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Fire Properties of Australian Timber Commonly Used in Building Industry

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Abstract— ***Small scale cone calorimeter tests have been carried out to study the fire performance of timber species for various densities, thicknesses, and heat flux exposure on local Australian timber species commonly used in the building industry. The testing was undertaken in accordance with the Australian Standard AS 3837 which is based on the ISO 5660 standard. The tests were undertaken for Ironbark, Grey (hard timber), Beech, Myrtle (firm timber) and Pine, Radiata (soft timber) with ranging densities between 450 – 1120 kg/m3, thicknesses of 9mm and 19mm and with heat flux exposure of 25 and 50 kW/m2. Beech, Myrtle was further tested to 75 kW/m2 to compare the characteristics of timber at this elevated heat flux exposure. Ironbark exhibited the best fire performances in most of the parameters analysed but the worst in heat release rate (HRR) and mass loss rate (MLR) values compared to Beech and Pine. Beech exhibited the best fire performance in HRR and MLR values. Several trends of fire characteristics were obtained with various parameters: density, thickness and heat flux from the testing undertaken. This study is aimed to enhance and provide a better understanding of local Australian timber species commonly used in the building industry and to initiate a set of test data which can be used for future fire engineering and modelling works. Future work studying the composition and other factors of various different timbers are important to be undertaken to further understand the driver of the fire behaviours in various timber species.***

Index Terms— ***Cone calorimeter, Fire properties, Heat Release Rate, Timber***

I. INTRODUCTION

Timber is one of the most common construction materials used in the Australian building industry as Australia has its vast variety of timber species. Solid timber is commonly used for structural framing, flooring, roof, wall and ceiling lining, external cladding and to make engineered wood in the building and construction industry. However, the combustibility of timber persists to limit its use as a building material as it is commonly restricted in building regulations in most countries including Australia for larger and taller buildings. For timber to be readily used in construction, it is important to develop a greater understanding of the fire properties and their fire performance of commonly used timber species in Australia. The development of simulation software such as the Fire Dynamic Simulator (FDS) has rapidly progressed over the years and is currently commonly used to simulate building fires. Small-scale testing for fire modelling as researched by [1] is an effective means to obtain empirical data for fire modelling purposes. With the existing research that has been undertaken to date, the general conclusion is that fire modelling has some limitations and must be aided by experimental data in order to predict enclosure fires accurately and realistically.

In Australia, the Forest and Wood Products Australia (FWPA) has undertaken a variety of small-scale testing for a diverse range of Australian timber species to improve the material database and understanding of fire properties for these local timber species [2]. However, these underlying test reports for the various timber species are difficult to attain and not readily available. Further, these individual reports do not analyse the fire properties in a consolidated manner to compare and contrast various local timber species and their impacting parameters to develop an understanding of their fire properties. Since, this has been found to be a gap in knowledge within the Australian building industry. Small-scale cone calorimeter tests using three Australian timber species, Grey (hard timber), Beech, Myrtle (firm timber) and Pine, Radiata (soft timber) were carried out in this study. The testing was undertaken in accordance with the Australian Standard AS 3837 which is based on the ISO 5660 standard. The empirical data obtained from this study is further aimed to initiate a comprehensive database, which will form reliable input parameters for future timber-based fire modelling, which is currently not readily available.

II. LITERATURE REVIEW

A. Introduction to Timber

Timber consist of elongated cells which are mostly in the longitudinal orientation of the stem. The cells are connected through openings which are known as pits which vary according to their functions. The three polymeric materials that make up timber cells include cellulose, hemicellulose and lignin [3]. The cellulose forms the cell walls and is responsible in providing the tensile strength to the timber. Hemicelluloses on the other hand grow around the cellulose and are a group of non-structural low molecular weight heterogeneous polysaccharides. The lignin is the polymer which provides the rigidity to timber and binds all the cells together – hence providing the shear strength to the timber [3]. It is important to note that the structure of the timber varies greatly depending on the timber species. In the construction industry, timbers are commonly categorised into hardwoods and softwoods, which do not reflect on the physical properties of the timber as the name, suggest. Hardwoods have higher hemicellulose content, which results in a higher density but weaker fibres compared to softwoods.

