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Effects of Fire-Retardant Treatment, Fire Scenarios, and Face Orientation on the Charring Behaviour of Indigenous Timber Species

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Abstract

The increasing use of timber as a sustainable construction material has heightened the need for improved understanding of its behaviour under fire exposure, particularly for indigenous timber species whose fire performance data remain limited. This study investigates the effects of fire-retardant treatment, fire scenarios, and face orientation on the charring behaviour of selected indigenous Nigerian timber species, namely Erythrophleum suaveolens and Anogeissus leiocarpa. Timber specimens were subjected to three fire exposure scenarios: FT-I, representing the ISO 834 standard fire; FT-II, representing a long-cool parametric fire; and FT-III, representing a short-hot parametric fire. Treated and untreated specimens were exposed under different face orientations, and char depth and charring rate were determined at predetermined exposure intervals. The results showed that charring rate varied with timber species, treatment condition, and fire scenario. Erythrophleum suaveolens consistently recorded lower charring rates than Anogeissus leiocarpa under all investigated conditions. Under FT-I, untreated E. suaveolens and A. leiocarpa recorded mean charring rates of 0.5196 and 0.7160 mm/min, respectively, which decreased to 0.4270 and 0.5782 mm/min after treatment. The highest charring rates occurred under FT-III, while treatment reduced charring rates by 12.21–25.51% across the investigated species and fire scenarios. Face orientation also influenced charring behaviour, with end-grain surfaces showing greater susceptibility to charring than side surfaces. Char depth increased progressively with fire exposure time, while treated specimens exhibited slower char development. Statistical analysis indicated that lognormal, Weibull, and normal distributions provided adequate descriptions of the observed charring rates. The findings demonstrate the potential of the fire-retardant treatment for reducing charring and provide useful experimental data for improving fire protection and fire-safe design of indigenous timber structures.

Keywords: *Charring Behaviour, Face Orientation, Fire-Retardant Treatment, Indigenous Timber, Parametric Fire.*

1.0 Introduction

All Timber has served as a key construction material for centuries due to its advantageous strength-to-weight ratio, ease of manipulation, renewability, and comparatively lower environmental impact when set against traditional materials like steel and reinforced concrete. Recently, heightened focus on sustainable construction and reducing carbon emissions has sparked renewed global interest in utilizing wood for structural purposes, especially in residential and low-rise buildings [1]. In contrast to steel and concrete, wood is a renewable resource that sequesters atmospheric carbon during its lifespan, thus aiding in climate change mitigation and promoting sustainable building methods. Nonetheless, the widespread use of wood for structural purposes is frequently limited by worries about its behavior when exposed to fire. Timber is a flammable substance that experiences thermal degradation when exposed to high temperatures, resulting in pyrolysis, ignition, and the development of a char layer. While this char layer serves as an insulating shield that slows down additional heat penetration into the timber member, ongoing exposure to fire gradually reduces the effective cross-sectional area, thereby lowering the load-bearing capability of timber structural components [2, 3]. Therefore, it is essential to comprehend the charring characteristics of timber for the fire-safe design of timber structures. Liu and Fischer [4] observed that the charring rate of timber decreased as the density increased, especially for timber densities exceeding 700 kg/m^3; nevertheless, a consistent charring rate of 0.65 mm/min was deemed appropriate for CLT and glulam subjected to a standard fire for up to 180 min if the CLT did not experience char fall-off. Friquin [5] pointed out that it is not possible to establish which properties or factors have the greatest influence on the charring rate of wood because of the large differences in the test conditions and methods, as well as among wood species and measurement techniques. Wang et al. [6] concluded that fire-retardant coatings do not have a significant effect on the overall charring rate, since they help to lower the internal temperatures during the early stages of fire exposure. The fire behaviour of timber is affected by a number of factors, such as the type of timber, its density, moisture content, the direction of the grain, the cross-sectional dimensions, the intensity of the fire, the length of time it is exposed to the fire, and the direction in that the surface is exposed [7]. Of these factors, the anatomical features of the different timber species have a significant effect on the rate of heat transfer and on the formation of char. Hardwood species that are dense tend to have lower charring rates than those that are low in density since their tightly packed cellular structure slows down thermal penetration and combustion [8]. In a similar way, moisture content is important in delaying ignition, as some of the heat absorbed is used up in evaporating the moisture before pyrolysis can start [2]. The variation caused by fire exposure is considerable and depends on the properties of the fuel, the ventilation conditions, the shape of the compartment, and the density of the fuel load. Although standard fire curves like ISO 834 offer a simplified version for use in structural fire testing, real building fires generally show much different temperature-time profiles. Since the charring behaviour of timber is strongly influenced by the thermal environment, it is useful to assess timber under both standard and parametric fire conditions in order to gain a more complete understanding of its fire performance. A further important point is the direction of the timber surface which is exposed. The longitudinal, radial, and tangential sides have different anatomical structures and therefore show different characteristics with regard to heat transfer and combustion behaviour. It has already been demonstrated in earlier studies that the direction in which the surfaces are exposed may affect ignition time, charring rate, crack formation, and the total fire resistance because of the variations in grain direction and cellular arrangement [9]. Yet this factor has attracted considerably less attention than other variables that influence the fire performance of timber, especially when it comes to indigenous tropical hardwood species.

