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ORIGINAL RESEARCH ARTICLE

COMPARISON OF EXPERIMENTAL CHARRING RATE OF SOME SELECTED CONSTRUCTIONAL WOOD SPECIES FROM SOUTH WESTERN NIGERIA WITH SELECTED CHARRING MODELS

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ABSTRACT

The rate at which timber chars varies between species and predominately dependent on density and moisture content. This study involved determination of charring performance of Nigerian wood species used for constructional purposes and comparing their charring rate with selected existing models. Six out of ten identified wood species commonly used for constructional purposes: Terminalia superba (Black Afara), Milicia excels (Iroko), Nauclea diderrichii (Opepe), Khaya ivorensis (Mahogany), Mansonia altissima (Mansonia), Tectona grandis (Teak) were selected for the study. The densities of the woods were determined at Moisture Contents (MC) of 9.0, 12.0, and 15.0%. Selected samples from each species, were exposed to fire at temperature ranges of 20° to 230°C for 30 min; 230° to 300°C for 30 min; 20° to 300°C for 60 min. The charring rate results based on 15% moisture content for all 0 - 30 min, 30 - 60 min and 0 - 60 min, being the ones having the lowest correlation values at each of the fire exposure time were analysed using ANOVA at $\alpha_{0.05}$ and compared with selected models; Australian standard AS 1720.4 relation, Eurocode EN recommendation and White's model. At 0-30 min fire exposure (20 to 230°C), and 15% MC, the experimental charring rate results showed significant regression relations at R2 = 0.9961, 0.8586, and 0.9523 for Eurocode EN recommendation, Australian standard AS 1720.4 relation, and White's model respectively. At 0-60 min fire exposure (20 to 300°C), and 15% MC, the results of experimental charring rate also showed significant regression relations at R^2 = 0.9925, 0.8926, and 0.9701 for Eurocode EN recommendation, Australian standard AS 1720.4 relation, and White's model respectively. Afara at 15.0% MC, and 20° to 300°C temperature, had the highest mean charring rates of 0.68 ± 0.02mm/min, while Opepe had the lowest charring rates of 0.47 ± 0.02 mm/min at the same MC level and temperature. The experimental test results indicated that density was a major predictor of the charring rate of constructional timber. Opepe specie, having the highest density exhibited the lowest charring rate and is recommended to ensure the safety and comfort of occupants in case of fire outbreak.

1.0 Introduction

Steel and concrete members (Bednarek, 1996) under fire have been extensively investigated in the last five decades. However, far fewer investigations have been carried out on timber structures (Bednarek, *et al.,* 2002). The keyword for timber's behaviour in fire is predictability, although it burns, it occurs at a predictable speed known as the charring rate (Adetayo and Dahunsi, 2018). The charring rate effect on wood makes it have superior fire performance over other structural alternatives; as wood members are exposed to fire, an insulating char layer is formed that protects the core of the section.

Under practical conditions of use, wood products always contain percentage of moisture, in the incipient of fire development, heating of potential fuel is taking place. Ignition is the start of flaming combustion, marking the transition to the growth period. In the growth period, the temperature of wood rise to a point when the moisture starts to evaporate (Janssens, 2002), most fires spread slowly at first on combustible wooden surfaces, then more rapidly as the fire grows, providing radiant feedback from flames and hot gases to other fuel items (Buchanan, 2001). When large timber members are exposed to a severe fire, the surface of the wood reaches its burning point at about 300°C (Bednarek, 2008), the wood initially ignites and burns rapidly. The burnt wood becomes a layer of char which loses all strength but insulates the solid wood below and thus prevents excessive temperature rise in the core. Inside the wood below the char layer, the moisture in the wood continues to evaporate. Some of this moisture travels out to the burning face, but some travels into the wood, resulting in an increase in moisture content of the heated wood a few centimeters below the char (Fredlund, 1993, White and Schaffer, 1981). The initial charring rate decreases to a slower steady rate which continues throughout the fire exposure. The charring rate is more or less constant and depends on the density and moisture content of wood and heat exposure (Purkiss, 1996). The layer of the char shrinks, making it thinner than the original wood, causing fissures which facilitate the passage of combustible gases to the surface (Drysade, 1998).

