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

COMPARING IN-DEPTH TEMPERATURE MEASUREMENT TECHNIQUES IN LARGE-SCALE TIMBER FIRE EXPERIMENTS

Ian Pope[1], Felix Wiesner[2], José Torero[3], Juan Hidalgo[4]

ABSTRACT: Large-scale timber fire experiments commonly utilize solid-phase thermocouples inserted from the 'back' of the timber elements, perpendicular to the heated surface, to estimate charring rates and characterise the heat transfer through the section. This thermocouple orientation can induce significant measurement errors, but it is often chosen due to the difficulty of inserting thermocouples from the 'side' in large panels. This paper investigates an alternative method of inserting thermocouples parallel to the heated surface in instrumented timber cylinders, which can be inserted into larger panels. This method was applied in a large-scale timber compartment fire experiment and compared with measurements from thermocouples inserted from the back. Thermocouples inserted from the back initially underpredicted the charring rate and in-depth temperature rise, but this error decreased over time. By minimising the thermal disturbance error, the instrumented cylinders provide more accurate temperature measurements during the early heating phase, but over time, they can induce other errors unless they are specifically designed to avoid this.

KEYWORDS: timber, thermocouple, compartment fire, temperature, charring

1 – INTRODUCTION

Temperature measurement is an integral part of many fire experiments and standard tests. Solid-phase, gas-phase and surface temperature measurements are all important components in characterising the thermal environment and response of specimens under investigation, and each comes with its own unique challenges. In-depth temperature measurements are extremely useful to quantify the thermal and thermo-mechanical performance of solid materials during fire exposure from bench-scale to large-scale experiments. As such, these measurements are essential in evaluating the fire performance of timber building elements.

Solid-phase temperature measurements in large-scale experiments suffer particular limitations due to the inherently challenging geometries. Nonetheless, these experiments are fundamentally important in the characterisation of fire dynamics [1–4], and a key part of this is the measurement of in-depth temperatures to characterise the solid-phase heat transfer [2–7].

For engineered timber materials, temperature measurements may also be used to indicate char fall-off or delamination of glued layers at elevated temperatures, and to estimate the charring rate and heat transfer through the section. For example, Emberley *et al.* [8] and Wiesner *et al.* [4] used in-depth temperature measurements to establish the energy balance at the charring front in timber samples. Large-scale experiments are an essential part of investigating these phenomena, because of the close interactions and inter-dependencies between these behaviours and the overall compartment fire dynamics [3–6]. Furthermore, the influence of gravity and mechanical stresses on char fall-off, combined with the stochastic nature of this phenomenon, necessitate the evaluation of larger geometries in configurations that represent real construction.

This paper is based on the work of a PhD thesis on solid-phase temperature measurement [9], with a particular focus on the effects of different measurement techniques when applied to large-scale fire experiments on cross-laminated timber (CLT). This study examines the temperatures measured by thermocouples following each technique, with additional comparison to the actual observed char depths, and provides recommendations for improving the accuracy of these measurements.

[1] Ian Pope, Advanced Fire Engineering (Buildings), DBI – The Danish Institute of Fire and Security Technology, Copenhagen, Denmark, ipo@dbigroup.dk, ORCID: https://orcid.org/0000-0002-3130-6868

[2] Felix Wiesner, Department of Wood Science, The University of British Columbia, Vancouver, Canada, ORCID: https://orcid.org/0000-0002-0231-4244

[3] José Torero, Department of Civil, Environmental and Geomatic Engineering, University College London, London, United Kingdom, ORCID: https://orcid.org/0000-0001-6265-9327

[4] Juan Hidalgo, School of Civil Engineering, The University of Queensland, Brisbane, Australia, ORCID: https://orcid.org/0000-0002-2972-5238

https://doi.org/10.52202/080513-0036

2 – BACKGROUND

Due to practical constraints, large-scale fire experiments commonly include thermocouples (TCs) inserted from the 'back' (unexposed side) of the construction materials [2,6,7,10–12], perpendicular to the heated surface. In general, this involves drilling a hole into the sample from the back face – when it would be too far to drill from the side – and inserting each thermocouple to the depth at which the measurement is desired. Without correction, this technique will result in a thermal disturbance when the conductivity of the sample is lower than that of the thermocouple, distorting the temperature measurement [13–15]. The magnitude of this error depends on the specific material properties, geometries and thermocouple characteristics [13,15]. For timber and laminated bamboo specimens, this error has been found to result in significant underestimation of temperatures and associated char depth estimates in the material during heating [14,16,17]. However, even with a large error, these measurements can be useful in identifying certain phenomena that result in large or rapid temperature changes, such as local ignition or extinguishment, char fall-off, and failure of protective layers. Nevertheless, techniques to correct or avoid these errors are highly valuable in improving the absolute temperature observations and analysis derived from them.

3 – PROJECT DESCRIPTION

As part of ongoing studies on fire dynamics and self-extinction in mass timber compartments [4,5], a large-scale fire experiment was conducted with an additional goal of evaluating new temperature measurement and correction techniques. The compartment was constructed from CLT panels, with timber surfaces on two lateral walls and the ceiling exposed. In-depth temperatures through the CLT panels were measured on each of the exposed surfaces by thermocouples inserted from the back – to determine the charring rates, thermal gradients, and char fall-off times.

Additionally, a new method for measuring temperatures in large panels was developed, wherein a cylindrical core was taken from the CLT panel and instrumented with thermocouples inserted from the side – around the circumference of the cylinder – at different distances from the heated surface. This is an extension of the approach used by Lange *et al.* [18] to instrument a brick in the wall of a furnace with thermocouples running parallel to the heated surface. This measurement technique avoids the large thermal disturbance errors induced by thermocouples inserted perpendicular to the heated surface, by ensuring that a significant length of the thermocouple wire near the tip runs along the same isothermal plane. These instrumented cylinders are similar to the samples used by Grønli in his bench-scale experiments [19], and the plug-type sensors used by Dow [20] and Brewer [21]. Maluk [22] also used similar cylindrical samples to measure the temperature profiles in different materials, which were embedded in insulation boards to ensure one-sided heating in standard furnace tests and equivalent radiant exposures.

Rather than taking cores directly from the CLT compartment panels, cylindrical samples were machined from a spare supply of CLT from the same manufacturer, with identical specifications. This approach allowed greater control over the sample quality and dimensions. These cylinders were then instrumented with thermocouples and placed into holes bored through the compartment panels.

