



Flexural and Charring Characteristics of Some Selected Hardwoods in Nigeria

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ABSTRACT

Wood is generally considered as either 'softwood' or 'hardwood'. Softwood is obtained from coniferous trees and hardwood comes from broad-leaved trees. Wood has been known for its ecological sustainability. Since wood by its nature is combustible, and may be a source of building collapse during fire incidence; hence, this investigation is focused on creating the awareness of the dependability of different wood species that has been recognized to perform well in fire. Experimental investigation was carried out on wood species namely; *Albizia* (Ayere), *Celtis mildbraedii* (Ita), *Pterygota macrocarpa* (Oporoporo), *Terminalia superba* (Afara white). Charring tests and Flexural strength tests were carried out using the ASTM C293. The fire resistance capacity of Oporoporo is 1.4 % higher in value than that of Ita. The flexural strength capacity of Ita is 10.5 % higher than that of Oporoporo. It was concluded that *Celtis mildbraedii* and *Pterygota macrocarpa* have excellent performance in terms fire resistance ability and flexural strength and as such be relied upon in the construction industry.

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INTRODUCTION

Wood is a type of wood that has been processed into beams and planks, etc. a stage in the process of wood production. Wood is mainly used for structural purposes but has many other uses as well.

It may be supplied either rough-sawn, or surfaced on one or more of its faces. Besides pulpwood, rough wood is the raw material for furniture-making and other items requiring additional cutting and shaping. It is also available in many species (Ohagwu and Ugwuishiwu, 2011).

Yakisugi, is the tradition of charring timber was developed as a wood preservation technique. The Japanese discovered that by creating a deep, controlled burn on the surface of Japanese Cedar panels, they could increase its durability (Dan, 2020). Fire-resistance of timber is very low. Of all the timber types, dense wood

offers the most resistance against fire but up to certain limit only. The thermal conductivity of timber depends upon various factors such as moisture content, density, porosity (The Constructor, 2019).

Although wood is classified as combustible material, a properly designed wood structure has been recognized as performing very well in fire. Light wood construction is normally protected from fire-by-fire resistant cladding materials, while heavy wood construction has good inherent fire resistance because a char layer is formed that retards the heat penetration. Maricar *et al*, (2022) in their research work on the flexural strength of glued laminated timber beams using the four-point loading system revealed that the load-deflection relationship of tested beam samples has both linear and non-linear phases. Strengthening laminated beams with GFRP increases the flexural strength and causes a shift



in the location of the crack from the shear area (Osmannezhad et al, 2014).

The ultimate moment of resistance and beam compressive strength is also increased with FRP (Fibre reinforced Plastic) Raftery *et al* (2011). When heavy wood members are exposed to a fire, the temperature of the fire exposed surface of the members is close to fire temperature. When the outer layer of wood reaches its burning point (about 300°C), the wood ignites and burns rapidly.

The burned wood becomes a layer of char which loses all strength but retains a role as an insulating layer preventing excessive temperature rise in the core (Collins, 2003).

The use of wood as a structural material is not new, in fact dating back many centuries. As time passes, developments in the various types of wood components which are available and their use in different structural forms have occurred; new advanced wood products are now available enabling structural engineers to achieve the performance and efficiency in building forms being demanded in the 21st century. There are thousands of species of tree from which wood can be obtained, each with different rates of growth, structural properties and degrees of durability. The wood supply chain has responded to nature's variability and now provides repeatable product supply from managed forests. The industry has also created grading processes to deliver reliable technical performance (grades) for these products. Wood is renewable and carbon dioxide

MATERIALS AND METHODS

Materials

Hardwoods: The hardwoods used in this research were selected from South-East and South-West of Nigeria forest. Each were sawn into different sizes (50 × 50 × 1000, 50 × 75 × 1000, 50 × 100 × 1000, 75 × 100 × 1000). Table 1 presents the botanical name, common name, location of forest, weight, volume, densities and BS 5268 classification.