The charring rate layer does not usually burn because there is insufficient oxygen in the flames at the surface of the char layer for oxidation to occur. Studies have shown that many factors are involved in wood charring, among them are density and wood moisture content, heat flux and oxygen concentration of the surrounding air, physic-chemical effects, including diffusion of condensable vapors inward, internal convection outward, kinetics of pyrolysis, and energetic of Pyrolysis (Shafizadeh, 1984). Of all these factors, density has a significant effect on the rate of charring (Adetayo and Dahunsi, 2017). The rate of mass loss is proportional to density; lower density allows more rapid heat penetration and provides greater surface area per unit weight which allow more heat influx in the wood. In terms of charring rate, (White, 1988), showed that it is inversely proportional to density. Hence, although the rate of mass loss increases with density, the rate at which the char develops is lower.

The rate of charring is little affected by the severity of the fire, so for an hour's exposure, the depletions are 40 mm for most structural timbers and 30 mm for the denser hardwoods (EN, 2004). This enables the fire resistance of simple timber elements to be calculated. The predictive method is published in EN 1995-1-2. It assumes that the charring rate of timber made of solid or glued-laminated hardwood decreases linearly with density, with a limit of 0.5 mm/min for density larger than 450 kg/m^3. For softwood species the standard provides a mean value of 0.7 mm/min for density larger than 290 kg/m^3.

The Australian Standard AS 1720.4 Timber Structures: Fire- resistance of structural timber, confirmed that large cross-section is able to carry load during a fire event as the char occurs on the outside of the element and the effective cross section of the timber is only slowly reduced, the insulating qualities of timber mean that although the temperature at the char layer may be 300°C, the temperature of the inner wood is considerably lower. The remaining uncharred cross sectional area of large wood member remains at low temperature and can continue to carry a load. In the development of an empirical model for charring rate, White (1988) tested eight structural hardwood species and used analytical methods to predict the endurance of the structural wood members in a fire based on the reduction of the cross section of the member due to charring of the wood.

Fires in buildings have always been a threat to human safety. That threat increases as larger numbers of people live and work in larger buildings throughout the world (Buchanan, 2001). Hence, the issue of fire safety has taken preeminence in the design and construction of timber structures. In Nigeria, limited information is available on the charring rate of hardwood species, and a good knowledge of the fire performance of wooden members is necessary to provide data for the rate of depletion of wooden members exposed to fire. Depletion rate is necessary to provide an environment with an acceptable low probability of loss of life or properties due to fire. This research is aimed to identify timber species used for constructional functions in Nigeria, evaluating their charring behaviour, comparing with the results derived from these models: White's model, Australian standard AS 1720.4 relation, and Eurocode EN recommendation.

2. Materials and Methods

2.1 Selection of Samples

The selected six structural wood species out of ten recommended frequently used species were gotten from timber markets Ibadan, Abeokuta Oyo, Lagos and Oshogbo towns of South Western Nigeria. Samples were taken from the heartwood region of the individual timber because of its lesser moisture contents as compared to the sapwood region (Timber manual Data file, 2004).

The six species were:

Afara (Terminalia superba)

Iroko (Milicia excelsa)

Mahogany (Khaya ivorensis)

Mansonia (Mansonia altissima)

Opepe (Nauclea diderrichii)

Teak (Tectona grandis)

Focus of the experimental test was on structural members used in beam, column and building roofs.

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2.2 Experimental Methods

Wood samples were tested inside electrical-fired furnace having temperature range capacity up to 1500°C, at the Department of Foundry, Federal Institute of Industrial Research (FIIRO), Oshodi, Lagos, Nigeria. Fifty-four samples cut into rectangular blocks; nine from each species and each of them having the dimension of 150mm x 150mm x 510mm (Figure 1) were tested at the moisture contents of 9%, 12%, and 15% and furnace exposure period of 0 – 30 min, 30 – 60 min, and 0 – 60 min. The specimens were held horizontally and subjected to the heat flux perpendicular to the wood grain according to both Eurocode EN recommendation and Australian standard AS 1720.4. Traditionally and in the procedure, it would be assumed that the charring front reaches when its temperature indicates 300˚C (Bednarek, 2008), assuming that ignition starts at this point. Samples were obtained for each wood species at varying moisture contents of 9%, 12%, and 15%. The moisture content of the samples were obtained as the ratio of the mass of removable water to the dry mass of wood samples. The dry mass is obtained by oven drying at 103 ± 2 °C for 24 hours as per ASTM D143-94.

