WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

EXPERIMENTAL DETERMINATION OF TIMBER CHAR RATES UNDER SIMULATED FULLY DEVELOPED FIRE EXPOSURE CONDITIONS

Paul England[1], Boris Iskra [2]

ABSTRACT: Char rates of timber exposed to the standard fire-resistance heating regime are well documented. However, char rate data for timber exposed to more severe fire exposures, that better represent fires in modern buildings, is limited. To generate data to address this knowledge gap, standardised test configurations and procedures were developed. Radiata pine specimens were exposed to the standard heating regime, as a benchmark, and more severe heating regimes from which char rates and temperature profiles were obtained. A single char rate could be derived for timber exposed to the standard heating regime. Significantly higher char rates were observed for the more severe heating regimes and three char rates were required to adequately define the charring behaviour with the highest char rate occurring in the first 15 to 20 minutes, reducing to an intermediate level and final steady state rate through the remainder of the test. Sections of the test specimens were also protected with 1- and 2-layers of 16 mm fire-grade plasterboard to obtain indicative char rate data applicable to protected timber elements.

KEYWORDS: timber, charring, fire-resistance, fire exposure

1 – INTRODUCTION

Design methods and supporting data to predict the fire-resistance of timber elements based on char rates, temperature profiles and structural properties of timber at elevated temperatures are provided in standards and codes, including Eurocode 5 EN 1995-1-2 [1] and Australian Standard AS/NZS 1720.4 [2]. The design methods and the available supporting data have focussed on predicting the performance of timber elements exposed to the standard fire-resistance heating regimes prescribed in national and international standards such as AS 1530.4 [3] and ISO 834-1 [4] or the parametric fires defined in Eurocode 5 EN 1991-1-2 [5] but there is limited data available under severe fire exposures that are more representative of the fully developed phase of ventilation-controlled fires in modern buildings.

This paper reports the results of a test program with standardised test configurations, thermocouple arrays and test procedures to determine char rates and temperature profiles under a range of fire exposures in low oxygen environments consistent with the fully developed phase of ventilation-controlled fires.

2 – BACKGROUND

2.1 DESIGN FIRES AND PERFORMANCE CRITERIA

Performance-based fire safety design frequently requires design fire scenarios to be defined. This is generally achieved by breaking down the fire scenario into a series of stages for convenience (e.g., incipient, growth, flashover, fully developed, decay and cooling). From a structural fire safety perspective, the fire safety strategy and specified performance criteria may require the structure to withstand the incipient, growth and flashover phases followed by the entire fully developed phase and subsequent decay and cooling phases without intervention; or simply withstand the design fire for sufficient time to facilitate an intervention and / or satisfy the applicable objectives (e.g., safe evacuation). Prescriptive regulations have tended to rely on fire-resistance tests to grade the performance of structural elements using established standard time-temperature relationships; but when undertaking performance designs, it is necessary to determine the performance of a structure when exposed to more representative fire exposures.

The performance of combustible structural elements such as Cross Laminated Timber (CLT) panels exposed to fire has been demonstrated to be sensitive to oxygen content in addition to heat exposure due to char oxidation and the

[1] Paul England, EFT Consulting, Melbourne, Australia, paul.england@eftconsult.net

[2] Boris Iskra, Forest & Wood Products Australia (FWPA), Melbourne, Australia, boris.iskra@fwpa.com.au

https://doi.org/10.52202/080513-0574

resulting increased char contraction which affects the protection provided by the char layer and may produce additional heat and volatiles if char oxidation occurs Schmid [6]. This is particularly evident in the decay and cooling phases where the proportion of oxygen in an enclosure tends to increase as the fire decays. It is therefore necessary to define the approximate enclosure oxygen content and airflows within fire enclosures in addition to thermal exposure when defining the fire exposure. Fig. 1 illustrates a design enclosure fire scenario, including oxygen content, in addition to enclosure temperatures.

2.2 OVERVIEW OF ENCLOSURE FIRE DYNAMICS WITH EXPOSED COMBUSTIBLE SURFACES

The total fire load in a building or enclosure includes a moveable component and fixed components such as combustible linings and structural materials (e.g. exposed CLT elements of construction or non-combustible structural elements with combustible linings). The total fire load provides an indication of the quantity of heat which could be released by the complete combustion of all the combustible materials.

In many occupancies, the moveable fire load can be considered as a series of fuel packages composed of a broad range of materials having different geometries and material properties. The rate of production of volatiles (i.e., mass burning rate) at elevated temperatures varies considerably between materials and under fire conditions, the surface temperature of fuel packages will increase at different rates due to differing geometries and thermal properties of fuel packages amongst other things causing further variations in the release rate of volatiles.

If the initial fire growth is sufficient, flashover will occur generating a rapid enclosure temperature rise followed by a more stable combustion phase within the enclosure if the fire is ventilation-controlled, provided excess volatiles are not sufficient to substantially reduce the inflow of air. The decay phase may last considerably longer than the fully developed phase particularly if fuel packages are consumed at different rates. For example, a thick timber bookcase may be consumed much slower than a polyurethane foam mattress of similar mass.

Combustible walls and ceilings (or applied combustible linings) exposed to fire conditions add a complication since they will release additional volatiles when exposed to a fully developed fire. The excess volatiles that do not undergo combustion in the enclosure will be expelled through openings; but as the moveable fire load component is consumed a larger proportion of the volatiles from the timber surfaces will undergo combustion within the enclosure, extending the duration of the ventilation-controlled fully developed fire phase.

