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The Comparative Analysis Of Fire Resistance Ability Of Available Roofing Planks In The South Western Part Of Nigeria

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ABSTRACT: The roof could be referred to as the single largest surface area of a house which is the framework on top of a building comprising of trusses on which a covering material is placed.However, planks, one of the available materials used for trusses are prone to fire attacks and as such necessitated the choice studying fire resistance ability of roofing planks in the South Western part of Nigeria.The study aimed at assessing and comparing the fire resistance abilities of different commonly used roofing planks available in the region. Four of these timbers were sampled and subjected to physical and mechanical tests to determine their properties and suitabilities. Some of the tests conducted were: moisture content, density, permeability, modulus of elasticity (compressive strength), and modulus of rupture (tensile strength) using a Universal Testing Machine (UTM) of capacity 600 KN.
The average moisture contents of the timber species were within acceptable limits, except for Osan, which slightly exceeded the recommended threshold. Oro exhibited the highest density and lowest coefficient of variation, indicating superior strength compared to other species.Permeability tests showed that Osan had the highest permeability, suggesting it catches fire more quickly. The modulus of elasticity results indicated that only Oro and Omo could resist fire for the specified duration, while Mahogany and Osan turned to charcoal. Oro demonstrated higher compressive strength, making it suitable for preventing gradual deflection in structures. Additionally, in the modulus of rupture test, Oro exhibited higher tensile strength, making it more suitable for structural applications.
Based on the findings, Oro was identified as the most suitable roofing plank due to its superior fire resistance properties. Theinformation provided by this study could be used by construction professionals and stakeholders in the timber industry to make informed decisions regarding the selection of roofing planks that meet required fire safety standards in the South Western part of Nigeria.

Keywords: fire, timber, resistance planks, tensile strength, rupture, construction

I. INTRODUCTION

Roofs are an essential component of buildings they provide shelter, security, and protection against weather elements. Roofing materials have an essential role in buildings as they provide protection against weather elements such as rain, wind, and sun. Unfortunately, roofing materials made from low-quality materials can pose significant fire hazards and compromise the safety of occupants. In Nigeria, fire outbreaks have frequently been linked to the use of substandard building materials, including roofing planks. In Nigeria, the roof structures and ceiling noggins of most buildings are constructed from timber that is a natural and renewable material, has a high strength-to-weight ratio and is easy to work with. It remains the most suitable materials for construction of carpentry, joinery as well as manufacturing purposes all over the world (Ezeagu, 2009). Some of the available timbers in Nigeria used for constructions works areApa (Afzeliaafricana), Ita

(Celtisoccidantalus), Oro (Antiarisafricana), Omo (Cordia millenii), Iroko (Miliciaexcelsa), Abura (Mitragynastipulousa), Mahogany (Khaya ivorensis) and Ayan (Prosopis africana). Therefore, products such as frames, doors, windows, wall paneling, roofs, floors and partitioning have been constructed from such timbers simply for their mechanical, durability and aesthetic characteristics (Babatola and Abubakar, 2011).

In Nigeria, the major area of structural utilization of wood is in roof construction; with the building industry alone consuming about 80% of the country's estimated 20 million cubic meters of annual lumber production (Alade and Lucas, 1982, Lucas and Olorunnisola 2002).

However, According to John, (2014), fire is a rapid chemical reaction that releases great quantitiesof heat. This chemical reaction always involves the oxidation of some fuel which is ageneric term that refers to anything that can burn (e.g. many gases, many liquids, paper,wood,cloth, plasticandmanyother materials).fire, a small word with serious meaning have a devastating effect on these timbers most especially when being used for roofing. Most people do not realize the destruction and damage fire can cause to human life and property and the outbreak of this poses a significant threat to all persons within a building and it can have serious financial and psychological implications.

Timber a building materialhas the disadvantage of being combustible. Consequently, timber structures are seen by many as creating an environment less safe than structures built of noncombustible materials such as steel and masonry. However, experience has shown that some timber structures have a fire resistance comparable, or greater than that of many noncombustible alternatives. Contrary to many people's expectations, timber used in construction performs well in fire. It will not flake, spall, melt, buckle or explode.

Although it burns but the keyword for timber's behaviour in fire is predictability. it occurs at a predictable speed known as the charring rate. 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. Thus, beams and columns can be designed so that a sufficient cross section of wood remains to sustain the design loads for the required duration of fire exposure. A standard fire exposure is used for design purposes.