Fire-retardant treatments have been created in order to enhance the fire resistance of timber. Among the fire-retardant chemicals most commonly used are boron compounds, especially borax (sodium tetraborate), since they are relatively cheap, environmentally acceptable and effective in reducing the flammability of wood. Fire-retardant works by encouraging the formation of char, inhibiting the emission of combustible volatile gases and decreasing the spread of flame during combustion [10]. Furthermore, as well as improving the fire performance, fire-retardant also protects against biological decay caused by fungi and insects, so that it functions as a multifunctional preservative in the case of timber [11]. While many studies have been carried out on the fire-retardant properties of boron compounds, the majority of the existing literature is concerned with temperate softwood species that are commonly used in Europe and North America. Previous studies have established the structural and mechanical characteristics of selected Nigerian timber species, providing a basis for their application in structural systems and further investigation of their performance under fire conditions [12, 13, 14, 15].There is still very little information available on the effectiveness of fire-retardant treatment for indigenous tropical hardwood species which are usually employed for structural purposes in developing countries, especially when considering different fire scenarios and various face orientations. Moreover, most of the earlier investigations have mainly focused on ignition characteristics or average charring rates, whereas only a small number of studies have looked at the combined effects of timber species, fire scenario, face orientation, and treatment on the time-dependent development of char depth. In Nigeria indigenous hardwoods such as Erythrophleum suaveolens and Anogeissus leiocarpa are commonly used for structural purposes due to their favourable mechanical properties and the fact that they are locally available. Yet there is still very little information on their charring characteristics when exposed to real-fire conditions. It is therefore necessary to obtain reliable experimental data concerning the charring behaviour of these types of wood if fire-safe timber design is to be improved and if indigenous timber is to be more widely adopted in sustainable building.

This study uniquely combines fire-retardant treatment, multiple fire scenarios, and face orientation to characterize the charring behaviour of two Nigerian indigenous timber species. It establishes species-specific charring rates and variability and uses these experimental results in structural fire and reliability assessment, providing new data for more realistic fire-resistance evaluation of indigenous Nigerian timber. In light of this, the present study examines the effect of borax treatment, different fire situations, and the way in which the surface of the timber is presented on the charring behaviour of a number of native timber species. It looks at the charring rates, the effectiveness of the treatment, the influence of the face orientation, and the accumulation over time of char depth under both standard and varying fire conditions. The results are expected to enhance the understanding of how timber behaves in a fire and to offer useful information for improving fire protection measures and the structural fire design of timber components.

2.0 Materials and Methods

2.1 Materials

2.1.1 Timber Species

The research made use of two native Nigerian hardwoods, specifically Anogeissus leiocarpa and Erythrophleum suaveolens. *Anogeissus leiocarpa* (African Birch), designated as "W," was sourced from timber sheds in Edo State, Nigeria, and is locally known as Atara, Marike, Ayin (Yoruba), and Marke (Hausa); it is widely available in Nigerian markets and is commonly used for roof trusses, furniture, joinery, and general construction, with whitish to pale-brown heartwood. *Erythrophleum suaveolens* (Tali), designated as "R," was sourced from timber sheds in Ondo State, Nigeria, and is locally known as Gwaska, Erun (Yoruba), and Tali (trade name); it is moderately available at a higher cost class and is commonly used for heavy construction, load-bearing members, bridge components, and railway sleepers, with reddish-brown heartwood of distinct colour.

The timber samples were then visually graded prior to preparing the specimens in order that only sound and defect-free specimens should be chosen for the experimental programme.

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a) Anogeissus leiocarpa *b) Erythrophleum suaveolens*

Plate 1: Timber Species

2.1.2 Fire-Retardant Treatment Solution

A fire-retardant solution was made and put on the timber samples in order to assess its effectiveness under various fire exposure conditions. The formulation of the treatment was developed on the basis of the principles suggested by [16] and then altered to improve its appropriateness for tropical hardwood species. The makeup of the fire-retardant solution is given in Table 1.

Table 1: Fire-Retardant Treatment Formulation (per litre of water)

Chemical Component	Quantity	Function
Zinc chloride ($ZnCl_2$)	100 g	Flame inhibitor and char promoter
Ferric chloride ($FeCl_3$)	50 g	Smoke suppressant
Boric acid (H_3BO_3)	50 g	Promotes glassy protective layer formation and provides endothermic cooling
Ammonium phosphate ($(NH_4)_2HPO_4$)	50 g	Enhances char formation and improves flame retardancy

2.2 Methods

The experimental programme was conducted using the following equipment: Electric muffle furnace, Digital weighing balance, Vernier caliper, Moisture meter, Thermocouples, Digital thermometer, Stopwatch, Steel ruler, Circular saw, Drying oven and Digital camera for specimen documentation.

