate that the general fire properties are comparable for the untreated timber and three copper based preservative treatments although the test procedures do not appear to identify the tendency for sustained smouldering combustion after the heat source is removed.

Attachment 2 Test Protocol for Testing 12mm thick samples at Irradiance of 25kw/m^2

Requirements - 12mm Treated Radiata Pine, cone calorimeter test series: Issue 4: 2 Dec 2021

General Information:
Test Standard adopted:
In accordance with AS3837/ISO 5660.1 and AS3959 except for **termination 10 minutes** after ignition to check for smouldering combustion after removal of heat source.
Laboratory:
Test Date(s):
General product data.

Timber Species Common Name	Radiata Pine
Timber Species Botanical Name	Pinus radiata
Nominal thickness	12mm
Nominal Density	550kg/m^3
Treatment Type	
Stated Treatment retention rate	

(Additional text as required)
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Test Conditions and Specimen configuration and mounting details

Parameter	Unit	Comments
Conditioning prior to test R.H. / temp / time	-	Specimens conditioned to constant mass at 23 ±2°C and 50 ±5% relative humidity.
Moisture Content	%	Equilibrium value (to be determined from a sample)
Test Orientation	H	With face with greatest proportion of Sapwood exposed to furnace as shown in Figure 1
Irradiance	25kW/m^2	
Exposure Duration	**10 minutes** after ignition	and then record weight of sample at 15min intervals after removal of heat source for 1h noting any signs of continued smouldering combustion. Final weight measurement 24-hours after test
Preparation and mounting	–	*Attention to this detail must be given to ensure 1-D exposure (i.e. no contributions from sides).*

Heat Source applied to face with most Sapwood	Heat Source applied to face with most Sapwood

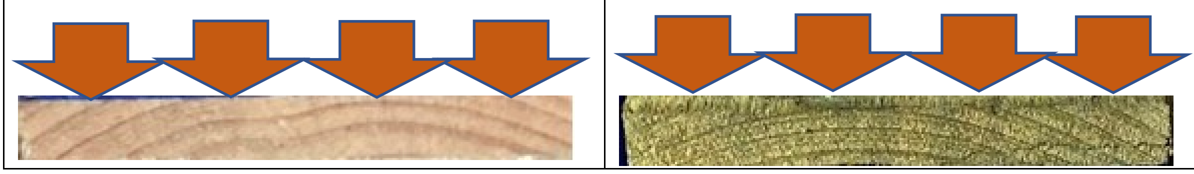


Figure 1 Heat Source Applied to Face with greatest proportion of Sapwood

Sapwood is expected to absorb more preservative than heartwood and therefore specimens with a greater proportion of sapwood exposed to the heat source are likely to demonstrate differences more clearly between the various preservative treatments. The samples have therefore been selected that include a high proportion of sapwood and the specimen should be orientated such that the face likely to have the greatest proportion of sapwood is exposed to the heat source as shown in Figure 1

Additional Measurements / Instructions
Additional instructions

- Measurement of temperature of rear face of specimen
- Ensure specimen sides are protected to maintain 1-D exposure
- Record weight after heating period at the nominated time periods and observe smouldering behaviour
- Provide a video of the test and still photos
- Measure extent of charring in cases where there is sufficient material remaining. For clarity use the terminology and measurements shown in Figure 2:

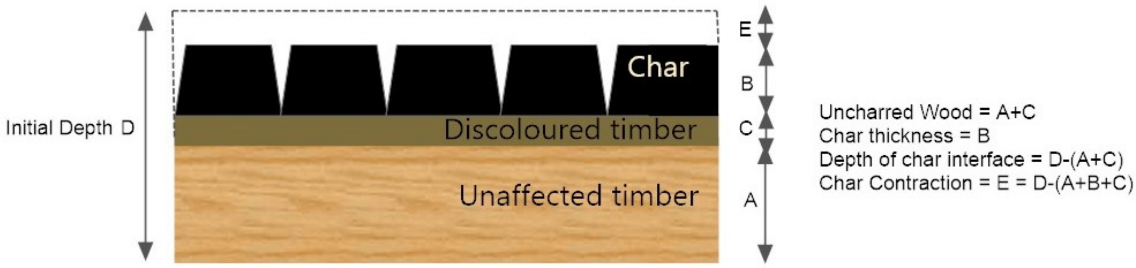


Figure 2 Char measurements

Char thicknesses should be measured close to the centre of the specimen,
Depending on heating rates there may be a clearly defined layer of discoloured wood that is discoloured but not charred. If so, this should be reported as dimension C with the unaffected wood identified as dimension A and them the uncharred wood would be the sum of A and C. If the discoloured layer is not well defined a single estimated value for uncharred timber (A+C) can be provided
The char thickness is identified as dimension D and should be measured and specified.
The char contraction E is then calculated from the original depth D – (A+B+C)

Test Results
Provide following graphs:

- HRR v time
- MLR v time
- EHC v time
- SEA v time

Provide an excel Spread sheet of the raw data in addition to the information required by the standard and requested in this document

Provide following tabulated data (S4-S6 columns only necessary to be completed if required by the test procedure to address variability and authorisation should be requested if more than 3 specimens are required to be tested)

Test stage	Parameter	Unit	S1	S2	S3	S4	S5	S6
Pre-test exposure	Thickness (D)	mm						
	Initial mass	g						
	Measured Density	kg/m^3						
	Measured Moisture content	%						
	Irradiance applied	kW/m^2	25	25	25			
Ignition	Time to ignition[1]	s						
	Mass at ignition	g						
	HRR @ ignition	kW/m^2						
First peak	Time to HRR peak	s						
	Peak HRR	kW/m^2						
	Time to MLR peak	s						
	Peak MLR	$g/(s.m^2)$						
	Peak EHC	MJ/kg						
	Peak SEA	m^2/kg						
	Peak CO yield	kg/kg						
	Peak CO_2 yield	kg/kg						
Average over 60s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Average over 120s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Average over 300s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						

Average over 600s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
	Rear temp of spec.[2]	°C						
Second peak (if occurs)	Time to HRR peak	-s						
	Peak HRR	kW/m^2						
	Time to MLR peak	s						
	Peak MLR	$g/(s.m^2)$						
	Peak EHC	MJ/kg						
	Peak SEA	m^2/kg						
	Peak CO yield	kg/kg						
	Peak CO_2 yield	kg/kg						
	Rear temp of spec.[2]	°C						
End of exposure period 600s after ignition	Time after ignition	s						
	Final mass	g						
	Mass pyrolised post-ignition	g/m^2						
	Total heat released	MJ/m^2						
	Rear temp of spec.[2]	°C						
Average from ignition to end of exposure preiod	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Other Criteria	$FIGRA_{0.2MJ}$[5]							
	MARHE[5]							
	Mass 15 minutes after exposure	g						
	Mass 30 minutes after exposure	g						
	Mass 45 minutes after exposure	g						
	Mass 60 minutes after exposure	g						
	Mass 24-h after exposure	g						
Other Obs.	Time to flame-out after ignition if occurs during test	s						
	Time to flame-out after removal from Radiant heat source	s						

	Estimated time to termination of smouldering combustion[4]							
	Char depth measurements[3]							
	A - unaffected wood layer	mm						
	B-char layer	mm						
	C-Discoloured wood layer	mm						
	Depth of uncharred timber (A+C)							
	Depth of char interface D-(A+C)	mm						
	Char Contraction E = D-(A+B+C)	mm						

Notes
1 Specify criteria used for ignition
2 If temperature recorded
3 Char depth if sufficient material for measurement 24-h after exposure
4 check when each mass loss measurement is taken after the end of the heating period.
5 FIGRA and MARHE provide benchmarks for the evaluation of the impact of weathering and / or other surface treatments. Calculation methods are provided in EN13823 and EN 45545-2 and these methods are nominated in Appendix B of AS 1530.8.1.

Classification – not applicable

Attachment 3 Test Protocol for Testing ≥ 38mm thick samples at Irradiance of 50 kw/m^2

Requirements – 41 mm Treated Radiata Pine, cone calorimeter test series: Issue 4: 2 Dec 2021

General Information:
Test Standard Adopted: In accordance with AS 5637.1 and ISO 5660.1 as appropriate with **test terminated 30 minutes after ignition** to check for smouldering combustion after removal from heat source

Laboratory:
Test Date(s):

General product data.

Timber Species Common Name	Radiata Pine
Timber Species Botanical Name	Pinus radiata
Nominal thickness	41mm
Nominal Density	550kg/m^3
Treatment Type	
Stated Treatment retention rate	

(Additional text as required)

Test Conditions and Specimen configuration

Parameter	Unit	Comments
Conditioning prior to test R.H. / temp / time		Specimens conditioned to constant mass at 23 ±2°C and 50 ±5% relative humidity.
Moisture Content	%	Equilibrium value (to be determined form a sample)
Test Orientation	H	
Irradiance	50kW/m^2	
Exposure Duration	**<u>30</u>** minutes after ignition	and then record weight of sample at 15min intervals after removal of heat source for 1h noting any signs of continued smouldering combustion. Final weigh measurement 24-hours after test
Preparation and mounting	–	*Attention to this detail must be given to ensure 1-D exposure (i.e. no contributions from sides).*

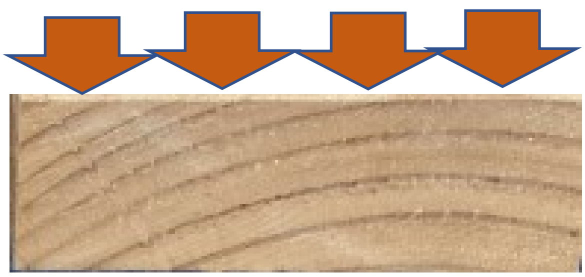
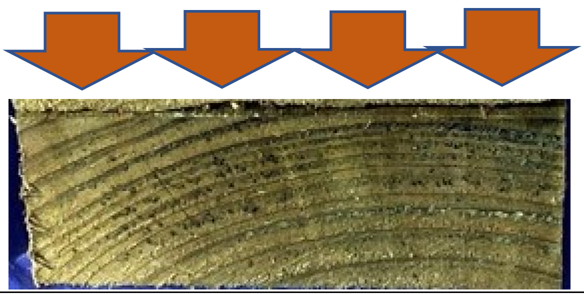
Heat Source applied to face with most Sapwood	Heat Source applied to face with most Sapwood
	

Figure 1 Heat Source Applied to Face with greatest proportion of Sapwood

Sapwood is expected to absorb more preservative than heartwood and therefore specimens with a greater proportion of sapwood exposed to the heat source are likely to demonstrate differences more clearly between the various preservative treatments. The samples have therefore been selected that include a high proportion of sapwood and the specimen should be orientated such that the face likely to have the greatest proportion of sapwood is exposed to the heat source as shown in Figure 1

Additional Measurements / Instructions

Additional instructions

- Measurement of temperature of rear face of specimen
- Ensure specimen sides are protected to maintain 1-D exposure
- Record weight after heating period at the nominated time periods and observe smouldering behaviour
- Provide a video of the test and still photos
- Measure extent of charring in cases where there is sufficient material remaining. For clarity use the terminology and measurements shown in Figure 2:

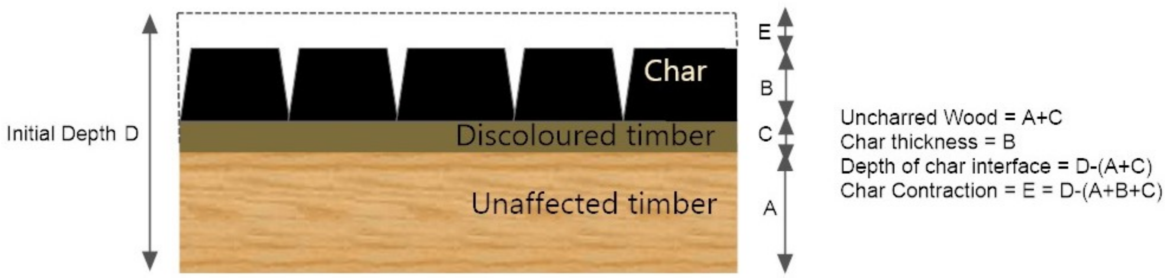


Figure 2 Char Measurements

Char thicknesses should be measured close to the centre of the specimen,

Depending on heating rates there may be a clearly defined layer of discoloured wood that is discoloured but not charred. If so, this should be reported as dimension C with the unaffected wood identified as dimension A and them the uncharred wood would be the sum of A and C.

If the discoloured layer is not well defined a single estimated value for uncharred timber (A+C) can be provided

The char thickness is identified as dimension D and should be measured and specified.

The char contraction E is then calculated from the original depth D – (A+B+C)

Test Results

Provide following graphs:

- HRR v time
- MLR v time
- EHC v time
- SEA v time

Provide an excel Spread sheet of the raw data in addition to the information required by the standard and requested in this document

Provide following tabulated data (S4-S6 columns only necessary to be completed if required by the test procedure to address variability and authorisation should be requested if more than 3 specimens are required to be tested).

Test stage	Parameter	Unit	S1	S2	S3	S4	S5	S6
Pre-test exposure	Thickness	mm						
	Initial mass	g						
	Measured Density	kg/m^3						
	Measured Moisture content	%						
	Irradiance to be applied	kW/m^2	50	50	50			
Ignition	Time to ignition[1]	s						
	Mass at ignition	g						
	HRR @ ignition	kW/m^2						
First peak	Time to HRR peak	s						
	Peak HRR	kW/m^2						
	Time to MLR peak	s						
	Peak MLR	$g/(s.m^2)$						
	Peak EHC	MJ/kg						
	Peak SEA	m^2/kg						
	Peak CO yield	kg/kg						
	Peak CO_2 yield	kg/kg						
Average over 60s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Average over 120s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Average over 300s after ignition	Av HRR	kW/m^2						
	Av MLR	$g/(s.m^2)$						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						

Average over 600s after ignition	Av HRR	kW/m^2						
	Av MLR	g/(s.m^2)						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
	Rear temp of spec.[2]	°C						
Second peak (if occurs)	Time to HRR peak	-s						
	Peak HRR	kW/m^2						
	Time to MLR peak	s						
	Peak MLR	g/(s.m^2)						
	Peak EHC	MJ/kg						
	Peak SEA	m^2/kg						
	Peak CO yield	kg/kg						
	Peak CO_2 yield	kg/kg						
	Rear temp of spec.[2]	°C						
End of exposure period 1800s after ignition	Time after ignition	s						
	Final mass	g						
	Mass pyrolised post-ignition	g/m^2						
	Total heat released	MJ/m^2						
	Rear temp of spec.[2]	°C						
Average from ignition to end of exposure	Av HRR	kW/m^2						
	Av MLR	g/(s.m^2)						
	Av EHC	MJ/kg						
	Av SEA	m^2/kg						
	Av CO yield	kg/kg						
	Av CO_2 yield	kg/kg						
Other Criteria	$FIGRA_{0.2MJ}$[5]							
	MARHE[5]							
	Mass 15 minutes after exposure	g						
	Mass 30 minutes after exposure	g						
	Mass 45 minutes after exposure	g						
	Mass 60 minutes after exposure	g						
	Mass 24-h after exposure	g						
Other Obs.	Time to flame-out after ignition if occurs during test	s						

	Time to flame-out after removal from Radiant heat source	s						
	Estimated time to termination of smouldering combustion[4]	s						
	Char depth after test [3]							
	A - unaffected wood layer	mm						
	B-char layer	mm						
	C-Discoloured wood layer	mm						
	Depth of uncharred timber (A+C)							
	Depth of char interface D-(A+C)	mm						
	Char Contraction E = D-(A+B+C)	mm						

Notes
1 Specify criteria used for ignition
2 If temperature recorded
3 Char depth measured 24h after test exposure
4 check when each mass loss measurement is taken after the end of the heating period.
5 FIGRA and MARHE provide benchmarks for the evaluation of the impact of weathering and / or other surface treatments. Calculation methods are provided in EN13823 and EN 45545-2 and these methods are nominated in Appendix B of AS 1530.8.1.