Tools and Equipment: The tools and equipment used include: 100kN digital universal Testing Machine capable performing the flexural strength test, ELF 1000°C furnace, water bath, circular saw, a pair of tongs.

neutral resource for construction, but world population grown, urbanization, and climate changes diminish this resource. The sustainable technologies must be used to extend timber service life as well as save forest resources by reuse of timber (Morozovs et al, 2021). Wood is categorized as either 'softwood' or 'hardwood'. Softwood is obtained from coniferous trees and hardwood comes from broad-leaved trees. Softwood and hardwood are botanical terms and do not necessarily refer to the density or hardness of the wood. Hardwood is obtained from the class of wood called Angiosperms and usually have broad leaves. The trees are grown in the tropics. They have slower growth rate and shorter fibers. They are relatively scarce due to their weight, high cost of felling and transportation difficulties from the forest (Fathi, 2010). Hardwoods are typically used for exposed structures and claddings where durability and particular aesthetic characteristics, such as colour or grain pattern, are required (Sita, 2016).

Timbers such as hardwood finds suitable application in the construction industry due to their versatility spanning from simple framing in housing projects to large scale public facilities. (Wasiu *et al*, 2022).

This research is focused on providing information on the flexural capacity and charring characteristics of the selected common timber species in Nigeria.

Methods

Preparation of wood samples: The hardwood samples collected namely: *Albizia*, *Celtis mildbraedii*, *Pterygota macrocarpa* and *Terminalia superba* were sawn in the sawmill located at Ijan, Ado-Ekiti. The log was sawn into different sizes (50 × 50 × 1000 mm, 50 × 75 × 1000 mm, 50 × 100 × 1000 mm, 75 × 100 × 1000 mm) in preparation for the laboratory investigation. The weight of samples was taken and their densities estimated from equation 1.

$$\text{Density } (\rho) = \frac{\text{mass}(m)}{\text{volume}(v)} \quad (1)$$

Table 1: Hardwood, sizes and location of forest

S/N	Botanical/ scientific names	Common / trade name	Location	Weight (kg)	Volume (m ³)	Density (kg/m ³)	BS 5268 Classification
1.	<i>Albizia</i>	Ayere	Enugu	2.15	0.00250	860	SC 6
				3.05	0.00375	813	
				3.60	0.00500	720	
				6.02	0.00750	802	
2.	<i>Celtis mildbraedii</i>	Ita	Ondo	2.19	0.00250	876	SC6
				3.15	0.00375	840	
				3.72	0.00500	744	
				5.92	0.00750	789	
3.	<i>Pterygota macrocarpa</i>	Oporoporo	Ondo	2.25	0.00250	900	SC6/SC7
				3.18	0.00375	848	
				3.69	0.00500	738	
				6.22	0.00750	829	
4.	<i>Terminalia superba</i>	Afara white	Ekiti	1.95	0.00250	780	SC5/SC6
				2.88	0.00375	768	
				3.50	0.00500	700	
				5.73	0.00750	764	

Charring test

The purpose of this test is to check the fire resistance of each species of the selected woods in different sizes and apparatus used were the ELF 1200°C Furnace, Thong, wood specimen and a stop watch. These samples (thirty-two) were of various sizes, species and types and they were all tested one after the other as shown in Fig. 2, 3

and 4 respectively. The power cable of the furnace was plugged and each specimen were placed in the furnace and the stop watch ready to start as soon as the machine was turned on. The temperature readings were recorded against temperature until the specimen was completely charred.



Figure 1: Wood in furnace in preparation for charring test



Figure 1: Commencement of Charring Test



Figure 2: ELF furnace showing the semi-final stage



Figure 3: ELF furnace showing the final stage of charr

Flexural Strength Test

The purpose of this test is to measure the flexural strength of each of all the wood sample of different species according to ASTM C293. The test was carried out using a digital universal testing machine (UTM) of 100kN capacity. The universal testing machine has a display unit, dial gauge measurement unit and system connector unit to measure, record and store all necessary

parameters of the beam samples. The testing machine was equipped with special bearing plates in order to obtain a uniform stress distribution over the cross section of the wood samples. Figure 4, 6, 7 and 8 shows the UTM in preparation for flexural strength test, loading of wood samples, datum check and measurement of failure parameters. As the sample is gradually loaded, readings such as failure load, peak load,

deflection and bending moment were automatically taken from the dial gauge and the timer of the universal testing machine. The flexural

strength for each sample tested is computed from equation 2.