If a large enough area of combustible elements of construction is exposed, sufficient volatiles may be produced to extend the fully developed phase beyond consumption of the moveable fire load, increasing the probability of structural failure and /or fire spread unless manual or automatic suppression is successful. This mode of failure can be prevented by fully encapsulating combustible elements but often this option is not preferred.

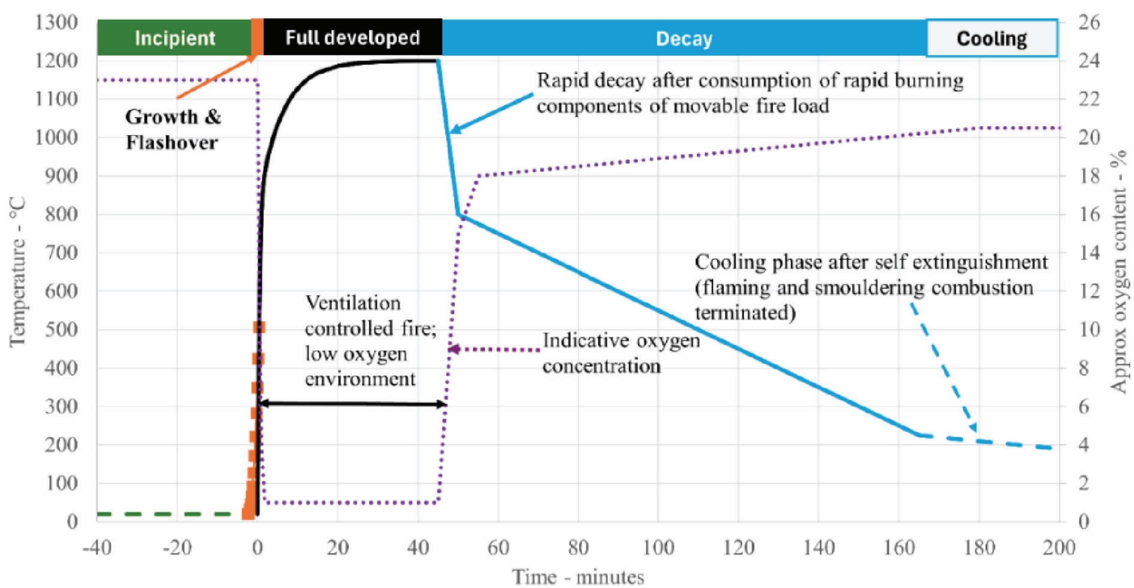


Figure 1. Schematic of a typical design fire exposure incorporating enclosure oxygen content and design fire phases

https://doi.org/10.52202/080513-0574

2.3 STRUCTURAL FIRE SAFETY STRATEGIES

If timber structural elements are exposed, a design strategy for relatively low risk applications, such as some low-rise buildings, may place a greater reliance on a combination of automatic intervention (e.g., an automatic sprinkler system) supplemented by evacuation strategies and timely fire brigade intervention. For higher risk buildings with exposed timber elements, such as high-rise residential buildings, a strategy may require a structure to withstand the fire growth and fully developed fire phases and subsequent decay and cooling phase if automatic suppression systems and other interventions fail. This strategy is sometimes referred to as "burnout resistant".

2.4 CHAR RATE DATA AND ENCAPSULATION DURING THE FULLY DEVELOPED PHASE

Whichever strategy is adopted, it is necessary to determine the following under fire exposure to the fully developed phase:

- the protection provided by applied encapsulation systems if installed,
- the char rate to define a residual timber section,
- the temperature profile across the residual section to predict the residual structural capacity and condition of the element during the fully developed phase,
- the pyrolysis rate which can be used to estimate the extension of the fully developed phase resulting from additional volatiles released from the exposed timber elements and increases flame projections from openings due to excess volatiles.

The parameters described in the first three dot points are the focus of the experimental work reported in this paper. Pyrolysis rates can be derived directly from mass loss measurements or an approximation of the mass loss rate obtained from the char rate.

2.5 CHAR RATE DATA AND ENCAPSULATION DATA DURING THE DECAY AND COOLING PHASES

If the combination of the remaining removeable fire load and exposed surfaces do not release sufficient volatiles to maintain a fully developed fire, the decay phase will begin. As the heat release rate predominantly from flaming combustion reduces within with the enclosure, the fire will revert to a fuel-controlled regime and oxygen concentrations will start to increase.

If it is necessary to determine the structural performance during the decay and cooling phases the following additional information is required:

- the conditions and timing for flaming combustion to cease and the potential for re-ignition to occur.
- the protection provided by applied encapsulation systems if installed,
- the char rate to define a residual timber section,
- the temperature profile across the residual section to predict the residual structural capacity and condition of the element during the decay phase,
- the pyrolysis rates,
- heat release rate from timber elements due to continuing flaming and char oxidation / smouldering combustion to enable conditions in an enclosure fire to be determined,
- the conditions necessary for smouldering combustion to stop and timing of combustion stopping if self-extinction is achieved,
- any increases in temperature of the residual section due to thermal inertia once combustion has stopped.