4 – EXPERIMENTAL SETUP

4.1 COMPARTMENT DESCRIPTION

The internal dimensions of the CLT compartment were 3.15 × 3.15 × 2.70 m, with a single opening being a door 0.85 m wide and 2.10 m high. The CLT panels that formed the walls and ceiling were 125 mm thick radiata pine, comprising three layers of 45-35-45 mm bonded with Purbond HBS polyurethane adhesive. Two lateral walls ('B' and 'D') as well as the ceiling ('E') were exposed, while the back wall ('C') and the front wall ('A' – incorporating the door) were both protected with two layers of 13 mm thick fire-rated plasterboard. The mean moisture content (MC) of the CLT panels ranged between 10-14 %, based on drying small samples in an oven at 103 °C [23]. A spare CLT cylinder that was not used in the experiment was also oven-dried, revealing a moisture content of 10.3 %.

A 1.0 × 1.0 m continuously fed kerosene pool in the centre of the compartment provided the moveable fuel load of approximately 3000 MJ. Flashover occurred 70 seconds after ignition of the pool fire. This was defined as the instant at which the temperature of the smoke layer exceeded 600 °C, based on the average of seven gas-phase thermocouples distributed around the compartment at 0.34 m below the ceiling. Due to sustained flaming on the exposed CLT surfaces, the compartment continued to burn for 41 minutes after ignition, until it was manually extinguished. Further details of the compartment setup are provided by Xu *et al.* [5].

4.2 INSTRUMENTATION

In the centre of each exposed CLT panel, eight thermocouples were inserted from the back (unexposed) side of the panel to distances of 5, 10, 20, 30, 45, 60, 80 and 100 mm from the internal heated surface. In this way, thermocouples were located at each of the two glue lines, and with a distribution that would allow interpolation of temperature profiles throughout the experiment.

Mineral-insulated metal-sheathed thermocouples of type K were used, with outer diameters of 1.5 mm. A CNC router with a stepped drill-bit was used to drill all the thermocouple holes, with a diameter of 2 mm for most of the length except for the final 8 mm closest to the tip,

https://doi.org/10.52202/080513-0036

which had a diameter of 1.5 mm. This allowed easy insertion of the thermocouples while still providing a tight fit near the tip.

As shown in Fig. 1(a), the thermocouples inserted from the back of the CLT were arranged in a circular cluster to balance the competing desires to measure temperatures from close to the same location and to avoid any thermal interactions between them. This follows the approach of Wiesner *et al.* [24,25] to ensure a tight arrangement of measurement points while maintaining a minimum separation distance between each point. This minimum distance was set at 30 mm, based on the recommendation of Reszka [26].

Instrumented CLT cylinders were inserted near the centre of each exposed panel, 200 mm (centre-to-centre) from corresponding clusters of thermocouples inserted from the back of the panel. This spacing was chosen to avoid any influence of the cylinder and surrounding insulation on the heat transfer and char fall-off near the cluster. Two cylinders ('ES1' and 'ES2') were located on either side of the central TC cluster on the ceiling, while one was positioned near the centre of each of wall B ('BS') and wall D ('DS'). Schematics of the compartment are shown in Fig. 1 (b)-(e), including the locations of clusters of TCs inserted from the back of the CLT panels, and the instrumented cylinders. An overall view of the inside of the compartment is given in Fig. 1 (a).