Classification – AS 5637.1 Group number

Attachment 4 Updates to Cone calorimeter Protocols for Stage 2

The enhancements to the protocols for testing 12mm thick palings as defined in Attachment 2 was to terminate exposure to the radiant heat flux applied to the three samples after 3, 5 and 10 minutes after flaming ignition rather than testing all three samples for the same period (e.g. 10 minutes after ignition). The 3-minute exposure times are more representative of, although still greater than, the flame residency periods for most bushfires. The flame residency period correspond to peak radiant heat exposures from the fire front for structures and other features that are outside the flame zone defined in AS 3959.

In addition, the heat flux values were varied to correspond to the radiant heat fluxes associated with the bushfire attack levels prescribed in AS 3959 with the flexibility to select other values to evaluate the sensitivity of findings to different heat fluxes.

The protocol for larger cross-section components provided in Attachment 3 successfully identified variations in the potential for preservative treatments to promote sustained smouldering combustion in radiata pine elements with larger cross-sections. Notwithstanding this a number of refinements to the protocol were incorporated in the Stage 2 program to evaluate the fire properties of preservative treated radiata pine and the sensitivity to variations in heat flux and exposure duration.

The main refinements to the protocol were;

- to terminate exposure to the radiant heat flux applied to four samples at 3, 5, 10 and 30 minutes after flaming ignition rather than testing three samples for the same time. As noted above the shorter exposure times are more representative of the flame residency periods for bushfires and provide information on the tendency to self-extinguish after shorter periods of exposure.
- options to apply a range of irradiance levels as alternatives to 50kW/m^2 level
- to obtain data on the progression of the char depth additional internal thermocouples were provided as detailed below for some specimens.

Where internal temperature data is to be recorded, the temperatures were measured at the positions shown in Figure 32. Holes were drilled from the sides of the specimen so that path of the thermocouple follows as far as practicable an isotherm. The thermocouple junctions were staggered to minimise the risk of interactions between thermocouples and the specimen.

The temperature data from commencement of the test to approximately 60 minutes after termination of heating was recorded by thermocouples located within 20mm of the centre of the specimen distributed radially at depths of 6,12,18,24 and 36mm from the exposed surface as shown schematically in Figure 32

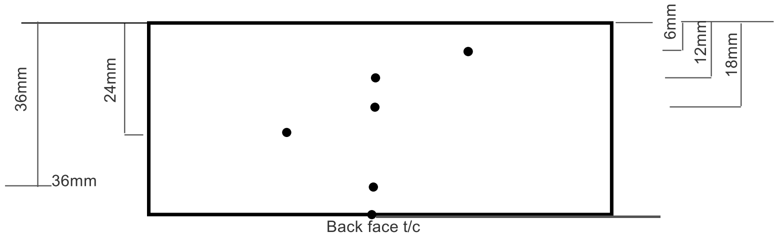


Figure 32 Internal thermocouple measurement positions for timber paling / framing cone calorimeter samples

Attachment 5 Supplementary procedures for pre-wetting tests

1) All specimens should be conditioned to equilibrium at 35 +/- 2°C and 25 +/- 2%RH and then weighed, and the moisture content measured with a moisture meter.
2) An initial cone calorimeter control test (S1) should be undertaken prior to pre-wetting
3) All remaining samples should then be sprayed with water for 5 minutes each side and weighed.
4) All except sample S2 should be returned to the conditioning enclosure at 35°C and 25% RH until just before each sample is tested.
5) The moisture content of S2 shall be measured with a moisture meter as described in procedure 1. Specimen S2 shall then be mounted, and the test run started 15 minutes after prewetting ± 6 minutes.
6) The target times for testing the remaining samples (S3 to S6) are the following times after pre-wetting 2h, 3h, 4h and 24h. The time between removal from the conditioning enclosure to testing should be as short as possible and not exceed 15 minutes.
7) Mass loss should be monitored after each cone test to check for sustained smouldering combustion as far as practicable. The duration of heating after ignition will be determined after the main cone test program is completed.

References

ABCB (2020). "National Construction Code 2019 Volume One Ammendment 1."

ASTM (1980). ASTM E69-80 Standard Test Method for Combustible Properties of Treated Wood by the Fire-Tube Apparatus. Philadelphia, PA, ASTM. **ASTM E69-80**.

ASTM (2002). ASTM E69-02 Standard Test Method for Combustible Properties of Treated Wood by the Fire-Tube Apparatus. Philadelphia, PA, ASTM. **ASTM E69-02**.

ASTM (2010). ASTM D2898 - 10 Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing. US, ASTM. **ASTM D2898**.

Babrauskas, V. (2003). "Ignition Handbook."

Browne, F. L. (1958). "Theories of the combustion of wood and its control."

Crielaard, R., J.-W. van de Kuilen, K. Terwel, G. Ravenshorst and P. Steenbakkers (2019). "Self-extinguishment of cross-laminated timber." Fire Safety Journal **105**: 244-260.

Evans, P. D., P. Beutel, R. B. Cunningham and C. F. Donnelly (1994). "Fire resistance of preservative-treated slash pine fence posts." Forest products journal **44**(9): 37.

Gardner, W. D. and J. A. White (2009). Assessing the ability of a large-scale fire test to predict the performance of wood poles exposed to severe bushfires. Australia, FWPA.

Hayward, D. (2007). Moisture Content of Exterior Timber in Bush Fire Conditions. Queensland, Timber Queensland Ltd.

ISO (2015). ISO 5660-1:2015 Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement), ISO. **ISO5660-1:2015**.

Janssens, M. (1991). "A thermal model for piloted ignition of wood including variable thermophysical properties." Fire Safety Science **3**: 167-176.

Kercher, A. and D. Nagle (2001). "TGA modeling of the thermal decomposition of CCA treated lumber waste." Wood Science and Technology **35**(4): 325-341.

LeVan, S. L. and H. C. Tran (1990). The role of boron in flame-retardant treatments. First International Conference on Wood Protection with Diffusible Preservatives:... Nashville, Tennessee, November 28-30, 1990. Madison, WI: Forest Products Research Society, 1990.: p. 39-41: ill.

Marney, D., L. Russell and R. Mann (2006). Combining fire retardant and preservative systems for timber products in exposed applications. Project no: PN04.2007, Forest and Wood Products Research and Development Corporation.

Miyake, A. and K. Morioka (2011). "Influence of metal oxides on the thermal ignition behaviour of woody biomass cellulose." Science and Technology of Energetic Materials **72**(3-4): 123-126.

Moghtaderi, B., V. Novozhilov, D. Fletcher and J. Kent (1997). "A new correlation for bench-scale piloted ignition data of wood." Fire safety journal **29**(1): 41-59.

Morrell, J. (2022). Radiata pine-Densities. B. Iskra.

Nakayama, J. and A. Miyake (2012). "Catalytic effect of copper (II) oxide on oxidation of cellulosic biomass." Journal of thermal analysis and calorimetry **110**(1): 321-327.

Nakayama, J. and A. Miyake (2013). "Thermal and evolved gas analyses of the oxidation of a cellulose/copper (II) oxide mixture." Journal of thermal analysis and calorimetry **113**(3): 1403-1408.

Russell, L., D. Marney, D. Humphrey, A. Hunt, V. Dowling and L. Cookson (2004). Combining fire retardant and preservative systems for timber products in exposed applications-state of the art review. Project no: PN04:2007, Forest and Wood Products Research and Development Corporation.

Sabatino, S. (2023). Update on Cone program and decay rate attachment.

SFPE (2002). SFPE Engineering Guide Piloted Ignition of Solid Materials Under Radiant Exposure. Maryland USA, Society of Fire Protection Engineers.
Spearpoint, M. J. and J. G. Quintiere (2001). "Predicting the piloted ignition of wood in the cone calorimeter using an integral model—effect of species, grain orientation and heat flux." Fire safety journal **36**(4): 391-415.
Standards_Australia (1998). AS/NZS 3837:1998 Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter. Sydney, Standards Australia.
Standards_Australia (2010). AS 1720.1—2010 Timber structures Part 1: Design methods. Australia, Standards_Australia. **AS 1720.1—2010**.
Standards_Australia (2018). AS 1530.8.1-2018 Methods for fire tests on building materials, components and structures - Part 8.1 Tests on elements of construction for buildings exposed to simulated bushfire attack - Radiant heat and small flaming sources. Sydney. **AS 1530.8.1-2018**.
Standards_Australia (2018). AS 3959 Construction of Buildings in Bushfire-Prone Areas. Sydney, Standards_Australia. **AS 3959:2018**.
Standards_Australia (2021). AS/NZS 1604.1:2021 Preservative-treated wood-based products Part 1:Products and treatment. Australia, Standards_Australia. **AS/NZS 1604.1:2021**.
Sweet, M. S. (1996). Fire performance of wood treated with combined fire-retardant and preservative systems, US Department of Agriculture, Forest Service, Forest Products Laboratory.
Tame, N., E. Kennedy and B. Dlugogorski (2005). "Formation of dioxin during smoldering of CCA treated wood char."
Tame, N. W., B. Z. Dlugogorski and E. M. Kennedy (2007). "Formation of dioxins and furans during combustion of treated wood." Progress in Energy and Combustion Science **33**(4): 384-408.
Terzi, E., S. N. Kartal, R. H. White, K. Shinoda and Y. Imamura (2011). "Fire performance and decay resistance of solid wood and plywood treated with quaternary ammonia compounds and common fire retardants." European Journal of Wood and Wood Products **69**(1): 41-51.
White, R. H., M. A. Dietenberger and N. M. Stark (2007). Cone calorimeter tests of wood-based decking materials. Proceedings of the 18th annual conference on recent advances in flame retardancy of polymeric materials. Norwalk, CT: BCC Research, c2007: ISBN: 1596232218: 9781596232211: Pages 326-337.
Wotton, B. M., J. S. Gould, W. L. McCaw, N. P. Cheney and S. W. Taylor (2012). "Flame temperature and residence time of fires in dry eucalypt forest." International Journal of Wildland Fire **21**(3): 270-281.
Wu, W., J. Hidalgo, J. Morrell and F. Wiesner (2021). Experimental study on smouldering of CCA treated timber.

Investigation of Preservative Treated Plantation Timber Fencing and Sleeper Markets in Bushfire Prone Areas

Stage 3 Final Report
Appendix 2

Analysis of Bushfire Losses associated with housing

(Final)

Prepared for

Forest & Wood Products Australia

by

Paul England

30 April 2024

Publication: Timber Fencing and Sleeper Walls Bushfire Hazard Literature Review

Project No: NIF144-2122 [NV054]

IMPORTANT NOTICE

This work is supported by funding provided to FWPA by the Department of Agriculture and Water Resources (DAWR).

ISBN: **New number (this is provided by FWPA upon publication)**

Paul England
EFT Consulting

Final report received by FWPA in April, 2024

Forest & Wood Products Australia Limited
Level 11, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

Executive Summary

This Appendix presents an analysis of bushfire losses associated with housing in Australia.

The findings of the statistical analysis of survey results were generally consistent:

- Light-weight external cladding systems were substantially more susceptible to damage than brick-veneer construction with tiled roofs, but similar proportions of losses occurred for timber and non-combustible lightweight wall cladding systems implying that the combustibility of timber was not the predominant cause for variations in losses between brick veneer and lightweight cladding systems.
- Houses with raised floors were substantially more susceptible to damage than slab on ground construction with the vulnerability increasing as the clearance to the ground reduced, but the losses for raised floors were similar for timber stumps and non-combustible stumps and piers implying that the combustibility of timber was not a predominant cause for variations in losses between timber stumps and other non-combustible sub floor supports. It should be noted that the majority of buildings were of older designs that may not have had insulation applied to the underside of the floor. The presence of insulation could increase or decrease the probability of house loss depending on the fire properties of the insulation material and method of application.
- House losses were substantially greater if the property was unoccupied, and no firefighting activities were undertaken.
- House losses were the lowest if the surrounding vegetation was predominately grass, highest if the vegetation was predominantly trees and intermediate if the surrounding vegetation was bushes. Overhanging trees or trees and bushes against a house significantly increase the risk of building loss.
- Timber framed windows did not significantly increase the risk of building loss compared to non-combustible window frames.
- Protecting the openable parts of windows with metal fly screens reduced the proportion of lost houses.

Statistical data on the performance of fencing was only included in the analysis of the 2013 NSW fires in the above surveys and was not identified as a top ranking variable.

Based on the analysis of fatalities the risk of a fatality occurring within a house as the result of failure of a house during a bushfire attack was estimated to be as follows.