B. The Combustion of Timber

Timber has a combustible nature and readily contributes to the fire load to a compartment/building when used as external/internal wall linings, ceilings or as flooring. Timber is anticipated to increase the risk of fire and flame spread in the event of a fire and reach flashover quicker. When timber reaches between 200-500℃, onset of charring of timber begins to occur [4]. The cellulose, hemicellulose and lignin begin to break down and thermally decompose into unstable volatile gasses, tar and carbonaceous char. This decomposition is called pyrolysis. The detailed study of the pyrolysis of timber has been undertaken by [5] and [6]. A summary of pyrolysis based on the temperature ranges was detailed out by [3].

During the pyrolysis process, gaseous products are produced by timber where some escape readily from the solid timber residue and the others do not escape. This non-volatile residue forms carbon-to-carbon bonds which are not breakable by pyrolysis until temperatures above 300℃, leaving a char layer which is an important characteristic in the combustion of timber [7]. The char layer formed acts as an insulation for the timber layer below it and slows down the decomposition of the underlying timber [8]. The char layer does not add any strength to the remaining timber but does assist in increasing the thermal resistance in a fire between the pyrolysis front and the underlying timber. With this understanding of the burning mechanism of timber, it is expected that the HRR decreases as the char layer acts as a barrier for the volatiles released from fuel and oxygen to the air. The combustion and structure of char produced varies significantly depending on the timber species and other influencing characteristics such as the density, thickness, moisture content and external heat flux of the fire [3].

C. Australian Timber

Australia has its variety of timber species which are locally grown. Compared to other timber manufacturing nations in the world, Australia has one of the lowest percentage of forest area to total land area [9]. The predominant areas to name a few include the coastal belt in the south west of Western Australia, pine plantations in South Australia, the Otway portion in the south of Victoria and the south east of Victoria, mountain forest areas of New South Wales and the gum forests and inland pine belt along the Murray River [9]. Australia has a vast variety of timber species categorized into hardwoods and softwoods – which are based on their densities. However, timber is combustible and therefore governed by building regulations in most countries including Australia.

In Australia, the National Construction Code (NCC) sets out the minimum necessary requirements for design and construction, performance and liveability of new buildings and new works in existing buildings across all Australian States and Territories. The use of timber in the construction industry is also bound by the NCC and Australian Standards that are called up in the NCC [10]. The NCC allows for concessions to the clauses where fire protected timber is used. For the aim of this research which considers the main application of timber material in construction for internal walls, ceilings and floor linings, the timber material are required to meet the fire hazard property requirements of the NCC.

D. Testing undertaken for Australian timber species

In Australia, limited testing data is readily available to analyse the various locally grown timber species. Some of these species and their various types which are also found worldwide have been tested in various research papers such as Merbau in [11], Red Oak in [12] and Pines [13] but has not been consolidated into a single study with the same testing parameters, conditions, procedures and research aims. A study undertaken by [14] appear to have tested various timber species commonly found in Australia and America and determined the HRR using the cone calorimeter testing for various thickness and density in accordance to the American Standard ASTM E 1354. The main aim of this research was to determine the parameters that impact on the fire performance of various timber species by analysing their fire resistance using American Standards ASTM E 119, the fire growth using a full-scale room burn test, HRR using ASTM E 1354 and the flame spread index using ASTM E-84. However, the data from this research is not suitable to form a local database as the tests were not undertaken to standard Australian testing requirements which can be repeated for various other local timber species. Forest and Wood Products Australia (FWPA) in Australia has undertaken a variety of small scale testing for various timber species to determine fire properties with the aim to achieve compliance with the Building Code requirements in order to determine their application and use [2].

