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Statistical Analysis of Malaysian Timber's Combustion Data from Cone Calorimeter Test

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ABSTRACT

The information on the combustion properties of local timber is crucial in Malaysia as the archival material related to this subject matter is found to be very limited in scope and incomplete. The heat release rate (HRR) is the most precious variable of combustion properties as it provides the key to understand and quantify the hazard in fires. Thus, this work is to verify the reliability of the HRR obtained from cone calorimeter tests conducted upon six Malaysian wood species: *Shorea laevis, Vatica rassak, Koompassia malaccensis, Heritiera, Shorea parvifolia* and *Cratoxylum arborescens*. The single factor one-way analysis of variance (ANOVA) was used to investigate statistically significant differences between the means of the HRR dataset of each species during the combustion tests at three different heat fluxes. Later, the confidence interval estimation was occupied to determine the range around the HRR dataset, where the means of the data was likely to be found. The intraclass correlation coefficient (ICC) test was also implemented to assess the reliability of the heat release rate data obtained from the cone calorimeter test. From the surveillance, the P-values of all the six species were higher than $\alpha = 0.05$, insinuating that the difference between the means of the dataset was not statistically significant. The confidence interval values consisting of the upper bound and lower bound limits indicate that the certainty that these ranges contain the true mean of the heat release rate dataset is 95%. Finally, the

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fact that heat release data received from the cone calorimeter test were highly reliable to statistically calculate the variation in measurements taken by a single instrument under the same condition confirmed by the ICC's values of 0.82 to 0.99 that reflect good to excellent correlations.

Keywords: ANOVA, combustion, cone calorimeter test, heat release rate, Malaysian timber

INTRODUCTION

Malaysia has always been known for its wood-based furniture, owing to its natural resources. Due to its qualities, Malaysian timbers are highly favoured for use as materials for furniture such as sofa, dining table and cabinet. As a result, Malaysia ranked amongst the top 10 largest exporters of furniture in the world and the country exports around 80% of its furniture production. In January 2019, Malaysia's largest export of major timber product is wooden furniture, portrayed the United States of America (USA) as the largest importer, followed by Japan and Australia (Malaysian Timber Industry Board, 2019). Under the National Timber Industry Policy, the furniture industry is targeted to contribute RM 12 billion in exports by 2020 (Ministry of Plantation Industry and Commodities Malaysia, 2009). With large markets in the USA, Japan and Australia, Malaysia is seen to have a strong position in the global furniture industry. This situation is supported by the tremendous growth in exports to the United Kingdom (UK), the United Arab Emirates (UAE), Saudi Arabia, Philippines and Russia. In expanding the export wing, Malaysia is now eyeing countries like Algeria, Greece, Puerto Rico and Libya as prospects for the new furniture market.

In the tropical rainforest of Malaysia, there are more than 3,000 species of trees categorized as hardwood, medium hardwood, light hardwood and softwood, which are categorized according to their density. These timbers are of high quality and ranged from very durable to durable wood (Tewarson, 1980). With varying physical texture, fabulous colour, and good manufacturing properties encouraged continuing world demand for Malaysian timber and timber-based furniture. However, timber is always considered as combustible material and the usage as furniture may notably add to the fire loading in the compartment and promote the spread of flame and speed up the outbreak of flashover.

When timber heated up to 500°C, the cellulose, hemicellulose, and lignin decomposed to unstable gases, tar (levoglucosan), and carbonaceous char (Lowden & Hull, 2013). The decomposition of timber follows a pattern which is considered as the mechanism of superposition of the individual components; starting with the decomposition of hemicellulose at 180°C-350°C, followed by the decomposition of cellulose at 275°C-350°C, and lastly the decomposition of lignin at 250°C-500°C (Kim et al., 2006). In a simple explanation, as a porous material, timber gets burned when exposed to high heat fluxes and goes through pyrolysis. It is a process where the high temperature exhibited by the firing trigger the timber components to decompose to a mixture of volatiles, tar, and highly reactive carbonaceous char. The timber experiences two oxidation phases in burning; (1) The gas-phase oxidation of the volatiles and tar, which produces flaming combustion; and (2) The solid-phase oxidation of the remaining char, which produces glowing or smouldering combustion. The smoke released from timber contains harmful gases, and the compositions influenced by combustion condition, the pattern of decomposition, ventilation, temperature, heat exposures, the oxygen and moisture present, the species of timber, any treatments or finishes that may apply and fuel chemical nature (Neviaser & Gann, 2004; Quintiere, 1982; Rasbash & Drysdale, 1982; Tewarson, 1980).