a) Digital Weighing Balance b) Stop Watch

Plate 2: Some Instruments Used

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2.2.1 Fire Testing Furnace

Fire exposure tests were conducted using a gas-fired furnace with internal dimensions of 1.5 m × 1.5 m × 1.5 m and a maximum operating temperature of 1200°C. The furnace temperature was controlled using a programmable logic controller (PLC). Furnace temperature data were logged at 10-second intervals throughout each fire exposure test.

a) Fire Testing Furnace b) Specimens in the Furnace

Plate 3: Furnace and specimen in the Furnace

Plate 4: Post-Test Specimen Showing Char Layer

2.2.2 Specimen Preparation

Timber specimens measuring 300 mm × 150 mm × 75 mm were prepared and used for the study. The specimens were visually inspected to ensure that only sound and defect-free timber was selected, after which they were cut to the required dimensions, conditioned to equilibrium moisture content, and labelled according to timber species, treatment condition, fire scenario, and specimen identification. A total of 120 specimens were prepared, comprising 10 specimens for each of the 12 experimental groups formed by two timber species, two treatment conditions (treated and untreated), and three fire exposure scenarios. Face orientation was evaluated on the same specimen and was therefore not treated as an additional factor in specimen allocation; hence, the radial, tangential, and longitudinal orientations were assessed using the same specimens within each experimental group.

2.2.3 Fire-Retardant Treatment

The timber specimens that had been prepared were split into two groups: one treated and the other not treated. The ones that were not treated acted as the control group, and the rest were treated with the new fire-retardant solution. The treatment process involved the following steps:

1. Prepare the fire-retardant solution in accordance with the formulation given in Table 1.
2. The chemical constituents were dissolved in water, with the water being constantly stirred until a homogeneous solution had been obtained.

3. Specimens were oven-dried at 60°C to constant mass.
4. Treatment solution was heated to 60°C to enhance penetration.
5. Place the timber specimens into the prepared solution and immerse them for 24 hours.
6. Allow the treated specimens to dry in air under laboratory conditions.
7. Treated specimens were reconditioned at 20 ± 2°C and 65 ± 5% RH for 14 days.
8. Before the fire testing, the oven conditioning of the treated specimens was carried out until a constant mass had been reached.
9. Final mass was recorded to determine chemical retention, with an average retention of 45–60 kg/m³.

2.2.4 Experimental Variables

The experimental programme considered both independent and dependent variables. The independent variables were timber species, fire-retardant treatment condition, fire scenario, face orientation, and fire exposure time, while the dependent variables were charring rate (mm/min) and char depth (mm).

2.2.5 Fire Exposure Scenarios

In order to examine the charring behaviour of the timber specimens, three different fire exposure situations were looked at.

2.2.6 Standard Fire

The standard fire exposure followed the ISO 834 standard fire curve presented as $\theta g,t=20+345\log10(8t+1)$

2.2.7 Long-Cool Parametric Fire

The long-cool parametric fire scenario represented prolonged fire exposure with a relatively lower peak temperature. Give the heating equation, $t^* = 0.63t$, peak temperature (891.85 °C at 43 min) and cooling equation.

However, the three fire exposure scenarios were selected to provide distinct thermal exposure conditions for assessing the charring behaviour of the selected timber species. FT-I represents the ISO 834 standard fire and provides the conventional reference condition. FT-II represents a long-duration, relatively low-intensity parametric fire, while FT-III represents [insert the actual definition of FT-III]. The selection of these scenarios enables comparison of timber charring under different fire severity and duration characteristics.

2.2.8 Short-Hot Parametric Fire

The short-hot parametric fire scenario represented rapid heating characterized by a high peak temperature over a short duration. Give the heating equation with $t^* = 23.86t$, peak temperature (1256.57 °C at 20 min) and cooling equation.

2.2.9 Face Orientation

The timber specimens were tested with the different exposed face orientations namely a radial face, a tangential face and a longitudinal face. The effect of the direction in which a surface was presented on charring behaviour was determined by comparing the charring rates and the way char depth developed for each exposed surface.

2.2.10 Fire Testing Procedure

The specimens were exposed to the designated fire scenarios in the furnace. Furnace temperature was recorded at 10-second intervals through the PLC controller throughout each test. Following completion of the prescribed fire exposure, each specimen was removed from the furnace and allowed to cool before being prepared for char-depth measurement.

2.2.11 Determination of Charring Rate

The one-dimensional charring rate (β) was determined using Equation 1

$$\beta = \frac{d_{char}}{t}\ (mm/min) \tag{1}$$

Where d_{char} is the charring depth and t is the time.