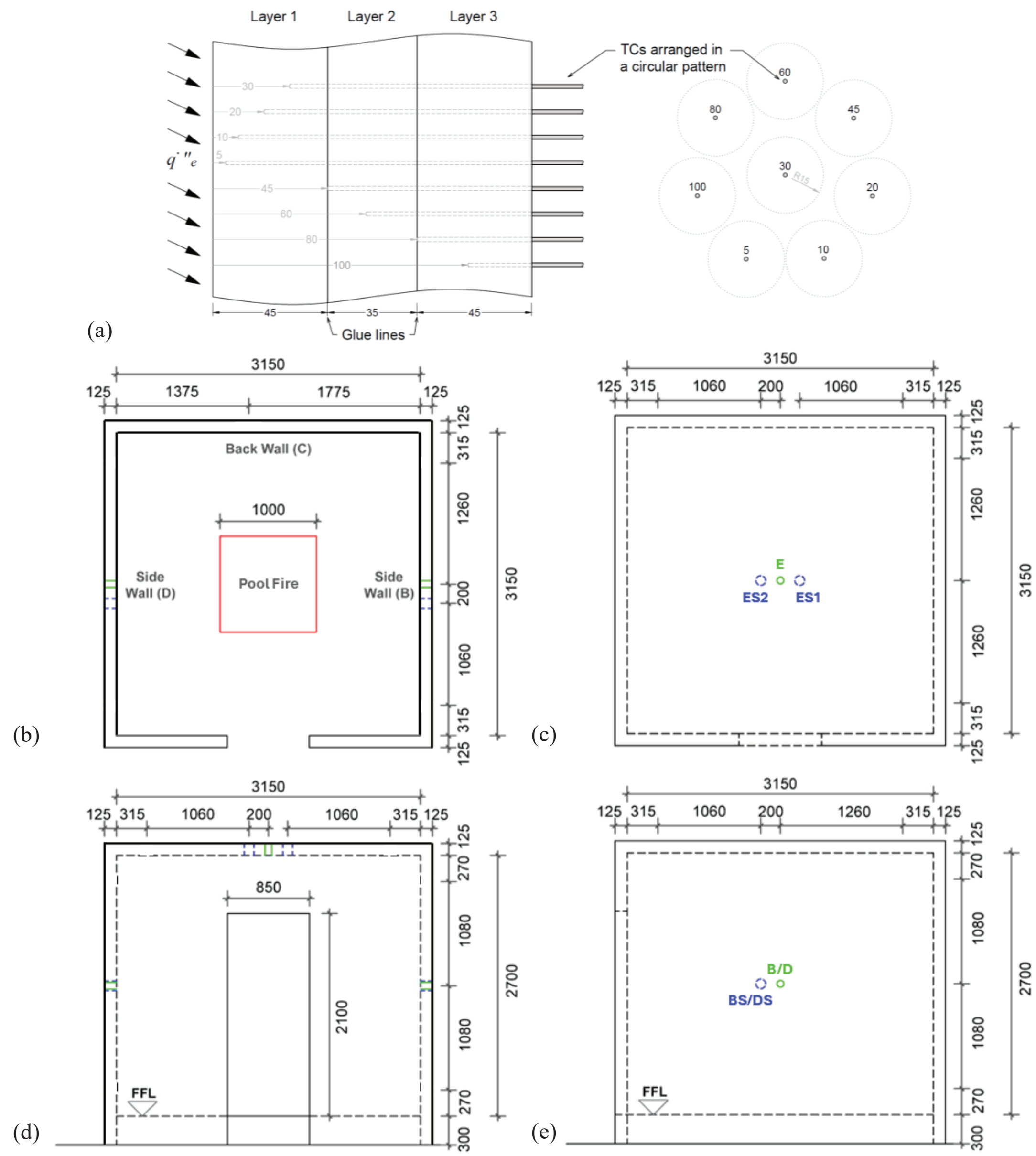

Figure 1. (a) arrangement of TC clusters inserted from the back, (b) plan view of compartment layout, (c) plan view of ceiling E, (d) front view, and (e) elevation of compartment side walls B/D, with TC clusters (green/solid) and instrumented cylinders (blue/dashed) indicated.

https://doi.org/10.52202/080513-0036

Fig. 2(c) is a diagram of the CLT cylinders, showing the placement of thermocouples from the side of the sample at each depth. The cylinders were 100 mm in diameter, allowing the thermocouples to be inserted 50 mm in from the side, parallel to the heated surface, with their tips at the centreline of the sample. This sample size was chosen to ensure a significant length of the thermocouple wire could run along the same isothermal plane as the tip, while also minimising the influence of boundary effects on the measurements at the centreline of the sample. Where the thermocouple wires exited the CLT, they were bent back along the sample so that they would extend out from the unexposed rear face of the panel. As shown in Fig. 2(b), the cylinders and thermocouples were wrapped in insulating ceramic paper and aluminium tape to protect the thermocouples from direct exposure, and to fill the gap between the cylinder and the surrounding panel. Finally, the gap around the cylinder on the internal side was covered with fire cement, and on the external side it was sealed with high temperature resistant silicone.

After the experiment, the CLT panels and cylinders were cut into sections, so that the final char layer depths in each could be measured.

5 – RESULTS AND DISCUSSION

As reported by Pope *et al.* [27,28], the gas temperatures in the compartment grew rapidly following ignition of the kerosene pool. As shown in Fig. 3, the compartment temperatures reached a steady state with a median between 1100-1200 °C, until most of the kerosene fuel was exhausted around 17 minutes after flashover. After this, gas temperatures gradually decreased for another 10 minutes, at which point char fall-off began to occur over a large area of the exposed timber surfaces. This led to another increase in the CLT burning rate and associated compartment temperatures, until the fire was manually extinguished 39.5 minutes after flashover (40.7 minutes after ignition).

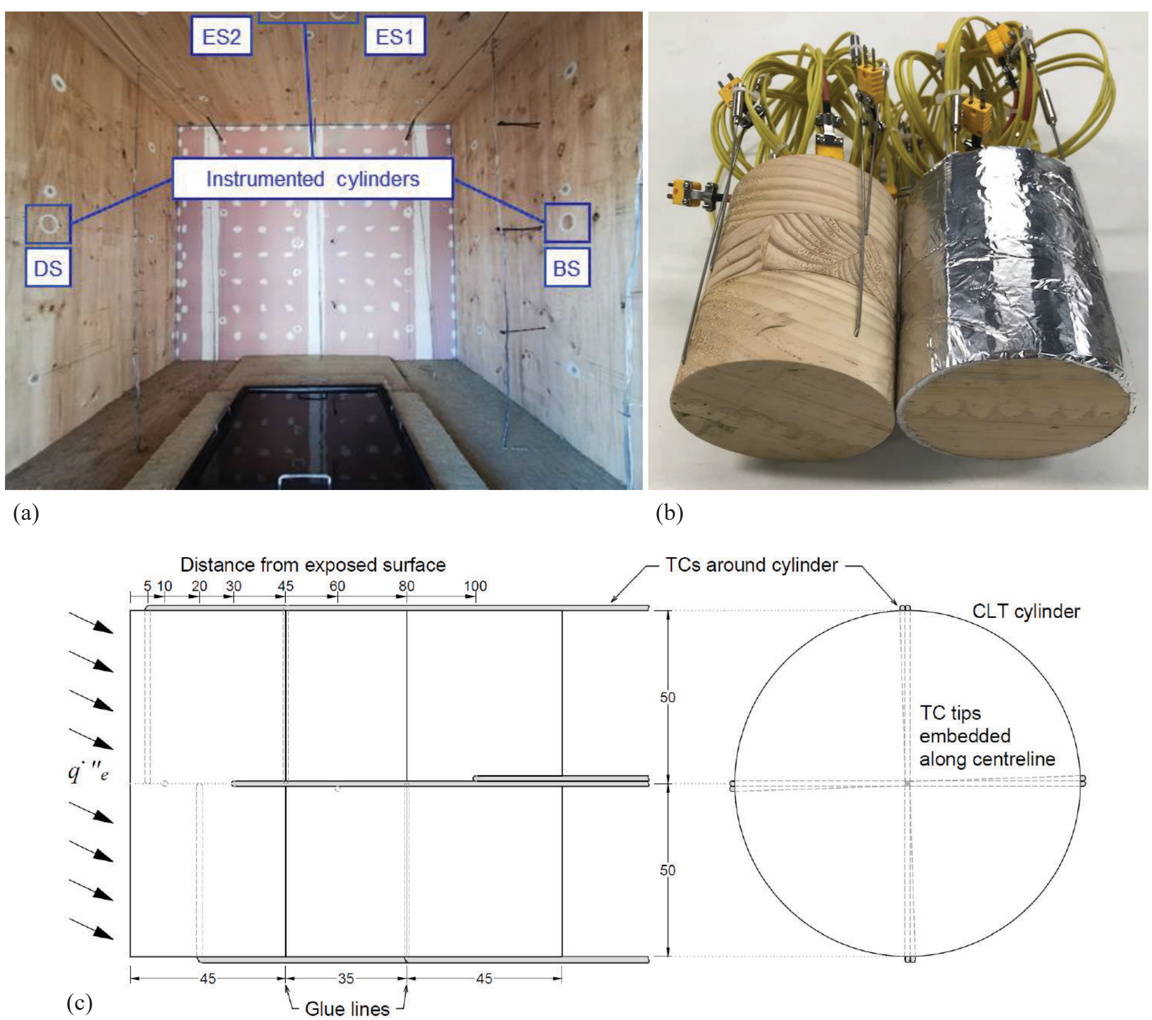

Figure 2. (a) internal view of compartment with instrumented cylinders indicated, (b) instrumented CLT cylinders with and without a covering of ceramic paper insulation and aluminium tape, and (c) diagram of an instrumented CLT cylinder.

