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ORIGINAL ARTICLE

One-dimensional charring rate of Glulam manufactured from Malagangai (*Potoxylon melagangai*) species treated with fire retardant

Zulhazmee Bakri[a], Zakiah Ahmad[b,*], Atikah Fatma Md Daud[c], Simon Aicher[d]

[a] Faculty of Engineering, Science & Technology, Infrastructure University Kuala Lumpur (IUKL), 43000 Kajang, Selangor, Malaysia
[b] Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[c] Politeknik Premier Sultan Salahuddin Abdul Aziz Shah, 40150 Shah Alam, Selangor, Malaysia
[d] Department Timber Constructions, Universität Stuttgart, Germany
[*]Corresponding Author: Zakiah Ahmad. Email: zakiah@uitm.edu.my

Abstract: This study investigates the one-dimensional charring behavior of glued laminated timber (glulam) manufactured from Malagangai (*Potoxylon melagangai*) under standard fire exposure conditions. Specifically, the research evaluates the effectiveness of a fire-retardant coating in enhancing the fire resistance of glulam. The fire retardant used in this study is a waterborne, transparent formulation designed for application on both newly processed and preservative-treated timber surfaces, offering an additional layer of protection against fire. To assess the fire performance of both treated and untreated glulam specimens, a fire resistance test was conducted in accordance with ISO 834 (equivalent to BS 476: Part 20). The charring rate of the specimens was measured based on the guidelines outlined in EN 13381-7:2014. The experimental findings indicate that while the application of the fire-retardant coating provides some level of protection, its impact on reducing the charring rate is relatively minor. The treated glulam exhibited a charring rate of 0.58 mm/min, whereas the untreated specimen had a slightly higher charring rate of 0.63 mm/min. Both values are lower than the standard charring rate of 0.65 mm/min prescribed in Eurocode 5. These findings contribute to a better understanding of the fire performance of tropical hardwood-based glulam and highlight the need for further research into optimizing fire-retardant treatments to enhance the fire resistance.

Keywords: One-dimensional charring rate, glue laminated (glulam) timber, fire test, Eurocode, tropical timber

1 Introduction

Initially, the development of engineered timber products (ETP) as glued laminated timber (glulam), laminated veneer lumber (LVL), and cross-laminated timber (CLT) was driven by the need for alternative materials that could effectively replace smaller-dimension sawn lumber and boards in light-frame construction. By engineering timber into larger, stronger, and more predictable components, these products have expanded the possibilities for timber construction, allowing for greater design flexibility and improved structural performance. Over time, ETPs have evolved beyond simple substitutes and are now widely used in advanced applications, including mass timber structures, high-rise buildings, and complex architectural designs, further demonstrating their versatility and efficiency in modern construction. From a technical perspective, modern ETPs generally exhibit superior and more consistent

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physical and mechanical properties compared to conventional solid timber [1-4]. These advancements result from engineered manufacturing processes that optimize the natural characteristics of wood while minimizing its inherent weaknesses. Key benefits of ETPs include a more uniform composition, enhanced dimensional stability, and improved strength and stiffness, making them highly reliable for structural applications.

Timber are naturally combustible materials, posing significant fire safety challenges. The fire resistance of timber plays a crucial role in structural design, especially as its use in construction continues to rise due to its sustainability, environmental benefits, and aesthetic qualities. Since raw timber functions as a solid fuel, fire safety regulations prescribe the use of protective measures to ensure that wooden elements achieve the required fire resistance levels, such as maintaining load-bearing capacity during a fire. Additional fire protection for wooden elements is typically achieved through the application of fire retardants, such as intumescent coatings or impregnation treatments, or by installing fire-resistant cladding on the exposed surfaces to enhance fire performance [5].

When timbers are exposed to flames, these materials begin to ignite at a surface temperature of approximately 270 ℃. According to the structural fire design guidelines outlined in Eurocode 5 [5], the onset of charring is defined as the moment when the surface temperature of the timber reaches 300 ℃. As the fire continues, the temperature within the timber increases, causing the boundary between the unaffected wood and the pyrolysis zone to gradually shift deeper into the material. The rate at which the boundary between burnt and unburnt wood progresses through the cross-section of the material when exposed to fire is referred to as the charring rate of timber. The charring rate is determined from the distance between the outer surface of the original member and the position of the char-line over the time of exposure [6]. The char layer acts as an insulation layer, which slows the burning and protects the rest of the cross section (see Charred samples for Light Red Meranti after 30 minutes of one-dimensional fire exposure in **Fig. 1**. In recent years, charring rates have gained significant attention from researchers and structural designers who seek to assess the loss of load-carrying capacity in timber beams and columns during and after fire tests [7–9].