These reports outline the group numbers and average specific extinction area for various timber species in Australia which achieve the NCC requirements for ceiling and wall linings. Additionally, the reports outline the critical radiant heat flux and smoke development rates which achieve the NCC requirements for floor linings. These parameters are determined by the cone calorimeter testing in accordance with AS3837. However, these underlying test reports for the various timber species are difficult to attain and not readily available. These individual reports do not analyse the fire properties in a consolidated manner to compare and contrast various local timber species and their impacting parameters to develop an understanding of their fire properties. This has

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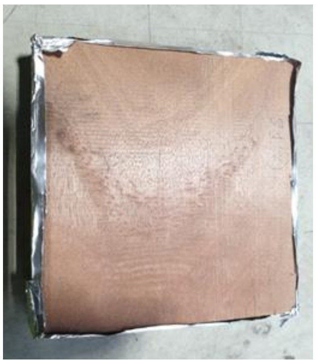
been found to a gap in knowledge within the Australian building industry.



(a)

(b)

(c)

Figure 1. (a) & (b) Specimen wrapped in aluminum foil prior to testing: (c) sample being tested

III. RESEARCH METHODOLOGY

A. Sample selection

In order to study the fire properties of Australian timber species, various important parameters were studied which include density, thickness of tested sample and the heat flux that the sample is exposed to. The density ranges used in this study include timber species of <600 kg/m3 which are considered soft timber, 600-800 kg/m3 which are considered firm timber and of >800 kg/m3 which are considered hard timber. To ensure relevance and to provide an insight for the building industry to understand the impact of thickness on the fire performance, thicknesses of 9 and 19mm have were tested in this research. In this research, all samples were exposed to a heat flux of 50 kW/m2 as outlined and recommended in the Australian Standard AS 3837. To compare and contrast the impact of heat flux exposure, all samples were also tested to 25 kW/m2. Table 1 outlines the testing specimens. 14 variations were tested and analysed to investigate the parameters that affect the fire properties and to initiate a comprehensive database for future fire engineering work. Each variation was re-tested to ensure the reproducibility and repeatability of the testing undertaken, resulting in 28 samples that were tested for the purpose of this research.

B. Sample preparation

Before the samples were tested, the weight of the samples were measured using a digital bench scale and placed in a conditioning cabinet to be conditioned to a constant mass at a temperature of (23±2)℃ and a relative humidity of (50±5)% in accordance with the ISO 554 Standard. The sample was collected from the conditioning cabinet and the mass was measured again. The sample was then wrapped in one layer of heavy-duty aluminum foil with the shiny side towards the sample. The foil covered the sides and bottom of the sample – leaving the testing surface exposed as shown in Figure 1 (a).

A fire blanket was used to avoid heat losses from the unexposed face of the sample tested. As shown in Figure 1 (b) a wire grid was used in the test over the exposed specimen to be tested. The wire was used to prevent the specimen from bending during the test due to the heat exposure causing other (non-tested) surfaces of the sample to be exposed. This measure was primarily aimed for the thinner (9mm) panel but was implemented for all tests to ensure consistency in the testing procedures and subsequently the results and data obtained.

C. Sample testing and result collection

To start the test, accurate laboratory conditions were entered into the software prompt. This includes the temperature, relative humidity and the atmospheric pressure. Pre-run calibrations were undertaken to calibrate the mass. A baseline data was run for 60s as required by the software. Once the sample was ignited (with flaming), a handheld stopwatch was started and after 10s of sustained flaming occurred on the sample, the data recording was begun. The HRR and smoke production rate were plotted against time on the monitoring screen. Other values such as percentage of oxygen, CO and CO2, the PDM (-), PDC (-), temperature, mass of sample and other variables was also monitored on the screen. Data intervals of 5 seconds was used in this testing in accordance with the recommendation in the Australian standard. Once sustained flaming was no longer observed, 'flameout' condition was reached and parameters such as HRR and sample mass begin to plateau, at this point, the test was terminated. The specimen was safely removed from the platform and the load cell was covered by the ceramic cover. The data obtained was saved for analysis and a new sample was then ready to be tested. Figure 1(c) shows a sample was being tested in the cone calorimeter.