Flaming combustion is expected to cease once incident heat fluxes drop below nominally 30 to 40 kW/m^2 depending on timber species, oxygen concentrations and air flows [7], provided the char layer is intact. Char oxidation / smouldering combustion is likely to continue for a considerable time increasing the depth of the char interface. If the incident heat flux drops below approximately 5 kW/m^2 the timber may self-extinguish [8] (i.e., smouldering combustion ceases in addition to flaming combustion) and the fire will transition to the cooling phase.

To obtain this data, modifications to standard fire-resistance tests are necessary supplemented by other test methods and sources such as the cone calorimeter and large or intermediate tests to obtain data at the higher oxygen concentrations more representative of the decay and cooling phases. An example of a test method that has been developed specifically to generate appropriate data for a range of fire exposures including those applicable to the decay and cooling phases has been described by Schmid [9].

During the cooling phase, in a similar manner to non-combustible elements, temperatures within the residual section may continue to increase largely due to the element's thermal inertia and in some instances migration of moisture causing further reductions in the loadbearing capacity.

2.6 APPLICABILITY OF FIRE-RESISTANCE TEST FURNACE DATA

The validity of applying furnace test results to timber members has been questioned on the assumption that combustible and non-combustible products are exposed to different thermal exposures when tested in furnaces compared to exposure to natural fires or that massive timber elements increase the fire load and the application of the fire-resistance testing framework is not applicable.

Schmid [10] investigated the above comments and found that:

- the thermal exposure in fire resistance tests of non-combustible materials and combustibles is similar
- the term fire exposure should be used to define the thermal exposure and the oxygen concentration when testing combustible elements to address the potential significant influence oxygen concentrations can have on the behaviour of combustible materials.

It was therefore determined that for the fully developed phase of a ventilation-controlled fire, it is appropriate to use a fire-resistance test furnace to simulate the fire exposure to determine charring rates, temperature profiles and mass loss since low oxygen contents are expected and representative temperatures can be generated.

The standard heating regime specified in AS 1530.4 [3] and ISO 834-1 [4] does not approximate to the rapid growth and high enclosure temperatures that can be generated by fires in many modern building enclosures; with wall and ceiling members or linings having low heat capacities and thermal conductivities. This is illustrated by comparing time-temperature plots of full-scale enclosure fire tests reported by Brandon [11] to the three heating regimes adopted for this study; which shows that the hydrocarbon heating regimes are more representative of the rapid growth and early peak temperatures that can occur in contemporary buildings – refer Fig. 2.

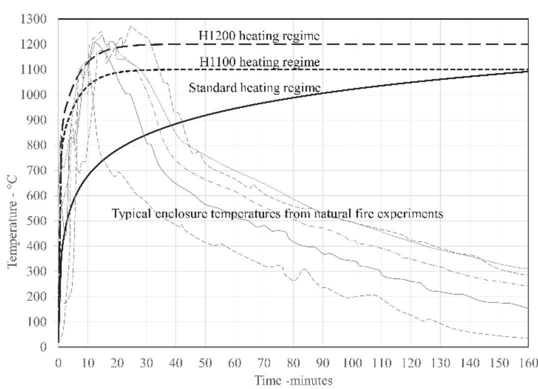


Figure 2. Heating regimes compared to typical temperatures from natural fire experiments

As a fire enters the decay phase, the heat release rate, predominantly from flaming combustion, reduces within the enclosure and a ventilation-controlled fire will tend to revert to a fuel-controlled regime and oxygen concentrations will start to increase. These conditions are not reproduced in standard fire-resistance tests and the data presented in this paper should not be directly applied to the decay phase without consideration of the effects of increased oxygen concentrations. Alternative test methods and equipment as highlighted in Section 2.5 may be more appropriate.

3 – PROJECT DESCRIPTION

The main test program comprised three similar experiments with the only significant variable between the tests being the thermal exposure. The test construction was selected to approximate to one-dimensional exposure conditions whilst facilitating accurate location of thermocouples, with thermocouple cables running along isotherms for at least 50 mm from the measuring junction. A preliminary test was undertaken to determine a suitable and practical form of specimen construction and instrumentation methods prior to undertaking the main program [12].

The three heating regimes comprised the standard fire-resistance heating regime specified in AS 1530.4 [3] and ISO 834-1 [4], a hydrocarbon heating regime specified in Appendix B of AS 1530.4 referred to as H1100 in this paper and a modified hydrocarbon regime (H1200) which is similar to the hydrocarbon heating regime but with the maximum steady state temperature of 1200°C. The three heating regimes are shown in Fig. 2 and are defined by the following relationships.

Standard heating regime: $T = 345\log10(8t + 1) + 20$ (1)

Standard hydrocarbon (H1100)

$$T = 1080\,(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}) + 20 \quad (2)$$

Enhanced hydrocarbon (H1200)

$$T = 1180\,(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}) + 20 \quad (3)$$

where T is the furnace temperature (°C) and (t) is the time from the start of the test (minutes).