Fig.1. Charred sample showing charred layer, pyrolysis and normal wood

The charring rate of timber is a complex phenomenon, as it is primarily influenced by several factors, including the species and density of the wood, with denser species typically charring at a slower rate. Moisture content also plays a crucial role, as higher moisture levels delay charring due to the time required for water evaporation. Additionally, fire exposure conditions such as temperature, duration, and oxygen availability significantly affect the rate of charring. The presence of fire retardants or protective surface treatments further alters charring behavior by enhancing the material's resistance to fire [10, 11].

Currently, in Malaysia, the structural design of timber is still based on the permissible stress design method, where strength classification is determined by strength grouping, unlike the Eurocode 5, which classifies strength based on strength classes. Therefore, the charring rate of Malaysian tropical timber is classified based on strength grouping, as shown in **Table 1**, whereas in Eurocode 5, charring rates are categorized according to timber density, as shown in **Table 2.**

Table 1. Notional rate of charring for the calculation of residual section based on MS 544: Part 9 [16]

Species	Charring rate (mm/min)
SG 1 to SG3	0.5
SG 4 to SG 5	0.7

Table 2. Design charring rates β_o and βn of timber in Eurocode 5 [6]

Species	Charring rate (mm/min)	
	β_o	β_n
a) Softwood and beech		
Glued laminated timber with a characteristic density of ≥ 290 kg/m³	0,65	0,7
Solid timber with a characteristic density of ≥ 290 kg/m³	0,65	0,8
b) Hardwood		
Solid or glued laminated hardwood with a characteristic density of 290 kg/m ³	0,65	0,7
Solid or glued laminated hardwood with a characteristic density of ≥ 450 kg/m ³	0,50	0,55
c) LVL		
with a characteristic density of ≥ 480 kg/m³	0,65	0,7
d)Panels		
Plywood	0,9 [a]	-
Wood panelling	0,9 [a]	-
Wood-based panel other than plywood	1,0 [a]	-

[a] The values apply to characteristic density of 450 kg/m ³and a panel thickness of 200mm;3.4.2 (9) for other thicknesses and densities.

Malaysian timbers classified under strength groups 1 and 3 have densities ranging from 750 to 1100 kg/m ³, whereas those in strength groups 4 and 5 exhibit densities between 550 and 1000 kg/m ³. This variation in density directly influences the fire performance of the timber, as denser woods generally char at a slower rate, contributing to improved fire resistance in structural applications. In BS 5268 [12], the charring rate is also classified in terms of density but the charring rate is not divided into one-dimensional and two-dimensional charring rate as shown in **Table 3.**

Table 3. Char rate from BS5268: Part 4 [12]

Species	Charring rate (mm/min)
Softwood < 640kg/m^3	0.83
Hardwood > 640kg/m^3	0.55
Softwood glued laminated timber	0.70

In recent decades, the determination of one-dimensional charring rates has been a major research focus, aiming to enhance the understanding of its characteristics in comparison to two-dimensional charring rate [13-15]. The application of glulam in the construction industry is still relatively new in Malaysia. Without established charring rate values for design, the use of glulam as a building material may face challenges in obtaining approval from fire authorities, as timber is considered a flammable material. Currently, the charring rate of glulam has not been incorporated into Malaysian standards due to a lack of studies. As observed in **Table 1**, there is no recorded charring rate value for glued laminated timber (glulam) and laminated veneer lumber (LVL) derived from Malaysian tropical timber. This absence of data highlights a gap in existing fire performance research for these engineered timber products. Such data would be essential for improving fire safety regulations and ensuring the effective application of Malaysian tropical timber in fire-resistant building designs using ETPs. Determining the charring rate of glulam made from tropical hardwood is crucial to prevent underestimating or overestimating its structural performance under fire exposure, especially if Eurocode 5 values are used directly. Therefore, this study investigates the charring rate of glulam made from Malaysian tropical timber under one-dimensional fire exposure. Additionally, a comparison is conducted between untreated glulam and glulam treated with a fire-retardant coating.

2 Specimen preparation and test methods

2.1 Materials

Two glulam beams, measuring 80 mm × 500 mm × 2000 mm (width × depth × length), were prepared using Malagangai, a durable Malaysian tropical timber. The beams were manufactured in a Malaysian glulam factory following the standards outlined in MS 758 [16]. The lamellae had a depth of 15 to 18 mm and were bonded using PRF adhesive. A few knots were present, and finger joints were also formed using PRF adhesive.

Two types of glulam beams were produced: one without treatment and the other coated with a fire-retardant. The fire-retardant used, Pyroprotect, was supplied by Rotafix Ltd. This waterborne, transparent coating is designed for application on both newly processed and preservative-treated timber surfaces. The prepared beams were then sent to SP Wood Technology in Stockholm for fire testing.