Table 1. Tested specimens / samples schedule

Sample ID	Density range, kg/m^3	Hardness	Timber density, kg/m^3 (approx. average)	Timber species name	Thickness, mm	Heat flux, kW/m^2	Application
S1.1	>800	Hard	1120	Ironbark, Grey	19	25	Structural purposes – heavy construction
S1.3						50	
S1.1					9	25	
S1.3						50	
S2.1	600-800	Firm	680	Beech, Myrtle	19	25	Flooring covering or floor lining materials
S2.3						50	
S2.5						75	
S2.1					9	25	
S2.3						50	
S2.5						75	
S3.1	<600	Soft	450	Pine, Radiata	19	25	Ceiling and wall lining materials
S3.3						50	
S3.1					9	25	
S3.3						50	

Table 2. Testing data/results obtained

Timber species, classification		**Ironbark, Grey – Hard**				**Beech, Myrtle – Firm**						**Pine, Radiata – Soft**			
Sample ID		**S1.1**		**S1.3**		**S2.1**		**S2.3**		**S2.5**		**S3.1**		**S3.3**	
Tested heat flux	**kW/m^2**	**25**		**50**		**25**		**50**		**75**		**25**		**50**	
Thick.	mm	9	19	9	19	9	19	9	19	9	19	9	19	9	19
Approx. density	kg/m^3	1120				680						450			
Time to ignition	s	381	390	70	71	229	206	38	44	17	15	202	107	26	25
Peak HRR	kW/m^2	214	147	311	200	147	100	248	135	281	176	187	118	248	127
Time to peak HRR	s	840	2070	520	1475	630	225	410	55	335	30	475	1175	295	810
Average HRR in 5 mins	kW/m^2	83	76	123	110	81	51	128	84	190	111	110	70	151	86
Average MLR	mg/s	50	60	90	90	30	50	60	50	100	70	30	40	60	50
Average SEA	m^2/kg	8.9	4.2	28	11	16	8.8	31	7	43	2	45	16	134	13
Effective HoC	MJ/kg	10	9	11	10	11	9	12	10	12	11	12	12	13	12
CO yield	kg/kg	0.11	0.04	0.03	0.02	0.23	0.07	0.05	0.05	0.03	0.02	0.11	0.06	0.05	0.04
CO_2 yield	kg/kg	1.0	0.90	1.0	1.00	1.1	0.8	1.1	1.0	1.1	1.0	1.2	1.2	1.2	1.2

IV. FINDINGS AND DISCUSSION

In the cone calorimeter tests undertaken, the following data and parameters were recorded as the test output. The main parameters that will be analysed and discussed in further detail in this research include the time to ignition, HRR, mass loss rate (MLR), specific extinction area, heat of combustion, CO and CO2 yield. Table 2 provides an overview of the data obtained from the tests undertaken to analyse the parameters that influence the fire characteristics of various Australian timber species.

A. Time to ignition

The time to ignition is the time at which sustained flaming is achieved on the surface of the sample tested which is exposed to the heat radiation. This parameter relates closely to the thermal inertia of the material. As outlined in Table 2 , at all different heat fluxes tested, the Pine with the lowest density was the earliest to ignite (proving most flammable) and the Ironbark with the highest density was the longest to ignite (proving least flammable) due to its higher critical heat flux – refer Figure 2. It appears that the higher the density of the timber species, the longer the time to ignition and less flammable the timber material. This correlation may be explained by thermal properties of timber such as the thermal conductivity and specific heat capacity, which are correlated to the material density. The higher the thermal conductivity, the longer the time of ignition [12]. It was found that the thickness of the sample did not affect the time to ignition of the specific timber species tested.