Generally, the works regarding timber fire study stands on the timber's primary reaction towards burning, which involves three stages of heat action (Tsatsoulas et al., 2009); preliminary (flameless) stage; main (flame) stage; and final (flameless) stage. The preliminary stage involves the dehydration and the release of liquid and volatile compounds while heating the timber to its decomposition temperature. The main flame stage includes the ignition of thermal decomposition products, flame spread by combustible gases, and an increase in heat release and mass-loss rates, which is the active process of decomposition. The final stage includes the slow burning of the residue and ashing of the remaining matter. However, this stage is not often reached (Tsatsoulas et al., 2009). There are numbers of research work done in different aspect of the reaction to fire of timber. Terrei et al. (2018) had set up an experimental tool attached to the cone calorimeter to study the process involved during the autoignition as this phenomenon was still in the grey area. Hou et al. (2017) investigated the combustion performance using cone calorimeter for three types of wood–aluminium composites and found that the peak HRR, average HRR, total heat release, and mean mass loss rate (MLR) of wood–aluminium composites with 1.6-mm-thick aluminium alloy sheet on the surface were decreased to 70.18%, 48.71%, 24.27%, and 80.60%, respectively. Rantuch et al. (2017) analyzed the possibility of floating flooring to ignite due to different densities of external heat flux using cone calorimeter to calculate the critical heat flux and concluded higher values had been calculated for the test conditions without the igniter (9.5 $kW.m^{-2}$ – 23.6 $kW.m^{-2}$) than for the conditions with the igniter (23.6 $kW.m^{-2}$ do 34.7 $kW.m^{-2}$). The effects of density, gas permeability, ring width, grain orientation, and heat flux, on the charring rate of six Chinese wood using cone calorimeter, had been studied by Wen et al. (2015) and led to the finding that density, gas permeability, and heat flux, but not the grain orientation, significantly affected the charring rate. Fateh et al. (2016) conducted an experiment using cone calorimeter to measure the yields of the gaseous emissions released during combustion of Maritime pine needles (*Pinus pinaster*) and the result showed that carbon dioxide and water were the main emissions during the experiments including about 5% of the carbon released as carbon monoxide and hydrocarbon at whatever the value of external heat flux selected. Khalfi et al. (2004)

determined that dense samples of wood waste furniture burned considerably better than the fibrous type with higher maximum HRR and a lower CO/CO_2 ratio in fire test using an open calorimeter.

The fire properties of heat release rate and time to ignition are known as essentials parameters for the performance-based fire safety engineering design (Babraukas & Peacock, 1992). Even though many works executed on the reaction to fire of timber, the archival material related to the Malaysian timber is found to be very limited in scope and incomplete (Wong, 1995). For instance, the records of the strength and physical properties of local timber are available (Lee et al., 1979; Tahir et al., 1996), but there is only a few information on the fire properties. To date, some studies (Marsono & Balasbaneh, 2015; Mohamed & Abdullah, 2014; Ratnasingam et al., 2016) conducted to rectify the issues and challenges of using local timber in Malaysia, but none conducted on the fire properties. There is a decreasing interest in using local timber for being the structure used in household furniture since timber considered as combustible material that may accumulate fuels in building fire. As timber produces heat, toxic gas, and smoke when burned, the products have adverse effects on the safety of occupants and at the same time, the fire may cause property losses. Therefore, there is an urge for knowledge on the combustion properties of Malaysian timber species particularly for the benefit of fire engineers for fire simulation modelling purposes. Thus, this work is to verify the reliability of the HRR obtained from the cone calorimeter tests using statistical analysis upon six species of local timber which are selected based on its application as indoor and outdoor furniture in Malaysia.

METHODS

Samples Preparation

Specimens of six timber species used in this work, *Shorea laevis, Vatica rassak, Koompassia malaccensis, Heritiera, Shorea parvifolia* and *Cratoxylum arborescens*. All specimens were prepared to be in the dimension of 100 mm × 100 mm × 30 mm squares. The solid timbers were untreated and kiln dried. Prior testing, the specimens were oven-dried at 70°C for 24 hours and kept in 50% relative humidity (Simpson, 1982).