At the time of test, the following data were recorded for the specimen properties:

Species

Ring orientation

Specimen dimensions

Specimen weight

Moisture content (percent)

Specimen density

The selected specimen of the wood species were gotten from timber markets at various locations in South Western region of Nigeria as mentioned earlier, the specimen dimensioned were taken and their corresponding weight with the aid of weighing balance were recorded. Specimen density were calculated by dividing the mass of the sample with their corresponding volume, and their moisture contents were obtained as the ratio of the mass of removable water to the dry mass of wood samples. They were positioned horizontally and perpendicular to the ring orientation in the electric furnace.

Figure 1: Measured specimen for the fire test on display

The specimen, was enclosed in the furnace to carry out fire exposure test as shown in Figure 2. The electric furnace was powered, the initial temperature of the electric furnace when switched on was 20°C (White, 2002). At the time of burner ignition, the following functions were done as simultaneously as possible.

Automatic temperature recorder was started

Stop watches started

Furnace temperature controller started.

The automatic temperature recorder was used autonomously to monitor and gather temperature data from the furnace in addition to the furnace temperature controller. The stop watch was used to monitor the time intervals of the fire exposure test.

Figure 2: Specimen burning inside furnace

Specimens were exposed to fire in three batches. The first batch went for the time of 0-30 min, the second batch for 30 - 60 min and the last batch was for full 0 – 60 min.

The first test for exposure period of 0 – 30 min was stopped at exactly when the stop watch reached 30 min, temperature reading was 20°C to 230°C.

Specimens exposed during the second period of 0 – 30 min were subjected to higher temperature from 230°C to 600° C.

The third test for exposure period 0 – 60 min, furnace temperature ranges between 20°C to 300°C.

When testing was completed, the charred wood was scrapped away from the samples and char depth was measured (Figure 3). The charred specimens were also cut in half to obtain the thickness of the charred slab and the char layer. For each specimen three sets of data were produced according to the time of exposure.

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Figure 3: Charred wood after 1-hour fire exposure

2.2 Charring Rate Models

The charring rate (mm/min) results were determined for the three moisture contents level of 9.0%, 12.0%, and 15.0% using linear formula, (EN, 2004).

$$\beta = \frac{d_{char}}{t} \quad (1)$$

β = Charring rate (mm/min)

d_{char} = thickness of char layer or char depth (mm)

t = time of fire exposure (min)

The results of the experimental charring rate were calculated and tabulated for each fire exposure time at moisture contents of 9.0%, 12.0%, and 15.0%. Experimental charring rate results were compared with the values predicted by three selected models.

The Australian standard (1990) expresses the notional charring rate β (mm/min) as a function of wood density:

$$\beta = 0.4 + [280/\rho]^2 \quad (2)$$

where: ρ is the wood density at 12% moisture content (kg/m^3).

In the development of charring models, Eurocode 5 (EN, 2004) recommendation has a simple constant charring rate relationship as follows:

$$d_{char} = \beta_o t \quad (3)$$

d_{char} = charring depth mm

β_o = charring rate (mm/min), usually between (0.5 to 0.8) mm/min

t = time in min.

In determining the remaining effective residual section for structural purposes, both standards EN and AS 1720.4 (2006), calculate an effective charred depth by adding a constant thickness of 7.5mm to the calculated value in order to take into account the heat-affected zone. That is, the effective depth of charring (in mm) is given by

$$d_c = \beta t + 7.5 \quad (4)$$

d_c = calculated effective depth of charring in millimetres (mm)

β = notional charring rate in millimetres per minute (mm/min) as calculated

t = time of exposure to heating regime specified in AS 1720.4 (min)

The effective residual cross section was obtained by subtracting the calculated effective depth of charring from all fire exposed surfaces of the timber member.