2.2 Construction of test specimens

The received glulam beams were stored in a climate chamber (20 ℃, 65% RH) for three days. The charring test specimens were prepared at SP Wood Technology approximately one week before the fire tests. The one-dimensional fire specimens were cut into different sections as shown in **Fig. 2**.

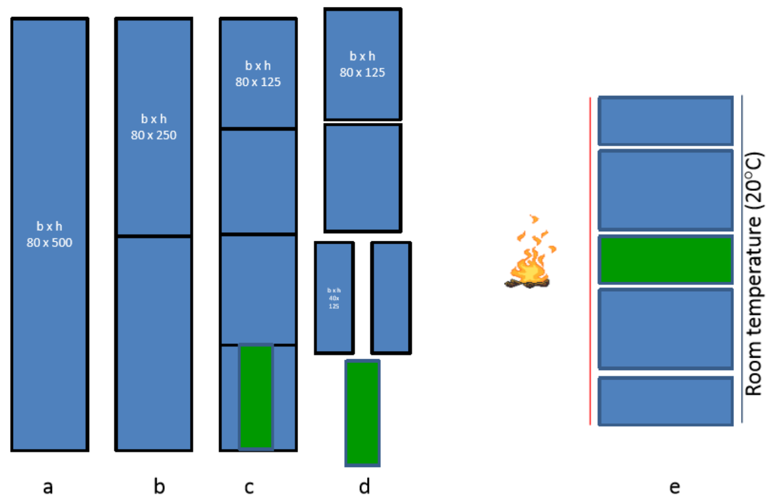


Fig. 2. (a) to (d) illustrate the assembly of the charring test specimen (approximate width: 270 mm) made from a glulam beam measuring 80 mm × 500 mm.

These specimens were made from centrally instrumented beams, taken from the lower side of each glulam beam (see **2d**) and face glued to form a beam of with a final geometry of approximately 1650 mm × 270 mm × 120 mm (length × width × depth) and consisted of multiple sizes. The timber density, including moisture content, was determined using end cuts from the glulam beams (approximately 365 mm in length). The depth of the instrumented beam, along with its density and moisture content, was measured before the test at both ends of the charring test specimens (see **Table 4**). The verification and evaluation of charring rate of the specimens were conducted in accordance with EN 13381-7 [17].

Table 4. Properties of the test specimens

Beam	Untreated	Fire retardant treated
Identification	A	B
Density[kg/m³]	799.7	798.4
Depth of the instrumented beam [mm] h_{ins}	123	124
Moisture Content	13.2%	12.1%

2.3 Installation of thermocouples for charring test specimens

Both charring test specimens were equipped with three measurement stations, each containing eight thermocouples. **Fig.3** and **Fig. 4** show the instrumented beam with thermocouple placements, as recommended in EN 13381-7 [17]. The thermocouples were positioned at the center of the beam, with a minimum horizontal distance of 6 mm.

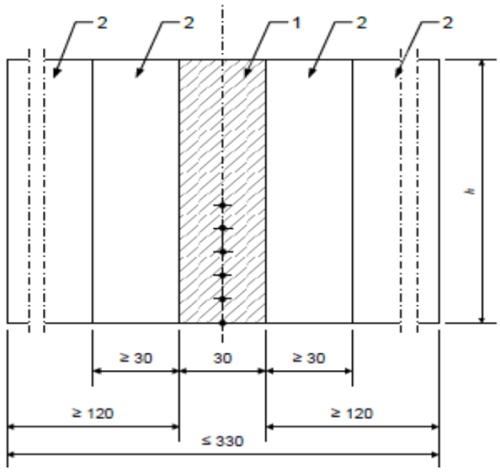


Fig. 3. Charring specimen with one and three instrumented beams protected by outer beams as given by EN 13381-7 [17].

Legend:

1. Instrumented timber beam
2. Non- instrumented timber beam

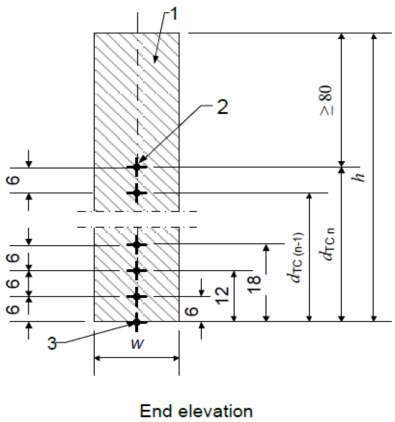


Fig. 4. Side elevation of the instrumented beam, dimensions in mm

Type K thermocouples were used for instrumentation, inserted from both sides of the instrumented beams with a horizontal spacing of 20 mm. Both charring test specimens had approximate dimensions of 1650 mm × 270 mm × 120 mm (length × width × depth). The density, including moisture content, was determined using end cuts from the glulam beams, each approximately 365 mm in length. **Fig. 5** illustrates the arrangement of 24 Type K thermocouples, organized into three stations or groups, each comprising eight thermocouples. The thermocouples were positioned with a total vertical spacing of 42 mm and a horizontal spacing (along the length) of 20 mm.