$$f_m = \frac{3f_{max}L}{2bh^2} \quad (2)$$

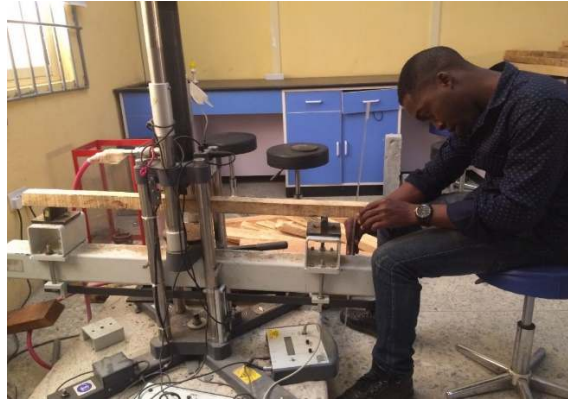


Figure 4: Flexural strength test using flexural testing



Figure 5 : Application of load on the wood sample machine and ASTM 293 C



Figure 6: Datum check for the flexural testing machine



Figure 7: Measurement of loading parameters

RESULTS AND DISCUSSION

Results of charring Tests

The charring test was carried out on all the selected woods samples and the results are presented as follows: **The Charring of 50mm × 50mm Samples for Albizia (Ayeré), Celtis mildbraedii (ita), Pterygota macrocarpa (Oporoporo) and Terminalia superba (Afara).**

The charring tests revealed that Oporoporo has the highest ability to withstand fire than other hardwood samples of same size (50mm × 50mm). It charred completely at about 943°C for 31 minutes compared to *Celtis mildbraedii (ita)*, *Albizia (Ayeré)* and *Terminalia superba (Afara)* which charred at 900°C for 25 minutes, 875°C for 24 minutes and 840°C for 23 minutes respectively.

shows an increase in temperature with time of charr.

The charring of 50mm × 75mm samples for Albizia (Ayeré), Celtis mildbraedii (ita), Pterygota macrocarpa (Oporoporo) and Terminalia superba (Afara)

From

Figure 9, it is observed that the *Celtis mildbraedii (ita)* has a higher resistance to high temperature and completely charred at 1000°C for 50 minutes; *Pterygota macrocarpa (Oporoporo)* charred at about 993°C for 45 minutes; *Terminalia superba (Afara)* charred at about 980°C for 37.5 minutes and *Albizia (Ayeré)* charred at 900°C for 30. These results show the importance of sizes/thickness of wood samples when considering fire resistance ability. The higher the thickness of wood samples, the better their fire resistance capacity. In this group, *Albizia (Ayeré)* seemed to be the least sample in terms of fire resistance.

The charring of 50mm × 100mm samples for Albizia (Ayeré), Celtis mildbraedii (ita), Pterygota macrocarpa (Oporoporo) and Terminalia superba (Afara)

In the case of 50mm × 100mm samples, it was observed that all beam samples tend to follow the same trend. That is, the higher thickness; the better the ability to withstand fire as shown in Figure 11. Nevertheless, it is observed that the *Terminalia superba (Afara)*, *Celtis mildbraedii (ita)* and *Pterygota macrocarpa (Oporoporo)* wood are having similar charring abilities.