A feature of the two hydrocarbon regimes is that after a rapid initial growth period, the heating regimes transition to steady state heating conditions. Four zones were defined (nominally 600 mm x 600 mm) in each specimen to evaluate different configurations as described below:

- Zone 1 was an exposed timber configuration
- Zone 2 was a replicant of the exposed timber configuration
- Zone 3 was additionally protected by 1-layer of 16 mm fire protective grade plasterboard
- Zone 4 was additionally protected by 2-layers of 16 mm thick fire protective grade plasterboard

4 – EXPERIMENTAL SETUP

4.1 GENERAL LAYOUT AND SPECIMEN ASSEMBLY

Each specimen was constructed from 25 softwood joists, 190 mm deep x 45 mm thick, separated by ceramic fibre insulation and screw fixed together after instrumentation, forming test panels nominally 1450 mm x 1550 mm to effectively provide one-dimensional fire exposure for determination of charring rates whilst facilitating accurate location of thermocouples and allowing thermocouple cables to be easily run along isotherms for at least 50 mm.

https://doi.org/10.52202/080513-0574

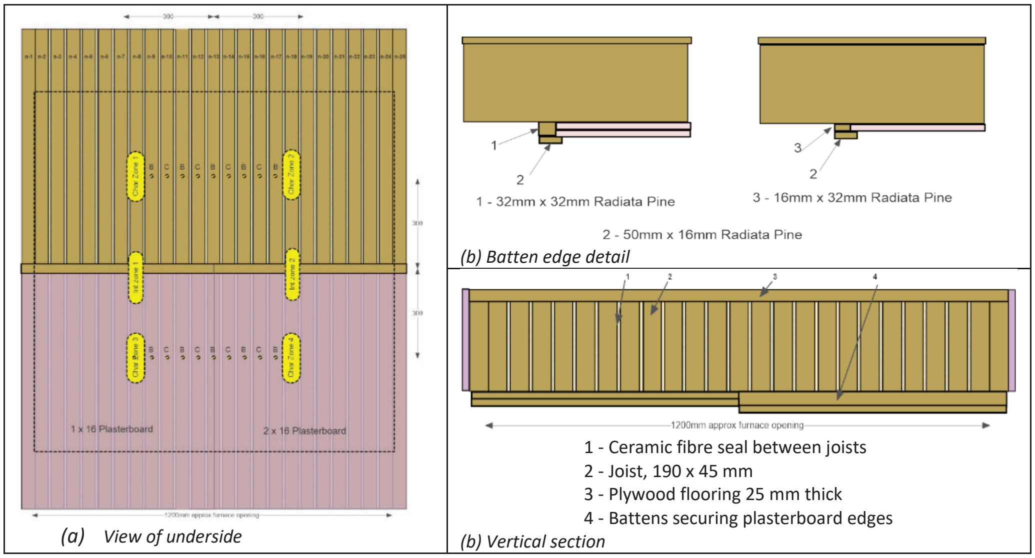


Figure 3. General specimen layout

The instrumented joists were selected such that, as far as practicable, the instrumented areas were free from knots and other imperfections which may impact on the results.

Plywood flooring, 25 mm thick, was fitted over the upper surface of each test panel to eliminate air flow through joints between joists. Four zones each 600 mm x 600 mm were defined on each specimen. Zones 1 and 2 were unprotected and zones 3 and 4 were protected by 1- and 2-layers of 16 mm thick fire-grade (FG) plasterboard respectively. Battens covered the intersection of the plasterboard protected zones with the unprotected zones.

The plasterboard was screw fixed to the joists at 200 mm centres around the perimeter with a minimum edge distance of 38 mm and at maximum 300 mm centres in the field. The edge distances were greater than the distances commonly adopted for plasterboard floor and wall linings and the spacing between fixings was reduced. These features were expected to substantially improve the retention of the boards compared to typical industry practice. The test configuration is shown in Fig. 3 and was similar for all three tests. Fire exposure was from the underside of the specimen.

4.2 MATERIALS

MGP10 untreated Radiata Pine (*Pinus radiata*) was selected as the species for determination of charring rates since it is the most common structural softwood used extensively throughout Australia, New Zealand and some other jurisdictions. The mean and standard deviation of the density and moisture content of the 25 joists used for each of the three specimens are summarised in Table 1 and the values for the individual joists that were instrumented to obtain detailed cross-section temperatures are provided in Table 2.

Untreated radiata pine was also used for battens to protect the edge of the fire grade plasterboard protection. The density range and moisture content of the battens is also provided in Table 1.

Other major components comprised:

- Insulation between joists - Ceramic fibre paper, 6 mm thick, density 179 kg/m^3
- Top surface - F11 plywood flooring, 25 mm thick, approximated density 523 kg/m^3
  Fire protective grade plasterboard, 16 mm thick, density 831 kg/m^3

Table 1 Density and moisture content for joists and battens used to construct specimens

Heating Regime	**Radiata Pine Joists**					**Radiata Pine Battens**	
	Number of Joists	*Density (kg/m^3)*		*Moisture Content (%)*		*Density (kg/m^3)*	*Moisture Content (%)*
		Mean	*St Dev*	*Mean*	*St Dev*		
Standard	25	558.4	37.9	13.4	1.6	500-590	13.4
H1100	25	543.4	39.3	12.3	1.5	500-590	13.4
H1200	25	551.2	44.5	13.1	1.2	474-627	13.2

Table 2 Density and moisture content of joists with fully instrumented cross-sections