Experimental Program

A standard cone calorimeter performed the experimental tests (Figure 1) built to comply with ISO5660-1:2002. The cone calorimeter used was a Fire Testing Technology (FTT) iCone Plus Calorimeter, manufactured in 2015 and upgraded in 2018. The data collection and calculations deployed the FTT Conecalc v6.5 software. The cone calorimeter is a fire testing tool deployed the principle of oxygen depletion based on the principle that the heat release per unit mass of oxygen consumed has a value of 13.1 MJ/kg. It is utilized by many researchers in the fire engineering field to get data of combustion properties for a material tested and used as input to models when predicting the fire conduct of that material (Babrauskas & Peacock, 1992). The principle idea of this equipment is to get the source of fuel's surface radiated under constant heat flux to ignition and then burned (Figure 2).

Figure 1. Cone calorimeter

Figure 2. Timber surface radiated to get burned

In this study, the cone calorimeter tests were conducted at three different constant incident heat fluxes: 35, 50, and 65 kW/m^2. The selection of the irradiances was based on the factor that it represented a possible range of incident heat fluxes to be counted in developing fire (Tsatsoulas et al., 2009). At each incident irradiance, the specimens were heated for 30 minutes. The test specimens were wrapped with 0.0 – 0.05 mm thick aluminium foil except for the top side and placed in a retainer frame/holder, resulting only 0.0088 m^2 of specimen surface area exposed to the radiant source. All specimens were imposed on the heat fluxes at horizontal orientation along with the pilot ignitor parallel to the grain and the cylindrical heater located 25 mm from the top surface of the specimens. Before the spark igniter was placed above the sample surface, and the actual burning test was started, baseline data was collected for 60 seconds. The experimental data was then measured from this baseline. The length of time required to create a steady flame state was recorded through visual observation. The test was triplicated for all species of timber, as shown in Table 1. Replication was needed as it is the repetition of an experimental condition so that the variability associated with the phenomenon such as random error of the analytical method could be estimated. The descriptive analysis was calculated to bring out the necessary valuable information of the data series. While the P-value for each set of replications was determined using the single factor ANOVA of Excel and the interpretation of the key results are detailed in the following section.

Table 1
The hardwood species for cone calorimeter tests

Species	Categories of hardwood	Heat flux	No. of tests
Shorea laevis	Heavy hardwood	35, 50, 65 kW/m^2	9
Vatica rassak	Heavy hardwood	35, 50, 65 kW/m^2	9
Koompassia malaccensis	Medium hardwood	35, 50, 65 kW/m^2	9
Heritiera	Medium hardwood	35, 50, 65 kW/m^2	9
Shorea parvifolia	Light hardwood	35, 50, 65 kW/m^2	9
Cratoxylum arborescens	Light hardwood	35, 50, 65 kW/m^2	9

RESULTS AND DISCUSSION

Differences Between Group Means

The variation of heat release rate to time for six Malaysian timber is as shown in Figure 3. From the observation, the shape of curves divulged the way untreated timber releases the heat in the combustion is alike in terms of the process that comprehends three stages (Kim et al., 2006). However, the values of heat released are different from one sample to another of the same species as it depends on many factors, such as the moisture content and density. The curves of each sample are found to be identical. The statistical analysis of single factor ANOVA used to analyse the data of heat release rate from the six species of Malaysian timber and the P-value for each species is as portrayed in Table 2. The P-value for all the timber species tested is higher than $\alpha = 0.05$, which means that the difference between the means of samples is not statistically significant. In this work, there must be no significant difference between the means to assure the consistency of the data obtained from the replications of the combustion test.

Table 2
The P-value of HRR for Malaysian timber under different heat fluxes

Category	Species	Heat Flux (kW/m^2)	HRR measurement's data count	P-value	
Heavy Hardwood - Density range: 800 – 1,120 kg/m^3	*Shorea laevis*	35	50	0.44	Differences between the means are statistically not significant
		50	50	0.76	
		65	50	0.07	
	Vatica rassak	35	50	0.17	
		50	50	0.77	
		65	50	0.92	
Medium hardwood - Density range: 720 – 880 kg/m^3	*Koompassia malaccensis*	35	50	0.15	
		50	50	0.42	
		65	50	0.15	
	Heritiera	35	50	0.19	
		50	50	0.94	
		65	50	0.09	

Table 2 (*continue*)