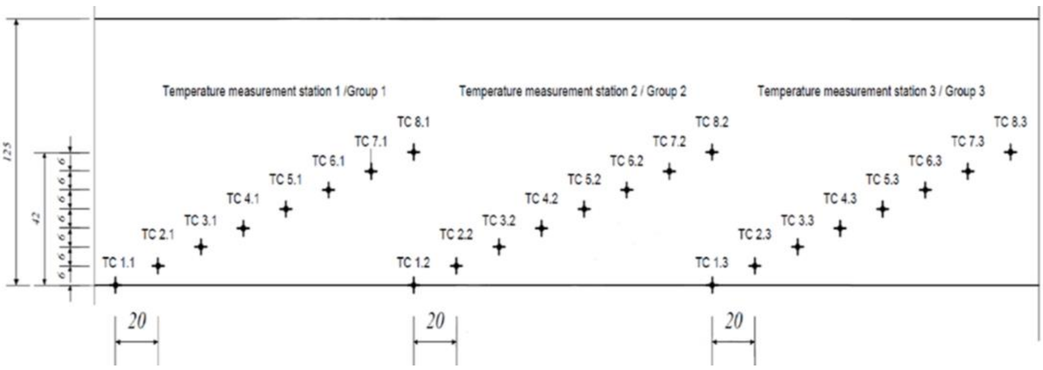


Fig. 5. Instrumentation of the instrumented beam of the charring test specimens with 3 temperature measurement stations.

2.4 Installation and mounting of the test specimen

Test specimens A (untreated) and B (fire-retardant treated) were mounted on the model-scale furnace by SP (see **Fig. 6**). A strip of stone wool, 50 mm wide with a density of 30 kg/m ^{3}, compressed to approximately 20 mm, was placed between the test specimens.

The charring rate was tested in accordance with EN 13381-7, a standard that applies to ceilings, fire resistance, building materials, and floors in general. Theoretically, the depth of char is typically calculated for standard fire exposure, which is primarily one-dimensional, with corner rounding explicitly considered [1]. However, in this experiment, the effect of corner rounding was disregarded for this reason.

The furnace temperature was measured using two plate thermometers, in accordance with EN 1363-1 [18], placed approximately 100 mm below the fire-exposed lower surface of the test specimen. Meanwhile, the furnace pressure was controlled by a pressure transmitter installed 250 mm below the fire-exposed lower surface of the test specimen. The furnace pressure was set to 10.9 Pa to achieve an overpressure of 13Pa at the fire-exposed lower surface. Additionally, the ambient air temperature was measured before and after the fire test.

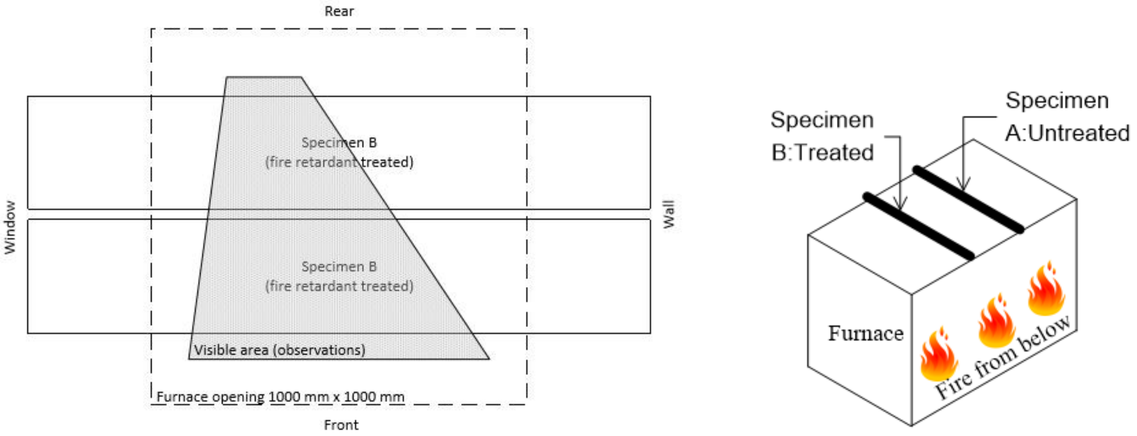
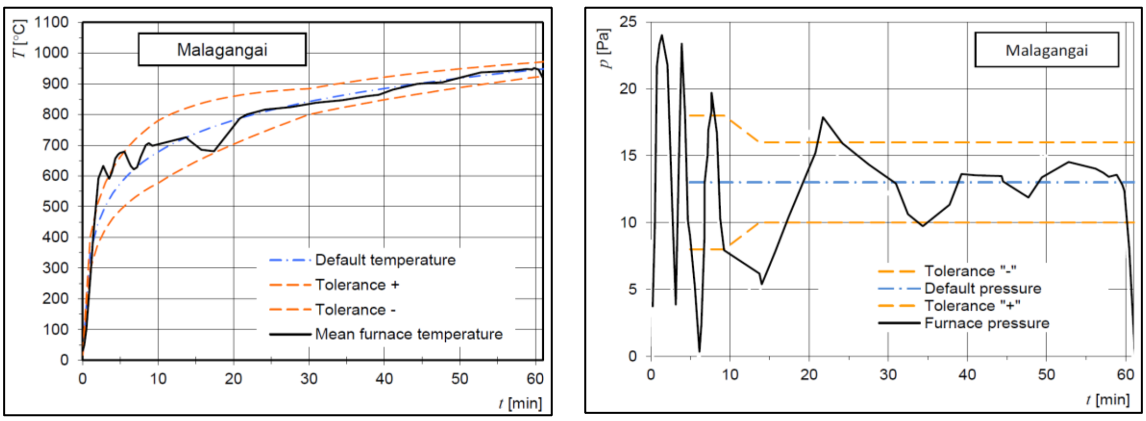