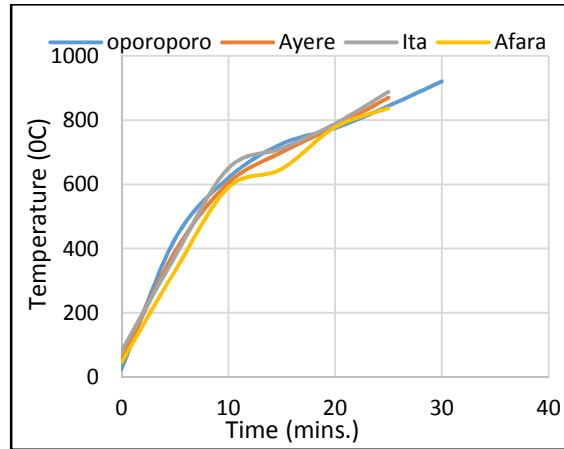


Figure 8: Graph of Temperature against Time for $50mm \times 75mm$ samples

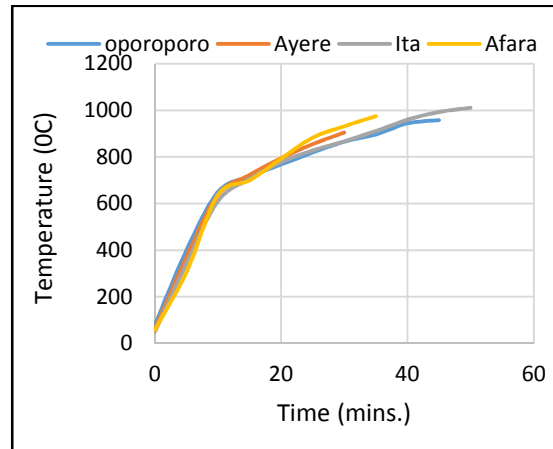


Figure 9: Graph of Temperature against Time for $50mm \times 50mm$ sample

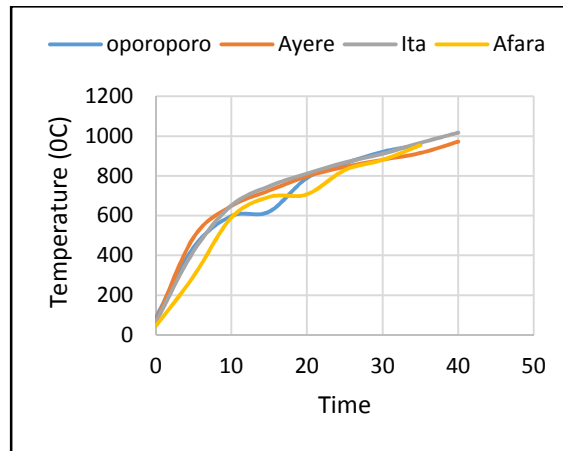


Figure 10: Graph of temperature against time for 75mm × 100mm samples

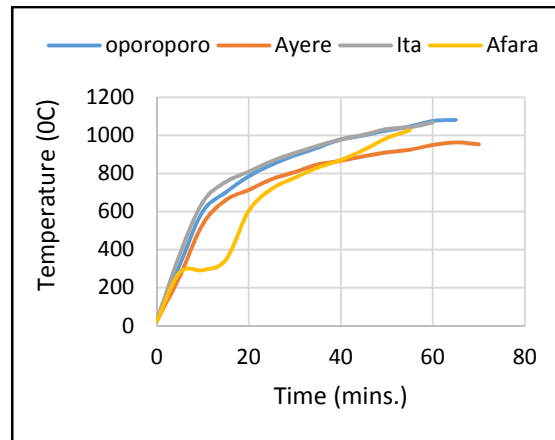


Figure 11: Graph of temperature against time for 50mm × 100mm samples

The range is about 970°C - 1030°C for 35-40 minutes while *Albizia* (*Ayere*) seemed to char completely at 980°C for 42 minutes. The average fire resisting abilities in this group is approximately 990.5°C for 37.5 minutes.

The charring of 75mm × 100mm samples for *Albizia* (*Ayere*), *Celtis mildbraedii* (*ita*), *Pterygota macrocarpa* (*Oporoporo*) and *Terminalia superba* (*Afara*)

All the wood sample samples tested in this group revealed similar charring abilities as shown in Figure 12. The average charring capabilities is in the range 975°C - 1090°C for 56-72 minutes. These results revealed that *Celtis mildbraedii* (*ita*), *Pterygota macrocarpa* (*Oporoporo*) and

Terminalia superba (*Afara*) have similar charring abilities while *Albizia* (*Ayere*) seemed the least. This property will enable careful selection of wood for variety of purpose.