2.2.12 Determination of Char Depth

Char depth was determined once after each fire exposure. The specimen was cut to expose the charred and uncharred timber interface, and the thickness of the charred layer was measured directly at designated locations using a Vernier caliper. The measured values were used to determine the representative char depth and charring rate for each specimen

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3.0 Results and Discussions

3.1 Charring Behaviour of Selected Indigenous Timber Species under Different Fire Scenarios

Figure 1 presents a comparison of the mean charring rates of untreated and fire-retardant-treated specimens of *Anogeissus leiocarpa* and *Erythrophleum suaveolens* under the three fire exposure scenarios. The results show that charring rate varied with timber species, treatment condition, and fire scenario. Under the FT-I standard fire scenario, the untreated *Anogeissus leiocarpa* exhibited a mean charring rate of 0.7160 mm/min, compared with 0.5782 mm/min for the treated specimens. Similarly, *Erythrophleum suaveolens* recorded a mean charring rate of 0.5196 mm/min in the untreated condition, which decreased to 0.4270 mm/min following treatment. Thus, treatment reduced the mean charring rate of both species under FT-I. Under the FT-II long-cool parametric fire scenario, the mean charring rate increased to 0.8470 mm/min for untreated *Anogeissus leiocarpa* and 0.6720 mm/min for untreated *Erythrophleum suaveolens*. Following treatment, these values decreased to 0.7436 mm/min and 0.5414 mm/min, respectively.The highest mean charring rates were observed under the FT-III short-hot parametric fire scenario. Untreated *Anogeissus leiocarpa* and *Erythrophleum suaveolens* recorded mean charring rates of 0.9958 mm/min and 0.7950 mm/min, respectively. Treatment reduced these values to 0.8532 mm/min and 0.5922 mm/min, respectively and similar pattern was recorded by [17, 18]. Moreover, the lower charring rates recorded for the treated specimens may be attributed to the protective effect of the fire-retardant treatment, which reduced the rate of thermal degradation and delayed char formation during fire exposure. Under FT-I, the treatment resulted in approximately 19.2% and 17.8% reductions in the mean charring rates of *A. leiocarpa* and *E. suaveolens*, respectively. It may be due to the formation of a thick char layer from the retardant itself, which acts as an insulating barrier [19] The difference between the two species also suggests that the effectiveness of the treatment is influenced by their inherent material characteristics. The *Erythrophleum suaveolens* consistently exhibited lower charring rates than *Anogeissus leiocarpa* under all three fire scenarios and treatment conditions. The results also indicate that increasing fire severity was associated with increased charring rate, while the fire-retardant treatment reduced charring in both timber species. However, the magnitude of the treatment effect varied with timber species and fire scenario.

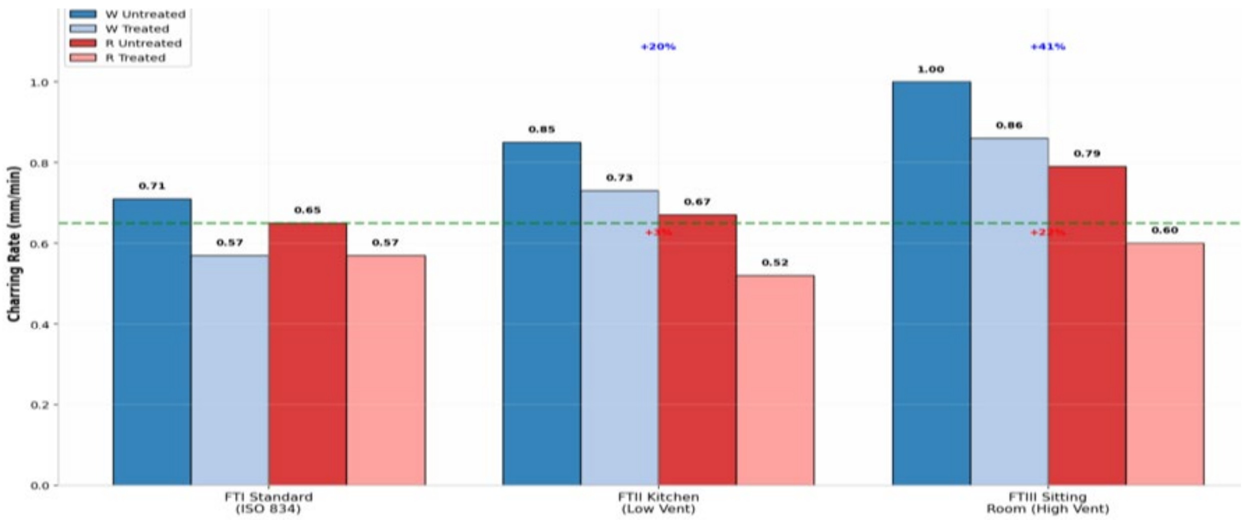

Figure 1: Comparison of Charring Rates of Treated and Untreated Timber Species under Different Fire Scenarios