Category	Species	Heat Flux (kW/m^2)	HRR measurement's data count	P-value	
Light hardwood - Density range: 400 – 720 kg/m^3	*Shorea parvifolia*	35	50	0.18	Differences between the means are statistically not significant
		50	50	0.28	
		65	50	0.73	
	Cratoxylum arborescens	35	50	0.59	
		50	50	0.20	
		65	50	0.21	

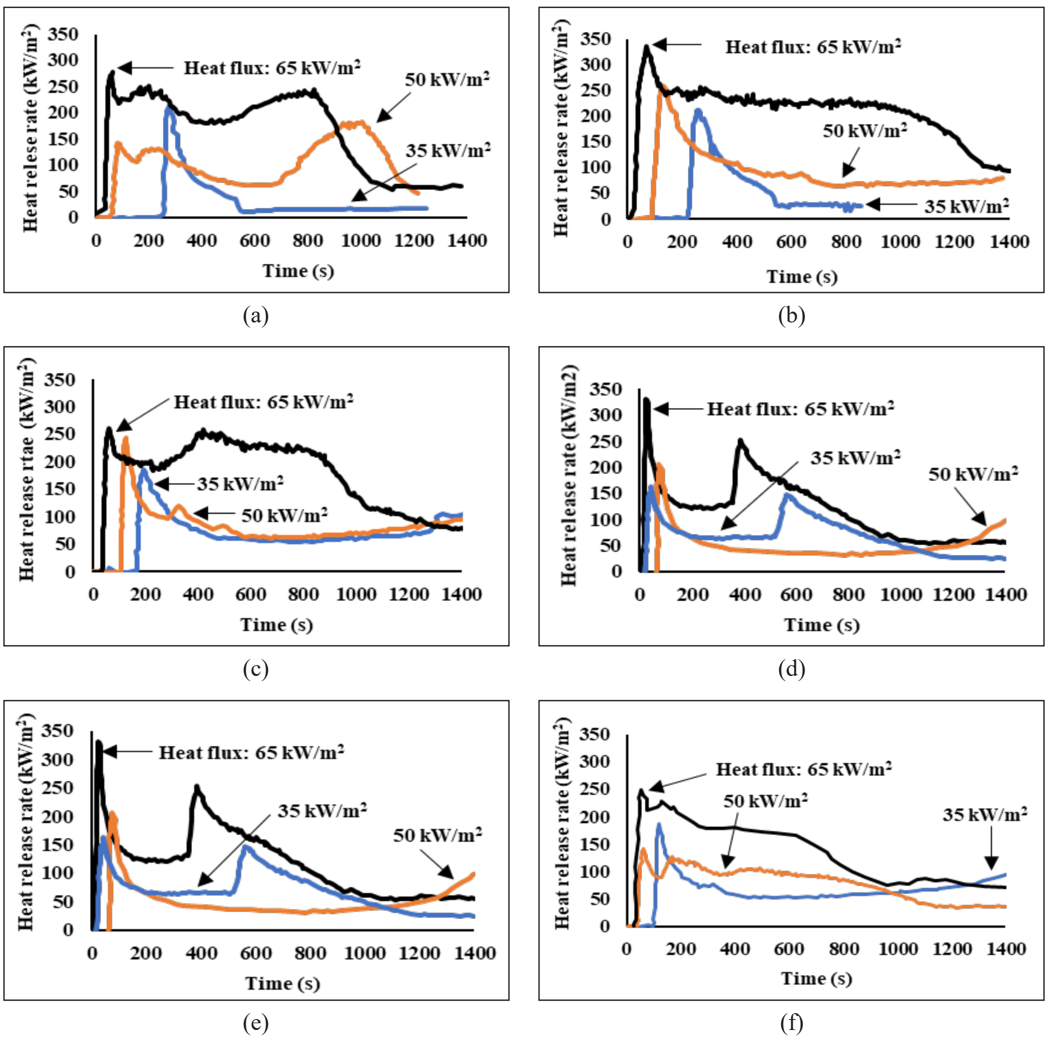

Figure 3. Variation of heat release rate with time of : (a) *Shorea laevis*; (b) *Vatica rassak*; (c) *Koompassia malaccensis*; (d) *Heritiera*; (e) *Shorea parvifolia*; and (f) *Cratoxylum arborescens* under different heat fluxes