The Results of the Flexural Strength Tests

The flexural strength tests of 50mm × 50mm Samples for *Albizia* (*Ayere*), *Celtis mildbraedii* (*ita*), *Pterygota macrocarpa* (*Oporoporo*) and *Terminalia superba* (*Afara*)

The flexural strength of the 50mm × 50mm samples increase with the application of load. The maximum failure load, mid-span deflection of the beam samples and the modulus of rupture are 0.6kN, 27.1mm and 0.29N/mm² for *Terminalia*

superba (Afara), 3.2kN, 25.2mm and 1.54N/mm² for *Albizia (Ayere)*, 2.1kN, 25.9mm and 1.01N/mm² for *Celtis mildbraedii (ita)* and 3.0kN, 16.4mm and 1.44N/mm² for *Pterygota macrocarpa (Oporoporo)* respectively. Figures 13,14 and 15 shows the graphical relationship between applied load and deflection; MoR and deflection and the loading rate of each sample. Figure 13 revealed an increase in deflection as the applied loading is increased. Similarly, the MoR in Figure 14 also increases with deflection. Figure 15 shows loading rate at an interval of 2 seconds. The loading increases with time until the sample failed in bending. In this category of size, *Albizia (Ayere)* and *Pterygota macrocarpa (Oporoporo)* recorded a higher MoR than other tested beam sample.

The flexural strength tests of 50mm × 75mm Samples for Albizia (Ayere), Celtis mildbraedii (ita), Pterygota

macrocarpa (Oporoporo) and Terminalia superba (Afara)

The flexural strength for 50mm × 75mm sample follows similar trends with the 50mm × 50mm beam samples. The maximum load, mid-span deflection and MoR for the beam samples are 0.6kN, 27.1mm and 0.19N/mm² for *Terminalia superba (Afara)*, 6.1kN, 28.9mm and 1.95N/mm² for *Albizia (Ayere)*, 8.4kN, 39.2mm and 2.69N/mm² for *Celtis mildbraedii (ita)* and 3.3kN, 29.8mm and 1.05N/mm² for *Pterygota macrocarpa (Oporoporo)* respectively. The MoR for *Albizia (Ayere)* and *Celtis mildbraedii (ita)* were found to be more promising in this group. These species proved stronger based on their capacity to withstand more load than other tested samples. Figures 16, 17 and 18 shows the graphical representation and relationship between applied load, MoR and deflection.

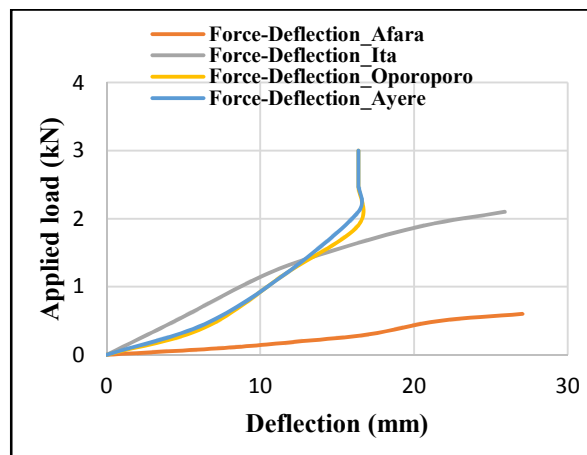


Figure 13: Load-Deflection curve (50 x 50 mm)

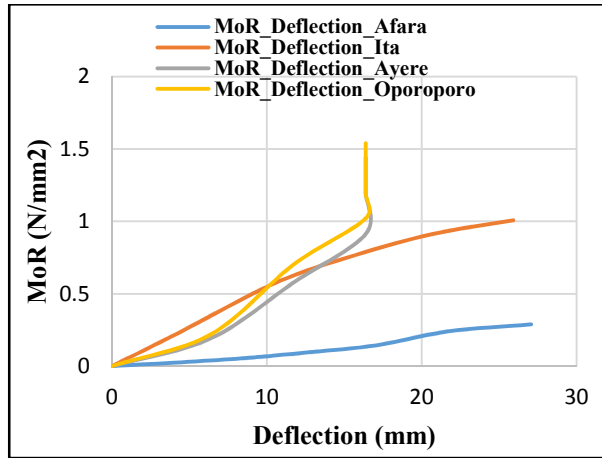


Figure 14: MoR-Deflection curve (50 x 50 mm)