Distance from Predominant. Vegetation - m	Typical BAL class / Ember hazard	Risk of fatality within a house
<20	Mainly BAL FZ	7.0×10^{-6}
20-50m	BAL 29 / BAL 40	1.5×10^{-6}
50-100m	BAL 12.5 - 19	2.4×10^{-7}
100-200	Low Ember Attack	1.4×10^{-7}
200-700	Very Low ember attack	$2. \times 10^{-8}$
Total	0-700m	1.1×10^{-6}

The probability of building loss based on pre-AS3959 houses and post AS 3959:2009 houses was estimated to be as follows:

Distance from Predominant. Vegetation - m	Typical BAL classification / Ember hazard	Prob of loss of pre-AS 3959 house/y	Prob of loss of post AS 3959 :2009 house/y
<20	Mainly BAL FZ	7.6×10^{-4}	2.5×10^{-4}
20-50m	BAL 29 / BAL 40	7.9×10^{-4}	2.6×10^{-4}
50-100m	BAL 12.5 -19	3.1×10^{-4}	7.8×10^{-5}
100-200	Low Ember Attack	2.0×10^{-4}	2.0×10^{-4}
200-700	Very Low ember attack	1.0×10^{-5}	1.0×10^{-5}

A large number of simplifications and approximations were needed to derive the above estimates but after taking this into account, the results still indicate there are limited opportunities to derive additional cost-effective construction requirements that would be expected to yield a significant net benefit after the application of AS 3959:2009 or 2018 requirements especially at distances more than 50m from the predominant vegetation.

Table of Contents

Appendix 2 Analysis of Bushfire Losses associated with housing

Overview

This study was undertaken as part of a timber fencing and sleeper wall hazard assessment. Part of the assessment required the quantification of the bushfire hazard associated with housing in order to provide a context for the net benefit if additional mandatory requirements are being considered.

The quantification of the bushfire hazard associated with housing has much broader application than fencing and sleeper walls and therefore this content has been published as a separate appendices.

In order to quantify the bushfire hazard it is necessary to derive estimates of the following:

- the numbers of houses and people exposed to bushfire risk
- the average number of houses and fatalities /annum
- the probability of loss of a house / annum
- the risk to life

Number and Distribution of Houses at Risk

Chen and McAneney (McAneney and Chen 2005) provided estimates of the number of houses in various distance groups from the bushland interface. Whilst other factors such as gradient, type of vegetation, prevailing and preceding weather conditions, presence of occupants and form of construction for housing influence house loss, it was noted by Chen and McAneney that distance from the bushland interface is the most important, and relatively easy to measure, and can therefore be used as a surrogate to estimate the number of houses in Australia that are at risk from bushfires.

Based on analysis of 8,161,680 houses in all major cities and surrounding areas, the distributions shown in Figure 1 were derived. Since no better information on a national basis is readily available, it will be assumed that the current distribution is similar to that shown in Figure 1 from the 2005 study. At 2016, there were an estimated 9,901,496 single dwellings in Australia based on ABS 2016 Census QuickStats (ABS 2017).

The private house commencement data for Australia between 2013 and 2019 averaged approximately 102,000 / annum with the annual values shown in Figure 2. The regulatory impact statement (RIS) supporting the 2009 edition of AS 3959 (ABCB 2009) estimated that approximately 10% of all new house building activity lies within Bushfire Prone areas (11,000 houses / annum); although it was highlighted that there are variations between jurisdictions. This percentage corresponds to buildings within approximately 250m of bushland based on Figure 1. New construction activity was estimated to be concentrated in the following areas which were considered to have moderate to very high bushfire risks:

- NSW 40%
- Victoria 25%
- Queensland 19%

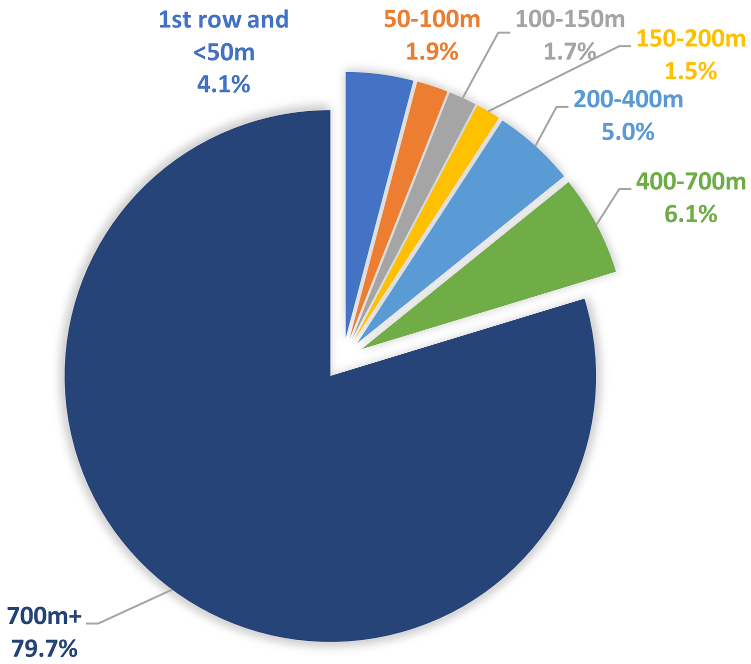


Figure 1 Distribution of Housing Relative to Bushland Interface from Chen and McAneney (McAneney and Chen 2005)

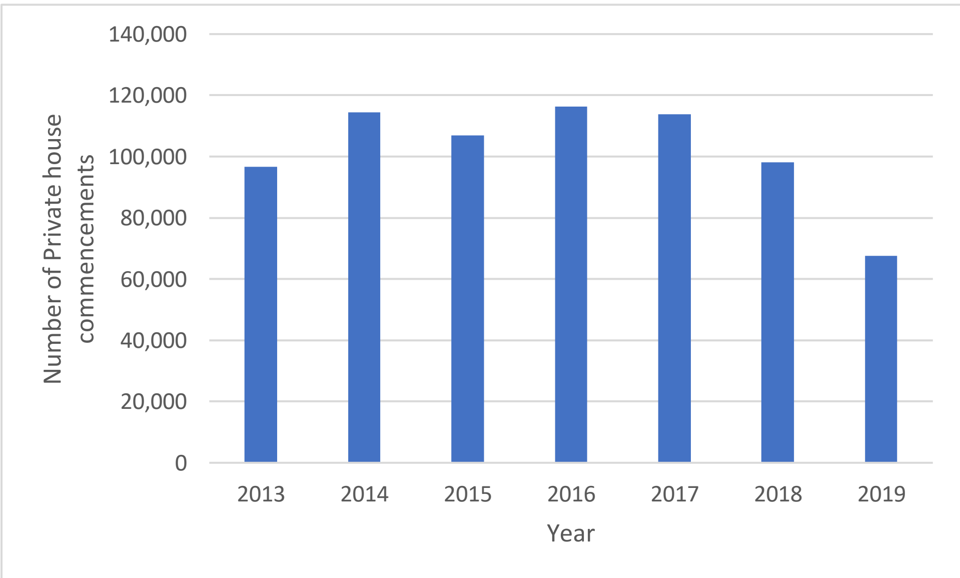


Figure 2 Number of Private house commencements - Australia derived from ABS Building Activity, Australia Data (Australian_Bureau_of_Statistics 2020)

A reasonable estimate for the total number of single dwellings (houses) in Australia at the end of 2021 would therefore be approximately 9.95million.

Since AS 3959 places no requirements on construction that is more than 100m from the predominant vegetation, it could be considered reasonable that only houses within 100m are exposed to a significant threat corresponding to 6% of all dwellings (597,000). However, house losses have been reported up to 700m from the fire front. Using the distribution of houses shown in Figure 1, 14.3 % of houses lie between 100 and 700m from bushland increasing the proportion of houses at risk to 20.3%

The insurance industry applies different criteria to AS 3959 to characterise the bushfire risk relating to a building and people; and the estimated populations within the insurance industry risk classifications for the major population centres are shown in Table 1 (SGS 2019).

This indicates that approximately 24% of the population are at medium risk or greater from bushfires in Australia. If an approximation is made that the number of houses is proportional to the population, the percentage of houses and people at risk could be expected to be similar which is consistent with the above findings (20.3% of housing stock and 24% of the population at risk).

Table 1 Population at risk from Bushfires for NSW, Victoria and Queensland 2017-2018 derived from SGS (SGS 2019)

Exposure	Greater Sydney	Rest of NSW	Greater Melb	Rest of Vic	Greater Brisbane	Rest of Qld	Total	Proportion (%)
Extreme	0	0	0	0	0	0	0	0
Very high	0	9,500	0	247,000	0	0	256,500	1.4
High	318,000	241,500	223,000	635,000		1,000	1,418,500	7.5
Medium	488,000	1,120,000	273,000	200,500	225.5	781,000	2,862,726	15.1
Low	2,830,000	1,261,000	2,889,500	491,500	2,231,500	1,601,500	11,305,000	60.0
No exposure	1,454,500	17,500	1,501,500	0	0	38,500	3,012,000	16.0
Total	5,090,500	2,649,500	4,887,000	1,574,000	2,231,726	2,422,000	18,854,726	100

Proportion of houses to which AS 3959 construction requirements and other bushfire planning measures apply

Generally, AS 3959 requires that a bushfire attack level (BAL) assessment is undertaken for all buildings within 100m of bushland and 50m of grassland; and if the BAL level is determined to be greater than LOW, AS 3959 construction measures apply. On this basis, BAL construction requirements would apply to less than 6% of the building stock based on Figure 1 if the distribution of new housing is similar to the existing house distribution.

However, following the Black Saturday Bush Fires, the subsequent Royal Commission recommendation 49 (Teague, McLeod and Pascoe 2010) stated;

> *"The State modify its adoption of the Building Code of Australia for the following purposes:*
>
> - *to remove deemed-to-satisfy provisions for the construction of buildings in BAL-FZ (the Flame Zone)*
> - *to apply bushfire construction provisions to non-residential buildings that will be occupied by people who are particularly vulnerable to bushfire attack, such as schools, childcare centres, hospitals and aged care facilities*
> - *other than in exceptional circumstances, to apply a minimum AS 3959-2009 construction level of BAL-12.5 to all new buildings and extensions in bushfire-prone areas."*

The third dot point is very significant to this study and was implemented through the Victoria Building Regulations. It results in a substantially larger proportion than 6% of new houses being constructed to bushfire standards even though a significant proportion will be in areas classified as BAL-LOW. This is because the Victorian legislation requires AS 3959 BAL-12.5 construction as a minimum in all Bushfire Prone Areas. The Victorian data has been extracted from Table 1 to calculate the percentage of houses in various risk categories.

Table 2 Population at risk from Bushfires in Victoria 2017-2018 derived from SGS (SGS 2019)

Exposure	Greater Melb	Rest of Vic	Total	Proportion (%)
Extreme	0	0	0	0
Very high	0	247,000	247,000	3.8
High	223,000	635,000	858,000	13.3
Medium	273,000	200,500	473,500	7.3
Low	2,889,500	491,500	3,381,000	52.3
No exposure	1,501,500		1,501,500	23.2
Total	4,887,000	1,574,000	6,461,000	100

Assuming the proportion of population and housing is similar, then it can be assumed that approximately 23% of houses are not at risk. But with the broader application of Bushfire Prone Areas and requirements for a minimum of BAL-12.5 construction in all bushfire-prone areas in Victoria, a best estimate for the proportion of new houses requiring bushfire protection of at least BAL-12.5 would be 76.7%.

Number of Houses Lost per Annum

(Chen and McAneney 2010) estimated that on average 105 house equivalents were lost to bushfires / annum in Australia from 1900 to 2009. (Blanchi, Lucas et al. 2010) estimated that there were approximately 156 house losses / annum from 1939-2009, 171 from 1959-2009 and 318 from 1999-2009. The 1999-2009 average of 318 was dominated by the 2009 Black Saturday bushfires where over 2000 houses were lost.

The 2009 Black Saturday Bushfires also reflected the greatest loss of life from bushfires in Victoria with 173 deaths (Teague, McLeod and Pascoe 2010)) and house losses between 2021 houses (Blanchi R, Leonard J et al. 2012) and 2133 houses (Teague, McLeod and Pascoe 2010)). In response to the event and subsequent Royal Commission, there was a move away from the policy of stay and defend to one that promoted early evacuation. The basis of this decision is reasonable and effective (i.e., manage the impact of the fire by limiting the number of people exposed), but based on the findings of earlier bushfire surveys such as those reported by (Ramsay, McArthur and Dowling 1996) following the 1984 Ash Wednesday Bushfires, it would be expected to lead to substantial increases in loss of property. Table 3 shows relative risk estimates based on survey results from the Otway ranges after the Ash Wednesday fires.

Table 3 Effect of Occupant Actions from (Ramsay, McArthur et al. 1996)

Occupant Action	Relative Risk of Destruction
Stayed	0.1
Left and returned within 30 mins	0.4
Left-stayed away	0.6
Unoccupied at the time of fire	1.0

House losses since the 2009 Black Saturday Bushfires have increased as indicated in Table 4, which summarises house loss estimates due to bushfires derived from various sources. *(Note: some variations from these estimates can be expected as more detailed results are published and verified).*

Table 4 Approximate house losses due to Bushfires in Australia from 2010 to 2020 derived from various sources

Bushfire Season	VIC	NSW	QLD	SA	WA	TAS	ACT	NT	Total
2009-10	0	10	0	13	38	3	0	0	64
2010-11	2	0	0	0	82	0	0	0	84
2011-12	0	0	0	0	32	0	0	0	32
2012-13	46	57	1	3	3	201	0	0	311
2013-14	76	228	0	10	57	0	0	0	371
2014-15	7	6	0	28	5	0	0	1	47
2015-16	146	1	2	91	166	0	0	2	408
2016-17	0	46	0	0	0	0	0	0	46
2017-18	18	71	3	0	1	0	0	0	93
2018-19	29	0	2	0	1	4	0	0	36
2019-20	396	2,448	48	151	1	2	0	5	3,051
Total	720	2,867	56	296	386	210	0	8	4,543
Ave/annum	65	261	5	27	35	19	0	1	413

For the purposes of this study, a conservative (over-estimate) of an average loss of 450 houses per annum across Australia will be assumed if no specific bushfire measures are incorporated in the design of housing, associated structures, and management of vegetation since currently only the proportion of new houses reflect current building standards.

(Blanchi, Lucas and Leonard 2007) reported the location of house losses by State for the period from 1939-2006 as shown in Figure 3 based on the data available with over 55% losses in Victoria.

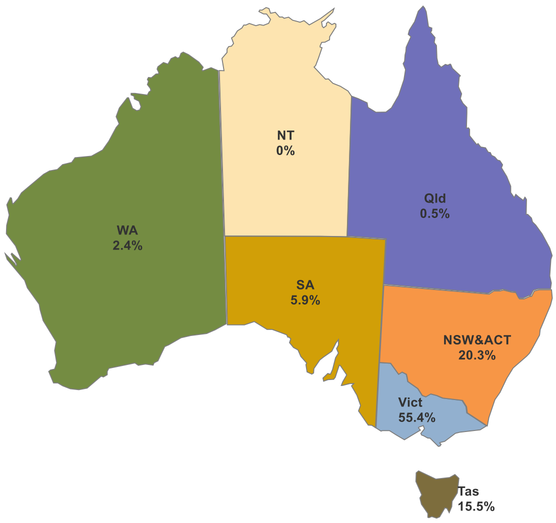


Figure 3 House Loss from Bushfires 1939-2006 based on Blanchi 2007(Blanchi, Lucas and Leonard 2007)

The proportion of house losses in Victoria increased as a result of the 2009 Black Saturday Bushfires but this has been subsequently offset by increased losses in other States, particularly WA, QLD and NSW and a drop in Victorian proportion of house losses since 2009 as shown in Table 4. Therefore, if losses are considered based on geographic locations, the distribution of losses shown in Figure 3 will be assumed.