Fig. 6. Arrangement of the specimens on the furnace

The room temperature during the test was estimated to be 22 ℃. The accuracy of temperature measurements was determined to $u_{max} = \pm 0.3$ ℃. However, due to the nature of fire resistance testing and the inherent challenges in quantifying measurement uncertainties, it is not possible to specify a definitive degree of accuracy for the results. Both charring test specimens were equipped with 24 thermocouples each, distributed across three measurement stations.

3 Results and Discussions

3.1 Furnace performance



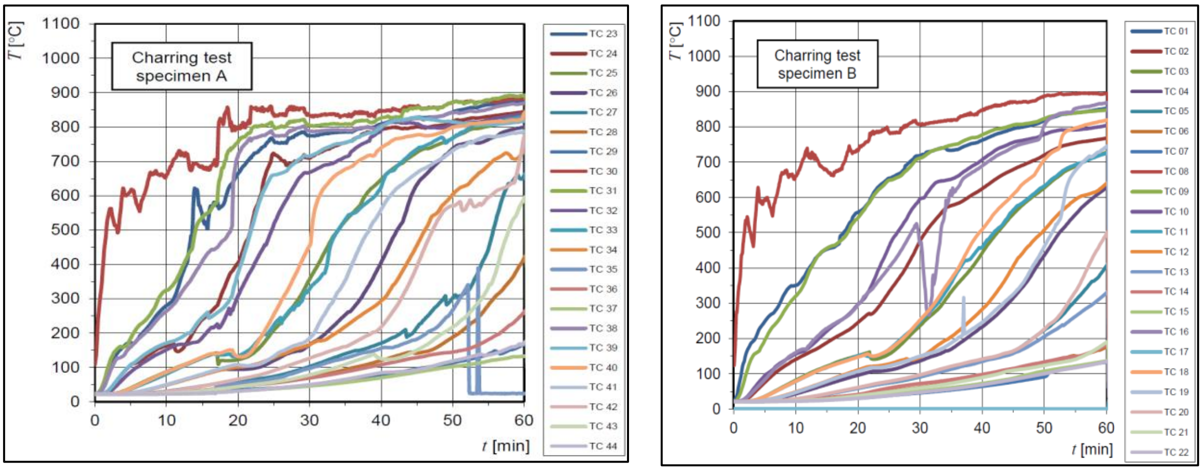
(a) (b)

Fig. 7. Furnace and the default temperature with the tolerated deviation specified in EN 1363-1 for; (a) untreated glulam and (b) fire-retardant treated glulam

Fig. 7 illustrate the furnace temperature and pressure in comparison with the default temperature and its tolerated deviation as specified in EN 1363-1 for Malagangai glulam, untreated and fire-retardant treated. During the first five minutes, when the temperature was below 500 ℃, the furnace temperature graph appeared moderately smooth. However, upon exceeding 600 ℃ between 7 and 20 minutes, fluctuations in the temperature curve were observed. After the 20-minute mark, the temperature stabilized and aligned with the default temperature.

3.2 Specimens' temperature measurement

Timber measurements in the test specimens during fire exposures are given in **Fig. 8** for untreated and treated glulam beams. From the data plotted in **Fig. 8**, it is apparent that the temperatures for both specimens are equal and thus valid for comparison purposes.