The Confidence Interval

The confidence interval is a range around a sample where a population means is likely to be found. The calculation for the determination of the confidence interval can be described as in Equation (1) (Curran-Everett, 2009):

$$\mu = \bar{x} \pm t_{\alpha/2}\, s/\sqrt{n} \qquad (1)$$

Where μ is the population mean; $\bar{x}$ is the sample mean; s is the sample standard deviation; n is the sample size; α is the type I error (the proportion of the time the confidence interval does not overlap the population mean; and $t_{\alpha/2}$ is the critical value of the Student's t-distribution for a two-tail confidence interval. The margin of error is $\pm\, t_{\alpha/2}\, s/\sqrt{n}$, which mean the value of confidence interval consists of the upper bound; $\mu + t_{\alpha/2}\, s/\sqrt{n}$ and the lower bound (Equation (2)):

$$\mu - t_{\alpha/2}\, s/\sqrt{n} \qquad (2)$$

The 95% confidence interval of HRR data obtained from the cone calorimeter test for each wood sample's replication is figured in Table 3. In this research, only the interval plot of means and confidence interval for heavy hardwood were applied as seen in Figure 4. Figure 4 shows that the certainty that the range of upper and lower bound interval of the heat release data contains the true mean is 95%. As the p-value from ANOVA (Table 2) conferred the differences between the means are not statistically significant, there is no reason to assess differences in group means.

Table 3
The mean, upper bound and lower bound limit for the HRR of Malaysian wood under different heat fluxes

Category	Species	Heat Flux (kW/m^2)	Replication	μ	Upper bound	Lower bound
Heavy Hardwood - Density range: 800 – 1,120 kg/m^3	*Shorea laevis*	35	Replication 1	103	236	-29
			Replication 2	88	247	-71
			Replication 3	85	226	-54
		50	Replication 1	82	170.5	-5.8
			Replication 2	85	170.1	-0.06
		65	Replication 1	157	168	145
			Replication 2	198	209	186
			Replication 3	160	171	148
	Vatica rassak	35	Replication 1	76	214	-62
			Replication 2	95	224	-33
			Replication 3	88	240	-62
		50	Replication 1	146	321	-29
			Replication 2	151	340	-40

Table 3 *(continue)*

Category	Species	Heat Flux (kW/m²)	Replication	μ	Upper bound	Lower bound
	Vatica rassak	50	Replication 3	138	277	-0.4
		65	Replication 1	177	396	10
			Replication 2	180	350	26
			Replication 3	170	380	13
Medium hardwood - Density range: 720 – 880 kg/m³	*Koompassia malaccensis*	35	Replication 1	77	162	-8
			Replication 2	89	208	-30
			Replication 3	71	143	-1.2
		50	Replication 1	129	261	-4
			Replication 2	119	245	-8
			Replication 3	112	231	-7
		65	Replication 1	168	333	2.3
			Replication 2	163	308	18.5
			Replication 3	192	360	25
	Heritiera	35	Replication 1	90	201	-21
			Replication 2	78	174	-18
			Replication 3	98	210	-14
		50	Replication 1	128	265	-9
			Replication 2	129	262	-4
			Replication 3	124	257	-8
		65	Replication 1	171	314	27
			Replication 2	142	278	5
			Replication 3	143	292	-6
Light hardwood - Density range: 400 – 720 kg/m³	*Shorea parvifolia*	35	Replication 1	103	227	-22
			Replication 2	108	235	-19
			Replication 3	85	212	-42
		50	Replication 1	90	156	25
			Replication 2	95	174	17
		65	Replication 1	195	367	22
			Replication 2	188	359	17
	Cratoxylum arborescens	35	Replication 1	88	223	-48
			Replication 2	97	200	-6
			Replication 3	99	213	-14
		50	Replication 1	82	160	4
			Replication 2	73	144	2.5
			Replication 3	68	142	-5
		65	Replication 1	179	334	25
			Replication 2	155	288	23
			Replication 3	157	307	8