Impact of distance from bushland (severity of exposure) on house losses

The severity of exposure reduces as the distance from bushland increases and therefore distance is a useful surrogate for severity of exposure. But it should be noted that vegetation types, weather, fuel moisture content and topography will also influence the fire severity.

Figure 4 through Figure 6 show the exposure classification based on distance from predominant vegetation and slope for various vegetation types using the Simple Method tables in AS 3959 (Standards_Australia 2018) using a forest fire danger index (FFDI) of 100.

A simplification to facilitate general risk estimates for the 3 vegetation classes shown below would be:

- Most houses within 20m of the predominant vegetation would be classified as being within flame zone or BAL-40 and for forest vegetation, depending on slope, buildings within 50m may be within flame zone.

- BAL-12 or 19 exposures (predominantly ember attack with lower levels of background radiation) apply to buildings more than 30m from shrubland, 40m from woodland, and 60m from forest vegetation.

- Between BAL-FZ and above BAL-19, buildings may be additionally subjected to high levels of radiant heat and ember attack.

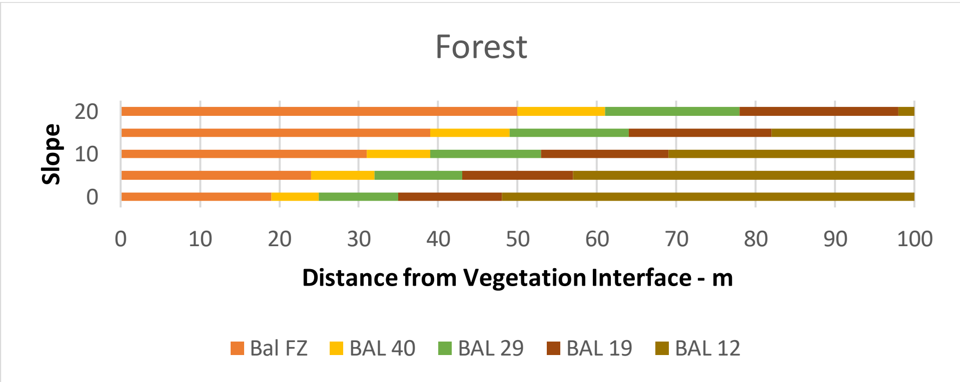


Figure 4 AS 3959 2009 BAL Levels v Distance from Forest for varying Downslopes for an FFDI of 100 using the Simple Method Tabulated Values

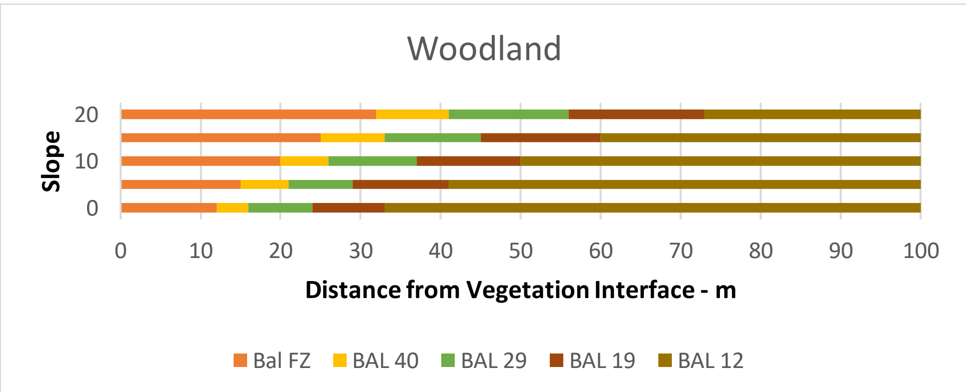


Figure 5 AS 3959 2009 BAL Levels v Distance from Woodland for varying Downslopes for an FFDI of 100 using the Simple Method Tabulated Values

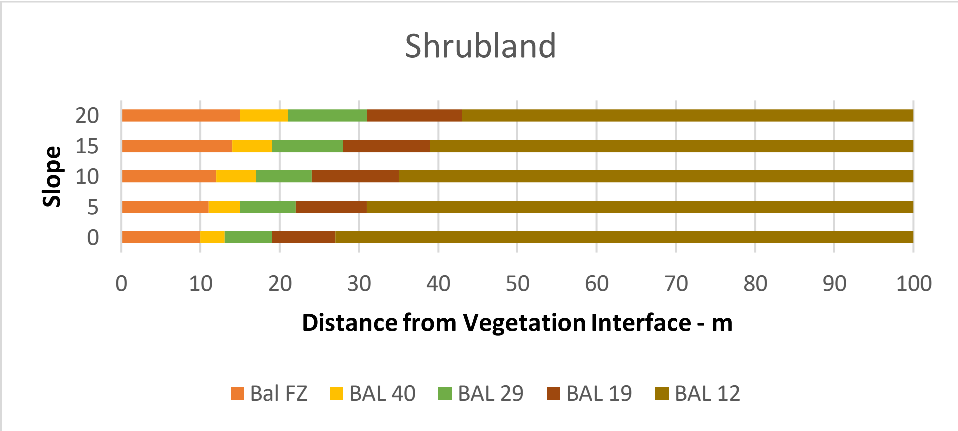


Figure 6 AS 3959 2009 BAL Levels v Distance from Shrubland for varying Downslopes for an FFDI of 100 using the Simple Method Tabulated Values

The Black Saturday fires can be broadly characterised by high wind levels and temperatures, with very dry fuels, with very high losses close to the predominant forest areas compared to the majority of major bushfires. This can be observed in Figure 7 which compares cumulative house losses with the distance from bushland from the following fires.

1967 Hobart bushfires from Ahern and Chladil
1983 Ash Wednesday bushfires – Otway ranges
1994 Sydney bushfires – Como-Jannali
2003 Canberra bushfires – Duffy
2009 Black Saturday Bushfires – Marysville
2009 Black Saturday Bushfires – Kinglake

Approximately 60% of the losses occurred within 10m of the bushland/forest for the Black Saturday Bushfires implying no or minimal fire separation from the predominant forest vegetation. For the other fires included in the comparison, there was substantial scatter with 60% of losses occurring between 25m and 175m. For 90% losses, the scatter was greatly reduced with the distance from bushland varying between 80m to approximately 110m; except for Duffy Canberra which was an outlier at approximately 300m. Losses were minimal for all cases at distances greater than 700m.

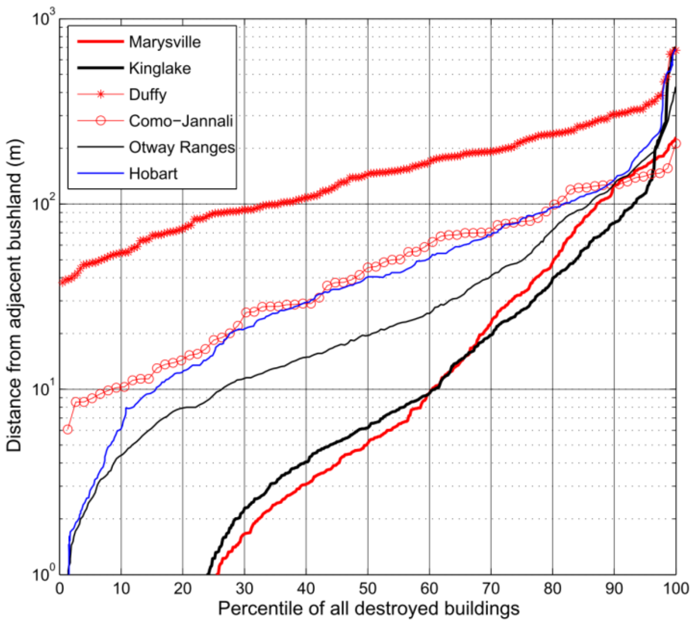


Figure 7 Cumulative distribution of homes destroyed in major bushfires including data from Black Saturday Bushfires in relation to distance from nearby bushland from Crompton (CROMPTON, CHEN et al. 2009)

The difference between the Duffy data and other results can be largely explained by the separation distance of the first row of houses from the predominant vegetation. In Duffy there were no houses to be lost within approximately 35m of the predominant vegetation. This then changes the proportion of houses lost further away from the vegetation. Since the majority of the houses were constructed prior to application of mandatory building standards providing protection against bushfires, the data is representative of the performance of buildings without application of bushfire protection measures for buildings. Marysville, Kinglake and Otway Ranges provide the most relevant plots for conditions with no or minimal separation of the interface between housing and the predominant vegetation.

The mean values from these three studies are summarised in Table 5 together with the mean values from all the summarised fires in Figure 7 except Duffy.

Table 5 Cumulative percentage of house losses for fires summarised in Figure 7

Max Distance from Bushland / Predominant Vegetation - m	Typical exposure conditions based on BAL classification approach	Cumulative Percentage of building losses - Vic Fires	Cumulative Percentage of building losses excluding Duffy
10	Mainly BAL FZ	50 %	37%
20	Mainly BAL FZ	63%	49%
50	BAL 29 / BAL 40	80%	70%
100	BAL 12.5 -19	89%	83%
200	Low Ember Attack	98%	97.5%
700	Very Low ember attack	100%	100%

Estimate of Probability of House Loss as a result of Bushfires based on distance from predominant vegetation for houses predominantly constructed prior to the application of AS 3959

Assuming an average of 450 houses are lost per annum due to bushfires in Australia, of which 55% occur in Victoria, the number of houses lost within various distance bands crudely linked to bushfire attack levels has been calculated in Table 6. An additional calculation has been performed for Victoria which has historically had the greatest house losses due to bushfires.

Table 6 Estimates of likely average house losses within various distance bands from predominant vegetation with minimal number of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Proportion of house loss - Vic Fires	Proportion of house loss - Aus excl. Duffy	Est Num of houses lost /annum -Vic fires	Est Num of houses lost /annum - Aus excl Duffy
<20	Mainly BAL FZ	63%	49%	155.9	220.5
20-50	BAL 29 / BAL 40	17%	21%	42.1	94.5
50-100	BAL 12.5 -19	9%	13%	22.3	58.5
100-200	Low Ember Attack	9%	14.5%	22.3	65.25
200-700	Very Low ember attack	2%	2.5%	4.9	11.25
Total	0-700m	100%	100%	247.5	450

Using the distribution of houses from Figure 1, together with the number of houses derived earlier in the Hazard Identification process, the probability of house loss / annum for houses located within various distance bands from the predominant vegetation can be estimated as shown in Table 7. These estimates should be treated as indicative only since available data is limited and simplifying assumptions were necessary. However, the analysis clearly highlights the substantially greater risks for houses within 50m of the predominant vegetation and the historically greater risk to houses within Victoria. The house loss data was based predominantly on housing that predates the application of AS 3959 and therefore the estimates in Table 7 are indicative of housing without application of AS 3959 provisions.

Table 7 Estimates of probability of house loss due to Bushfires within various distance bands from predominant vegetation with minimal number of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Proportion of houses[1]	Est Num of houses - Vic[2]	Est Num of houses – Aus[3]	Prob of house loss / y - Vic	Prob of house loss / y - Aus
<20	Mainly BAL FZ	2.9%	74,446	288,550	0.0021	0.00076
20-50m	BAL 29 / BAL 40	1.2%	30,805	119,400	0.0014	0.00079
50-100m	BAL 12.5 -19	1.9%	48,775	189,050	0.00046	0.00031
100-200	Low Ember Attack	3.2%	82,147	318,400	0.00027	0.00020
200-700	Very Low ember attack	11.1%	284,948	1,104,450	0.000017	0.000010
Total	0-700m	20.3%	521,121	2,019,850	0.00047	0.00022

Notes
1 From Figure 1 with distribution within 50m of vegetation estimated with allowance for dwellings located within the vegetation
2 Estimated 25.8% of single dwellings in Victoria based on population distribution
3 Based on estimate of approx. 9.95 million single dwellings in Australia allowing for new construction since the 2016 census (ABS 2017).

Estimates of the effectiveness of AS 3959 2009/2018 provisions.

Surveys and statistical analysis on the performance of houses constructed to AS 3959 provisions are very limited because the majority of existing housing predates the mandatory application of AS 3959.

Estimates based on surveys undertaken since 2009 are summarised below but due to the very low sample sizes, varying / unknown extents of compliance, variations in bushfire exposures and other variables, there is a high level of uncertainty associated with these estimates.

Wye River VIC 2015 with Supplementary Analysis

A survey was undertaken following the 2015 Bushfire that impacted Wye River / Separation Creek area (Leonard, Opie et al. 2016) in which over 100 houses were lost.

The study found "...*seven examples of houses built to the regulatory standards, which have been in place since 2010, that were impacted by fire. Of these seven houses, four were lost to fire and three survived. Although the number of buildings in this sample is small, it does suggest a higher survival rate than the 80% loss rate experienced in the region affected by fire. The fourteen houses built to planning and building regulatory standards between 2003 and 2010 fared much better; three were lost to fire and eleven survived.*"

A subsequent review of documentation, based on additional information obtained from the local council relating to site classifications (Haslam 2016), identified at least one property that had been included in the post 2010 group but had been designed to comply with the 1999 edition of AS 3959 rather than the 2009 edition. Additional houses were also identified within the fire impacted area that appear not to have been included in the Leonard, Opie et al report which had been published before the documentation identifying the classification of additional houses had been identified. A revised estimate of the proportion of losses for houses constructed in accordance with the current edition of 2009 falling within the fire perimeter identified by (Smith 2016) is approximately 30% (n=10) compared to the general 80% loss rate.

An assessment of the BAL levels for the townships of Wye River and Separation Creek had been undertaken by Terramatrix before the 2016 bushfire and the findings confirmed after the fire (Boura 2016). The assessment indicated that a large proportion of the townships fell within a BAL-FZ classification as defined in AS 3959:2009. However, none of the houses designed and constructed since 2009 had been classified as requiring BAL-FZ construction. The three houses designed and constructed since 2009 that were lost were classified as BAL-40 but all three were constructed on blocks where 50% or more of the allotment was located within an area defined as BAL-FZ in the Boura report.