Heating Regime	Joist Ref / Zone	Protection Applied to Timber	Density (kg/m^3)	Moisture Content (%)
Standard	2-8 / Z1	None (timber exposed)	555	14.4
	2-18 / Z2	None (timber exposed)	555	11.4
	2-8 / Z3	16mm thick fire grade PB protection	555	14.4
	2-18 / Z3	2 x 16mm thick fire grade PB protection	555	11.4
H1100	3-8 / Z1	None (timber exposed)	546	12.7
	3-18 / Z2	None (timber exposed)	541	13.1
	3-8 / Z3	16mm thick fire grade PB protection	546	12.7
	3-18 / Z3	2 x 16mm thick fire grade PB protection	541	13.1
H1200	4-8 / Z1	None (timber exposed)	552	14.1
	4-18 / Z2	None (timber exposed)	552	11.0
	4-8 / Z3	16mm thick fire grade PB protection	552	14.1
	4-18 / Z3	2 x 16mm thick fire grade PB protection	552	11.0

4.3 EQUIPMENT AND INSTRUMENTATION

Overview

The tests were performed using an intermediate scale LPG furnace at the Jensen Hughes NATA accredited laboratory in Australia (formerly Warringtonfire Australia). An area 1.2 m x 1.2 m of the underside of the specimen was subjected to the heating conditions. At the end of the heating period, each specimen was raised 200 – 400 mm above the furnace to expose the underside of the specimen to the laboratory atmosphere with some residual heating from the furnace before extinguishing the specimen and removing charred material.

Monitoring furnace exposure

The furnace temperature was monitored by four mineral insulated metal sheathed (MIMS) Type K thermocouples with wire diameters not greater than 1 mm, an overall diameter of 3 mm, and the measuring junction insulated from the sheath as prescribed by AS 1530.4:2014 [3]. In addition, two plate thermometers with 100 mm x 100 mm x 0.7 mm thick plates were included in the furnace. These were manufactured to comply with ISO 834-1 [4] and EN 1363-1 [13].

The internal furnace pressure was monitored 100 mm below the soffit of the specimen underside.

The furnace gas flow was measured with a gas flow meter and air flow was estimated based on previous correlations. The oxygen content was measured manually with a combustion meter using a collection probe 100 mm below the specimen underside.

Char zone temperatures

At the centre of each quarter section of the specimen, a char array of thermocouples was provided to monitor the progression of the char front during the test. The arrays were based on AS/NZS 1720.4 [2] requirements with thermocouples at 10 mm vertical centres but with additional thermocouples to measure approximate time of commencement of charring / ignition on the soffit of the joist, and temperature measurements 5 mm, 150 mm and 190 mm above the soffit for additional information as shown in Fig. 4(a). The thermocouple Type B configuration as shown in Fig. 4(c) was adopted having junctions at the mid-width of the section (inserted 22.5 mm) and run through horizontal holes to the side surface and are then run along the timber face along the expected isotherm for a minimum of 27.5 mm to ensure the thermocouple followed the expected isotherm for at least 50 mm. The thermocouples are spaced at nominally 20 mm centres along the length of the timber member with the side of entry generally alternating.

Interface zones

Temperatures were also measured at the interface between exposed timber zones and plasterboard protected zones to identify char and temperature profiles at transitions between protected and unprotected areas. Temperatures were measured at positions shown in Fig. 3 and Fig. 4(c).

Type B and Type C thermocouple comparisons

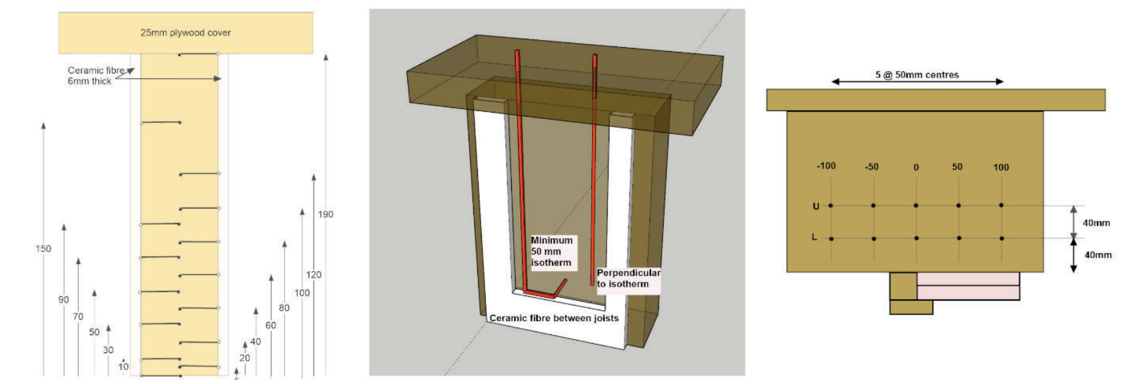
Temperatures of infill joists between the char zones were measured at depths of 40 mm and 80 mm above the timber joist soffit to provide supplementary data regarding potential variability of results. The approximate measurement positions are shown in Fig. 3(a) with B indicating configuration B cable runs and C indicating configuration C runs were used.