White (2002), established an empirical model for the charring rate based on four tests on hardwood species with extensive sets of specimens. Species were hard maple (Acer sp.), yellow-poplar (Liriodendron tulipera), red oak (Quercus sp.) and basswood (Tilia sp.).

The following non-linear relation was proposed:

$$t = m{x_c}^{1.23} \quad (5)$$

The linearization of Eqn(5) through logarithmic transformation yields Eqn (6) as follows:

$$\ln t = \ln m + 1.23 \ln x_c \quad (6)$$

t = the time of exposure (min),

x_c = charred depth from original fire-exposed surface (mm),

m = reciprocal char rate (min/mm)

The reciprocal char rate was given by White (2002) as

$$m = -0.147 + 0.000564\rho + 0.012u + 0.532f_c \quad (7)$$

where: ρ = oven-dry density (kg/m^3)

u = moisture content (percent), and

f_c = char contraction factor, defined as the thickness of the char layer at the end of the fire exposure divided

by the original thickness of the wood layer that has charred (Tran and White, 1992).

An expression for the char contraction factor for hardwood species was obtained as follows;

$$f_c = 0.529 - 0.00036d + 0.002\rho \quad (8)$$

d = depth of char (preservative) penetration (mm) (3 for low to 36 for highly treatable species).

3. Results and Discussion

The effect density of each wood species were glaring on the results of the calculated charring rates, it showed that wood species with low density wood exhibited high charring rate and vice-versa.

The mean charring rate results for specimens exposed for 0 to 30 minutes fire interval, temperature ranged of 20° to 230°C are illustrated in Tables 1 to 3. Afara of 9, 12 and 15% MC had the highest charring rates of 0.84±0.02 mm/min, 0.82±0.02 mm/min and 0.82±0.02 mm/min respectively, while Opepe had the lowest charring rates of 0.48±0.02 mm/min, 0.48±0.02 mm/min and 0.47±0.03 mm/min respectively at the three MC levels.

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Table 1: Charring rate of Samples at 9% MC (0-30) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	25.20	0.84	0.02	0.80	0.86
Iroko	532	19.30	0.64	0.02	0.62	0.66
Mahogany	439	19.70	0.66	0.02	0.64	0.69
Mansonia	566	19.40	0.65	0.02	0.63	0.67
Opepe	630	14.30	0.48	0.02	0.45	0.50
Teak	505	19.50	0.65	0.02	0.62	0.67

Table 2: Charring rate of Samples at 12% MC (0-30) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	24.60	0.82	0.02	0.79	0.85
Iroko	544	19.60	0.65	0.02	0.63	0.68
Mahogany	451	19.50	0.65	0.02	0.63	0.67
Mansonia	580	18.70	0.62	0.03	0.58	0.65
Opepe	686	14.40	0.48	0.05	0.44	0.55
Teak	569	19.40	0.65	0.02	0.63	0.68

Table 3: Charring rate of Samples at 15% MC (0-30) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	469	24.80	0.82	0.02	0.79	0.85
Iroko	614	19.50	0.65	0.02	0.62	0.68
Mahogany	521	21.30	0.71	0.03	0.68	0.74
Mansonia	591	18.90	0.63	0.02	0.60	0.66
Opepe	752	14.10	0.47	0.03	0.45	0.51
Teak	657	19.40	0.65	0.02	0.62	0.68

Specimens exposed for the second period of fire of 30 minutes, 230° C to 600° C temperature experienced more intense heating, and as expected, charred at a greater rate. Tables 4 to 6 showed the results of specimens exposed to fire at the MC levels. Both Iroko and Teak species had the lowest charring rates of 0.71±0.02 mm/min at 9% MC and 0.69±0.02 mm/min at 12% MC respectively. At 15% MC, Iroko exhibited the lowest (0.67±0.02 mm/min) while Afara exhibited the highest (0.88±0.05 mm/min) charring rates.