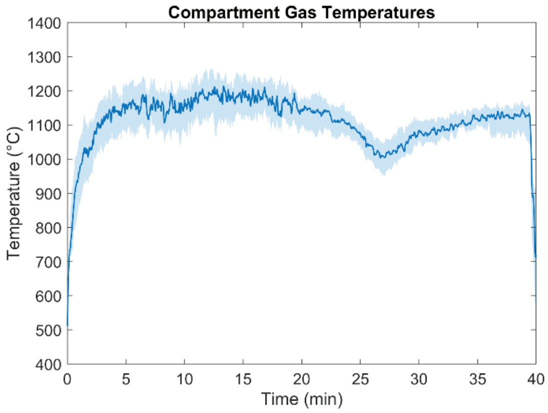

Figure 3. Median gas temperatures in the compartment, bounded by the 25th and 75th percentile temperatures (shaded), from [27].

5.1 IN-DEPTH TEMPERATURES

In-depth temperature measurements from the centre of each exposed CLT panel (wall B, wall D, and ceiling E) are shown in Fig. 4(a), (c), and (e), with the corresponding measurements from the instrumented cylinders. As expected, there is a clear impact of the thermal disturbance error on the results, but there are further differences in the measurements that point to the influence of each instrumentation method:

(1) At each depth, the initial temperature rise, up to 100 °C, is more rapid for the side-inserted thermocouples, which would be expected due to the lower temperature disturbance error of these measurements. However, the time at which temperatures begin to rise for each depth in the CLT cylinders also appears to be earlier, particularly at greater depths. This would not seem to be explained by the same temperature disturbance phenomenon, since this should not change the time at which the thermal wave reaches each depth.

(2) The moisture evaporation plateau at 100 °C is far more pronounced for the side-inserted thermocouples and lasts for much longer. In many cases there is no significant plateau for the thermocouples inserted from the back, even though the moisture contents of the CLT panels and cylinders were very similar (the MC of the cylinders was at the lower end of the range for the panels). Consequently, the impact of the temperature disturbance error above 100 °C was not apparent in some cases, as the faster initial temperature rise of the side-inserted thermocouples was counteracted by the longer moisture plateau.

It is not clear what is causing the differences in times at which the temperature rise is first measured, or the different sizes of the moisture plateaus for each thermocouple orientation. It may be that edge effects around the cylinders are accelerating the heat diffusion to each depth, and the orientations of the thermocouple holes may be creating different pathways for moisture to travel and/or accumulate along. Without more information, it is impossible to say which measurements are 'more correct' at each depth and time, or whether one technique is inducing additional errors.

(3) After 25-30 minutes, pieces of char from the outer lamella (45 mm thick) began to fall off in many locations. This can be seen in the inflection and rapid increase in temperatures measured by thermocouples inserted from the back at this moment, as the insulation provided by the char layer is lost and the rate of heat transfer to the residual section is accelerated. For the CLT cylinders, this char fall-off is inhibited by both the layer of ceramic paper wrapped around the circumference and the side-inserted thermocouples holding the char in place. Beyond this time, the heat transfer conditions for the cylinders and the rest of the CLT panel are no longer comparable.

(4) Thermocouples inserted from the back of the panel may also prevent or delay char fall-off locally, particularly when they are oriented horizontally (on the walls). Post-fire images of thermocouples of both orientations holding pieces of char in place can be found in Fig. 6(a)-(d).

(5) Due to shrinkage of the charring wood, the rear-inserted thermocouples eventually protrude through the surface of the char to be exposed directly. This was not necessarily the case for the side-inserted thermocouples, because the surrounding char bent the parallel section of the wire backwards as it shrunk. This deformation of the thermocouples was likely facilitated by softening of the sheath at high temperature. As a result, the tips of the side-inserted thermocouples moved during the experiment, shifting further from the initial position of the heated surface. This movement is a potential complication for all thermocouples inserted parallel to the heated surface of a shrinking (or swelling) material. Photographs showing the bent thermocouple wires can also be found in Fig. 6(a) and (b).

From these measurements, in-depth temperature profiles were estimated by interpolation, using a shape-preserving cubic hermite polynomial function in MATLAB. Studies have shown the influence of the chosen function on the interpolated results [24,29,30], and this is most important when there is an inflection in the temperature profile, since each thermocouple will take only a point-measurement that provides no information about nearby changes in gradient. Consequently, the accuracy of the interpolated profiles at lower temperatures is highly dependent on the location and thickness of any moist region undergoing endothermic evaporation that could create an inflection. In the absence of this information, a smooth, shape-preserving function was chosen to simply connect the data points. These temperature profiles are shown for intervals of 5, 15, 25 and 35 minutes after flashover in Fig. 4(b), (d), and (f).