The BAL-FZ provisions are substantially more stringent than the BAL-40 provisions and therefore the outcomes may have been different if BAL-FZ construction had been adopted.

The issue of compliance of buildings within bushfire prone areas (BPAs) has been investigated by the VBA who undertook 35 audits of documentation on buildings in 2020 (VBA 2020). There were an average of 13 circumstances of insufficient information and an average of 15 non-compliances per audit (building). This indicates potentially poor levels of compliance which can influence losses considerably.

Linksview Wildfire NSW 2013

(Price and Roberts 2022) examined the role of construction codes on the impact of houses exposed to the fire, by extracting details of 'construction year' and 'standard' for 466 houses from the archives of the relevant council. The fire destroyed 195 houses in the Blue Mountains (NSW) in 2013. The study found that houses built to standards imposed from 2000 fared better than previous standards, though post-2000 houses assessed at Flame Zone level were vulnerable. It should be noted that a performance-based approach is required by NSW regulations for buildings within BAL-FZ and therefore the construction of buildings with potential BAL-FZ exposures may have varied from the prescriptive solutions provided by AS 3959:2009.

The number of houses built after the 2001 introduction of "*Planning for Bushfire Protection*" were the least likely to be lost, provided they were not built in the flame zone, with only 16.6% of such houses impacted. Those in the flame zone ("PBP Beyond" or "PBP 2006 FZ"), had a much higher level of impact (42.8% impacted). The older construction codes ("Old" and "PCD 1984") had a mean impact of 65.5%; nearly three times higher than the post-2001 codes.

Of the sample evaluated, 21 houses were built according to the *Planning for Bushfire Protection* after 2010 (after the release of AS 3959:2009). Of the 11 houses in the Flame Zone, six were impacted while none of the houses outside the Flame Zone were impacted. This equates to overall losses of 6 from 21 (29%) and 6 from 11 (55%) of houses within flame zone.

Estimates of effectiveness of AS3959 based on analysis of surveys and probability of loss of AS 3959 compliant housing

Based on the above two fires, the effectiveness of AS 3959 measures was estimated in Table 8; however due to the small sample size, unknown levels of compliance and other factors such as the extent of occupant intervention or fire brigade intervention, the prevailing weather conditions etc, these estimates have a high level of uncertainty.

Table 8 Estimated effectiveness of AS3959-2009 Construction measures based on analysis of losses

Fire	Losses from pre AS 3959 houses (%)	Losses (AS 3959:2009 requirements) (%)	Losses (AS 3959:2009 requirements) excluding buildings within flame zone (%)	Estimated effectiveness of AS 3959:2009 measures (%)
Wye River	80	30	0	62.5
Linksview	66	29	0	56
Mean	73	30	0	59

Note. Effectiveness is based on the reduction of losses from the proportion of pre AS 3939:1999 houses lost.

Preliminary information was reported in Issue 241 of ECOS (Nicoll 2018), which indicated that, based on the information gathered after the Tathra fire, a 100% survival rate is indicated for new houses built after the introduction of the 2009 Code (AS 3959 (Standards_Australia 2009)). This has yet to be confirmed in published technical literature.

The NCC Verification Method V2.7.5 (an extract is provided in the text box below) provides some indication of the expected performance of buildings when exposed to bushfire.

V2.7.2 Buildings in bushfire prone areas

(a) Compliance with P2.7.5 is verified if the ignition probability for a building exposed to a design bushfire does not exceed 10%.

(b) Bushfire design actions must be determined in consideration of the annual probability of a design bushfire derived from—
  (i) assigning the building or structure with an importance level in accordance with (c); and
  (ii) determining the corresponding annual probability of exceedance in accordance with Table V2.7.2.

(c) A building or structure's importance level must be identified as one of the following:
  (i) Importance level 1 – ....
  (ii) Importance level 2 – where the building or structure is not of importance level 1 or 4 and is a Class 1a or 1b building accommodating 12 people or less.
  (iii) Importance level 4 – ......

If ignition is interpreted as internal ignition which is likely to lead to building loss and a single dwelling is classified as importance level 2, then V2.7.2 requires the probability of loss of a house to be below 10% when exposed to 1 in 50-year weather conditions. This is substantially below the average losses of 30% derived from fires that were less severe than a 1 in 50-year weather event but was selected based on the assumption that the values were policy neutral (i.e. they reflected the current regulatory requirements).

The Verification Method is silent on whether a building should be assumed to be occupied at the time of a fire and the extent of fire-fighting activities (or not) but does require consideration of the probability of non-complying construction of critical aspects of an approved design; and the probability of critical aspects of an approved design being fully functional during the life of the building.

Based on the Victorian compliance audit there appears to be the potential for significant improvements in compliance levels which may reduce the proportion of houses lost to some extent. Further significant reductions could be attained if occupants stay and defend but such a policy may increase the risk to life.

The high losses within BAL-FZ exposures identified in the surveys are also evident in the probability of loss estimates derived in Table 7 based on the analysis of a large number of major bushfires and distributions of losses based on the distance from the predominant vegetation.

Based on the information available, and assuming an effective administration system is operating, the following will be assumed:

- a 10% probability of loss of an AS 3959 compliant house classified as being exposed to BAL-12.5, 19 or 29 conditions.

- a 30% probability of loss of an AS 3959 compliant house classified as being exposed to BAL-40 or BAL-FZ conditions.

Causes of significant house losses in Australia identified by statistical analysis of survey results

A number of studies have been undertaken in Australia to identify causes of house losses during bushfires based on statistical analysis. This is considered to provide the most objective input for a hazard assessment.

Relative risk for various materials and methods of construction from 1983 Ash Wednesday fires.

A detailed survey was undertaken after the 1983 Ash Wednesday bushfires that occurred in Victoria and South Australia in 1983 resulting in 76 fatalities and 2463 houses being destroyed.

A survey of approximately 1150 houses in the Otway Ranges of Victoria with varying degrees of damage as indicated in Table 9, was undertaken by CSIRO with findings being reported by (Ramsay 1985, Ramsay, McArthur and Dowling 1987, Ramsay, McArthur and Dowling 1996). Additional (but incomplete) data was also analysed from the January 1994 NSW bushfires (Ramsay, McArthur and Dowling 1996). As the data was incomplete, but broadly consistent with the Ash Wednesday data, the following discussion will focus on the 1983 bushfires.

In relation to the Otway fires, Ramsay noted that *"the large number of houses, evenness of fire attack and wide spread of building design and materials meant that statistical analysis of the data collected was appropriate"*. The data therefore provides a useful indication of the performance of a range of building materials and systems.

Table 9 Otway Ranges Survey – Extent of Damage to surveyed buildings (from (Ramsay, McArthur and Dowling 1996))

Extent of Damage	% of surveyed buildings

Not ignited	38
Damaged	8
Destroyed	54

The relative risk of destruction based on various cladding materials from the Ash Wednesday bushfires are summarised in Table 10 with timber assigned a reference value of 1.

Table 10 Otway Ranges Survey – Relative Risks for different wall cladding materials (from (Ramsay, McArthur and Dowling 1996))

Wall Cladding	Relative Risk of Destruction
Masonry	0.4
Fibre cement	0.8
Timber	1.0

Predominant construction methods at the time would be expected to be timber-frame with brick-veneer, asbestos cement board or timber weatherboard cladding. The insulating properties and general mechanical properties at elevated temperatures would be expected to be at least comparable for asbestos cement boards compared to modern cellulose fibre boards of a similar thickness.

These results show a clear distinction between masonry walls, which can be considered to be a relatively heavy form of construction and thermally thick (i.e. heat is unlikely to penetrate to the internal surface based on exposure to bushfire / burning debris sources), and potentially light-weight, thermally thin cladding systems such as timber weather boards, fibre cement boards and metal sheeting.

From the results in Table 10, it can be observed that the difference in the relative risk of destruction between houses with timber and fibre cement wall cladding is relatively small compared to the difference between masonry and all common forms of light-weight cladding systems and that masonry veneer housing presents a substantially lower risk. This implies that the combustibility of weatherboard cladding is secondary to other factors associated with lightweight construction, that may account for the large variation in performance of timber or fibre cement compared to brick veneer linings.

The relative risk of destruction based on various roof cladding materials from the Ash Wednesday bushfires are summarised in Table 11 with fibre cement assigned a reference value of 1.

Table 11 Otway Ranges Survey – Relative Risks for different roof cladding materials (from (Ramsay, McArthur and Dowling 1996))

Roof Cladding	Relative Risk of Destruction
Tiles	0.4
Steel Deck	0.7
Corrugated iron	0.9
Fibre cement	1.0

As for the walls, there is a large difference between lightweight and heavy weight construction.

The relative risk of destruction based on building height above ground level from the Ash Wednesday bushfires are summarised in Table 12 with stumps (unenclosed sub-floor) assigned a reference value of 1.

Table 12 Otway Ranges Survey – Relative risks based on building elevation (from (Ramsay, McArthur and Dowling 1996))

Elevation	Relative Risk of Destruction
Slab on ground	0.2
High >2m	0.4
Low <2m	0.5
Stumps	1.0

Slab on ground presents the lowest risk which can be explained by removal of the vulnerability to attack from the underside and at ground level.

Where there is a significant elevation the risk level is intermediate, but the risk level is greatest for stumps, with an unenclosed sub-floor space, where the elevation of parts of the structure may be relatively small leading to a vulnerability from burning embers and debris at ground level. It should be noted that the sub floor for houses of this era is likely to have been uninsulated. To satisfy modern requirements for thermal efficiency insulation is generally required. Depending on the fire properties of the insulation selected and method of application the resistance to bushfire attack may be increased or decreased

The relative risk of destruction based on occupant action from the Ash Wednesday bushfires are summarised in Table 13 with "unoccupied at the time of fire" assigned a reference value of 1.

Table 13 Otway Ranges Survey – Relative risks based on occupant action (from (Ramsay, McArthur and Dowling 1996))

Elevation	Relative Risk of Destruction
Stayed	0.1
Left and returned within 30 mins	0.4
Left-stayed away	0.6
Unoccupied at the time of fire	1.0

These outcomes show a substantial reduction in risk where occupants stayed with a structure compared to those that left. This is significant when considering the relative impact of stay and defend and early evacuation strategies.

The relative risk of destruction based on various vegetation types from the Ash Wednesday bushfires are summarised in Table 14 with trees assigned a reference value of 1.

Table 14 Otway Ranges Survey – Relative Risks for different surrounding vegetation (from (Ramsay, McArthur and Dowling 1996))

Vegetation Type	Relative Risk of Destruction
Grass	0.1
Shrubs	0.4
Trees	1.0

These outcomes highlight the significant variations in risk associated with different types of vegetation.

Canberra 2003 Duffy fires

A report was prepared for the ACT coroner presenting the results of a survey (Blanchi and Leonard 2005) after the 2003 Canberra fires in which 516 houses were lost and there were four fatalities. The survey generally followed similar approaches for data collection to the surveys undertaken following the Ash Wednesday and Sydney 1994 fires, but the range of data reported was more limited.

Blanchi and Leonard selected a square survey area within Duffy for a detailed survey of over 229 houses as it presented the highest density of damage and destruction. This sample differed from other studies in that there were no houses in close proximity to the bushland / forest (i.e. all houses were > 35m from bushland / forest) and therefore the exposure of the houses was predominantly to ember attack. If radiant heat exposure occurred directly from the fire front it would have been at a low level.

Blanchi and Leonard estimated that 65% of the destroyed houses were subjected to ember attack only, approximately 29% to ember attack and some radiant heat and 3% due to flame contact from adjacent vegetation. The distribution of radiant heat sources was not identified in this data but examples in the text of radiant heat from adjacent structures and vegetation were provided. The vegetation would most likely have been ignited by embers possibly supported by low levels of radiant heat from the fire front in a limited number of cases.

The following features of the surveyed houses were identified:

- 85% of the houses were stated to be built around 1970
- 73% had 1 functional level; 22% had 2 functional levels
- 84% were supported on brick piers
- 99% of external skin of the walls were brick
- 92% of the subfloors were enclosed with brick
- 3% of windows fitted with roller shutters and 6% with other shutters
- 57% of windows fitted with metal fly wire
- 90% of roofs tiled
- 5% of houses with gapped treated pine decking, 19% with gapped other timber decking, 1% tongue and grove decking, 6% other decking, 69% none or non-combustible.

The report postulated that fire spread from outbuildings could present a significant risk and provided some data, but it was not possible in all cases to determine if the fire spread was from the house to outbuildings or vice versa.

House to house spread, or probable house to house spread, was estimated to have occurred in approximately 11% of the destroyed buildings and approximately 23% of the surviving buildings which led to the conclusion that a substantially greater number of buildings would have been lost without occupant and /or fire brigade intervention.

This is also reflected in the estimates of the risk reduction shown in Table 15. Although the sample size was small, these results are consistent with other surveys summarised in this report.

Table 15 Canberra 2003 fires – Relative risks based on known occupant actions (derived from (Blanchi and Leonard 2005)) with additional analysis from (England 2020)

Action	Num - Survived	Num - Destroyed	Probability of loss	Relative Risk of Destruction
Stayed	21	2	0.09	0.11
Left after fire front passed	4	2	0.33	0.41
Left before fire front passed	7	8	0.53	0.66
Unoccupied at the time of fire	1	4	0.8	1.0

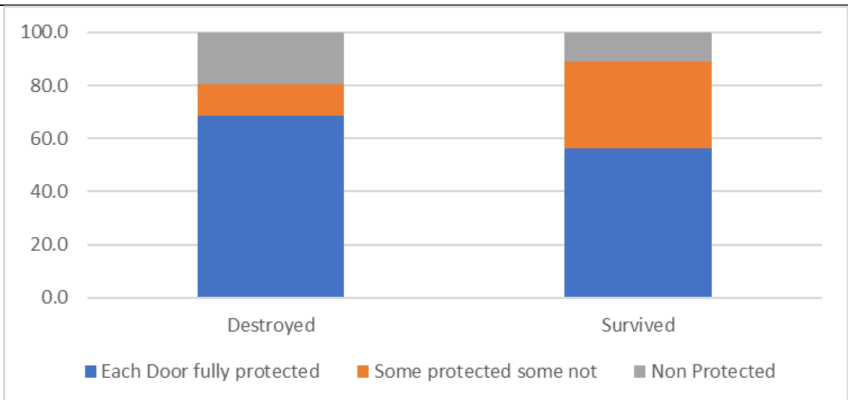
Only a limited amount of survey data was reported relating to the performance of building elements – mainly comprising data relating to the screening of doors and openable parts of windows and framing materials. This data is summarised in Table 16 and indicates some improvement in the performance of windows with mesh screens but shows little variation with window framing materials.