Timber undergoes thermal degradation, also called pyrolysis when exposed to fire by converting the timber to char and gas pyrolysis results in a reduction in density. The resulting pyrolysis gas undergoes flaming combustion as it leaves the charred wood surface. Glowing combustion and mechanical disintegration of the char eventually erode the outer char layer. The linear rate at which wood is converted to char is referred to as the charring rate. After a high initial charring rate and under standard fire exposure, the charring rates tend to be fairly constant. Determining the charring rate is critical to evaluating fire resistance, because char has virtually no load-bearing capacity. There is a fairly distinct demarcation between char and uncharred wood. The charring rate sometimes refers to the weight loss. This rate of weight loss is also called burning rate in some reports. 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 (BSI, 1987). This enables the fire resistance of simple timber elements to be calculated.Thomas (1960) noted that in the standard fire resistance test, the rate of heat transfer to the surface increases with time.

The Southwestern region of Nigeria has experienced a notable surge in fire incidents partly due to the use of such low-quality roofing planks. It is therefore crucial to conduct a comparative analysis of the fire resistance properties of various roofing planks available in South Western Nigeria to help identify the most suitable roofing planks that guarantee a sufficient level of protection against fire hazards. The aim of this study is to test and compare the fire resistance properties of various roofing planks in South Western Nigeria using standardized laboratory tests to provide useful information to stakeholders in the building construction sector such as builders, architects, and regulatory agencies. The results obtained from this study will help in promoting fire safety in the region and assist prospective property owners in making informed decisions about the most fire-resistant roofing materials to procure.

However, **t**he statement of the problem for this projectwas in two-folds. Firstly, the use of substandard roofing planks has led to an increase in fire incidents in the region, thereby compromising the safety of inhabitants and causing economic losses to property owners, businesses, and communities. Secondly, there is limited data available on the fire resistance properties of different types of roofing planks in the region, hindering professionals in the construction industry such as architects, builders, and regulatory agencies in identifying the most suitable and fire-resistant roofing planks to use in buildings.

The high frequency of fire incidents, including fatalities and financial losses, associated with substandard roofing planks highlight the significant problem that currently exists in South Western Nigeria. The consequences of using low-quality roofing materials further exacerbate the problem and affects the socio-economic and environmental fabric of the region. Failure to address this problem could further lead to dire consequences, including increased loss of life and extensive financial losses for those affected by the fire incidents.

Moreover, the lack of information on fire-resistant roofing planks makes it difficult for builders to select appropriate roofing materials to use in their buildings. As a result, builders may continue to use substandard roofing planks, increasing the likelihood of future fire outbreaks, which has significant implications for the property industry and the region at large.

Therefore, the comparative analysis of the fire resistance properties of available common roofing planks in South Western Nigeria is essential to provide relevant data that will help identify the most suitable, cost-effective, and fire-resistant roofing materials that meet the required standard for fire safety in the region.

The aim of this study is to assess and compare the fire resistance properties of different roofing planks commonly used in Southwestern region to identify the most optimally suitable roofing planks that meet the required standards for fire safety through the following objectives**:**

- to evaluate the fire resistance properties of commonly used roofing planks in South Western Nigeria through laboratory testing such as moisture content, density, permeability etc.
- to compare the fire resistance properties of the selected roofing planks to identify the most fire-resistant roofing planks suitable for use in the region.
- to provide relevant data to architects, builders, regulatory agencies, and suppliers of roofing materials to assist them in selecting suitable and fire-resistant roofing materials that meet the required standard for fire safety in the region.
- to recommend fire-resistant roofing materials that comply with the required standards for use in building designs in South Western Nigeria.

This study is imperative in construction industry due to Improvement Public Safety, reduction in Financial losses, guidance in Industry, compliance with Safety Standards and better Environmental Considerations

The study mainly covered the identification of commonly used roofing planks in South Western Nigeria by selecting different types commonly used in the region. Followed by the laboratory testing which involve conducting experiments on samples of the roofing planks to assess their ignition resistance, flame spread, fire resistance, and smoke development to to determine their fire resistance properties. The data collation and analysis of relevant data and information on previous fire incidents in South Western Nigeria was carried out to help in providing an overview of the prevailing situation fire outbreak in the region and highlight the need for proper fire safety measures.