https://doi.org/10.52202/080513-0036

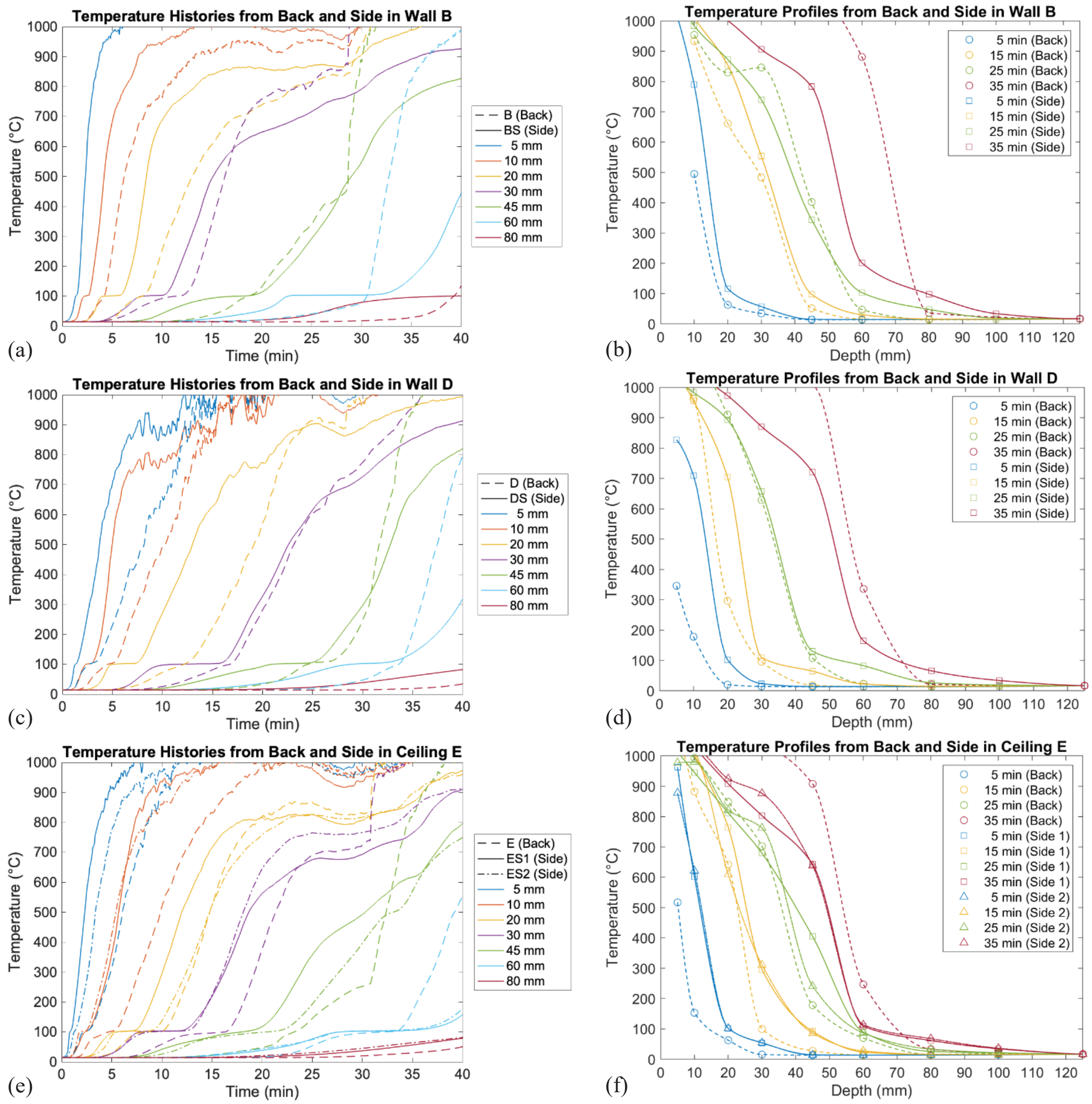

Figure 4. Temperature histories and profiles measured by TCs inserted from the back (dashed) or from the side with instrumented cylinders (solid or dash-dot) in (a)-(b) wall B, (c)-(d) wall D, and (e)-(f) ceiling E.

The in-depth temperature profiles also demonstrate the effects noted in points (1)-(5) above. Initially, the temperature profiles are consistently higher for the measurements from the side, but this changes over time due to the incidence of char fall-off between 25-35 minutes for the rear-inserted measurements. The temperature rise up to 100 °C is much faster for the side measurements at all times, but at higher temperatures the profile of measurements from the back exceeded that of the side measurements in some cases. This was caused by the difference in moisture plateaus for each measurement technique, as described in point (2).

5.2 CHAR DEPTHS AND HEATED DEPTHS

In-depth temperature profiles were calculated for every 10 seconds after flashover, and these profiles were used to track the positions of the 300 °C and 60 °C isotherms up until extinguishment, 39.5 minutes after flashover. The former is commonly used to track the base of the char layer, while 60 °C was semi-arbitrarily chosen to represent the 'heated depth'. By estimating the locations of these isotherms at each point in time, the average charring and 'heating' rates can be calculated by dividing these depths by the time of exposure. These results are shown in Fig. 5 for each exposed surface. In each of these figures, the time is noted in minutes after flashover.