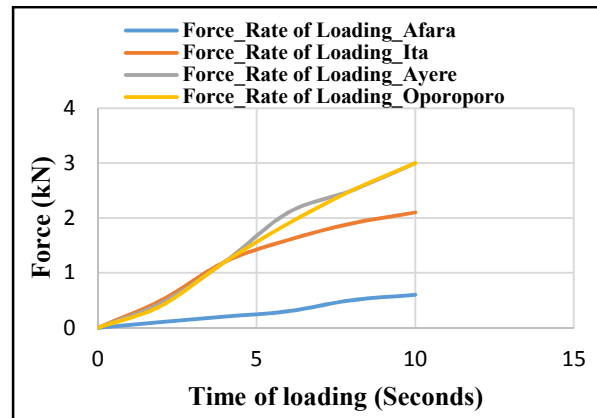


Figure 15: Force-Time curve (50 x 50 mm)

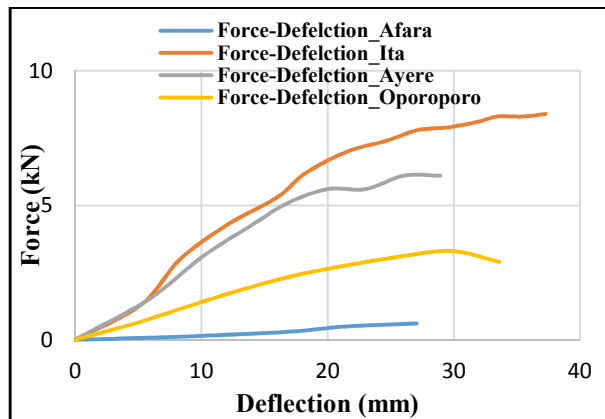


Figure 16: Force-Deflection curve (50 x 75 mm)

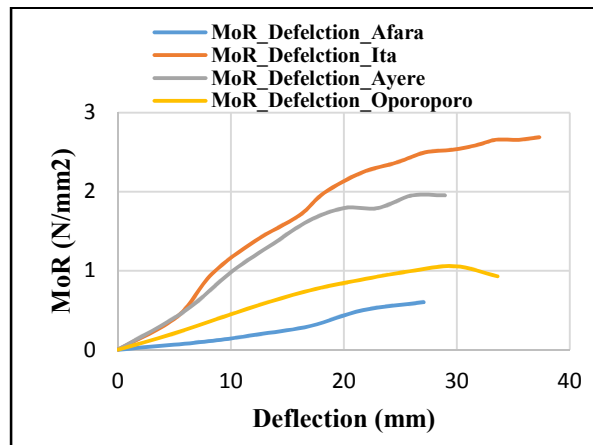


Figure 17: MoR-Deflection curve (50 x 75 mm)

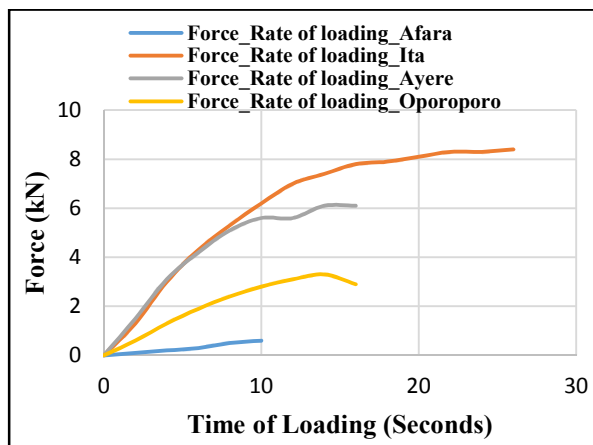


Figure 18: Force-Time curve (50 x 75 mm)

The flexural strength tests of 50mm × 100mm Samples for Albizia (Ayere), Celtis mildbraedii (ita), Pterygota macrocarpa (Oporoporo) and Terminalia superba (Afara)