Unexposed face / encapsulation temperature data

The upper surface of the flooring was measured using fibreglass insulated and sheathed type K thermocouples with wire diameters less than 0.5 mm soldered to 12 mm x 0.2 mm thick copper discs covered with 30 mm x 30 mm x 2.0 mm thick inorganic insulating pads in accordance with AS 1530.4 requirements

Additional temperature measurements were taken at the interface of the plasterboard sheets and timber joists using fibreglass insulated and sheathed type K thermocouples with wire diameters less than 0.5 mm soldered to 12 mm x 0.2 mm thick copper discs for comparison against temperatures measured using a sandwiched MIMS cable.

https://doi.org/10.52202/080513-0574



a) Joist temperature measurement positions for char zones (thermocouple fitted in Type B configuration)	b) Thermocouple configuration: Type B cables run along isotherm for a minimum of 50 mm Type C cables perpendicular to isotherm	c) Timber measurement positions for interface zones (thermocouples fitted in Type B configuration)

Note: MIMS Type K thermocouples with wire diameters not greater than 0.5 mm and an overall diameter of the sheath of 1.5 mm with the measuring junction insulated from the sheath were fitted using configuration B (thermocouple wires running at least 50 mm from junction along the expected isotherm except were comparisons between configuration B and C are being obtained).

Figure 4. Thermocouple configurations for measuring internal temperatures of timber joists.

4.4 TEST METHODS

Three similar specimens were prepared and exposed to different time-temperature heating regimes with the tests continuing until the char depths had exceeded approximately 95 mm.

5 – RESULTS

The estimated timber char rates and protection provided by the plasterboard are summarised in Table 3 when exposed to the standard, H1100 and H1200 heating regimes. The furnace oxygen content measured 100 mm below the soffit of the specimen during all three tests was below 4% which is representative of a ventilation-controlled regime.

The char rates were determined by plotting the char depth against exposure time, using linear regression to determine the line of best fit and calculating its gradient or calculating the average char rate where data was limited for the protected specimens. For the standard heating regime, a single value could be derived for the whole test period with the equation forced to pass through the origin (Fig. 5a), but for the hydrocarbon regimes there were discontinuities to the char rate yielding an initial rapid growth phase, intermediate phase and steady state phase (Fig. 5b).

Relationships for temperature profiles within the residual timber sections have been proposed by Janssens [14] and Frangi [15] based on data from other species exposed to the standard heating regime. Janssens estimates were based on a model for a semi-infinite solid assuming penetration depth of 32 to 35 mm and was validated using 63mm thick specimens with char depths of approximately 13mm. Frangi validated results against timber elements constructed from Norway spruce *(Picea abies)* including timber panels 140 mm thick and test durations from 30 to 110 minutes which varied with the char depth (or test duration).

To compare specimen internal temperature profiles when exposed to the different heating regimes, temperatures were plotted against the distance from the 300°C isotherm (assumed char interface) for char depths of 30 mm, 50 mm, 70 mm and 90 mm from the initial heated face. Refer Fig. 6. It can be observed that on the uncharred side of the isotherm (temperatures below 300°C), the temperature profiles are similar for all the heating regimes at the same char depth, implying that within the range of evaluated fire exposures, differences in externally imposed heat impact the char rate (speed of progression of the 300°C isotherm) but the heat flow relative to the 300°C isotherm is similar. This is potentially a significant finding since if the char depth and heat contours below 300°C in the residual timber section are similar, the residual loadbearing capacity of a structural member is also likely to be similar. Thus, char depth can be used as a determinant of an equivalent fire resistance in a similar manner to mean cross-section temperature being used for structural steel under one dimensional heating configurations - see Fig. 8

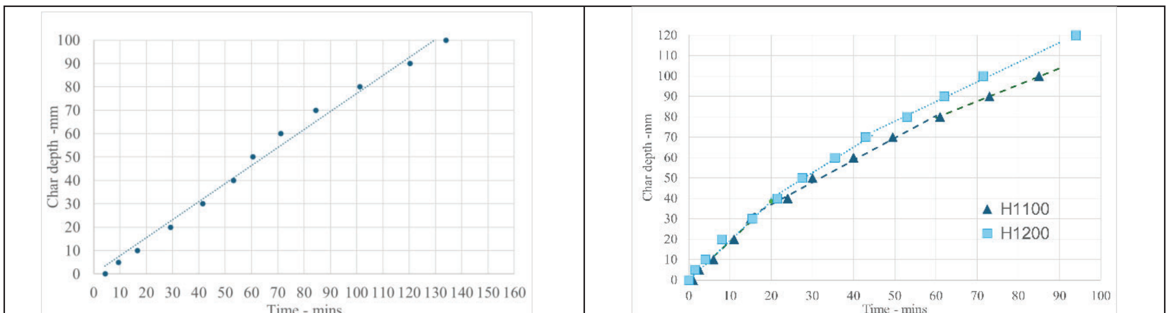
It is also noteworthy that for char depths between 30 mm and 90 mm the profiles varied significantly from estimates based on the methods of Janssens and Frangi, with the temperature dropping from approximately 300°C to 100°C, over a distance of 10 mm but there was some variation in the temperature profile below 100°C for different char depths which was more consistent with predictions using the Frangi method.

The temperature variations were investigated further by using data obtained from the H1100 heating regime which are shown in Fig. 7 and confirm that there is a trend for temperatures to reduce more rapidly if the char depth is lower. Contours could be defined in a similar manner to mechanical properties in Eurocode 5 using linear relationships with a discontinuity at 100°C and different profiles below 100°C can be included to address variations in char depth. An indicative approach is shown in Fig. 7.