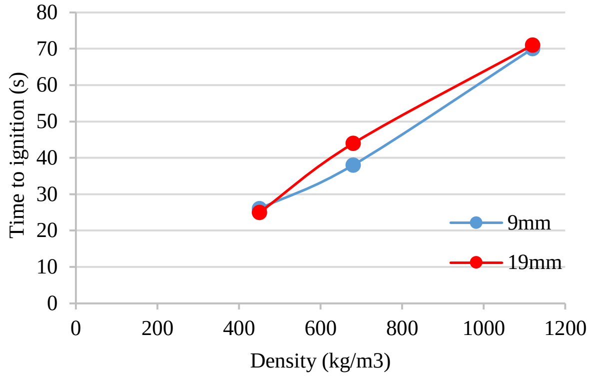


Figure 2. Plot of time to ignition against density for the samples at 50kW/m^2

B. HRR with varying timber species and densities

As Figure 3 illustrates, for each of the timber species tested, the first peak immediately after ignition was lower than the second peak similar to results obtained in testing undertaken by [15] and [16]. Consistently across the testing carried out, the timber species with the highest densities had the longest period of sustained flaming whilst the lowest density timber species had the shortest. The timber with the highest density, Ironbark recorded the highest peak HRR values compared to the other tested species at the same thickness and heat flux exposure. On the other hand, no obvious trend was noticed between the firm timber species, Beech and soft timber species, Pine – which might be due to their relatively close density in comparison to Ironbark. The average HRR rate at 5 minutes after ignition is used for the analysis as it is proposed to predict the time to flashover in a corner room burn test, ISO 9705 [11]. The average HRR of the Ironbark is the highest whilst the average HRR of the Beech is the lowest. The total heat generated throughout the testing timeframe is influenced by both the HRR and the time to sustained [12]. Interestingly, the Beech timber species (firm – medium density) proved the best and superior fire characteristics amongst the three timber species with the lowest peak HRR and lowest average HRR. This may be attributed to the higher content of lignin in the timber species which results in a fairly constant thermal decomposition rate during combustion [12].

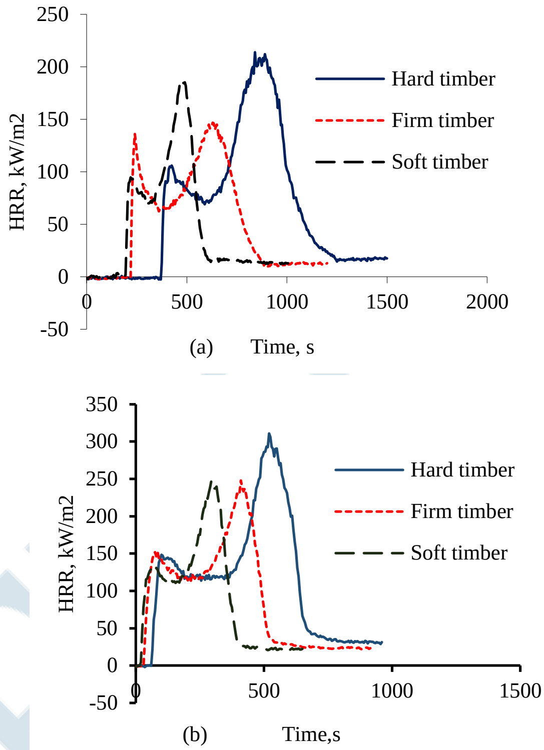
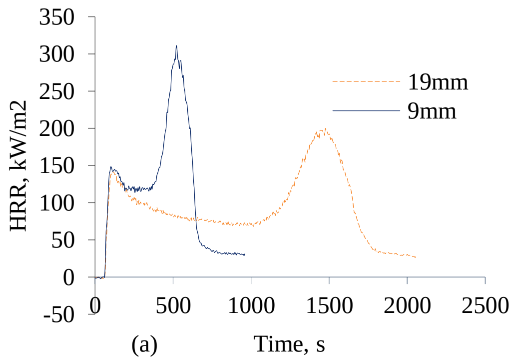


Figure 3. Comparison between various 19mm timber species (a) at 25kW/m^2 (b) at 50kW/m^2

Therefore, despite the highest density timber species resulting in the highest HRRs, no clear trend was seen for the lowest and medium density timber species. This suggests that there are no clear correlations between the timber density and the magnitude of the HRR from the cone calorimeter test. As such, other factors such as the composition and inorganic timber morphology play an important role in understanding the fire behaviours and characteristics of various timber species in Australia. This conclusion is consistent with other research conducted by [16] and [12].