3.2 Effects of Face Orientation on the Charring Behaviour of Selected Indigenous Timber Species

Figure 2 shows the effect of face orientation on the charring behaviour of untreated and fire-retardant-treated specimens of Anogeissus leiocarpa and Erythrophleum suaveolens in the three different fire scenarios. In each case the base-to-side charring ratio was above 1.0, which means that the end-grain charred more quickly than the side surfaces since it is more permeable and has a higher rate of heat penetration. The base-to-side charring ratio increased as the fire severity increased, the greatest values being obtained in the FT-III (high-ventilation) fire scenario, which proves that greater exposure to intense fire increased the end-grain's susceptibility to thermal degradation. In every fire scenario, Erythrophleum suaveolens showed a lower base-to-side charring ratio than Anogeissus leiocarpa, which means that it had a more even charring behaviour and was more resistant to fire penetrating in a directional manner. The fire-retardant treatment lowered the base-to-side charring ratio for both types of timber, proving that it is effective at reducing the vulnerability of the end grain and at promoting a more uniform development of char. Yet the degree of improvement was less noticeable in the more severe FT-III fire scenario, implying that the treatment became less effective as the fire intensity increased. The findings show that face orientation, type of timber, the kind of fire, and fire-retardant treatment all had an effect on charring behaviour; they underline the need to take end-grain exposure into account when carrying out fire-safe design and detailing of timber structural members, especially in severe fire situations.

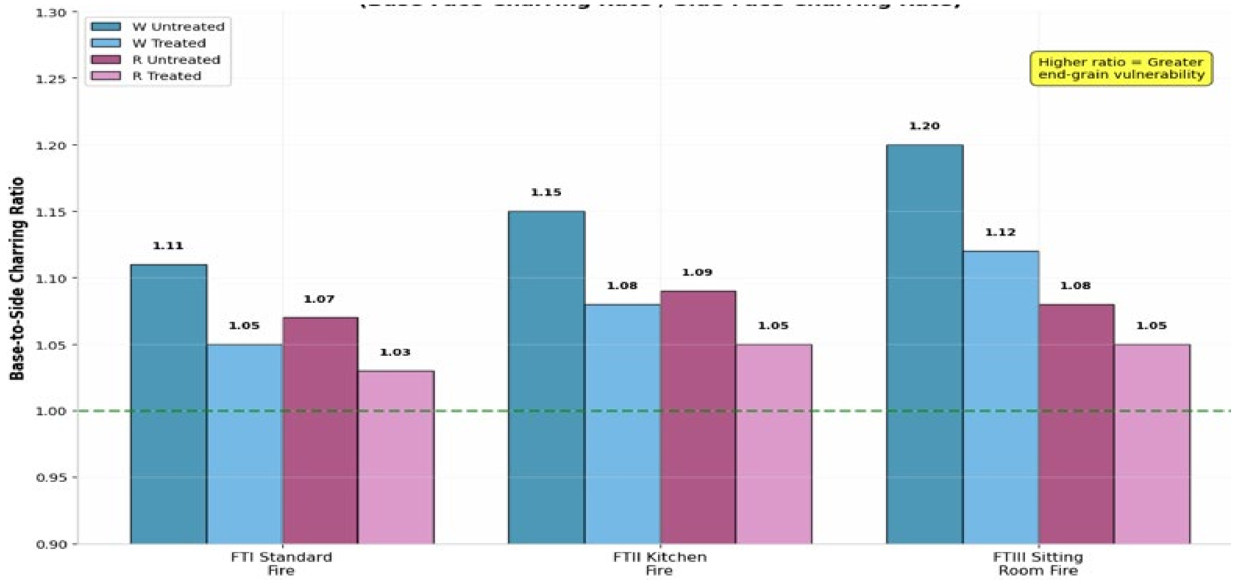

Figure 2: Effect of Face Orientation on the Charring Behaviour of Treated and Untreated Timber Species under Different Fire Scenarios

3.3 Effects of Timber Species and Fire Scenario on Fire-Retardant Treatment Effectiveness

Figure 3 and Table 2 show the effectiveness of the fire-retardant treatment in reducing the charring rates of *Anogeissus leiocarpa* and *Erythrophleum suaveolens* under the three fire scenarios. The results indicate that the effectiveness of the treatment varied with both timber species and fire scenario. For *Erythrophleum suaveolens*, the treatment reduced the charring rate by 17.82%, 19.43%, and 25.51% under FT-I, FT-II, and FT-III, respectively. For *Anogeissus leiocarpa*, reductions of 19.25%, 12.21%, and 14.32% were obtained under FT-I, FT-II, and FT-III, respectively. The treatment therefore reduced charring in both timber species under all three fire scenarios, with the greatest reduction observed for *Erythrophleum suaveolens* under FT-III. However, fire-retardant coatings do not significantly affect the overall charring rate, they help to reduce internal temperatures in the early stages of fire exposure [17].The results indicate that the effectiveness of the fire-retardant treatment depended on both timber species and fire exposure scenario.