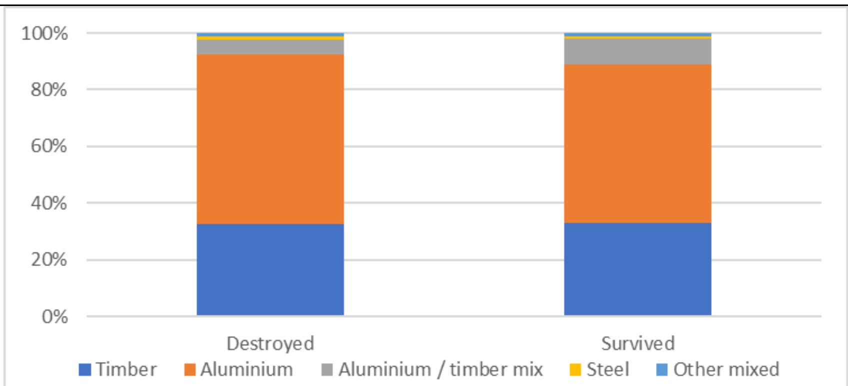
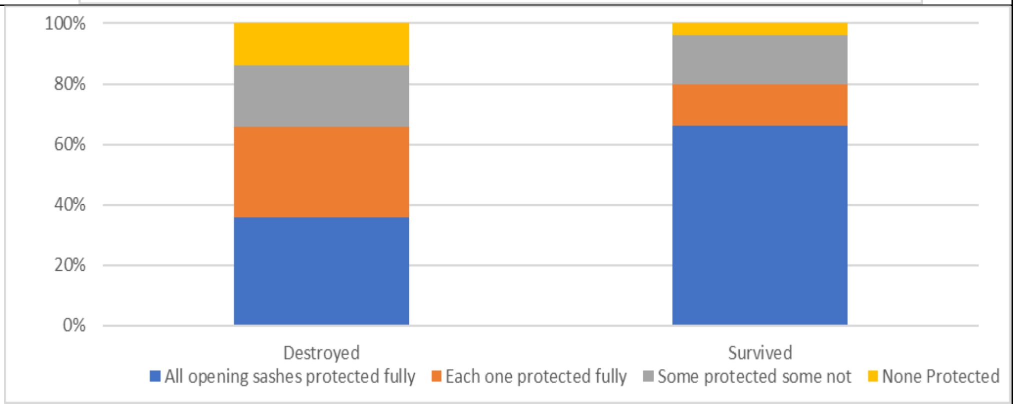
Blanchi and Leonard indicated that the window framing material was predominantly aluminium and there was insufficient data to identify a correlation between window frame type and the risk of house loss. However, it is noted that;

- *"approximately 33% of the buildings had timber window frames and this proportion did not change appreciably between the buildings that survived or were destroyed.*
- *over 55% of the buildings had aluminium frames and a similar but slightly higher proportion of buildings with aluminium window frames were destroyed compared to buildings that survived.*

Therefore, it is considered reasonable to conclude that the performance of windows with aluminium and timber frames was similar during the fires and did not make a significant difference to house survival".

Table 16 Building element performance derived from (England 2020) based on data extracted from (Blanchi and Leonard 2005)

Construction element description	Comparative results with cases where the construction element was unknown distributed proportionately.
Screening of doors	

Window frame construction	
Window protection with mesh	

Of direct relevance to this study, Blanchi and Leonard stated that the contribution of fencing systems to the risk to the main residential structure was observed in many cases in Duffy but no statistical data to quantify or support this statement was provided. Some anecdotal evidence in the form of post fire photographs and observations from residents were included in the Blanchi and Leonard report to support this claim, but in most cases burning vegetation may have been a major contributor to fire spread.

Black Saturday Bushfires 2009

The 2009 Black Saturday Bushfires can be broadly characterised by high wind speeds and temperatures with dry fuels with a large proportion of houses close to or within the predominant forest vegetation. The proximity of houses to the predominant vegetation provides a significant variation to the Canberra fires. The Black Saturday Bushfires resulted in approximately 173 deaths (Teague, McLeod and Pascoe 2010)) and 2021 to 2133 houses lost (Blanchi R, Leonard J et al. 2012), (Teague, McLeod and Pascoe 2010)).

A report prepared by the Bushfire CRC for the Royal Commission (Bushfire_CRC 2009) included results from a survey. A sample of 1065 houses were surveyed. Approximately 58% of the houses were destroyed, and 42% were untouched or suffered superficial damage.

The survey identified that 13% of the damaged or destroyed houses had been impacted by a combination of fire and wind with less than 1% identified as being damaged or destroyed solely as a result of wind.

The main modes of attack, where the mode could be identified, are summarised below:

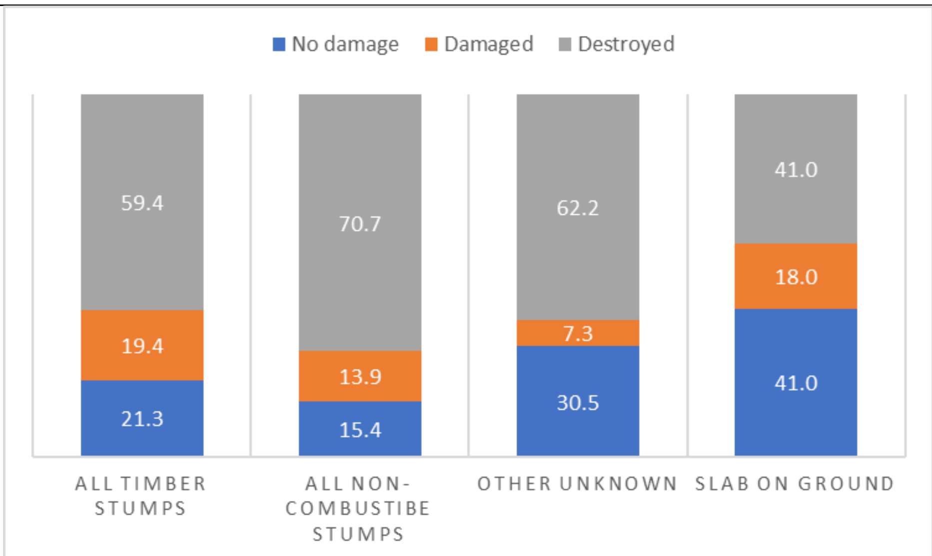
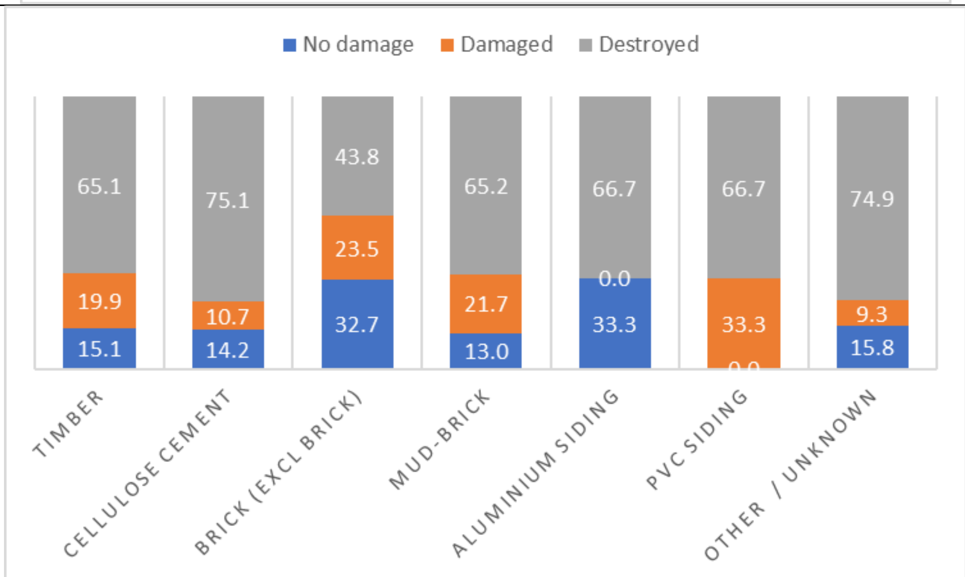
- Embers only 27%
- Embers and some radiant heat 47%
- Predominant Radiant Heat 7%

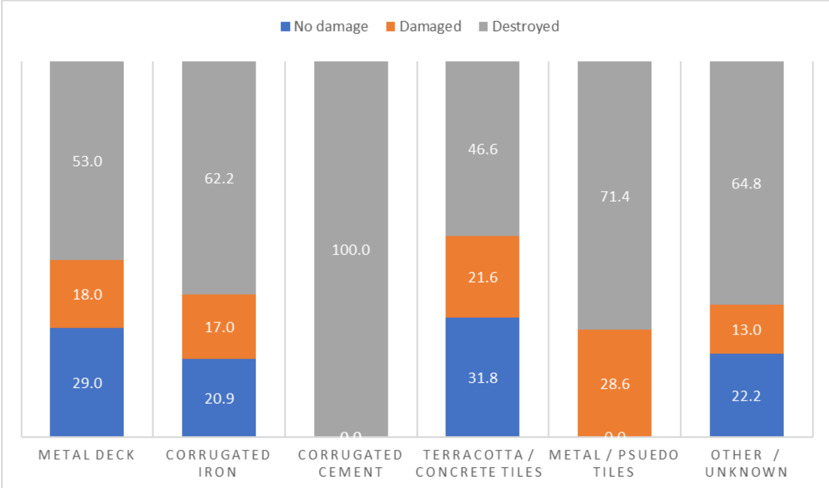
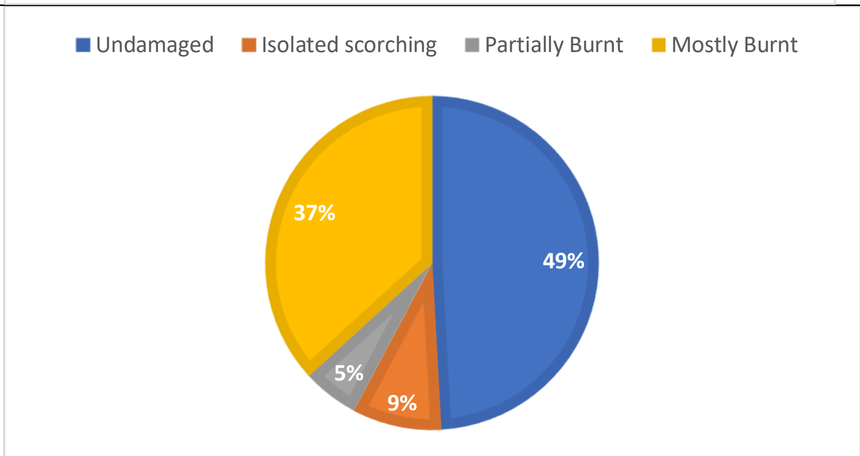
- Flame contact 19%

Where defence occurred, the proportion of houses lost was approximately 33% compared to 78% with no defence. The reduction in the proportion of losses where a property was defended was less than other bushfires possibly due to the severity of exposure for properties within or close to forest vegetation.

The survey data reported relating to the performance of building elements (Bushfire_CRC 2009) is summarised in Table 17.

Table 17 Building element performance derived from (England 2020) based on data extracted from (Bushfire_CRC 2009)

<table>
<tr><td>Construction element description</td><td>Comparative results with cases where the construction element was unknown distributed proportionately.</td></tr>
<tr><td>Types of Floor Construction</td><td>
</td></tr>
<tr><td>External Wall Cladding</td><td>
</td></tr>
</table>

<table>
<tr><td>Construction element description</td><td>Comparative results with cases where the construction element was unknown distributed proportionately.</td></tr>
<tr><td>Roof Cladding</td><td>
</td></tr>
<tr><td>Damage to Decks</td><td>
</td></tr>
</table>

No data from the survey identifying the proportion of building losses relative to the proximity of timber fencing was reported.

From the reported data, it is noteworthy that slab on ground floor construction resulted in a significantly lower probability of building loss compared to raised floor construction; but there was no significant difference between the use of non-combustible stumps, timber stumps and stumps of unknown construction indicating that house loss was not sensitive to the materials used for stumps. The sub-set of treated pine was separately identified and showed lower probabilities of loss but the report (Bushfire_CRC 2009) postulated that *"this may be due to the fact that treated pine elements tend to burn to completion once ignited, leaving little evidence of their existence, and this may have led to a poor detection rate of this stump type in destroyed house wreckage."* If the stumps were consumed and the material used was not identified by checking records, the stumps would most likely have been classified as unknown which had a similar house loss rate to other materials used for stumps. Therefore, it is reasonable to conclude that the probability of house loss is largely independent of the stump materials.

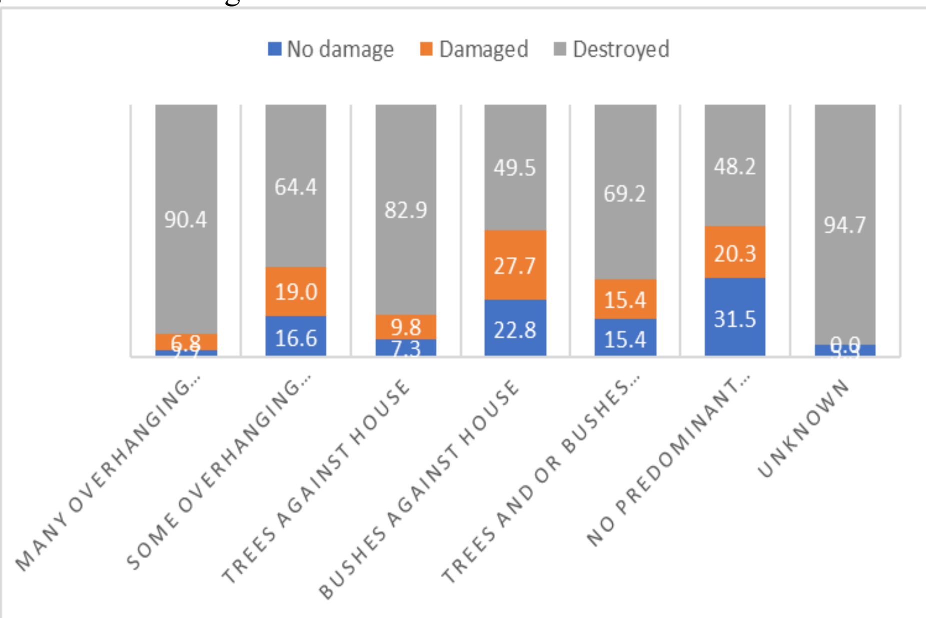
The results from external wall cladding also showed that the house loss rate for timber cladding was similar to other lightweight cladding systems such as cellulose cement sheeting, but that the house loss rate was lower if the outer skin of a wall was of brick construction.