The flexural strength results for the 50mm × 100mm is presented as follows:

MoR = 2.16N/mm², δ = 30.5mm, F = 8.1kN for *Albizia (Ayere)*, MoR = 2.05N/mm², δ = 29.8mm, F = 8.0kN for *Pterygota macrocarpa (Oporoporo)*, MoR = 0.84N/mm², δ = 22.5mm, F = 3.5kN for *Terminalia superba (Afara)* and MoR = 2.74N/mm², δ = 45.5mm, F = 11.4kN for *Celtis mildbraedii (ita)*. Figures 19, 20 and 21 shows the

graphical representation of the MoR, loading rate and deflection. *Celtis mildbraedii (ita)* exhibit a higher potential for strength compared to other beam samples.

The flexural strength tests of 75mm × 100mm Samples for Albizia (Ayere), Celtis mildbraedii (ita), Pterygota macrocarpa (Oporoporo) and Terminalia superba (Afara)

The flexural strength results for the 50mm × 100mm is presented below:

MoR = 3.3N/mm², δ = 24.1mm, F = 21.1kN for *Albizia (Ayere)*, MoR = 3.1N/mm², δ = 37.7mm, F = 19.4kN for *Pterygota macrocarpa*

(*Oporoporo*), $MoR = 2.05N/mm^2$, $\delta = 23.8mm$, $F = 12.8kN$ for *Terminalia superba* (*Afara*) and $MoR = 2.3N/mm^2$, $\delta = 24.6mm$, $F = 14.4kN$ for *Celtis mildbraedii* (*ita*). Figures 22, 23 and 24 shows the graphical representation of the MoR, loading rate

and deflection. In this group, *Albizia* (*Ayere*) and *Pterygota macrocarpa* (*Oporoporo*) exhibit a higher potential for strength compared to other beam samples.

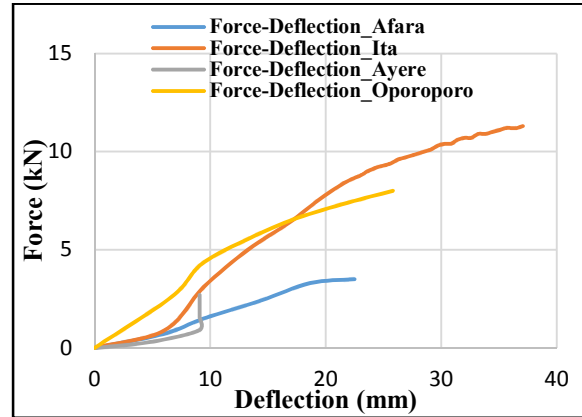


Figure 19: Force-Deflection curve (50 x 100 mm)

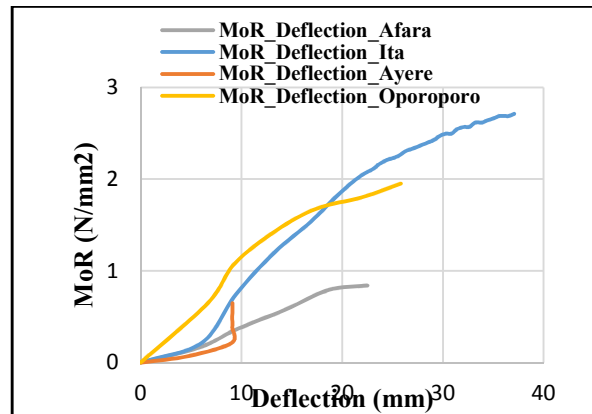


Figure 20: MoR-Deflection curve (50 x 100 mm)

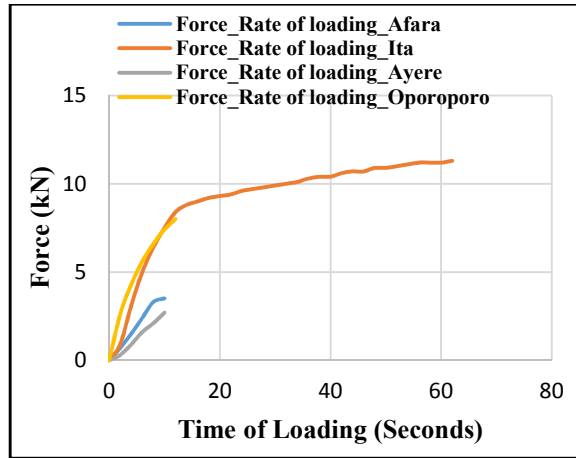


Figure 21: Force-Time curve (50 x 100 mm)