Comparison of the fire resistance properties of the selected roofing planks were done to identify the most fire-resistant and cost-effective roofing planks for use in the region. Hence, the presentation of recommendations for the roofing planks that meet the required standards for fire safety to be used in building design and construction in South Western Nigeria.

The study is limited to the following areas:

i. Limited Sample Size: The study's findings highly depend on the number of roofing plank samples used for testing. A small sample size might not provide a comprehensive understanding of how different roofing planks operate in different situations, limiting the analysis's reliability.

ii. Regional Bias: The study's location is limited to South Western Nigeria, which means that the analysis of the roofing planks' fire resistance properties may only be applicable to the region. The characteristics of the region, such as weather patterns and other environmental factors, may play a substantial role in determining the fire resistance of the planks.

iii. Limited Testing Conditions: The study's laboratory testing may not necessarily represent real-life scenarios, and this can affect the reliability of the determination of the planks' fire resistance properties.

iv. Unavailability of some Roofing Planks: Some types of roofing planks used in other parts of the world might not be readily available in South Western Nigeria, and this would affect the study's ability to compare the fire resistance properties of some unavailable planks.

v. Lack of historical data: The lack of comprehensive historical data on fire incidents resulting from substandard roofing planks may limit the analysis of the study as information used for analysis would have to be recovered by other ways other than historical data.

II. MATERIALS AND METHODS

Materials

Timber species used for this study were logs obtained from famous Sango plank market in Ibadan, Oyo State, Nigeria which are: Oro (Antaris Africana), Omo (Cordia Millenii), Mahogany (Khaya ivorensis) and Osan (ChrysophyllumAlbidum). Fourseasoned selected timber logs that have attained equilibrium moisture condition (EMC) sawn into (75 mm x 150 mm x 2700 mm) commercial sizes were carefully selected and purchased and transported to Wood Processing Workshop of the Department of Wood Products Engineering, University of Ibadan, Nigeria. For Modulus of Elasticity and Modulus of Ruptures tests, 60 No. Species of 50 mm×75 mm×300 mm each, that is, 12 pieces per specie, while for moisture content and density tests, a total 10 test samples each of size 50 mm x 50 mm x 100 mm were processed with circular machine and planning machine to the standard sizes in accordance with EN 408. The timber species used are Oro, Omo, Osan and Mahogany.

Methods

The physical properties of the selected timber species were determined. The mechanical properties were also determined. The characteristic values of material properties (i.e. mechanical properties and density) of the timber species were determined too. From the results of the characteristic values of mechanical properties, the minimum values were recommended based on the specification.

Determination of Moisture Content

A total number of ten (10) specimens of size 50 mm x 50 mm x 50 mm were randomly taken from each of air-dried timbers, weighed and thereafter specimens were oven-dried to a constant weight.

Moisture content used was calculated using:

$$MC = \frac{w_1 - w_2}{w_2} \times 100\%$$

Where: MC is the moisture content,

w_1 is the initial weight of the timber before oven-dried,

w_2 is the final weight of the timber after oven-dried.

Determination of Density

Twenty (20) timber specimens of sizes 50 mm x 50 mm x 100 mm were randomly cut from each of species and oven- dried to a constant weight. Density was calculated using

$$p = \frac{W}{V} (kg/m^3)$$

Where: p is the timber density,

W is the weight of the timber specimen and

V is the volume of the timber specimen.

Determination of Permeability

Twenty (20) timber specimens of sizes 25 mm x 50 mm x 100 mm were randomly cut from each of species and tested for permeability test. The samples were weighted and calculated using

$$p = \frac{\text{Absorbed Weight} - \text{Initial Weight}}{\text{Initial Weight}}$$

Where: p is the permeability

Determination of Mechanical Properties of Wood

Mechanical Properties of Wood are the characteristics of a material in response to externally applied forces including elastic properties which characterize resistance to deformation and distortion, and strength properties which characterize resistance to applied loads (Winandy, 1994).

The Universal testing machine (UTM) of 600 kN capacity with computer interface for data acquisition and analysis was used for mechanical tests. Tests carried out include three point bending strength (MOR and MOE). Thus, each set of the tests, failure loads were recorded for computation of failure stresses, mean failure stress, standard deviation and coefficient of variation. The corresponding load deformation graphs were plotted automatically.