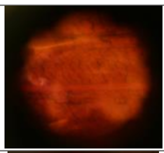
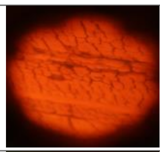
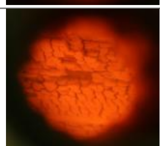
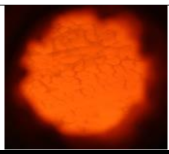


(a) (b)

Fig. 8. Temperature measurements in charring test for; (a) specimen A (untreated) and (b) specimen B (fire retardant)

A clear trend of increasing temperature is observed from the start (0 minutes) up to minute 30. All thermocouples functioned properly, and this type of TC was able to resist temperatures up to 1200 ℃. Both specimens show an initial rapid increase in temperature within the first 10 minutes, especially for the thermocouples positioned closer to the fire-exposed side. After this initial rise, the temperature continues to increase more gradually before stabilizing for some thermocouples. After exceeding 800 ℃, the temperature curve remains relatively unchanged until minute 60. This is because of the formation of char prevents the fire from spreading deeper into the timber core [10, 19, 20]. The highest temperatures (~900-1000 ℃) are reached around 50-60 minutes, particularly for the most exposed layers.

Table 5. Exposed surface observed from the rear end of the furnace

No	Surface Conditions	Time (m:s)	No	Surface Conditions	Time (m:s)
1		16:54	2		25:30
3		28:36	4		30:30
5		49:36	6		51:24

Specimen A shows greater fluctuations in temperature, suggesting more severe charring and potential structural instability. The temperature rise is more irregular, which may indicate delamination, cracks, or structural degradation occurring at different time points as indicated at 51:15 (min: sec) in **Table 5**. Meanwhile, specimen B demonstrates a smoother temperature progression, which could be attributed to the fire-retardant treatment or better integrity of the material under fire exposure. Specimen A reaches higher peak temperatures faster, which may indicate more aggressive burning compared to Specimen B.

Specimen B likely has better fire resistance compared to Specimen A, as evidenced by more gradual heating and less variation in temperature readings. The significant fluctuations in Specimen A suggest greater structural degradation over time, leading to potential delamination or failure. The fire-retardant coating in Specimen B appears to have effectively slowed down heat penetration and charring.

Table 5 presents a visual representation of the fire-exposed surface of the test specimen at different time intervals, as observed from the rear end of the furnace. The images illustrate the progressive thermal degradation and charring of the timber as the fire exposure continues. The progression from initial heating to full charring is evident over time.

At initial heating phase (16:54 – Image 1), the surface appears to be in the early stages of thermal exposure, showing initial discoloration and surface cracks due to heat expansion. Moisture evaporation and pyrolysis begin, but the material is still largely intact. Moisture evaporation and liquid was observed seeping from the glue lines of Specimen B can be seen in **Fig. 9**.

Fig.9. Moisture evaporation and foam on the surface of the charring test specimen B (fire-retardant treated)

At intermediate stage (25:30 - 30:30 - Images 2, 3, and 4), surface cracks become more pronounced, and the color deepens due to carbonization. As the surface temperature exceeds ~300 ℃, the timber is undergoing pyrolysis, leading to the formation of a protective char layer. By 30:30, deeper cracks and material loss can be observed, suggesting the onset of structural degradation.

At advanced stage (49:36 - 51:24 - Images 5 and 6), the timber surface is severely charred, glowing red due to high heat retention. Some portions have delaminated or fallen off, exposing inner layers and further combustion occurs inside exposed cavities. In general, Specimen A has bigger flame spread than Specimen B.

(a) (b)

Fig. 10. Charred specimens after extinguishing work; (a) Wall side (top end in the image) and (b) Window side (bottom end in the image) with fire retardant treated specimen (left) and untreated specimen (right)

There is a notable difference between untreated timber and fire-retardant-treated timber, with the latter significantly reducing flame spread, as previously discussed. **Fig. 10** shows the surface conditions of the specimens after approximately 60 minutes of fire exposure from both the wall and window sides. These images clearly show that glulam without fire retardant experiences greater material loss.

3.3 Charring Rate Assessment

The one-dimensional charring rate β_0 was calculated in accordance with EN 13381-7:2014. Using the determined times at 300°C, $t_{300,i,j}$, the charring rate β_{ij} between 2 consecutive depths for each temperature measurement station j is calculated according to Equation 1.

$$\beta_{i,j} = \frac{d_{i+1} - d_i}{t_{300,i,j} - t_{300,i}} \quad (1)$$

The mean value β_j for all measurement stations j were calculated following Equation 2.