Table 4: Charring rate of Samples at 9% MC 30 minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	28.20	0.94	0.02	0.91	0.96
Iroko	532	21.30	0.71	0.03	0.67	0.74
Mahogany	439	24.60	0.82	0.03	0.80	0.86
Mansonia	566	26.70	0.89	0.05	0.83	0.94
Opepe	630	24.30	0.81	0.02	0.78	0.84
Teak	505	21.30	0.71	0.03	0.67	0.74

Table 5: Charring rate of Samples at 12% MC (30) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	27.90	0.93	0.02	0.91	0.95
Iroko	544	20.70	0.69	0.02	0.66	0.72
Mahogany	451	24.60	0.82	0.01	0.80	0.84
Mansonia	580	25.50	0.85	0.01	0.84	0.86
Opepe	686	23.70	0.79	0.03	0.77	0.84
Teak	569	20.70	0.69	0.02	0.66	0.72

Table 6: Charring rate of Samples at 15% MC 30 minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	469	26.40	0.88	0.05	0.80	0.94
Iroko	614	20.10	0.67	0.03	0.63	0.71
Mahogany	521	23.70	0.79	0.03	0.76	0.83
Mansonia	591	24.60	0.82	0.03	0.80	0.86
Opepe	752	23.40	0.78	0.03	0.75	0.82
Teak	657	20.70	0.69	0.02	0.67	0.71

The results of fire exposure test for specimens that were exposed for 0 to 60 minutes time interval, temperature ranged of 20° C to 300° C are shown in Tables 7 to 9. As the exposure time increased (0 – 60 minutes), the charring rate gradually increasing. Afara having the lowest density of 444 kg/m^3 at both 9% and 12% MC among the species exhibited the highest charring rate of 0.74±0.02 mm/min. Opepe species of 9.0, 12.0 and 15.0% MC had the lowest charring rates of 0.47±0.03 mm/min, 0.48±0.05 mm/min and 0.47±0.03 mm/min respectively.

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Table 7: Charring rate of Samples at 9% MC (0-60) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	44.50	0.74	0.02	0.71	0.77
Iroko	532	33.40	0.56	0.01	0.55	0.58
Mahogany	439	35.70	0.59	0.02	0.57	0.62
Mansonia	566	33.20	0.55	0.02	0.53	0.59
Opepe	630	28.30	0.47	0.03	0.44	0.50
Teak	505	29.40	0.49	0.03	0.46	0.54

Table 8: Charring rate of Samples at 12% MC (0-60) minutes fire exposure

Species	Mean Density (Kg/m^3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	444	44.50	0.74	0.02	0.71	0.76
Iroko	544	32.30	0.54	0.02	0.51	0.56
Mahogany	451	33.70	0.56	0.01	0.55	0.58
Mansonia	580	32.80	0.55	0.02	0.53	0.58
Opepe	686	28.60	0.48	0.05	0.44	0.55
Teak	569	29.20	0.49	0.02	0.47	0.52

Table 9: Charring rate of Samples at 15% MC (0-60) minutes fire exposure

Species	Mean Density (Kg/m3)	Mean Char Depth (mm)	Mean Actual Charring Rate (mm/min)	Standard Deviation	Minimum (mm/min)	Maximum (mm/min)
Afara	469	40.80	0.68	0.02	0.65	0.71
Iroko	614	30.20	0.50	0.02	0.48	0.52
Mahogany	521	33.90	0.56	0.03	0.54	0.60
Mansonia	591	33.70	0.56	0.02	0.53	0.59
Opepe	752	28.40	0.47	0.03	0.45	0.51
Teak	657	29.20	0.49	0.02	0.46	0.52

3.1 Comparisons of Experimental Charring Rate results and Selected Models

The results of the experimental charring rates based on 15.0% MC, having lowest correlation values at each of the fire exposure time interval were compared with the selected models as shown in Table 10 to 12.