C. HRR with varying panel thickness

For all the samples tested, the 9mm panels were consumed in the test faster than the 19mm panels as shown in Figure 4.



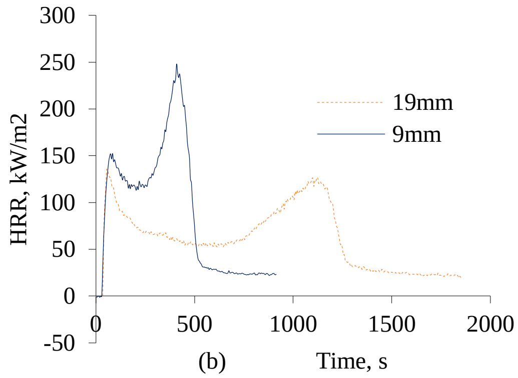


Figure 4. HRR curve of Ironbark (a) at 50kW/m^2 (b) at 25kW/m^2 for 9mm and 19mm panels

Despite similar ignition times to sustained flaming, the 9mm panels did not exhibit sustained flaming as long as the 19mm panels. In addition, all the 9mm panels resulted in a significantly higher peak heat release rate and average heat release rate. The results are consistent with a study undertaken by [14] where panels that are not thermally thick have a direct correlation between the thickness of the panel and the heat release rate obtained. [17] further, suggest that panels must be a minimum of 38mm to be considered thermally thick which is in line with the results obtained as the tested panels do not appear to provide results consistent with a thermally thick panel. Therefore, from the results obtained, the thickness of the panel is understood to have a direct correlation with the heat release rate. The thicker panels display a superior fire behaviour and characteristics compared to the thinner panels due to their lower peak HRR and lower average HRR at 5 minutes.

D. Mass Loss Rate (MLR)

The MLR is the rate of change of the specimen mass during the test undertaken. The MLR provides an understanding of the level of pyrolysis, volatilisation and burning of the tested timber species and samples under constant heat flux. The MLR may also be measured using the cone calorimeter. The MLR at each time interval can be determined using a five-point numerical differentiation as outlined in the ISO 5660-1 standard. This method was further adopted in the AS 3837:1. The MLR is understood to be closely related to the HRR, specific extinction area and the CO yield. It provides an indication of the volatilisation, level of pyrolysis and burning of the samples when tested to a constant heat flux. Understanding this parameter provides an indication of the propensity for flame spread for the sample tested (Xu et al., 2015).