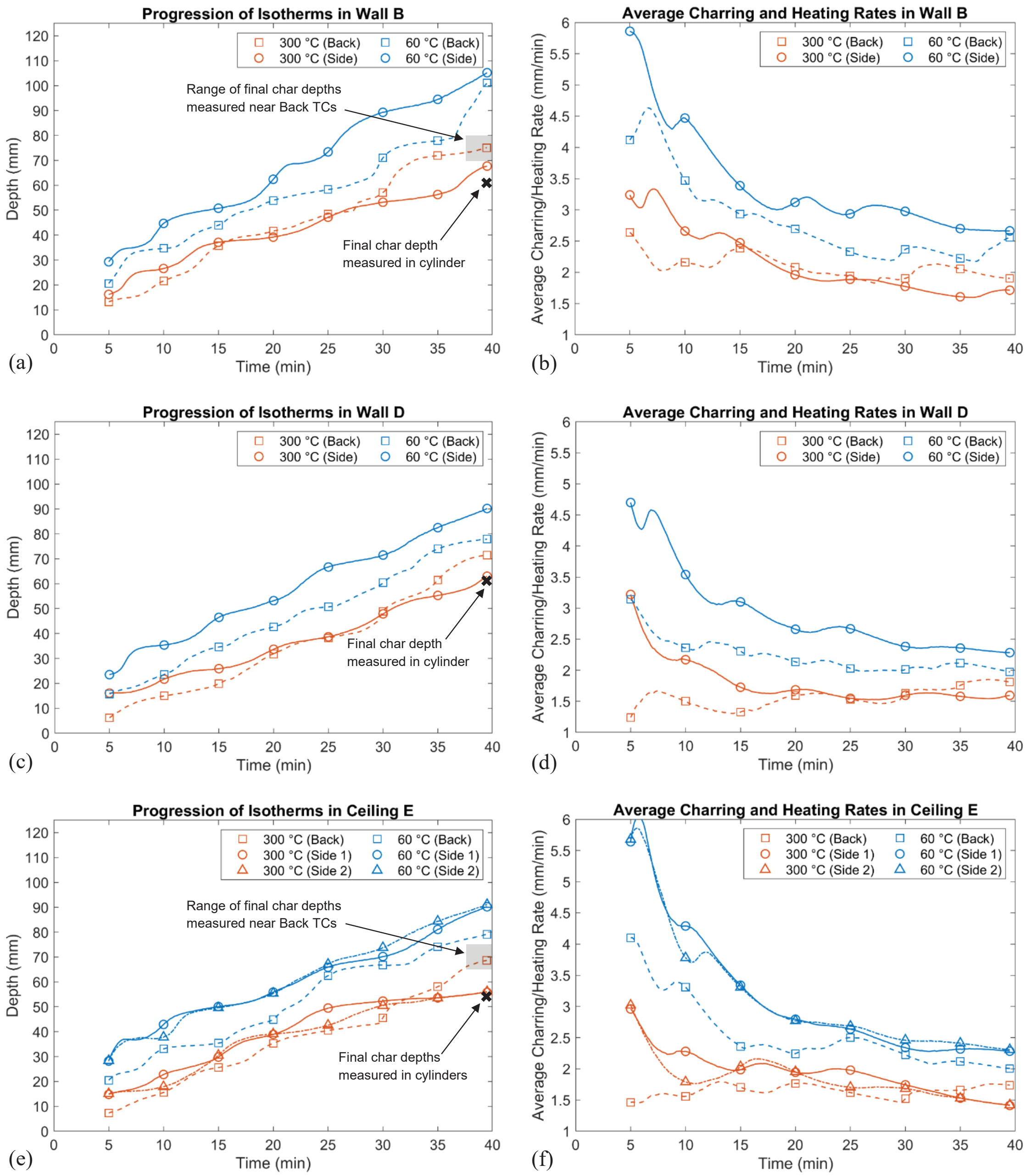

Figure 5. Progression of 300 °C and 60 °C isotherms, and average charring and 'heating' rates derived from TCs inserted from the back (dashed) or from the side with instrumented cylinders (solid or dash-dot) in (a)-(b) wall B, (c)-(d) wall D, and (e)-(f) ceiling E.

As a result of the thermal disturbance error, the initial charring rates are significantly higher for measurements from the side than from the back, but this gap is greatly reduced after the first 15-20 minutes. After 25-35 minutes, char fall-off near the rear-inserted thermocouples accelerates the charring rate measured at these locations, which eventually rises above that of the cylinders. Due to the effects noted in points (1)-(5), it is difficult to say which set of values are more 'correct' – i.e., which are more representative of the values for a CLT panel without any effects from the instrumentation.

In any case, the measurements of the instrumented cylinder are not representative of the rest of the panel once char fall-off begins.

As shown in Fig. 6(e) and (f), the final char depths after extinguishment were measured by cutting the CLT panels and cylinders through the measurement points to visually observe the thickness of the residual section. These measurements are indicated in Fig. 5 and presented in Table 1 along with the calculated char depths at extinguishment (39.5 minutes after flashover).

https://doi.org/10.52202/080513-0036

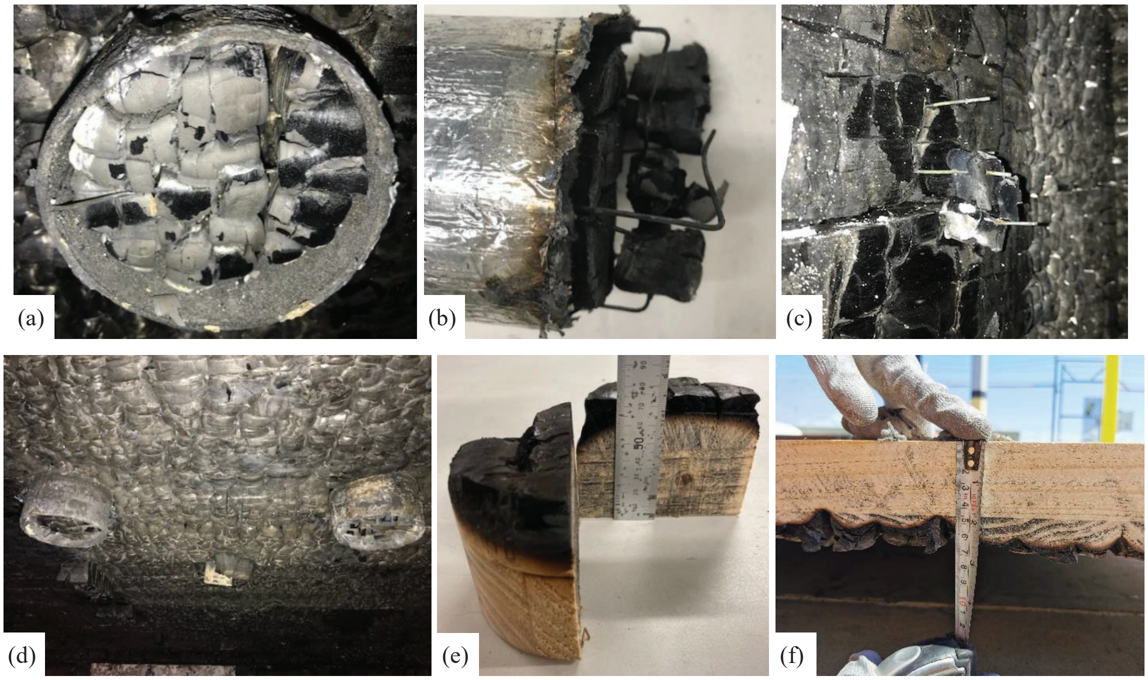

Figure 6. (a) instrumented cylinder protruding through a wall, (b) TCs in cylinder deformed due to char shrinkage, (c) TC cluster holding char in place, (d) cylinders protruding from the ceiling, (e) residual section of a cylinder, and (f) measurement of char layer depths on a CLT panel.

The char layer in the CLT panels was not uniform but 'wavy' (see Fig. 6(f)), with significant variation due to localised cracking or char fall-off. For this reason, the char measurements for the CLT panels are presented as ranges that represent the maximum and minimum values in the immediate vicinity of the thermocouple cluster. The char lines in the cylindrical samples displayed a curvature towards the edge, likely due to the insulated boundaries and shrinkage of the char creating a gap that could enhance the heat transfer around the perimeter.