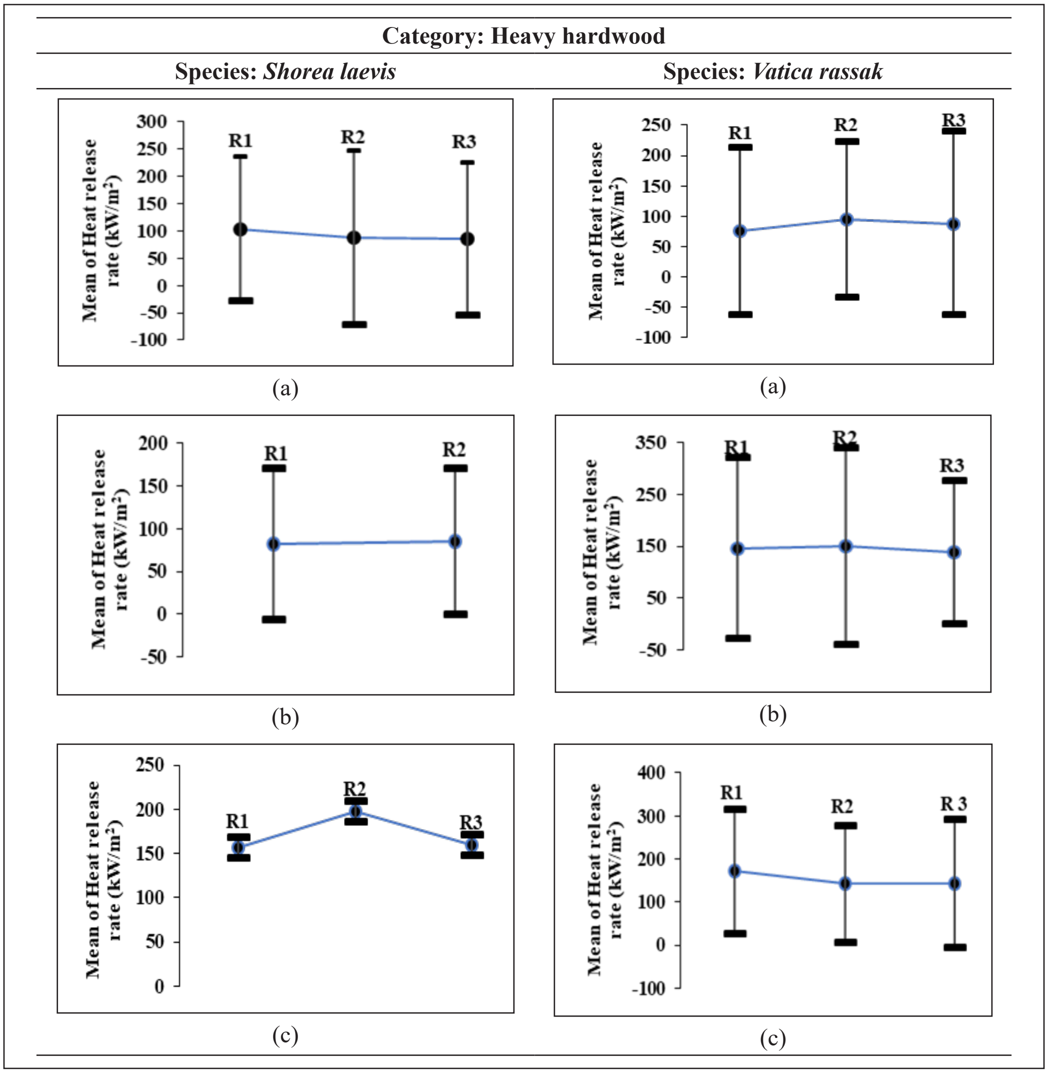

Figure 4. Interval plot to display mean and confidence interval of combustion test for heavy hardwood; (a) At Heat flux of 35 kW/m^2; (b) At Heat flux of 50 kW/m^2; and (c) At Heat flux of 65 kW/m^2

Intraclass Correlation Coefficient

The intraclass correlation coefficient (ICC) is a measure of the reliability of measurements. It assesses the reliability of measurement for data that has been collected as groups or sorted into groups, and the coefficient ranges from 0 to 1. The high value of ICC, which is close to 1, indicates a high similarity between values from the same group. The ICC analysis is constructed to check the reliability of the heat release rate measurements obtained from the replications of the combustion test at different heat fluxes, and the results are recorded in Table 4.