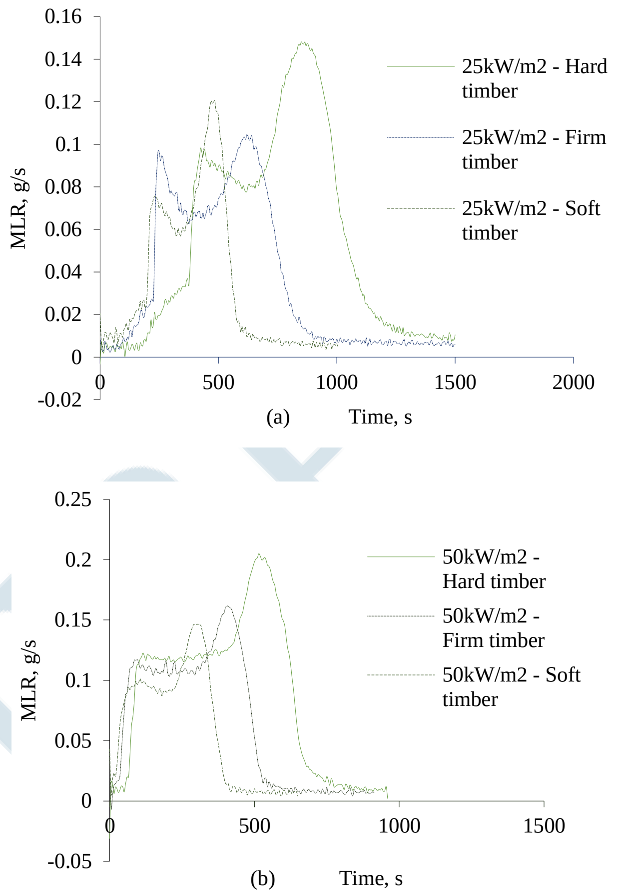


Figure 5. MLR curve (a) at 25kW/m^2 (b) at 50kW/m^2 for all timber species – 9mm

1) *MLR with varying timber species and densities*

Similar to the HRR trend, the MLR of the hard timber is greater than the other two timber species tested. The firm and soft timber species appear to have similar average MLRs despite their curve trends being slightly varied. The high MLR of the Ironbark reflects the least favourable fire hazard property, contributing the most to flame spread in the event of a fire compared to the Beech and Pine timber species – refer Figure 5.

2) *MLR with varying heat flux and thickness*

The effect of heat flux on the MLR was analysed for the 9 mm Beech timber species as the timber species was exposed to three different heat fluxes – i.e., 25, 50 and 75 kW/m^2. The MLR trend obtained is illustrated in Figure 6 (a). A similar trend was obtained for the tested samples for the 19mm. Similar to the observations obtained for the HRR trend, the MLR for the 19mm panels obtained were more consistent over a longer period of time with lower peaks in the MLR values obtained as illustrated in Figure 6 (b). However, for MLR, more importantly, the average MLR over the burning period between the 9mm and 19mm do not appear to be significantly different as outlined in Table 2. This suggest that the thickness of the panel does not affect the average MLR over the entire burning period.

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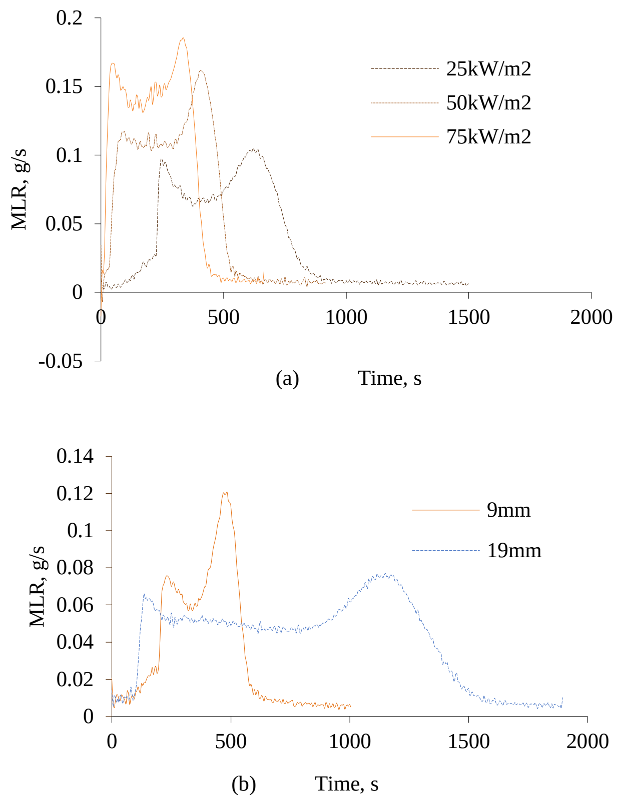

Figure 6. MLR curves for Beech timber (a) for different heat fluxes & (b) different thicknesses

V. CONCLUSION

This report presents the results of small-scale testing on three local timber specimens with varying thickness, densities and heat flux exposure. The testing procedures adopted in this study were in accordance with the Australian testing standard AS 3837 and the International standard ISO 5660.1 for cone calorimeter tests [18] and [19]. From the results analysed, it was found that the time to ignition was dependent on the density and heat flux exposure. The HRR did not exhibit obvious trends with the density of the timber tested. However, the thickness of the panels and the heat flux exposed showed clear correlations with the HRR values obtained. The MLR trends obtained in this study followed closely to the HRR trends. Comparing the timber species tested in this research, Ironbark exhibited the lowest average surface extinction area, effective heat of combustion and CO_2 yields followed by Beech and Pine, suggesting a linear trend of these parameters with the density of timber tested. The effective heat of combustion was found to decrease with the increase in heat flux exposure and panel thickness tested. CO yield recorded did not show a clear correlation with the density of the samples tested.