The measurements in Table 1 show that the final char depth calculations from both thermocouple orientations were reasonably accurate, with a maximum error of 11 %. Specifically, the measurements from side-inserted thermocouples in three of the four cylinders were less than 4 % off the measured values. For the fourth cylinder (BS), the larger error may have been caused by a crack in the char layer near the tip of the thermocouple at a depth of 60 mm. This could have created a positive bias in the thermocouple temperatures that would shift the calculated profile. The calculated final char depths from the rear-inserted thermocouples fall roughly in the middle of the range of char depths observed near these locations. This is consistent with studies that show the thermal disturbance error decreasing over time [13–15]. However, for shorter exposure times, measurements from the back are likely to underestimate the depth of the char layer. In contrast, measurements from the instrumented cylinders may become less representative for longer heating times if they prevent char fall-off that would otherwise occur.

In all cases, the estimated position of the 60 °C isotherm was markedly deeper for the measurements from the side, typically by 10-15 mm. This is an important difference when determining the 'heated depth', at which point the mechanical properties would be assumed to deteriorate significantly in a material such as wood.

While methods exist for correcting the thermal disturbance error below the char layer [13–15], the applicability of these methods is limited by the effects of moisture on the heat transfer. The proposed correction methods do not account for these effects, such as the endothermic evaporation plateau, which can be very significant (as shown in Fig. 4).

Table 1. Final char depths after extinguishment

Location	**Orientation**	**Calculated char depth**	**Measured char depth**	**Difference**	
		(nearest mm)	***(nearest mm)***	***(mm)***	***(%)***
Wall B	Back (B)	75	70–80	-5–5	-6–7
	Side (BS)	68	61	7	11
Wall D	Back (D)	72	–	–	–
	Side (DS)	63	61	2	3
Ceiling E	Back (E)	69	65–75	-6–4	-8–6
	Side (ES1)	56	54	2	4
	Side (ES2)	56	54	2	4

It is important to note that the accuracy of values shown in Fig. 5 and Table 1 is sensitive to the interpolation function used and the lack of information about the real

https://doi.org/10.52202/080513-0036

temperatures between measurement points. As such, it is better to avoid relying on values calculated for a single point in time, but rather to use trends over longer periods. In this regard, it may be useful to calculate regressions over certain time periods that can provide information about the average charring or heating rates in that period, while reducing the influence of discrete values. This could be applied in a piece-wise manner to account for significant changes in slope that may occur with phenomena such as char fall-off.

6 – CONCLUSIONS

The following conclusions can be drawn from this study:

- The temperature disturbance error was clearly seen in measurements from thermocouples inserted perpendicular to the heated surface. These thermocouples measured much lower temperatures during the early stages of heating, at least until the evaporation plateau was reached at each location. Consequently, charring rates and surface heat fluxes derived from these measurements may also be significantly underestimated during this period.
- For dimensionally stable materials, the technique of measuring in-depth temperatures with thermocouples inserted into the side of instrumented cylindrical sample cores is likely to provide accurate results.
- However, for materials that shrink (or swell) or experience fall-off of outer layers during heating, this measurement technique may interfere with these phenomena. Measurements from this technique will become less representative of an 'undisturbed' sample after the onset of these behaviours.
- Over time, the relative error in the estimation of char depths from thermocouples inserted perpendicular to the heated surface reduces, but it may be significant for shorter periods. Moreover, in-depth heating below 100 °C is consistently underestimated by this method.
- For cross-laminated timber, if char fall-off is to be observed without interference, thermocouples of either orientation in that area should only be placed precisely at the bond line of interest, without passing through any other lamellae between that bond line and the heated surface. Furthermore, any insulation wrapped around instrumented cylinders, should not be continuous across the bond line.
- Further study is needed to ascertain whether thermocouple holes in either orientation induce an additional disturbance in the heat transfer through the surrounding material, due to the creation of artificial pathways for moisture migration and accumulation.

7 – ACKNOWLEDGEMENTS

This project was funded by the ARC Future Timber Hub (IH150100030) and received generous support from QFES, XLam, Hyne Timber, Lend Lease, Knauf and Rockwool International A/S. The authors are extremely grateful to QFES for providing their research facility and engagement with the project. Dr Wiesner was supported by the National Centre for Timber Durability and Design Life. Dr Pope is supported by the Innovation Fund Denmark, the Danish Agency for Higher Education and Science, and DBI. Staff and students helping with the project, particularly Dr A. Solarte and Dr D. Soriguer, are gratefully acknowledged.

8 – REFERENCES

[1] J. Stern-Gottfried, G. Rein, L.A. Bisby, J.L. Torero, Experimental review of the homogeneous temperature assumption in post-flashover compartment fires, Fire Safety Journal 45 (2010) 249–261. https://doi.org/10.1016/j.firesaf.2010.03.007.

[2] P. Kotsovinos, E. Rackauskaite, E. Christensen, A. Glew, E. O'Loughlin, H. Mitchell, R. Amin, F. Robert, M. Heidari, D. Barber, G. Rein, J. Schulz, Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: CodeRed #01, Fire and Materials (2022). https://doi.org/10.1002/fam.3049.

[3] R.M. Hadden, A.I. Bartlett, J.P. Hidalgo, S. Santamaria, F. Wiesner, L.A. Bisby, S. Deeny, B. Lane, Effects of exposed cross laminated timber on compartment fire dynamics, Fire Safety Journal 91 (2017) 480–489. https://doi.org/10.1016/j.firesaf.2017.03.074.

[4] F. Wiesner, H. Xu, D. Lange, V. Gupta, I. Pope, J.L. Torero, J.P. Hidalgo, Large-scale compartment fires to develop a self-extinction design framework for mass timber-Part 2: Results, analysis and design implications, Fire Safety Journal 152 (2025) 104346. https://doi.org/10.1016/j.firesaf.2025.104346.

[5] H. Xu, I. Pope, V. Gupta, J. Cadena, J. Carrascal, D. Lange, M.S. McLaggan, J. Mendez, A. Osorio, A. Solarte, D. Soriguer, J.L. Torero, F. Wiesner, A. Zaben, J.P. Hidalgo, Large-scale compartment fires to develop a self-extinction design framework for mass timber—Part 1: Literature review and methodology, Fire Safety Journal 128 (2022) 103523. https://doi.org/10.1016/j.firesaf.2022.103523.

[6] D. Hopkin, W. Węgrzyński, M. Spearpoint, I. Fu, H. Krenn, T. Sleik, C. Gorska, G. Stapf, Large-Scale Enclosure Fire Experiments Adopting CLT Slabs with Different Types of Polyurethane Adhesives: Genesis and Preliminary Findings, Fire 5 (2022) 39. https://doi.org/10.3390/fire5020039.