According to Table 4, the ICC is the average measure for all groups of replications of each species at the specific heat fluxes. The average measures elucidate how consistent are the samples of the same species react in combustion relative to each other on average from sample to sample. Hinge on 95% confidence level of ICC estimation, values less than 0.5 is considered as poor, between 0.5 and 0.75 is moderate, between 0.75 and 0.9 contemplates good correlation, while the ICC of 0.9 onwards is an excellent sign of reliability (Koo & Li, 2016). All six species timber samples conceived from optimal to excellent ICC range in the reliability test, which firmed on the high reliability and consistency of the data resulted from the cone calorimeter. The *Shorea laevis*, *Heritiera*, and *Cratoxylum arborescens* inscribed the ICC values between 0.928 to 0.998 at three different irradiances charged indicating excellent agreement between the replications with low variability. The 95% confidence intervals of ICC, ranging from 0.722 to 0.999, also strengthened the reliability for the data from the cone calorimeter. Additionally, the Cronbach's alpha values denote high internal consistency between the replications for the six species of Malaysian timber in the combustion test. In simple words, the data obtained from the combustion test replications are relative to one another for each species, and the consistency of data provided form with the combustion tests are highly reliable.

Table 4
The intraclass correlation coefficient (ICC) for HRR between repetitions of cone calorimeter test

Category	Species	Heat flux (kW/m^2)	ICC	95% Confidence interval		Cronbach's Alpha
				Upper bound	Lower bound	
Heavy hardwood	*Shorea laevis*	35	0.943	0.966	0.906	0.948
		50	0.992	0.996	0.985	0.993
		65	0.972	0.990	0.833	0.990
	Vatica rassak	35	0.918	0.955	0.843	0.935
		50	0.879	0.927	0.806	0.878
		65	0.974	0.984	0.957	0.975
Medium hardwood	*Koompassia malaccensis*	35	0.866	0.920	0.780	0.877
		50	0.937	0.963	0.897	0.942
		65	0.976	0.990	0.906	0.988
	Heritiera	35	0.944	0.969	0.896	0.954
		50	0.998	0.999	0.995	0.997
		65	0.928	0.961	0.859	0.944
Light hardwood	*Shorea parvifolia*	35	0.957	0.978	0.909	0.968
		50	0.820	0.868	0.754	0.821
		65	0.841	0.902	0.722	0.864
	Cratoxylum arborescens	35	0.937	0.962	0.898	0.939
		50	0.947	0.971	0.901	0.957
		65	0.966	0.983	0.922	0.977

CONCLUSION

Most of the combustibility tests for timber and timber-based products comprised heating a predefined quantity of the test sample for a set span and conducted to collect data on fire properties. The fire properties data are used for (i) fire modelling; (ii) prediction of real-scale fire behaviour; and (iii) pass/fail tests. The cone calorimeter is a fire testing tool that deployed the rule of oxygen depletion based on the principle that the heat release per unit mass of oxygen consumed has a value of 13.1 MJ/kg. This tool is utilized by many researchers in the fire engineering field to get combustion data for materials tested and these valuable findings are used as input to fire models and software when predicting the fire conduct.

The replications of the combustibility test are intended to observe the reliability and consistency of the data obtained from cone calorimeter tests. The main objective of this study was to assess the reliability and consistency of the timbers through replication of each predefined combustion test. The heat release rate curves obtained from the replications of combustion tests under three different heat fluxes of 35, 50 and 65 kW/m2 disclosed identical curves for *Shorea laevis, Vatica rassak, Koompassia malaccensis, Heritiera, Shorea parvifolia* and *Cratoxylum arborescens*. In order to assess the reliability and the consistency of the replications, the statistical analysis of single factor ANOVA was used to determine statistically the significant differences between the means of samples for each species tested in the combustibility test. From the observation of ANOVA analysis, the P-value of all the six species were higher than $\alpha = 0.05$, which means that the difference between the means of samples is not statistically significant. These P-values were an indication that the replications of combustion tests are closely alike between one another. Besides that, the range of interval indicates 95% certainty that the upper and lower bound limit contains the true mean of the samples. The reliability of the heat release rate data obtained from the replications was measured using the ICC test and resulted optimal to excellent ICC range. The ICC's outcome firmed the fact that the data from the cone calorimeter are reliable to statistically calculate the variation in measurements taken by a single instrument under the same conditions. The consequences of the statistical analysis of ANOVA, the confidence interval of means and the ICC test performed in this study lead to the confirmation that the results and reports of timber combustion properties obtained by the cone calorimeter are highly reliable.

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REFERENCES

Babraukas, V., & Peacock, R. D. (1992). Heat release rates: The single most important variable in fire hazard. *Fire Safety Journal, 18*(3), 255-272.

Curran-Everett, D. (2009). Explorations in statistics: Confidence intervals. *Advances in Physiology Education*, *33*(2), 87–90.