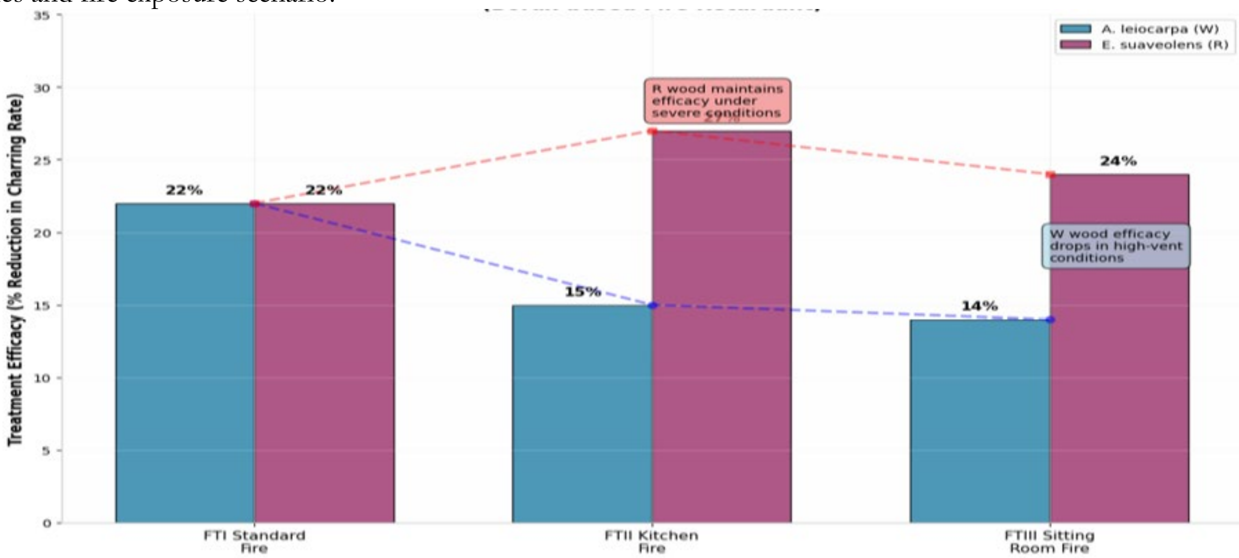

Figure 3: Variation in Fire-Retardant Treatment Effectiveness across Timber Species and Fire Scenarios

Table 2: Effectiveness of the Fire-Retardant Treatment in Reducing Charring Rate

Timber Species	Fire Scenario	Treated Charring Rate (mm/min)	Untreated Charring Rate (mm/min)	Reduction (%)
E. suaveolens	FT I	0.4270	0.5196	17.82
E. suaveolens	FT II	0.5414	0.6720	19.43
E. suaveolens	FT III	0.5922	0.7950	25.51
A. leiocarpa	FT I	0.5782	0.7160	19.25
A. leiocarpa	FT II	0.7436	0.8470	12.21
A. leiocarpa	FT III	0.8532	0.9958	14.32

3.4 Time-Dependent Char Depth Accumulation under Different Fire Scenarios

Figure 4 shows how char depth developed with increasing fire exposure time for untreated and fire-retardant-treated specimens of Anogeissus leiocarpa and Erythrophleum suaveolens under the three different fire scenarios. The data indicate that, for all the specimens, char depth increased almost linearly with exposure time, which means that the cross-section of the timber was being lost progressively as a result of the fire exposure. Throughout the exposure period, untreated Anogeissus leiocarpa always had the highest char depths, while fire-retardant-treated Erythrophleum suaveolens showed the lowest values. This proves that both the type of timber and the fire-retardant treatment have a combined effect on reducing the progression of charring. The variation in the rate at which char depth built up depended on the fire scenario, the greatest increase being seen in the case of the FT-I standard fire since it had a longer exposure time, while FT-II and FT-III caused charring to progress more rapidly even though their exposure periods were shorter. [8] established that the charring depth in wood increases roughly linearly with time under constant high-temperature exposure, at least until significant char buildup occurs. A fire-retardant treatment always lowered the rate of char depth development for both types of timber, although the improvement was more evident in Erythrophleum suaveolens. Broadly speaking, the findings show that char depth increased as fire exposure time increased, and that the type of timber and the fire-retardant treatment had a significant effect on the rate of charring as well as on the residual cross-sectional dimensions of the timber members.