From Table 10 and Figure 4, at fire exposure interval of 0-30 minutes, temperature ranged 20°C to 230° C, the results of experimental charring rate were similar to Eurocode EN model, and close to both Australian relation and White's model

Table 10: Comparisons of experimental Charring model with the selected Charring models result for 15% MC (0 – 30) minutes fire exposure 20°C to 230°C temperature

Experimental results (mm/min)					Calculation models result (mm/min)		
Species	Density (kg/m^3)	Char depth (mm)	Charring Rate (mm/min)	Standard Deviation	Australian standard Model (mm/min) β=0.4+[280/ρ]^2	Eurocode5 model(mm/ min) dchar= β0 t	White's Model (min/mm1.23) t =m xc1.23
Afara	469	24.80	0.82	0.02	0.76	0.83	0.58
Iroko	614	19.50	0.65	0.03	0.61	0.65	0.77
Mahogany	521	21.30	0.71	0.02	0.69	0.70	0.70
Mansonia	591	18.90	0.63	0.03	0.62	0.63	0.81
Opepe	752	14.10	0.47	0.02	0.54	0.47	1.16
Teak	657	19.40	0.65	0.02	0.58	0.64	0.78

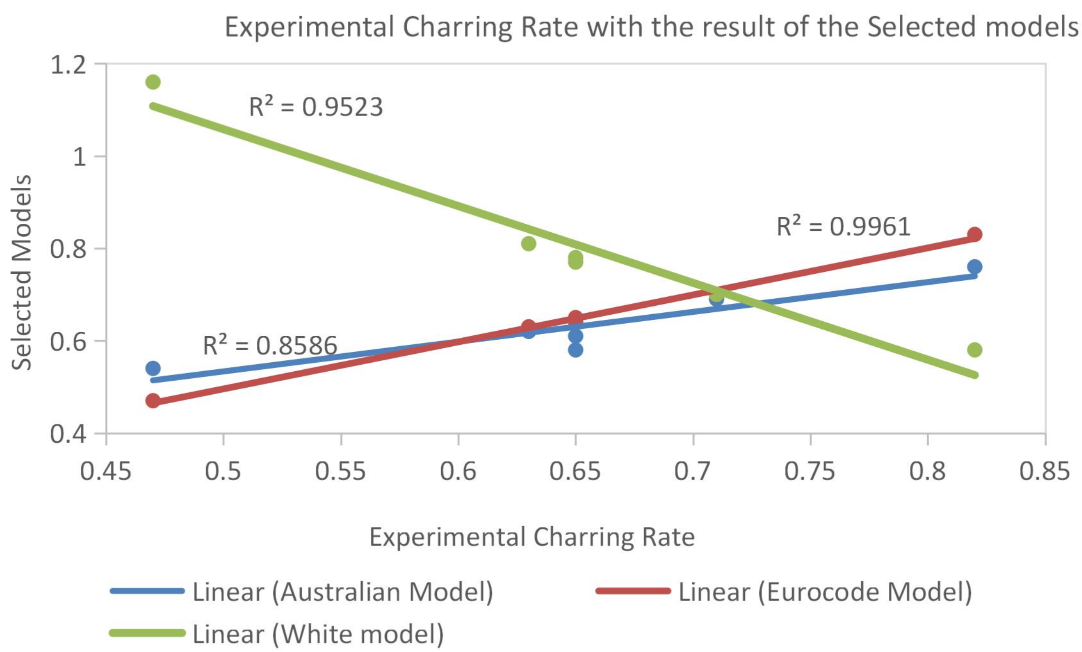

Figure 4: Comparison of Experimental Charring model with the result of Selected Charring models for 15% MC (0-30 minutes) fire exposure temperature at 20°C to 230°C.

At fire exposure of 30 minutes interval, temperature ranged 230°C to 600° C, the results of experimental charring rate were similar to both Eurocode EN model and White's model, but far from the results of Australian Standard relation as shown in Table 11 and Figure 5.

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Table 11: Comparisons of experimental Charring model with the selected Charring models result for 15% MC 30 minutes fire exposure 230°C to 600°C temperature

Experimental results (mm/min)					Calculation models result (mm/min)		
Species	Density (kg/m^3)	Char depth (mm)	Charring Rate (mm/min)	Standard Deviation	Australian standard Model (mm/min) β=0.4+[280/ρ]2	Eurocode5 model (mm/min) dchar= β0 t	White's Model (min/mm1.23) t =m xc1.23
Afara	469	26.40	0.88	0.02	0.76	0.89	0.54
Iroko	614	20.10	0.67	0.02	0.61	0.67	0.75
Mahogany	521	23.70	0.79	0.02	0.69	0.79	0.61
Mansonia	591	24.60	0.82	0.02	0.62	0.81	0.58
Opepe	752	23.40	0.78	0.02	0.54	0.77	0.62
Teak	657	20.70	0.69	0.02	0.58	0.69	0.72