Table 3 Protection provided by plasterboard and timber char rates under different heating regimes

Heating regime	**Plasterboard performance (minutes) (L1 / L2)**[1]			**Char rates (mm/minute)**					
				Protected Zones 3 and 4 (L1 / L2)[1]			**Exposed timber – Zones 1 & 2**		
	RISF[2] *250°C*	*MIMS*[3] *300°C*	*Board fall-off L1 / L2*	*Protected*	*After fall-off*	*After char layer fully developed*	*Initial*	*Inter-mediate*	*Steady state*
Standard	33 / 96	39 / 105	121 / 140	0.4 / 0.27[5]	1.35 / 1.47	-	0.77		
H1100	18 / 48	25 / 53	49 / 69	0.71 / 0.76	1.47 / 1.53	1.13 / 0.94	1.90	1.09	0.81
H1200	15 / 31	19 / 33	22 / 30	- / -[4]	1.51[4] / 1.5[4]	1.13 / 1.04	1.92	1.26	0.96

Notes: 1. Results expressed in the L1 / L2 format refer to the areas protected by 1- and 2-layers of plasterboard respectively.
2. RISF - Resistance to the Incipient Spread of Fire, is the time for an interface temperature, measured by a thermocouple soldered to a copper disc, to exceed 250°C and is used to determine the encapsulation time for protected lightweight timber construction.
3. Time to exceed 300°C at the interface with timber measured with Mineral Insulated Metal Sheathed (MIMS) thermocouple.
4. Board fall off time approximates to commencement of charring at interface. Char rates for 7 mins after board fall off were 2.2 mm/min (L1) and 2.7 mm/minute (L2) before attaining a value of approximately 1.5 mm/minute.
5. Char depth 10 mm.



a) Standard heating regime
b) H1100 and 1200 heating regimes

Figure 5. Char interface depth v time for radiata pine exposed to the standard, H1100 and H1200 heating regimes

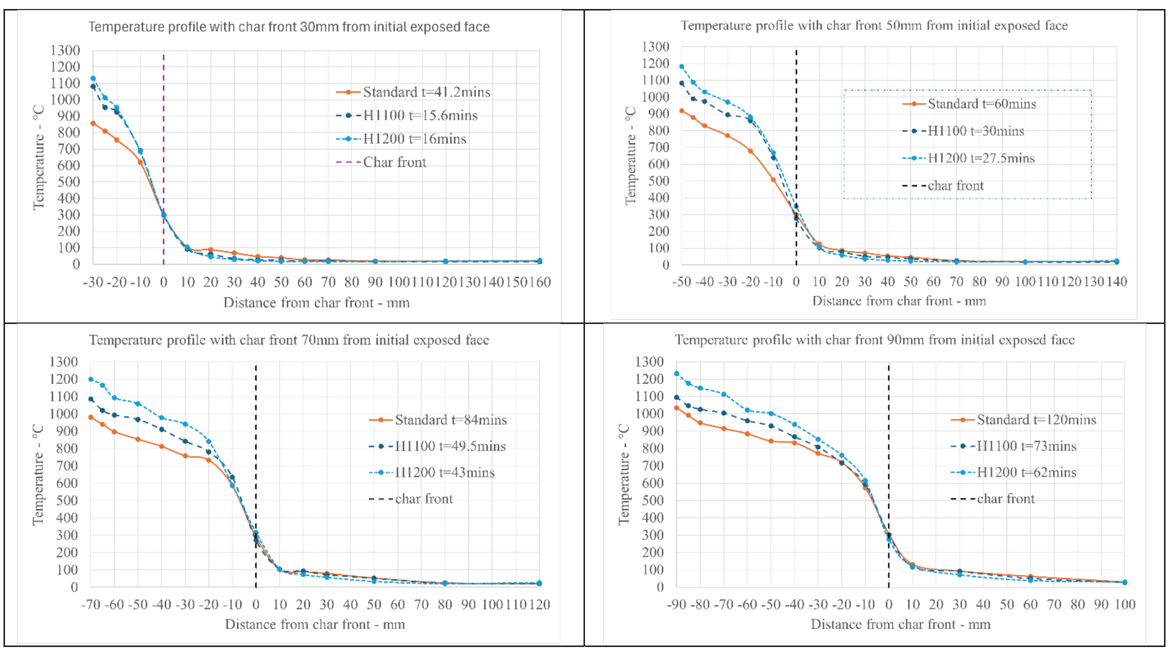


Figure 6. Temperature profiles based on distance from the char front (300°C isotherm) for varying char thicknesses

https://doi.org/10.52202/080513-0574

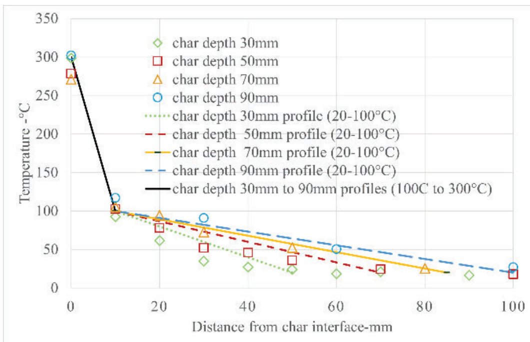


Figure 7 Indicative timber temperature profiles - H1100 regime

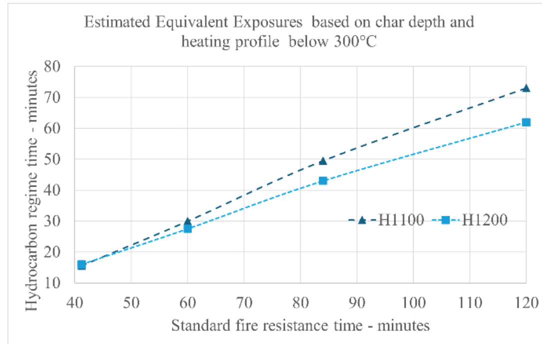


Figure 8 Equivalent fire exposures based on char depth and temperature profiles

6 – CONCLUSIONS

The experiments described in this paper were undertaken to determine char rates and associated temperature profiles for radiata pine under a range of fire exposure conditions relevant to fully developed ventilation-controlled enclosure fires in modern buildings.