REFERENCES

[1]. Ira, J., Hasalová, L., Šálek, V., Jahoda, M. & Vystrčil, V. 2020. 'Thermal Analysis and Cone Calorimeter Study of Engineered Wood with an Emphasis on Fire Modelling', Fire technology, 56, 1099-1132.

[2]. Warrington fire 2016. 'Regulatory Information Report - Assessment of Plywood for the use as a wall and ceiling lining with respect to the Building Code of Australia NCC 2015 Volume 1 Specification C1.10. Australia', Forrest and Wood Products Australia Limited, Australia.

[3]. Lowden, L. A. & Hull, T. R. 2013. 'Flammability behaviour of wood and a review of the methods for its reduction', Fire Science Review, 2, 1-19.

[4]. Hurley, M. J. E. 2016. SFPE handbook of fire protection engineering, New York, Springer, 2016.

[5]. Reszka, P. 2008. 'In-depth temperature profiles in pyrolyzing wood.

[6]. Yang, L., Chen, X., Zhou, X., Fan, W. J. C. & Flame 2003. 'The pyrolysis and ignition of charring materials under an external heat flux', Combustion and Flame, 133, 407-413.

[7]. Browne, F. L. 1958. Theories of the combustion of wood and its control, Report No. 2136, Madison, Wisconsin, USDA Forest Service, Forest Products Laboratory.

[8]. Buchanan, A. H. & Abu, A. K. 2017. Structural design for fire safety, John Wiley & Sons.

[9]. Wallis, N. K., 1963:-Australian Timber Handbook. Angus and Robertson, Sydney.

[10]. Australian building codes board. 2021. National Construction Code [Online]. Australia ABCB [Accessed 29 April 2021].

[11]. Xu, Q., Chen, L., Harries, K. A., Zhang, F., Liu, Q. & Feng, J. 2015. 'Combustion and charring properties of five common constructional wood species from cone calorimeter tests', Construction & building materials, 96, 416-427.

[12]. Hao, H. L., Chow, C. L., & Lau, D. (2020b). Effect of heat flux on combustion of different wood species. Fuel, 278, 118325.

[13]. Janssens, M. 1991. 'Rate of heat release of wood products', Fire safety journal, 17, 217-238.

[14]. White, R. H. & Usda, F. 2000. 'Fire performance of hardwood species', Madison, Wisconsin, USDA Forest Service, Forest Products Laboratory.

[15]. Maake, T., Asante, J. & Mwakikunga, B. 2020. 'Fire performance properties of commonly used South African hardwood', Journal of Fire Sciences, 38, 415-432.

[16]. Haurie, L., Giraldo, M. P., Lacasta, A. M., Montón, J. & Sonnier, R. 2019. 'Influence of different parameters in the fire behaviour of seven hardwood species'. Fire safety journal, 107, 193-201.

[17]. Hao, T. & White, R. 1992. 'Burning Rate of Solid Wood Measured in a Heat Release Rate Calorimeter'. Fire and Materials, 16, 197-206.

[18]. Standards Australia 1998. Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter. AS/NZS 3837:1998', Standards Australia, Australia.

[19]. International Organization For Standardization, A. I. B. 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 5660-1:2015/Amd 1:2019], Geneva, Switzerland: ISO, 2015.

[20]. Tsantaridis, L. 2003. Reaction to fire performance of wood and other building products - cone calorimeter results and analysis, KTH - Royal Institute of Technology, Stockholm, 2003.