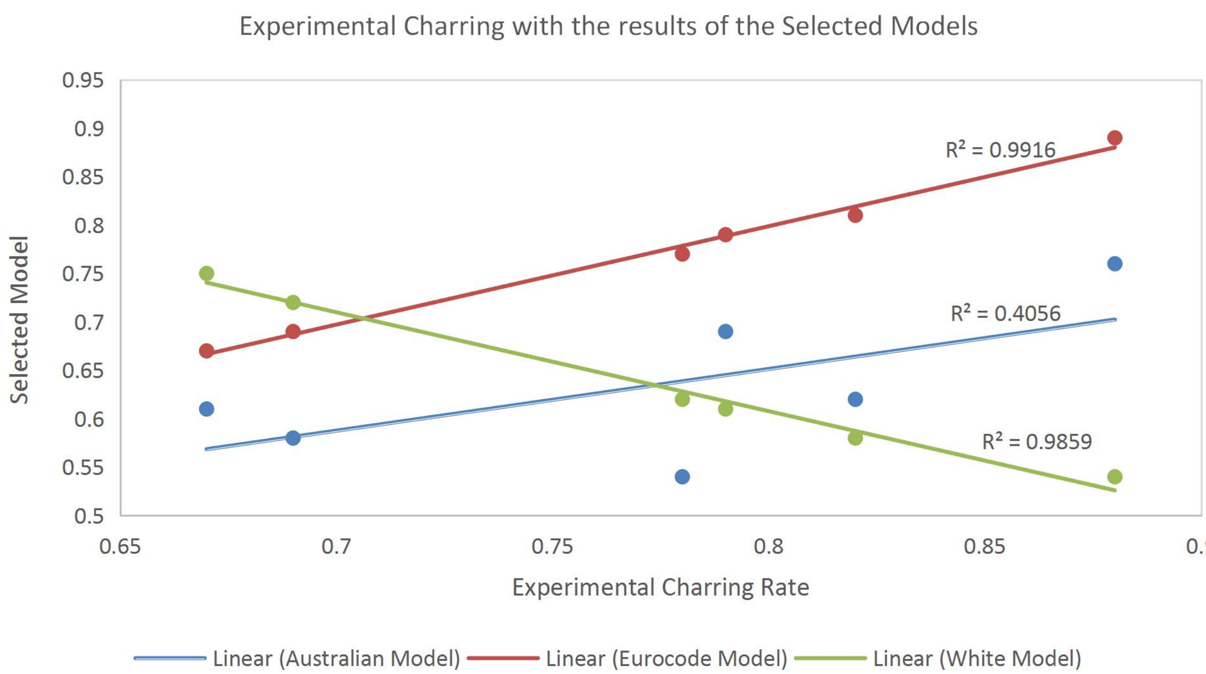

Figure 5: Comparison of Experimental Charring model with the result of Selected Charring models for 15% MC (30 minutes) fire exposure temperature at 230°C to 600°C.

At fire exposure interval of 0-60 minutes, temperature ranged of 20° C to 300° C. the experimental charring rates results were close to the three selected models results as shown at both Table 12 and Figure 6.

Table 12: Comparisons of experimental Charring model with the selected Charring models result for 15% MC (0 – 60) minutes fire exposure 20°C to 300°C temperature

Experimental results (mm/min)					Calculation models result (mm/min)		
Species	Density (kg/m^3)	Char depth (mm)	Charring Rate (mm/min)	Standard Deviation	Australian standard Model (mm/min) $\beta=0.4+[280/\rho]^2$	Eurocode5 model (mm/min) dchar= β0 t	White's Model (min/mm1.23) t =m xc1.23
Afara	469	40.80	0.68	0.02	0.76	0.68	0.63
Iroko	614	30.20	0.50	0.02	0.61	0.49	0.91
Mahogany	521	33.90	0.56	0.03	0.69	0.57	0.78
Mansonia	591	33.70	0.56	0.03	0.62	0.56	0.79
Opepe	752	28.40	0.47	0.02	0.54	0.47	0.98
Teak	657	29.20	0.49	0.02	0.58	0.48	0.95