[7] F. Wiesner, A. Bartlett, S. Mohaine, F. Robert, R. McNamee, J.-C. Mindeguia, L. Bisby, Structural Capacity of One-Way Spanning Large-Scale Cross-Laminated Timber Slabs in Standard and Natural Fires, Fire Technology 57 (2021) 291–311. https://doi.org/10.1007/s10694-020-01003-y.

https://doi.org/10.52202/080513-0036

[8] R. Emberley, A. Inghelbrecht, Z. Yu, J.L. Torero, Self-extinction of timber, Proceedings of the Combustion Institute 36 (2017) 3055–3062. https://doi.org/10.1016/j.proci.2016.07.077.

[9] I. Pope, Solid-phase temperature analysis and correction for multi-scale fire experimentation, PhD Thesis, The University of Queensland, 2023. https://doi.org/10.14264/4b9870d.

[10] A.I. Bartlett, R.M. Hadden, J.P. Hidalgo, S. Santamaria, F. Wiesner, L.A. Bisby, S. Deeny, B. Lane, Auto-extinction of engineered timber: Application to compartment fires with exposed timber surfaces, Fire Safety Journal 91 (2017) 407–413. https://doi.org/10.1016/j.firesaf.2017.03.050.

[11] J. Su, P. Leroux, P.-S. Lafrance, R. Berzins, K. Gratton, E. Gibbs, M. Weinfurter, Fire testing of rooms with exposed wood surfaces in encapsulated mass timber construction, National Research Council of Canada. Construction, 2018. https://doi.org/10.4224/23004642.

[12] J. Su, P.-S. Lafrance, M. Hoehler, M. Bundy, Fire Safety Challenges of Tall Wood Buildings - Phase 2: Task 3 - Cross Laminated Timber Compartment Fire Tests, National Institute of Standards and Technology, 2018. https://doi.org/10.18434/T4/1422512.

[13] J.V. Beck, Thermocouple temperature disturbances in low conductivity materials, Journal of Heat Transfer 84 (1962) 124–131. https://doi.org/10.1115/1.3684310.

[14] I. Pope, J.P. Hidalgo, J.L. Torero, A correction method for thermal disturbances induced by thermocouples in a low-conductivity charring material, Fire Safety Journal 120 (2021) 103077. https://doi.org/10.1016/j.firesaf.2020.103077.

[15] I. Pope, J.P. Hidalgo, R.M. Hadden, J.L. Torero, A simplified correction method for thermocouple disturbance errors in solids, International Journal of Thermal Sciences 172 (2022) 107324. https://doi.org/10.1016/j.ijthermalsci.2021.107324.

[16] L. Terrei, Z. Acem, V. Marchetti, P. Lardet, P. Boulet, G. Parent, In-depth wood temperature measurement using embedded thin wire thermocouples in cone calorimeter tests, International Journal of Thermal Sciences 162 (2021). https://doi.org/10.1016/j.ijthermalsci.2020.106686.

[17] R. Fahrni, J. Schmid, M. Klippel, A. Frangi, Correct temperature measurements in fire exposed wood, in: WCTE 2018 - World Conference on Timber Engineering, Seoul, Republic of Korea, 2018.

[18] D. Lange, J. Sjöström, J. Schmid, D. Brandon, J. Hidalgo, A Comparison of the Conditions in a Fire Resistance Furnace When Testing Combustible and Non-combustible Construction, Fire Technol 56 (2020) 1621–1654. https://doi.org/10.1007/s10694-020-00946-6.

[19] M.G. Grønli, A Theoretical and Experimental Study of the Thermal Degradation of Biomass, PhD Thesis, The Norwegian University of Science and Technology, 1996.

[20] M.B. Dow, Comparison of measurements of internal temperatures in ablation material by various thermocouple configurations, National Aeronautics and Space Administration, Langley Research Centre, Hampton, Va., 1964.

[21] W.D. Brewer, Effect of thermocouple wire size and configuration on internal temperature measurements in a charring ablator, National Aeronautics and Space Administration, Langley Research Centre, Hampton, Va., 1967.

[22] C. Maluk, Development and application of a novel test method for studying the fire behaviour of CFRP prestressed concrete structural elements, PhD Thesis, The University of Edinburgh, 2014.

[23] Standards Australia Limited, AS/NZS 1080.1:2012 Timber – Methods of test, Method 1: Moisture content, 2012.

[24] F. Wiesner, Structural behaviour of cross-laminated timber elements in fires, PhD Thesis, The University of Edinburgh, 2019.

[25] F. Wiesner, R. Hadden, S. Deeny, L. Bisby, Structural fire engineering considerations for cross-laminated timber walls, Construction and Building Materials 323 (2022) 126605. https://doi.org/10.1016/j.conbuildmat.2022.126605.

[26] P. Reszka, In-Depth Temperature Profiles in Pyrolyzing Wood, PhD Thesis, The University of Edinburgh, 2008. http://hdl.handle.net/1842/2602.

[27] I. Pope, H. Xu, V. Gupta, J. Carrascal, D. Lange, M. McLaggan, J. Mendez, A. Solarte, D. Soriguer, J.L. Torero, F. Wiesner, J.P. Hidalgo, Fire dynamics in under-ventilated mass timber room compartments, in: Proceedings of the 12th Asia-Oceania Symposium on Fire Science and Technology (AOSFST 2021), The University of Queensland, Online, 2021.

[28] I. Pope, V. Gupta, H. Xu, F. Wiesner, D. Lange, J.L. Torero, J.P. Hidalgo, Fully-developed compartment fire dynamics in large-scale mass timber compartments, Fire Safety Journal 141 (2023) 104022. https://doi.org/10.1016/j.firesaf.2023.104022.

[29] C. Gorska, J.P. Hidalgo, J.L. Torero, Fire dynamics in mass timber compartments, Fire Safety Journal 120 (2020) 103098. https://doi.org/10.1016/j.firesaf.2020.103098.

[30] F. Wiesner, R. Hadden, L. Bisby, Influence of Adhesive on Decay Phase Temperature Profiles in CLT in Fire, in: Proceedings of the 12th Asia-Oceania Symposium on Fire Science and Technology (AOSFST 2021), The University of Queensland, Online, 2021.