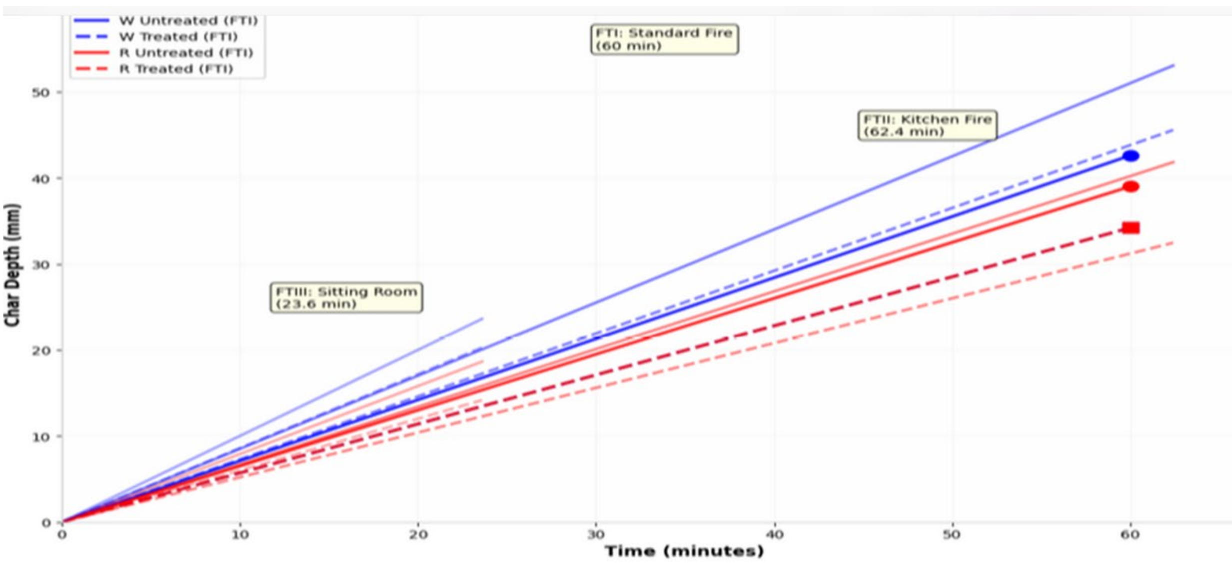

Figure 4: Time-Dependent Char Depth Development of Treated and Untreated Timber Species under Different Fire Scenarios

3.5 Statistical Analysis of Charring Rate

3.5.1 Probability Distribution of the Charring Rate of Treated and Untreated Timber under Different Fire Exposure Scenarios

Table 3 shows that the mean charring rate increased from FT-I to FT-III for both treated and untreated specimens. Treatment consistently reduced the charring rate in both timber species. For *Erythrophleum suaveolens*, the reduction was 17.82%, 19.43%, and 25.51% under FT-I, FT-II, and FT-III, respectively, while *Anogeissus leiocarpa* recorded reductions of 19.25%, 12.21%, and 14.32%, respectively. *Erythrophleum suaveolens* generally exhibited lower charring rates than *Anogeissus leiocarpa*, indicating better resistance to charring. The standard deviations were low, ranging from 0.0061 to 0.0347 mm/min, indicating relatively consistent results. The lognormal distribution was the best fit in eight of the twelve cases, followed by Weibull in three cases and normal

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distribution in one case. All KS p-values were greater than 0.05, confirming the adequacy of the selected probability distributions.

Table 3: Statistical Summary and Best-Fit Probability Distributions for Charring Rate

Timber Species	Treatment	Fire Test	Mean Charring Rate (mm/min)	Standard Deviation	Normal Distribution (R^2)	Best-Fit Distribution	KS p-value
R	Treated	FT I	0.4270	0.0182	0.9513	Lognormal	0.9840
		FT II	0.5414	0.0153	0.8959	Lognormal	0.5124
		FT III	0.5922	0.0094	0.9146	Lognormal	0.8047
	Untreated	FT I	0.5196	0.0347	0.8590	Weibull	0.6034
		FT II	0.6720	0.0283	0.8705	Weibull	0.7169
		FT III	0.7950	0.0061	0.7819	Normal	0.5186
W	Treated	FT I	0.5782	0.0110	0.9599	Lognormal	0.8753
		FT II	0.7436	0.0347	0.8926	Lognormal	0.5388
		FT III	0.8532	0.0281	0.9157	Lognormal	0.6506
	Untreated	FT I	0.7160	0.0288	0.9577	Lognormal	0.9927
		FT II	0.8470	0.0152	0.9455	Lognormal	0.9377
		FT III	0.9958	0.0305	0.9147	Weibull	0.7512

4.1 Conclusions

Based on the experimental investigation conducted, the following conclusions were drawn:

1. The fire scenario had a significant effect on the charring rates of the indigenous timber species studied, the charring rates rising as the severity of the fire increased, the highest rates being observed in the case of the FT-III (high-ventilation) fire scenario. Erythrophleum suaveolens always showed lower charring rates than Anogeissus leiocarpa, which shows that it has better inherent fire resistance.
2. The orientation of the face had a significant effect on the charring rates of the timber specimens, end-grain (base) surfaces always showing higher charring rates than the side surfaces in all the fire situations, which showed that they were more susceptible to fire penetrating in the direction of the longitudinal grain.
3. The fire-retardant treatment was effective in reducing the charring rates of both types of timber in all the fire situations considered, but the extent of this reduction varied according to the type of timber and the fire scenario, fire-retardant proving to be more effective on Erythrophleum suaveolens than on Anogeissus leiocarpa.
4. The greater the time that the specimens were exposed to fire, the greater the depth of the char formed in all of them. The specimens that had been treated with a fire-retardant always showed a smaller depth of char than those that had not been treated, which shows that the treatment was effective in slowing down the charring process during fire exposure.
5. The statistical analysis showed that the charring rates of the treated and untreated timber specimens were adequately described by appropriate probability distributions. The lognormal distribution was the predominant best-fit model, while the Weibull and normal distributions best described a few cases. The goodness-of-fit results confirmed the suitability of the selected distributions for characterising the charring behaviour of the investigated timber species.
6. Future studies should consider additional parametric fire curves, ventilation conditions, heating rates, and cooling phases to provide a more comprehensive representation of realistic compartment fires.