Specimen test preparation

Wood specimens were tested in a cylindricalgas-fired furnace.Four Eightsamples tested were done in Four groups. Four specimens of dimension 300mm x 50mm x75mm blocks from one board of the Fours species were tested at moisture content level of 9, 12, and 15 percent, at the furnace exposure period of (0 – 10 minutes), (0 – 20 minutes), (0 – 30 minutes), and (0 – 60 minutes). The specimens were held vertically and subjected to the nominated heat flux perpendicular to the wood grain. Traditionally and in the procedure, it would be assumed that the charring

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front reaches when its temperature indicates 300℃, assuming that ignition starts at this point. At time of test, the following data were recorded for the specimen properties: 1. Species 2. Ring orientation 3. Specimen dimensions 4. Specimen weight 6. Moisture content (percent). The gas furnace was fired, the furnace temperature as at when switched on was 20°C. At 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. Specimens were exposed to fire in four batches; first batch went for time (0-10minutes), second batch for (0 - 20minutes), third batch for (0 – 30) and the last batch was for full 60minutes. The first test for exposure period (0 – 10 minutes) was stopped at exactly when the stop watch reached 10 minutes, temperature reading was 280°C.

Samples exposed during the second period (0 minutes – 20 minutes) were subjected to the same temperature (300° C) and this increased according to the time – temperature curve AS 1530. 4, 1990 as the test progressed. Effects of increased level of irradiance on the charring rate were also observed. The third and the forth test for exposure period of (0 – 30 minutes) and (0 – 60 minutes) respectively was terminated when the furnace temperature reached 300°C. When testing completed, the charred wood was taking to testing laboratory and strength was carriedout. For each specimen three sets of data were produced. Results of the test were based on an interface temperature of 300°C.

Test Specimen Arrangements

The test specimen arrangements for various mechanical property tests carried on the timber species using Universal Testing Machine (UTM) of capacity 600 kN in Department of Wood Products Engineering Laboratory, University of Ibadan, Nigeria.

Procedure used in Carry out the work

The comparative analysis of the fire resistance ability was conducted by using the following methodology:

i. Identification of Roofing Planks: The study selected a representative sample of roofing planks commonly used in construction in South Western Nigeria to serve as specimen.

ii. Preparation of Samples: The specimens were prepared according to the standard testing procedures, which involved cutting them into small pieces with equal dimensions that fitted into the testing apparatus.

iii. Laboratory Testing: The specimens were then tested for their heat resistance properties using standard testing procedures. The specimens were exposed to different levels of heat, ranging from low to high temperature to evaluate their behaviour and performance under extreme heat conditions.

iv. Analysis of Results: After the laboratory testing was completed, the data obtained from specimen were analyzed and compared to determine which type of roofing plank offers the best fire-resistant properties.

v. In conclusion, a comparative analysis of the fire resistance ability of various roofing planks in South Western Nigeria would require a properly designed methodology that takes into account the standard testing procedures, statistical analysis, and limitations of the study. The findings of the study would be instrumental in guiding the selection of roofing materials to promote public safety and minimize the incidence of building fires.

III. RESULTSANDDISCUSSION

Physical Properties of Timber Species

MoistureContent

The average moisture contentsof Oro (Antaris Africana), Omo (Cordia Millenii), Mahogany (Khaya ivorensis) and Osan (ChrysophyllumAlbidum) were 13.61,19.29,15.73and24.95%,respectively with corresponding coefficient of variation 18.66, 18.00, 15.17 and 25.55 as presented in Table 1,This result is satisfactory; since it is not higher the maximum recommended moisture content of 20 % forair-dried timber specimens and the decay of these timbers at such moisture content is greatly reduced(Lamideet al., 2020) except Osan that have more than that but less than 25%. Hussin and Al-Bared (2014) also emphasized that moisture content of timber is oneof the most important properties that influences the durability against the fungi and the fire and the resultshowed that there is a small variation in moisture content values among specimens of all species. Thisindicatesthat thedata ismoreconsistent and showed that Osan has more moisture content than others and Oro has least.