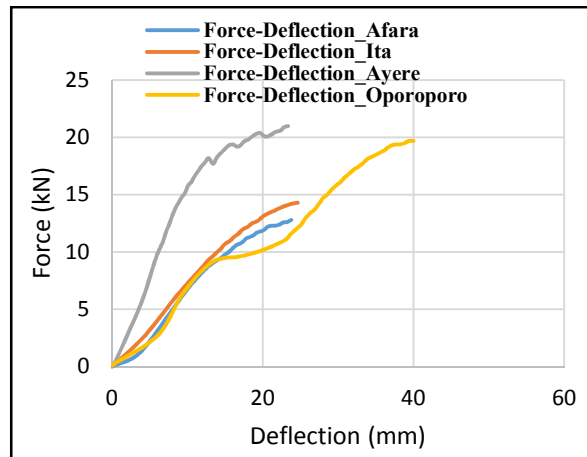


Figure 22: Force-Deflection curve (75 x 100 mm)

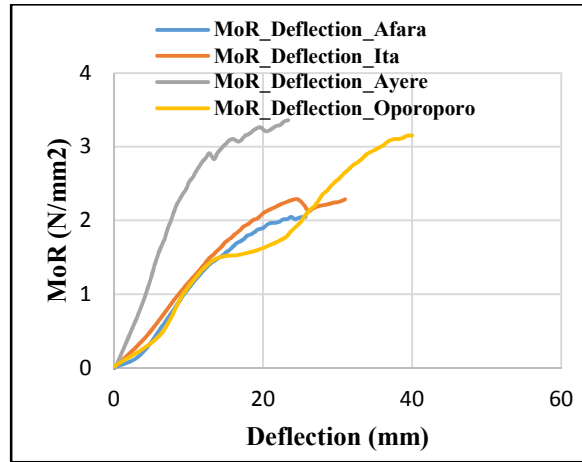


Figure 23: MoR-Deflection curve (75 x 100 mm)

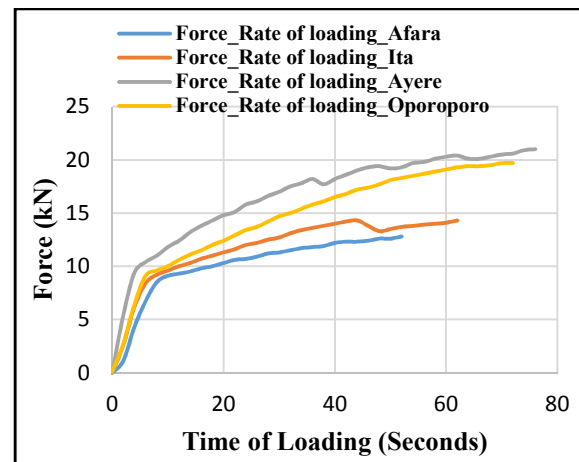


Figure 24: Force-Time curve (75 x 100 mm)

CONCLUSIONS

- i. The charring characteristics for all the hardwood species tested revealed an increase in fire resisting ability with increase in depth of sections. *Pterygota macrocarpa* and *Celtis mildbraedii* have similar fire resisting capacity.
- ii. Experimental results on the flexural strength (MoR) showed higher average modulus of rupture for *Celtis mildbraedii* (2.32N/mm²) and *Pterygota macrocarpa* (2.1N/mm²) than other tested beam samples. Generally, Ita

and Oporoporo have excellent strength and fire resisting ability judging from the experimental results.

- iii. Charring of timber when carefully carried out can help to repel insects attack.

RECOMMENDATIONS

Since Oporoporo and Ita species of different sizes has higher charring resistance; it is recommended that they could be better timbers to resist fire on any structural framework.



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