A practical method to determine one-dimension charring rates using a configuration incorporating ceramic fibre interlayers and laminated timber elements was developed which includes four zones. Two zones were used for determination of char rates from unprotected timber and two zones for the determination of charring rates for protected timber elements. Preliminary comparative testing was undertaken to provide confidence in the methods and results and identify variations between different thermocouple configurations. The procedures and configurations developed can be used to provide standardised procedures for evaluation of other species and different heating regimes.

Char rate data and temperature profiles for Australian grown radiata pine with no protection and protected by 1- or 2-layers of 16mm fire protective grade plasterboard exposed to different heating regimes, were generated successfully providing useful information for fire safety engineers and researchers to validate models.

As expected, the hydrocarbon heating regimes produced higher charring rates and earlier deterioration of protection systems. Whilst the enhanced fixing configuration for the plasterboard protection systems significantly improved board retention under standard fire exposure conditions, the higher temperatures from the H1100 and H1200 heating regimes substantially reduced the retention time. Further investigation on a larger scale, particularly under the H1200 regime, could provide further insights

A single char rate was derived for exposed radiata pine subjected to the standard heating regime but varying char rates with a greater magnitude were observed for the more severe heating regimes with a tri-linear relationship being required to adequately define the charring behaviour.

Analysis of the temperature profiles identified that similar profiles were obtained for all heating regimes provided the char depth was the same. Char depths from 30 mm to 90 mm were considered, covering common fire resistance periods specified for structural members in prescriptive Australian regulations. This is a significant finding in that the structural capacity of timber elements is likely to be similar if the char depth is the same irrespective of the heating regimes the members have been subjected to within the range of fire exposures considered. Equivalent fire exposures can be determined from Fig. 8 based on equivalent char depths and temperature profiles. Further work to potentially increase the field of application beyond the fire exposures considered in this study would be beneficial.

An example of simplified temperature profiles was derived which assumes bi-linear relationships with a discontinuity at 100°C as shown in Fig. 7 which is compatible with Eurocode 5 approach to mechanical property reduction factors.

7 – REFERENCES

[1] CEN, EN 1995-1-2:2004. Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design. CEN, 2004. 2004, CEN: Europe.

[2] Standards_Australia, AS/NZS 1720.4 Timber structures - Fire resistance of timber elements. 2019, Standards Australia: Sydney.

[3] Standards_Australia, AS 1530.4 Methods for fire tests on building materials, components and structures Part 4: Fire-resistance tests for elements of construction. 2014, Standards Australia: Sydney.

[4] ISO, ISO 834-1 Fire Resistance tests - Elements of Building Construction- Part 1 General Requirements Including Ammendment 1 2012. 1999, ISO: Switzerland.

[5] British_Standards_Institution, Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire. 2002.

[6] Schmid, J., et al., "Timber under real fire conditions–the influence of oxygen content and gas velocity on the charring behavior". In: World Conference on Timber Engineering. 2016: Vienna.

[7] Cuevas, J., J.L. Torero, and C. Maluk, "Flame extinction and burning behaviour of timber under varied oxygen concentrations". In: Fire Safety Journal, 2021. 120: p. 103087.

[8] Crielaard, R., et al., "Self-extinguishment of cross-laminated timber". In: Fire Safety Journal, 2019. 105: p. 244-260.

[9] Schmid, J., A. Totaro, and A. Frangi. "The behaviour of timber in the decay phase-Charring rates, char recession, heat release and glowing combustion under various exposure levels and gas velocities". In: Proceedings of the 11th International Conference on Structures in Fire (SiF2020). 2020. University of Queensland.

[10] Schmid, J., et al. "The use of furnace tests to describe real fires of timber structures". In: Proceedings of 10th International Conference on Structures in Fire. 2018. Ulster University.

[11] Brandon, D., et al., "Final Project Report Fire Safe implementation of visible mass timber in tall buildings – compartment fire testing". 2021, RISE Research Institutes of Sweden AB: Sweden.

[12] England, P. and B. Iskra. "Determination of Notional Char Rates for Protected and Unprotected Timber When Subjected to Variations in Heating Regimes, Test Duration and Thermocouple Configurations". In: International Scientific Conference on Woods & Fire Safety. 2024. Springer.

[13] CEN, EN1363-1:2020; Fire resistance tests—Part 1: General requirements. 2020: Brussels.

[14] Janssens, M.L. and R.H. White, "Temperature profiles in wood members exposed to fire". In: Fire and Materials, 1994. 18(4): p. 263-265.

[15] Frangi, A. and M. Fontana, "Charring rates and temperature profiles of wood sections". In: Fire and Materials V 27, 2003(2): p. 91-102.

https://doi.org/10.52202/080513-0574