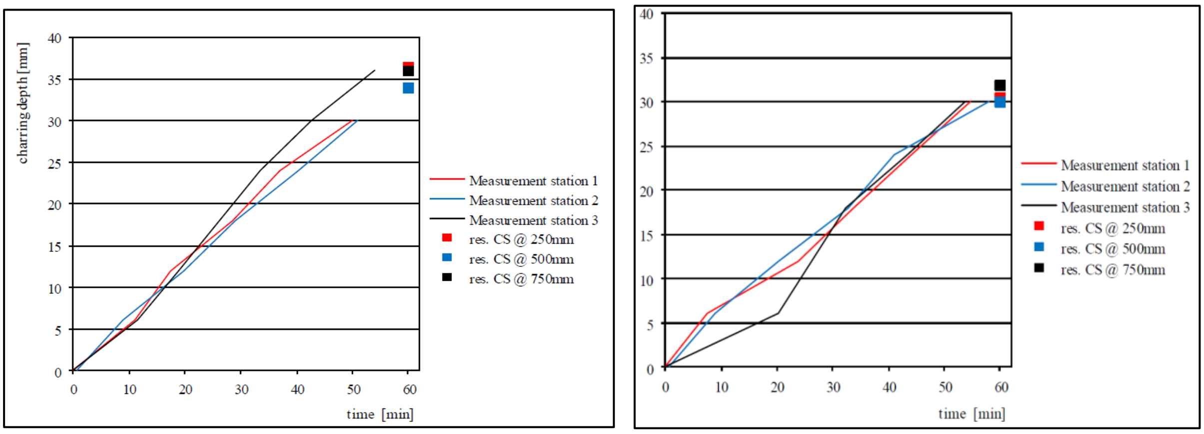
$$\beta_j = \sum_{i=1}^{n} \frac{\beta_{i,j}}{n} \quad (2)$$

When no measurement was available for thermocouples at the surface of the charring test specimen, the start of charring was assumed to be at t =0 minutes.

3.3.1 Char depth measurement

Fig.11 illustrates the relationship between char depth and time for Specimens A and B at Stations 1, 2, and 3, corresponding to timber sections located at 250 mm, 500 mm, and 750 mm along the specimen length, respectively. Both graphs indicate an increase in char depth over time, demonstrating the typical behavior of timber exposed to fire. Initially, the charring rate is relatively slow, but after approximately 10–20 minutes, it accelerates as the heat penetrates deeper into the material.

The graph for untreated glulam shows a slight variation in char depth among measurement stations, with the third station (750 mm) experiencing the most significant charring towards the end. In contrast, the graph for fire-retardant treated glulam shows a more consistent charring rate across the three measurement stations, suggesting more uniform fire exposure. At the 60-minute mark, both graphs indicate a final char depth of approximately 30 to 35 mm. However, in the graph for untreated glulam, the residual cross-section of timber at 750 mm appears to be more affected compared to the graph for fire-retardant treated glulam.



(a) (b)

Fig. 11. Charring depth and the residual cross-section measurements at Stations 1, 2 and 3 for; (a) Specimen A and (b) Specimen B

3.3.2 Charring test Specimen A (untreated timber)

Table 5, **Table 6**, and **Table 7** present the charring readings for three stations (1, 2, and 3) of untreated glulam. All charring rate analyses were conducted when the thermocouples reached approximately 300 ℃, as this is the temperature at which timber begins to char [21–24].

These tables show an insignificant difference in charring rate values between the stations (approximately 10%). **Table** indicates that the highest charring rate was recorded by the thermocouples at position 3. However, the actual mean charring rate, β_j for untreated glulam calculated in accordance with Eq. 2 of EN 13381-7:2014, is 0.63 mm/min.

Table 5. Station 1 charring rate measurement

Group	Measurement Station 1						
Thermocouple	TC 23	TC 24	TC 25	TC 26	TC 27	TC 28	TC 29
Position	2	3	4	5	6	7	8
time [min]/depth [mm]	6	12	18	24	30	36	42
t_{300} [min]	11.0	17.5	28.5	37.1	50.0	-	-
$\beta_{i,j}$ [mm/min]	0.54	0.94	0.55	0.69	0.47	-	-
β_j [mm/min]	0.64						

Table 6. Station 2 charring rate measurement

Group	Measurement Station 2							
Thermocouple	TC 30	TC 31	TC 32	TC 33	TC 34	TC 35	TC 36	TC 38
Position	1	2	3	4	5	6	7	8
time [min]/depth [mm]	0	6	12	18	24	30	36	42
t_{300} [min]	0.7	8.9	19.9	29.0	40.4	51.0	-	-
$\beta_{i,j}$ [mm/min]	-	0.68	0.55	0.65	0.53	0.56	-	-
β_j [mm/min]	0.59							