Fateh, T., Richard, F., Batiot, B., Rogaume, T., Luche, J., & Zaida, J. (2016). Characterization of the burning behavior and gaseous emissions of pine needles in a cone calorimeter-FTIR apparatus. *Fire Safety Journal*, *82*, 91-100.

Hou, J., Cai, Z., & Lu, K. (2017). Cone calorimeter evaluation of reinforced hybrid wood-aluminum composites. *Journal of Fire Sciences*, *35*(2), 118-131.

Khalfi, A., Trouvé, G., Delfosse, L., & Delobel, R. (2004). Influence of apparent density during the burning of wood waste furniture. *Journal of Fire Sciences*, *22*(3), 229–250.

Kim, H. S., Kim, S., Kim, H. J., & Yang, H. S. (2006). Thermal properties of bio-flour-filled polyolefin composites with different compatibilizing agent type and content. *Thermochimica Acta*, *451*(1-2), 181-188.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155-163.

Lee, Y. H., Chik, E. A. R., & Chu, Y. P. (1979). *The strength properties of some Malaysian timbers*. Kuala Lumpur, Malaysia: Malaysian Timber Industry Board.

Lowden, L., & Hull, T. (2013). Flammability behaviour of wood and a review of the methods for its reduction. *Fire Science Reviews*, *2*(1), 1-19.

Malaysian Timber Industry Board. (2019). *Malaysian Timber E-Stats 2019 - Export (January)*. Kuala Lumpur, Malaysia: Malaysian Timber Industry Board.

Marsono, A. K., & Balasbaneh, A. T. (2015). Combinations of building construction material for residential building for the global warming mitigation for Malaysia. *Construction and Building Materials*, *85*, 100–108.

Ministry of Plantation Industry and Commodities Malaysia. (2009). *National timber industry policy 2009-2020*. Kuala Lumpur, Malaysia: Malaysian Timber Industry Board (MTIB).

Mohamed, S., & Abdullah, R. (2014). Timber use practices in Malaysia’s construction industry: Single-family residential building sector. *Pertanika Journal of Tropical Agricultural Science*, *37*(4), 475-482.

Neviaser, J. L., & Gann, R. G. (2004). Evaluation of toxic potency values for smoke from products and materials. *Fire Technology*, *40*(2), 177-199.

Quintiere, J. G. (1982). Smoke measurements: An assessment of correlations between laboratory and full-scale experiments. *Fire and Materials*, *6*(1), 145-160.

Rantuch, P., Hrusovsky, I., Martinka, J., Balog, K., & Hirle, S. (2017). Determination of the critical heat flux for floating flooring. *Wood Research*, *62*(6), 973-982.

Rasbash, D. J., & Drysdale, D. D. (1982). Fundamentals of smoke production. *Fire Safety Journal*, *5*(1), 77-86.

Ratnasingam, J., Liat, L. C., Ramasamy, G., Mohamed, S., & Senin, A. L. (2016). Attributes of sawn timber important for the manufacturers of value-added wood products in Malaysia. *BioResources*, *11*(4), 8297-8306.

Simpson, W. T. (1982). Importance of relative humidity and temperature control in conditioning wood products. *Wood and Fiber*, *14*(2), 94-103.

Tahir, H. M., Midon, M. S., Chu, Y. P., Kasby, N. A. M, & Mohd, R. (1996). *Handbook of structural timber design: Simple solid members*. Kuala Lumpur: Forest Research Institute Malaysia (FRIM).

Terrei, L., Acem, Z., Georges, V., Lardet, P., Boulet, P., & Parent, G. (2018). Experimental tools applied to the ignition study of spruce wood under cone calorimeter. *Journal of Physics: Conference Series, 1107*(3), 1-6.

Tewarson, A. (1980). Heat release rate in fires. *Fire and Materials*, *4*(4), 185-191.

Tsatsoulas, D., Phylaktou, H. N., & Andrews, G. (2009). Thermal behaviour and toxic emissions of various timbers in cone calorimeter tests. *WIT Transactions on The Built Environment*, *110*, 181-194.

Wen, L., Han, L., & Zhou, H. (2015). Factors influencing the charring rate of Chinese wood by using the cone calorimeter. *BioResources*, *10*, 7263-7272.

Wong, W. S. (1995). *Timber structures in Malaysian architecture and buildings*. University of Tasmania at Launceston. Retrieved January 21, 2019 from https://eprints.utas.edu.au/21980/1/whole_WongWai-Sung1997_thesis.pdf