These results imply that other mechanisms such as ember penetration through unprotected gaps / openings, the formation of gaps by various means including window breakage allowing entry of embers or conduction through thermally thin cladding materials may be more relevant than restricting the use of materials.

Most of the glass in the survey was identified as plain (71%) or unknown (22%) with only 3% being identified as toughened therefore meaningful comparisons on the potential reduction in losses from the use of toughened glass cannot be made based on the data provided.

The sensitivity of loss statistics to vegetation adjacent to buildings was investigated with respect to overhanging branches and presence of trees / bushes against the building. The comparative extent of damage for the various conditions are shown in Figure 8.

The results confirm that trees overhanging or against a structure significantly increase the risk of building loss as do trees against a house.



The sample categories and sample numbers comprised:

many overhanging trees	73
some overhanging trees	247
trees against house	41
bushes against house	101
trees or bushes against house	78
No predominant vegetation adjacent to house	197
Unknown	19
Total	756

Figure 8 Comparison of extent of damage for vegetation conditions against or above the building. Derived from Victorian 2009 bushfire research response: Final Report (Bushfire_CRC 2009)

Survey results were also recorded relating to combustible ground cover against the building (i.e. no separation of vegetation from the building).

The sample comprised:

317 Combustible cover adjacent to the house
47 Combustible cover not adjacent to the house

The proportion of houses lost was approximately 62% with combustible cover adjacent to a house and 49% where there was no combustible cover adjacent to a house.

Examination of the determinants of damage to houses in the 2013 NSW fires

A more recent statistical analysis was undertaken using data from 540 houses exposed to the Linksview or Mt York fires in New South Wales in October 2013 (Price, Whittaker et al. 2021). Analysis was undertaken on 85 potential predictor variables which were assigned to the following six themes: preparedness actions (including defensible space), response actions (including defence), house construction, landscape fuels, topography and weather.

The potential predictor variables included the following of direct relevance to this study which were linked to the preparedness action theme:

- Fence material
- Distance to the nearest fence
- Fence height
- Percentage of Openings in the fence

Eleven variables were shared among the top 20 ranks in both the Random Forest and individual model analyses, including;

- defence,
- vegetation cover 40 m to the west,
- the west south-west aspect,
- wall cladding, and
- distance to nearest burnt building.

Of note was that lightweight cladding systems such as timber, asbestos and cement sheet scored similarly reflecting the findings from earlier statistical analyses together with defence of the property by occupants or fire fighters and proximity / extent of vegetation cover.

The state of the lawn (dry or green) and the type of the base supporting the house were ranked highly in the individual models but not in the Random Forest Model. This is presumed to be because defence and vegetation cover tend to be dominant.

Price, Whittaker et al noted that *"the presence of a gas bottle and deck type had large effects according to the individual models but were not in the Random Forest model, probably because the sample of houses was small for these variables"* (n=69 for presence of a gas bottle and n=110 for deck type)

The variables associated with fencing were not amongst the top 20 ranks, implying that fencing did not have a significant impact on house loss.

The analysis identified defensive action and preparedness, as the primary themes / drivers of the fire impact on houses. The preparedness theme however included a large number of variables (over 50% of the nominated variables) some of which were shown to have a major impact (high ranking) such as the provision of defensible space (e.g. distance to forest) whilst others such as fencing were low ranking and therefore would be expected to be less critical.

Conclusions from statistical analysis of post bushfire surveys

The findings of the statistical analysis of survey results were generally consistent:

- Light-weight external cladding systems were substantially more susceptible to damage than brick-veneer construction with tiled roofs, but similar proportions of losses occurred for timber and non-combustible lightweight wall cladding systems implying that the combustibility of timber was not the predominant cause for variations in losses between brick veneer and lightweight cladding systems.

- Houses with raised floors were substantially more susceptible to damage than slab on ground construction with the vulnerability increasing as the clearance to the ground reduced, but the losses for raised floors were similar for timber stumps and non-combustible stumps and piers implying that the combustibility of timber was not a predominant cause for variations in losses between timber stumps and other non-combustible sub floor supports. It should be noted that the majority of buildings were of older designs that may not have had insulation applied to the underside of the floor. The presence of insulation could increase or decrease the probability of house loss depending on the fire properties of the insulation material and method of application.

- House losses were substantially greater if the property was unoccupied, and no firefighting activities were undertaken.

- House losses were the lowest if the surrounding vegetation was predominately grass, highest if the vegetation was predominantly trees and intermediate if the surrounding vegetation was bushes. Overhanging trees or trees and bushes against a house significantly increase the risk of building loss.

- Timber framed windows did not significantly increase the risk of building loss compared to non-combustible window frames.

- Protecting the openable parts of windows with metal fly screens reduced the proportion of lost houses.

Statistical data on the performance of fencing was only included in the analysis of the 2013 NSW fires in the above surveys and was not identified as a top ranking variable.

Investigations of life loss associated with buildings

The following data is extracted from the life and house loss database (Blanchi R, Leonard J et al. 2012) which contains data on bushfire related life loss in Australia between 1901-2011 during which 825 fatalities were recorded (733 civilian and 92 fire fighters). Blanchi noted that the fatalities tended to be dominated by a few major bushfires such as the Ash Wednesday 1983, Black Saturday 2009, with 10 fire days accounting for 65% of all civilian fatalities.

Data from the latter period 1965 to 2011 in which 482 fatalities were recorded has been used where appropriate to provide data with the most relevance. The distribution of fatalities during this period are shown in Figure 9 which shows the majority of fatalities occurred in Victoria; consistent with the distribution of property losses. The average number of civilian and fire fighter deaths during this period was approximately 11 / annum and the average number of civilian deaths was estimated to be approximately 9 /annum.

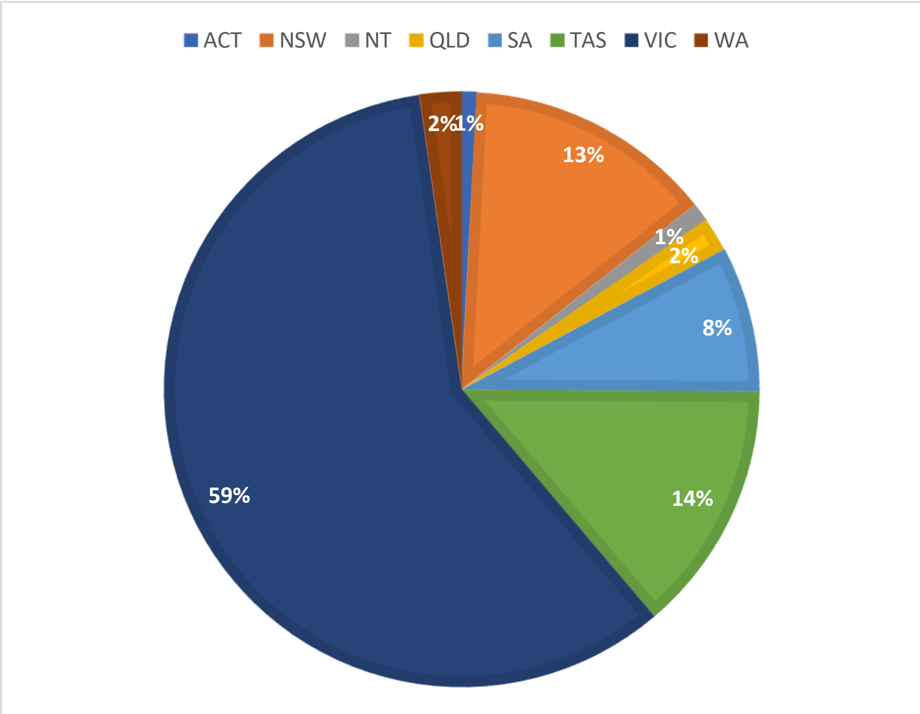


Figure 9 Bushfire fatalities by State and Territory between 1965 and 2011 derived from (Blanchi R, Leonard J et al. 2012)

The distributions of locations of fatal exposures (n=376 civilians) between 1996 and 2011 were:

- Inside structure: 44.4% (167)
- Inside Vehicle: 12.0% (45)
- Open air: 42.0% (158)
- Unknown: 1.6% (6)

A subset of 116 fatalities from the life loss database was selected where the residential address and fatal exposure were well known, comprising;

- 19 Inside a structure (other than their residence (e.g neighbouring house or bunker))
- 18 Inside a vehicle
- 79 Open air

For this subset approximately 40% of fatalities occurred within 20m of the residence, 61% within 100m and 84% within 1km.

The main activities of the fatalities prior to exposure were identified as:

- Late evacuation 48.3%
- Outside saving livestock and livelihood or defending wider property 20.7%
- People sheltering as a group 11.2%

10 residences of the deceased were undamaged
89 residences of the deceased were completely destroyed of which 20 were used as a refuge.

Based on the proportion of house losses, approximately 10% of the late evacuees may have survived if they had remained in their house and therefore 90% of late evacuations leading to fatalities may have been at least in part due to their residence providing inadequate protection, i.e. 43.5% (48.3x0.9) of open air (outside) and inside a vehicle fatalities. An upper estimate of fatalities associated with loss of a residence would then be:

Inside a structure		44.4%
Inside a vehicle	12.0 x 0.435….	5.2%
Open air	42.0 x 0.435….	18.3%
Estimate of maximum total civilian fatalities associated with house loss		67.9%

Therefore, it can be estimated that an average of approximately 6 civilian deaths per annum can be associated with the loss of houses due to bushfires. It should be noted that most of the houses that these fatalities were associated with would not have been constructed in accordance with AS 3959:2009 or later construction requirements.

Bushfire Actions with potential to ignite and facilitate fire spread

Direct Actions

Many researchers have identified bushfire actions that occur at the urban interfaces (Ramsay and Dawkins 1993, Leonard, Blanchi and Leicester 2004, England, Chow and Zillante 2006, Caton, Hakes et al. 2017)

There are three primary direct actions or modes of attack from bushfires that can cause ignition of timber fencing and sleeper walls. These comprise the following.

- burning embers (sometimes referred to as burning brands or firebrands),
- radiant heat, and
- direct flame contact.

Exposure to burning embers may occur for periods ranging from a few minutes to several hours depending on the fire and prevailing weather conditions. There is limited data on the ember size distributions, burning rate, flux of embers produced by bushfires and at various distances from the fire front to validate models developed to predict distributions of embers. Some data is available from examination of burn marks through plastic sheets and similar objects either obtained from surveys after major fires, e.g. Angora fire in the US (Manzello and Foote 2014), or large scale fire experiments e.g. Project Vesta (Gould, McCaw et al. 2008).

The threat posed to structures and fencing from direct ember attack and secondary fires started by embers can be inferred by examining house loss data from a number of major fires. Based on a model that was found to be conservative compared to the crown fire experiments (Cohen 2004), ignition of timber elements is unlikely to occur solely as a result of radiant or convective heat direct from the fire front at distances more than 30m. This distance is similar to the minimum BAL-29 separation distance for forest vegetation over land with 5° slope (refer Figure 4). It is therefore reasonable to assume that house loss at distances beyond 30m would be predominately due to ember ignition or ember ignition of secondary fires. Based on analysis of Australian data (Ahern and Chladil 1999), house loss occurred up to distances of approximately 700m from the fire front interface in isolated circumstances with a typical cumulative distribution shown in Table 18.

Table 18 Cumulative distribution of burnt dwellings derived from (Ahern and Chladil 1999)

Distance from Interface (m)	Dwellings Burnt (%)
15	35
30	55
40	63
88	81
100	85
181	95
350	99

As expected, this shows an exponential reduction in losses as the distance from the fire front increases reflecting lower concentrations of embers that will tend to have less mass and energy due to the increased time available for ember combustion whilst airborne.

If a fence is in close proximity to a fire front, it may also be exposed directly to significant radiant heat and in some cases direct flame contact from the fire front. Generally, the duration of the peak radiant heat and / or convection / flame contact from the fire front is limited to the time for fine forest fuels to be consumed and is typically less than one minute. For typical examples refer (Gould, McCaw et al. 2008) and (Cohen 2004). The peak radiant exposure in the Australian Bushfire test method called up in AS 1530.8.1 (Standards_Australia 2018) is maintained for 2 minutes providing a large margin of safety; and to evaluate systems in the flame zone, AS 1530.8.2 (Standards_Australia 2018) requires 30 minutes exposure to the standard fire test heating regime of AS 1530.4 (Standards_Australia 2014) which also addresses to some extent the potential for secondary fires involving adjacent houses.

Secondary Actions

Prevailing weather conditions or modified conditions generated by severe bushfires may induce structural failures of fencing, timber or other materials, components in addition to influencing the extent of ember attack, magnitude of exposure and direct flame attack from the fire front. In addition, debris may be carried by the wind or in extreme cases elements of construction such as fence panels and posts may be uplifted and impact adjacent buildings. If vulnerable areas such as windows are impacted, the building may be opened up facilitating the entry of burning embers.

Secondary fires occurring in close proximity to houses have been identified by numerous researchers including (Ramsay 1985, Ramsay and Dawkins 1993, Blanchi and Leonard 2005, Hakes, Caton et al. 2017) as potentially increasing the risk from bushfires. These secondary fires may be ignited by burning embers, radiant heat or flame contact from the fire front. Secondary fires may also increase the risk of ignition and fire spread along fences and sleeper walls.

Typical examples of secondary fires include;

- collections of windblown embers, particularly where there are re-entrant corners
- existing debris including leaf litter ignited by burning embers
- ignition of combustible mulch by embers
- ignition of vegetation in close proximity to a house, timber fence or sleeper wall
- ignition of adjacent structures (houses, sheds etc)
- ignition of combustibles such as furnishings close to buildings or gas bottles.

If timber fencing is ignited, it may also expose a house to an additional secondary fire but it may also provide some protection to the house from embers, radiant heat and flame contact direct from the fire front. The potential exposure from timber fencing and sleeper walls is reviewed in more detail in the following section.

There can be considerable variation in the severity of these secondary fires. For example, AS 1530.8.1 (Standards_Australia 2018) adopts small burning cribs to simulate exposure to potential collections of debris on horizontal surfaces whilst exposing elements to a radiant heat flux; whereas an adjacent structure will produce a very large heat source with durations of several hours although peak exposures may be limited to 10-30 minutes as applied by the AS 1530.8.2 test method.