Table 7. Station 3 charring rate measurement

Group	Measurement Station 3						
Thermocouple	TC 38	TC 39	TC 40	TC 41	TC 42	TC 43	TC 44
Position	2	3	4	5	6	7	8
time [min]/depth [mm]	6	12	18	24	30	36	42
t_{300} [min]	11.5	19.0	26.2	33.5	42.8	54.0	-
$\beta_{i,j}$ [mm/min]	0.52	0.81	0.83	0.64	0.53	-	-
β_j [mm/min]	0.67						

3.3.3 Charring test specimen B (treated timber with fire retardant)

Table 8. Station 1 charring rate measurement

Group	Measurement Station 1						
Thermocouple	TC 01	TC 02	TC 03	TC 04	TC 05	TC 06	TC 07
Position	2	3	4	5	6	7	8
time [min]/depth [mm]	6	12	18	24	30	36	42
t_{300} [min]	7.5	23.8	33.7	44.2	54.6	-	-
$\beta_{i,j}$ [mm/min]	0.80	0.37	0.61	0.57	0.58	-	-
β_j [mm/min]	0.58						

Table 9. Station 2 charring rate measurement

Group	Measurement Station 2							
Thermocouple	TC 08	TC 09	TC 10	TC 11	TC 12	TC 13	TC 14	TC 15
Position	1	2	3	4	5	6	7	8
time [min]/depth [mm]	0	6	12	18	24	30	36	42
t_{300} [min]	0.6	9.0	20.2	32.9	41.0	58.0	-	-
$\beta_{i,j}$ [mm/min]	-	0.67	0.53	0.47	0.74	0.35	-	-
β_j [mm/min]	0.55							

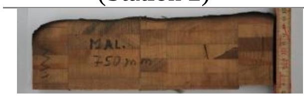
Table 10. Station 3 charring rate measurement

Group	Measurement Station 3					
Thermocouple	TC 16	TC 18	TC 19	TC 20	TC 21	TC 22
Position	2	4	5	6	7	8
time [min]/depth [mm]	6	18	24	30	36	42
t_{300} [min]	20.2	32.3	43.4	53.8	-	-
$\beta_{i,j}$ [mm/min]	0.30	0.99	0.54	0.58	-	-
β_j [mm/min]	0.60					

Meanwhile, Table 8, Table 9, and Table 10 present the charring rate values for Specimen B, which was treated with a fire retardant. The analysis method used is the same as that for Specimen A using Equations 1 and 2. What is interesting in this data is that the mean charring rate value, β_j, for Specimen B is 0.58.

A summary of the charring rate measurements derived from these data is provided in **Table 11** along with the residual cross-section.

Table 11. Charring rate of Specimens, A and B from different length positions

Specimen	**Residual cross-section Distance (mm)**	**Charring rate (mm/min)**	**Specimen**	**Residual cross-section Distance (mm)**	**Charring rate (mm/min)**
A (untreated)	 Length position 250 mm (Station 1)	0.64	B (treated)	 Length position 250mm (Station 1)	0.58
	 Length position 500 mm (Station 2)	0.59		 Length position 500mm (Station 2)	0.55
	 Length position 750 mm (Station 3)	0.67		 Length position 750mm (Station 3)	0.60

The untreated timber (Specimen A) has a smaller residual cross-section, meaning it has lost more material due to fire exposure. The treated timber (Specimen B) retains more material, confirming the protective effect of fire retardants.

The charring rate for untreated glulam is 0.63 mm/min which is smaller than the value in Eurocode 5 as shown here in **Table 2.** With the application of fire retardant, the charring rate of glulam is marginally enhancing the charring rate by 8%, reducing the charring rate to 0.58 mm/min.

The previous findings also support the present study, concluding that the application of fire retardants to timber can alter its combustion properties and reduce surface flame spread [25]. This is consistent with previous literature, which demonstrates that fire retardants can effectively reduce the charring rate of timber [26–29].

4 Conclusions and recommendations

The following conclusions can be drawn from this study:

i. The one-dimensional charring rate for Specimen A (untreated Malagangai timber) is 0.63 mm/min.

ii. The one-dimensional charring rate for Specimen B (Malagangai timber treated with fire retardant) is 0.58 mm/min.

iii. The charring rates of the tested glulam Malagangai timber meet the Eurocode 5 requirements for a characteristic density of $\geqslant$ 450 kg/m³ .

iv. Fire retardant marginally improved the charring rate of Malagangai glulam.

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CRediT authorship contribution statement

Zulhazmee Bakri: Analysis and Writing. **Zakiah Ahmad**: Conceptualization, Funding acquisition, Supervision, Writing and editing. **Atikah Fatma Md Daud**: Analysis. **Simon Aicher**: Arranging for the test at SP Wood Technology, Supervision and Review of the report.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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