References

[1] A. H. Buchanan and A. K. Abu, *Structural Design for Fire Safety*, 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, 2017.

[2] R. H. White and M. A. Dietenberger, "Wood products: Thermal degradation and fire," in *Fire Retardant Materials*, A. R. Horrocks and D. Price, Eds., 2nd ed. Cambridge, U.K.: Woodhead Publishing, 2010.

[3] European Committee for Standardization (CEN), *EN 1995-1-2: Eurocode 5: Design of Timber Structures—Part 1-2: General—Structural Fire Design*. Brussels, Belgium: CEN, 2004.

[4] J. Liu and E. C. Fischer, "Review of the charring rates of different timber species," *Fire and Materials*, vol. 48, no. 1, pp. 3–15, 2023, doi: 10.1002/fam.3173.

[5] K. L. Friquin, "Material properties and external factors influencing the charring rate of solid wood and glue-laminated timber," *Fire and Materials*, vol. 35, no. 5, pp. 303–327, 2011, doi: 10.1002/fam.1055.

[6] X. Wang, S. Zhang, and Z. Wan, "Charring rate and temperature distribution of timber in fire: The role of fire-retardant treatments, moisture, and tree species," *Structures*, vol. 75, 2025, doi: 10.1016/j.istruc.2025.108676.

[7] A. H. Buchanan, *Structural Design for Fire Safety*. Chichester, U.K.: John Wiley & Sons, 2001.

[8] K. L. Friquin, *Material Properties and External Factors Influencing the Charring Rate of Solid Wood and Glue Laminated Timber*, master's thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2011.

[9] P. Reszka and J. L. Torero, "In-depth temperature measurements in wood exposed to fire," *Fire Safety Journal*, vol. 43, no. 4, pp. 315–324, 2008.

[10] E. Baysal, M. K. Yalınkılıç, M. Altınok, A. Sönmez, H. Peker, and M. Çolak, "Some physical, biological, mechanical, and fire properties of wood polymer composite (WPC) pretreated with boric acid and borax mixture," *Construction and Building Materials*, vol. 21, no. 9, pp. 1879–1885, 2007, doi: 10.1016/j.conbuildmat.2006.05.026.

[11] S. N. Kartal, N. Ayrilmis, and Y. Imamura, "Decay and termite resistance of plywood treated with various fire retardants," *Building and Environment*, vol. 42, no. 3, pp. 1207–1211, 2007, doi: 10.1016/j.buildenv.2005.11.018.

[12] J. M. Kaura, I. Abubakar, I. Aliyu, U. Hassan, and H. Peker, "EN 338 strength grade and uncertainty models of material properties for Nigerian grown *Terminalia superba* (White Afara) timber specie," *Nigerian Journal of Technology*, vol. 34, no. 1, pp. 21–27, 2015, doi: 10.4314/njt.341.887.

[13] A. A. Ozovehe, T. A. Sulaiman, A. Ocholi, J. M. Kaura, and A. Mohammed, "Effects of loads ratio variation on the safety of timber concrete composite floor," *FUOYE Journal of Engineering and Technology*, vol. 7, no. 2, pp. 269–273, 2022.

[14] I. M. Adamu, I. Abubakar, J. A. Sadeeq, A. Mohammed, and T. A. Sulaiman, "Development of EN338 strength grades for selected Nigerian timber types," *Journal of Environmental Spectrum, Faculty of Environmental Sciences*, vol. 4, no. 1, pp. 57–65, 2024.

[15] Y. Yau, T. A. Sulaiman, A. M. Umar, I. Bello, I. Garba, A. Mohammed, A. A. Sabari, and M. Abdullahi, "Experimental study on shear properties of *Gmelina arborea* cross-laminated timber panels by short span bending," *Journal of Sustainable Engineering and Technology*, vol. 1, no. 2, pp. 180–193, 2024.

[16] L. A. Lowden and T. R. Hull, "Flammability behaviour of wood and a review of the methods for its reduction," *Fire Science Reviews*, vol. 2, no. 4, pp. 1–19, 2013, doi: 10.1186/2193-0414-2-4.

[17] X. Wang, S. Zhang, Z. Wan, "Charring rate and temperature distribution of timber in fire: The role of fire-retardant treatments, moisture, and tree species**,"** *Structures*, vol. 75**,** 2025, 108676. https://doi.org/10.1016/j.istruc.2025.108676

[18] X. Zheng, M. He, Z. Li, G. Lou, G Li. "Experimental investigation into the effect of transparent fireproof coatings on charring behavior of glued laminated timber exposed to fire," *Fire Safety Journal*, vol. 150, 2024, 104274. https://doi.org/10.1016/j.firesaf.2024.104274

[19] P. Mitrenga, M. Vandlíčková, M. Konárik. "Experimental Investigation of Fire—Technical Characteristics of Selected Flame Retardants for the Protection of Wooden Structures," *Coatings*, vol. 15, no. 2, 193; 2025. https://doi.org/10.3390/coatings15020193

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