Conclusions

Based on the preceding analyses the following approximate estimates have been made which are considered to reflect an overestimate of the losses between 2009 and 2020. (Note: The period between 2009 and 2020 included two seasons with house losses greater than 2000 and significantly overestimates the long-term trend but may reflect higher frequencies of major fires that could occur from climate change in the future).

- 450 houses lost due to bushfires per annum across Australia, assuming nominally 10% of houses comply with AS 3959:2009 or later,
- an average of 6 civilian fatalities per annum associated with housing within a bushfire prone area assuming nominally 10% of houses comply with AS 3959:2009 or later.

Using these estimates, the probability of house loss and the risk of a fatality associated with a house in a bushfire prone area have been estimated for various distance bands from bushland in Table 19 and Table 20.

It should be noted that AS 3959 does not prescribe any bushfire specific standards for buildings more than 100m from predominant vegetation; but Victorian regulations issued following the Royal Commission into the 2009 fires, require the BAL 12.5 classification and construction standards to be applied to new houses in Bushfire Prone areas including buildings beyond 100m of the interface with predominant vegetation. Since most of the houses lost pre-date the application of AS 3959 or were not required to be constructed in accordance with the standard it has been assumed that AS3959 construction requirements had not been applied beyond 100m from the predominant vegetation when using survey results from previous fires.

Table 19 Estimates of probability of house loss due to Bushfires within various distance bands from predominant vegetation with 10% of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Proportion of houses[1]	Est Num of houses	Prob of house loss existing / y - Aus
<20	Mainly BAL FZ	2.9%	288,550	7.6×10^{-4}
20-50m	BAL 29 / BAL 40	1.2%	119,400	7.9×10^{-4}
50-100m	BAL 12.5 -19	1.9%	189,050	3.1×10^{-4}
100-200	Low Ember Attack	3.2%	318,400	2.0×10^{-4}
200-700	Very Low ember attack	11.1%	1,104,450	1.0×10^{-5}
Total	0-700m	20.3%	2,019,850	2.2×10^{-4}

Note 1 Proportion of houses within the typical BAL classification

Table 20 Estimates of risk to life associated with housing in bushfire prone areas within various distance bands from predominant vegetation with 10% of houses constructed to AS 3959 standards

Distance from Pred. Veg - m	Typical BAL class / Ember hazard	Prop. of houses.	Est pop. at 2.6 people / house	Prop / number of fatalities [1]	Risk of fatality within a house
<20	Mainly BAL FZ	2.9%	750,230	87% / 5.22	7.0×10^{-6}
20-50m	BAL 29 / BAL 40	1.2%	310,440	8% / 0.48	1.5×10^{-6}
50-100m	BAL 12.5 - 19	1.9%	491,530	2% / 0.12	2.4×10^{-7}
100-200	Low Ember Attack	3.2%	827,840	2% / 0.12	1.4×10^{-7}
200-700	Very Low ember attack	11.1%	2,871,570	1%/0.06	$2. \times 10^{-8}$
Total	0-700m	20.3%	5,251,610	100% / 6	1.1×10^{-6}

Note 1 Percentage of fatalities inside structures derived from cumulative loss profile of fatalities inside a structure v distance from forest in Life and House Loss Database (Blanchi R, Leonard J et al. 2012)

Approximate estimates of the probability of a building exposed to bushfire attack being lost are summarised in Table 21. Due to the limited data available there is significant uncertainty in these values.

The 10% probability of loss for buildings up to BAL-29 constructed to AS 3959:2009 or later was based on Verification Method H7V2 in NCC Volume Two which states, amongst other things;

(1) Compliance with H7P5 is verified if the ignition probability for a building exposed to a design bushfire does not exceed 10%.

Although the 10% value specified in verification method H7V2 also applies to BAL 40 and BAL FZ an estimate of 30% has been adopted to account for the substantially increased severity of exposure particularly in BAL FZ.

The values for pre AS-3959:2009 construction were loosely based on losses of unoccupied houses from bushfire events and also account for the high vulnerability of glazing systems in pre-AS 3959-2009 construction.

Table 21 Estimated probability of loss of buildings exposed to bushfire attack

BAL Level	Pre-AS 3959:2009 Construction	AS 3959:2009 Construction or later
12.5,19 or 29	40%	10%
40, FZ	90%	30%

Using the above estimates the probability of house loss for buildings not constructed to AS 3959 and those constructed to AS 3959-2009 or later has been calculated in Table 22.

Table 22 Estimated probability of loss of housing

Distance from Pred. Veg - m	Typical BAL classification / Ember hazard	Prob of loss of pre-AS 3959 house/y	Prob of loss of post AS 3959 :2009 house/y
<20	Mainly BAL FZ	7.6×10^{-4}	2.5×10^{-4}
20-50m	BAL 29 / BAL 40	7.9×10^{-4}	2.6×10^{-4}
50-100m	BAL 12.5 -19	3.1×10^{-4}	7.8×10^{-5}
100-200	Low Ember Attack	2.0×10^{-4}	2.0×10^{-4}
200-700	Very Low ember attack	1.0×10^{-5}	1.0×10^{-5}

The above probabilities were used to calculate the average loss / annum and average loss over the design life associated with a house constructed to pre-AS 3959:2009 standards to post AS3959:2009 standards. An average cost to clear a site and rebuild of $750,000 and a design life of 50 years were assumed, and no depreciation was assumed but could be incorporated if more accurate estimates are required. The results are summarised in Table 23. Notwithstanding the above simplifications, the results indicate there are limited opportunities to derive additional cost-effective construction requirements that would be expected to yield a significant net benefit after the application of AS 3959:2009 or 2018 requirements especially at distances more than 50m from the predominant vegetation.

Table 23 Estimated average loss per house per annum and over a 50 year design life.

Distance from Pred. Veg. m	Typical BAL classification / ember hazard	Av loss per annum @ current worth		Av loss over design life @ current worth	
		Pre AS3959 2009 house	Post AS3959 2009 house	Pre AS3959 2009 house	Post AS3959 2009 house
<20	Mainly BAL FZ	$570	$187	$28,500.00	$9,375.00
20-50m	BAL 29 / BAL 40	$593	$195	$29,625.00	$9,750.00
50-100m	BAL 12.5 - 19	$233	$59	$11,625.00	$2,925.00
100-200	Low Ember Attack	$150	$150	$7,500.00	$7,500.00
200-700	Very Low ember attack	$8	$8	$375.00	$375.00

Based on the initial conservative assumption of average house losses per annum of 450 the average value of lost houses across Australia was estimated to be approximately $335 million for the pre-2009 housing stock. If all housing complied with post AS 3959:2009 construction requirements it was estimated that the number of houses lost would be reduced to 193 at a cost of approximately $144.5 million. Refer to Table 24 for further details.

Table 24 Estimated annual house losses due to bushfires in Australia if all housing within 100m of the predominant vegetation was constructed to pre-AS3959 construction standards compared to post 2009 construction standards

Dist. from Pred. Veg -m	Typical BAL classification / ember hazard	Est. num. of houses	Annual cost of lost houses pre2009 const. -$ million	Annual cost of lost houses post 2009 const. -$ million	Houses lost pre-2009 construction / annum	Houses lost post 2009 construction / annum
<20	Mainly BAL FZ	288,550	164.5	54.1	219	72
20-50m	BAL 29 / BAL 40	119,400	70.7	23.3	94	31
50-100m	BAL 12.5 - 19	189,050	44.0	11.1	59	15
100-200	Low Ember attack	318,400	47.8	47.8	64	64
200-700	Very Low ember attack	1,104,450	8.3	8.3	11	11
0-700	Total	2,019,850	335.2	144.5	447	193

When considering these average values, it should be noted that there are substantial variations in losses with many years having minimal losses, but severe fire seasons have resulted in losses of 2000 houses in a single season in the 2009 Black Saturday fires and 2019-20 fire season based on houses predominately constructed to pre AS 3959:2009 building standards.

References

ABCB (2009). Final Regulatory Impact Statement for Decision (RIS 2009-02) – Proposal to Revise the Building Code of Australia requirements for Construction in Bushfire Prone Areas. Australia.

ABS (2017). 2016 Census QuickStats, ABS.

Ahern, A. and M. Chladil (1999). "How far do bushfires penetrate urban areas."

Australian_Bureau_of_Statistics. (2020). "Building Activity, Australia - Reference period June 2020." Retrieved 9/12/2020, 2020, from https://www.abs.gov.au/statistics/industry/building-and-construction/building-activity-australia/latest-release#data-download.

Blanchi R, Leonard J, Haynes K, Opie K, K. M. James M, Dimer de Oliveira F and V. d. H. R (2012). Life and house loss database description and analysis -report to the Attorney-General's Department. CSIRO EP-129645, CSIRO and Bushfire CRC.

Blanchi, R. and J. Leonard (2005). Investigation of bushfire attack mechanisms resulting in house loss in the ACT bushfire 2003, Bushfire Cooperative Research Centre.

Blanchi, R., C. Lucas and J. Leonard (2007). House Loss and weather conditions: An overview of weather condition during major bushfire that lead to house loss. TASSIE FIRE, Hobart, AFAC/Bushfire CRC.

Blanchi, R., C. Lucas, J. Leonard and K. Finkele (2010). "Meteorological conditions and wildfire-related houseloss in Australia." International Journal of Wildland Fire **19**(7): 914-926.

Boura, J. (2016). Wye River & Separation Creek BAL Assessment Report. Victoria, Terramatrix.

Bushfire_CRC (2009). Victorian 2009 bushfire research response: Final Report, Bushfire CRC.

Caton, S. E., R. S. P. Hakes, D. J. Gorham, A. Zhou and M. J. Gollner (2017). "Review of Pathways for Building Fire Spread in the Wildland Urban Interface Part I: Exposure Conditions." Fire Technology **53**(2): 429-473.

Chen, K. and J. McAneney (2010). Bushfire Penetration into Urban Areas in Australia: A Spatial Analysis. Report for the Bushfire CRC.

Cohen, J. D. (2004). "Relating flame radiation to home ignition using modeling and experimental crown fires." Canadian Journal of Forest Research **34**(8): 1616-1626.

CROMPTON, R. P., K. CHEN, R. A. PIELKE JR and K. HAYNES (2009). "Normalised Australian Bushfire Building Damage and Fatalities."

England, J. P. (2020). Practical Measures to Build Climate and Disaste Resilience at the local, regional and national level – AS3959 and timber construction. Melbourne, FWPA.

England, J. P., V. Chow and G. Zillante (2006). Recent Research and Developments for the performance based design of Buildings in Bushfire Prone Areas. The Future of Fire Safety Engineering. Gold Coast, Engineers Australia Society of Fire Safety.

Gould, J. S., W. McCaw, N. Cheney, P. Ellis, I. Knight and A. Sullivan (2008). Project Vesta: fire in dry eucalypt forest: fuel structure, fuel dynamics and fire behaviour, CSIRO PUBLISHING.

Hakes, R. S. P., S. E. Caton, D. J. Gorham and M. J. Gollner (2017). "A Review of Pathways for Building Fire Spread in the Wildland Urban Interface Part II: Response of Components and Systems and Mitigation Strategies in the United States." Fire Technology **53**(2): 475-515.

Haslam, E. (2016). Further information on Building Classifications. P. England.

Leonard, J., R. Blanchi and R. Leicester (2004). "On the development of a risk-model for bushfire attack on housing."

Leonard, J., K. Opie, R. Blanchi, G. Newnham and M. Holland (2016). Wye River/Separation Creek Post-bushfire building survey findings, CSIRO.
Manzello, S. L. and E. I. Foote (2014). "Characterizing firebrand exposure from wildland–urban interface (WUI) fires: results from the 2007 Angora Fire." Fire Technology **50**(1): 105-124.
McAneney, J. and K. Chen (2005). "The Bushfire Threat in Urban Areas." Australasian Science **26**(1).
Nicoll, R. (2018). Raising hope out of ashes of the Tathra bushfire. ECOS, CSIRO. **Issue 241**.
Price, O. and B. Roberts (2022). "The role of construction standards on building impact of the 2013 Linksview Wildfire, Australia." Fire Safety Journal **128**: 103545.
Price, O. F., J. Whittaker, P. Gibbons and R. Bradstock (2021). "Comprehensive Examination of the Determinants of Damage to Houses in Two Wildfires in Eastern Australia in 2013." Fire **4**(3): 44.
Ramsay, G. C. (1985). "How bushfires set houses alight: lessons from Ash Wednesday." Ecos **no. 43 (Autumn 1985)**.
Ramsay, G. C. and D. Dawkins (1993). Handbook 36 Building in Bushfire Prone Areas -. Information and Advice. Australia, Standards Australia. **HB 36-1993**.
Ramsay, G. C., N. A. McArthur and V. Dowling (1996). Building in a fire-prone environment: Research on building survival in two major bushfires. Proceedings Linnean Society of New South Wales, Linnean Society of New South Wales.
Ramsay, G. C., N. A. McArthur and V. P. Dowling (1987). "Preliminary results from an examination of house survival in the 16 February 1983 bushfires in Australia." Fire and Materials **11**(1): 49-51.
SGS (2019). The growing risk of natural perils-pre-emptive action needed. SGS-Insights.
Smith, T. (2016). Wye River and Separation Creek - Geotechnical, Land Capability and Wastewater Solutions Geotechnical Assessment, Coffey Geotechnics.
Standards_Australia (2009). AS 3959 Construction of Buildings in Bushfire-Prone Areas. Sydney, Standards_Australia. **AS 3959:2009**.
Standards_Australia (2014). AS 1530.4 Methods for fire tests on building materials, components and structures Part 4: Fire-resistance tests for elements of construction. Sydney, Standards Australia. **AS 1530.4:2014**.
Standards_Australia (2018). AS 1530.8.1-2018 Methods for fire tests on building materials, components and structures - Part 8.1 Tests on elements of construction for buildings exposed to simulated bushfire attack - Radiant heat and small flaming sources. Sydney. **AS 1530.8.1-2018**.
Standards_Australia (2018). AS 1530.8.2-2018 Methods for fire tests on building materials, components and structures - Part 8.2: Tests on elements of construction for buildings exposed to simulated bushfire attack—Large flaming sources. Sydney. **AS 1530.8.2-2018**.
Standards_Australia (2018). AS 3959 Construction of Buildings in Bushfire-Prone Areas. Sydney, Standards_Australia. **AS 3959:2018**.
Teague, B., R. McLeod and S. Pascoe (2010). Final report, 2009 Victorian bushfires royal commission, Parliament of Victoria, Melbourne Victoria, Australia.
VBA (2020). Building Audit Program - Class 1a Buildings in Bushfire Prone Areas September-December 2020. Victoria, Victoria Building Authority.