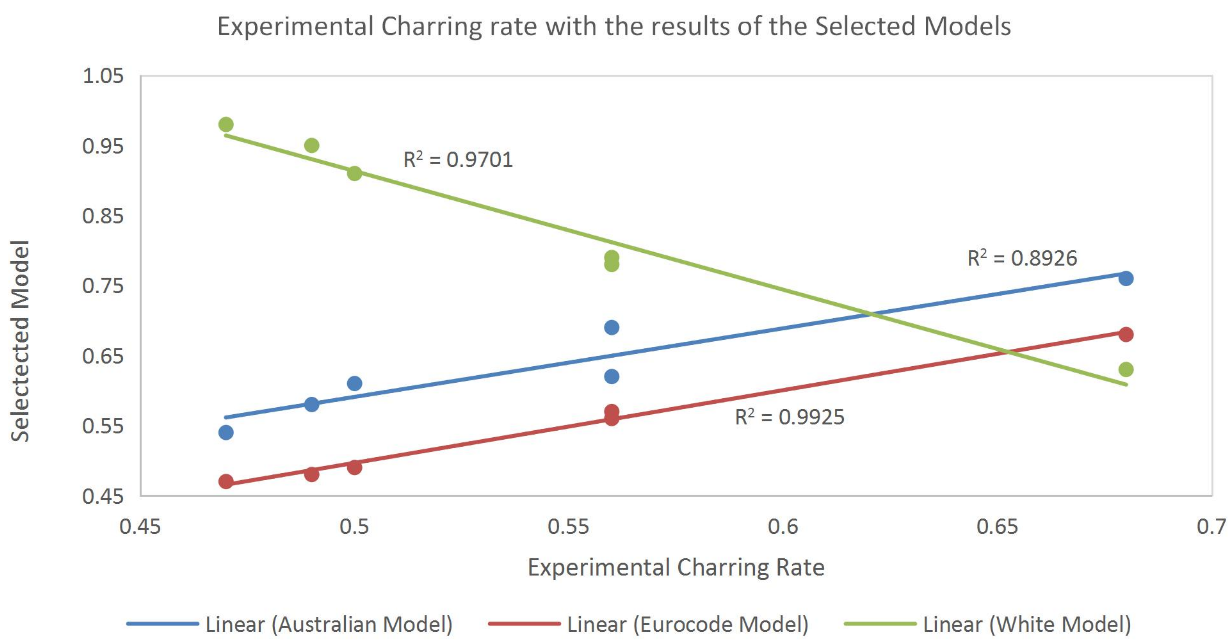

Figure 6: Comparison of Experimental Charring model with the result of Selected Charring models for 15% MC (0-60 minutes) fire exposure temperature at 20°C to 300°C.

4.0 Conclusion

The charring rates behaviour of, constructional wood species has been studied through literature review, laboratory experiments and calculations. From the experimental results of the fire exposure test, it can be concluded that density and moisture content are of great importance properties of wood, as the moisture content increases, the wood density also increases, wood with higher density exhibited higher resistance to fire. The experimental charring rate results

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were similar to the two of the three selected models of Eurocode 5 and White's mode and close to the results obtained by Australian standard model.

Heavy wood or similar members under sever fire exposure, but not absolute extreme conditions will char at similar rates to those found in fire-resistance electric furnace tests, with charring rates roughly 0.5 to 0.8 mm/min. The research showed that the charring rate of wood species was optimum at 12 percent moisture content with Opepe species which had the highest density exhibited the lowest charring rate of 0.48 mm/min.

Based on the results obtained in this study, the following recommendations are made:

(1) The charring rate of timber presented in this study were limited to only six timber species. There is the need to consider the charring rates of other timber species.

(2) Determination of the charring rate for different wood species with varying dimensions and check their variations and similarities.

(3) Systematic research on how various material properties and external factors influence the charring rate of structural wood.

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