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Table1:AverageResults ofMoisture Content for TimberSpecies

Timber	Min	Max	Mean	Std.Dev.	C.V
Oro	11.67	20.63	13.61	2.54	18.66
Omo	13.16	22.86	19.29	3.47	18.00
Mahogany	11.32	20.41	15.73	2.39	15.17
Osan	16.00	40.00	24.95	6.37	25.55

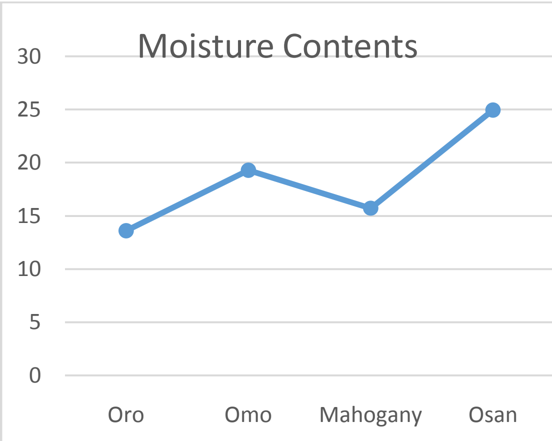

Figure 1: Graph showing the relationship between the Moisture Contents of Species

Density

Densityisthemainfactorofdeterminingthetimberstrengthaccordingto(Raja-HussinandAl-Bared2014).Inthiswork,themeanvaluesofdensity(ρ)forOro,Omo,MohaganyandOsanwere780.60,349.55, 657.07 and 482.648 kg/m^{3}respectively withthe corresponding valuesof standarddeviationof34.04,46.91, 124.49 and 25.22 showin Table 2 below. Similarly, the species coefficients of variation were given in the sameorder as 4.36, 13.42, 18.94, and 5.23.The results revealed that the average coefficient of variations of meandensity fortimberstestedwas11%whichdescribesbettervariabilityoftimberdensity requiredforstructuralmaterials in domesticbuildings (FWPA,2014). Oro is the species that have larger mean value density and lower coefficients of variation. This show that Oro has more strength than others due to its larger average means value of density than others (Fig. 2).

Table2: AverageResults ofDensityforTimberSpecies

Timber	Min	Max	Mean	Std.Dev.	C.V
Oro	728.57	832.79	780.60	34.03	4.36
Omo	281.36	439.67	349.55	46.91	13.42
Mahogany	504.10	819.17	657.07	124.49	18.94
Osan	441.38	518.75	482.65	25.22	5.23

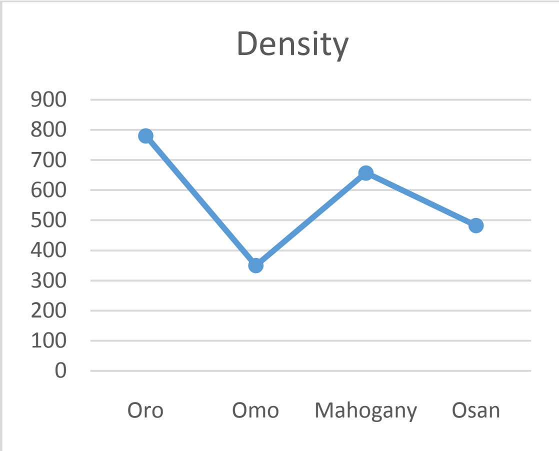

Figure 2: Graph showing the relationship between the Density of Species

Permeability

Permeability is the capacity of a materials to transmit water or other fluids such as water. The variation on pressure permeability of wood is due to the variable structural of different species and the behavior of wood substance with liquid. Permeability of wood is a property of wood that greatly influences it processing and its impregnation with preserving chemical or it seasoning aid conditioning for use as lumber (Walker, 2006).

Inthiswork,themeanvaluesofpermeabilityforOro,Omo,MohaganyandOsanwere0.0114,0.0174, 0.0302 and 0.0314 respectively withthe corresponding valuesof standarddeviationof7.71, 0.0014, 0.0044 and 0.0109 in Table 3. Similarly, the species coefficients of variation were given in the sameorder as 67.63, 8.0783, 14.65 and 34.76. The results revealed that Osan has larger average mean value and can be concluded that the higher the permeability of wood the quicker it catch fire.

Table3: AverageResults ofPermeabilityforTimberSpecies

Timber	**Min**	**Max**	**Mean**	**Std.Dev.**	**C.V**
Oro	0	0.0208	0.0114	7.71	67.63
Omo	0.0161	0.0196	0.0174	0.0014	8.0783
Mahogany	0.0259	0.0385	0.0302	0.0044	14.65
Osan	0.0116	0.0395	0.0314	0.0109	34.76

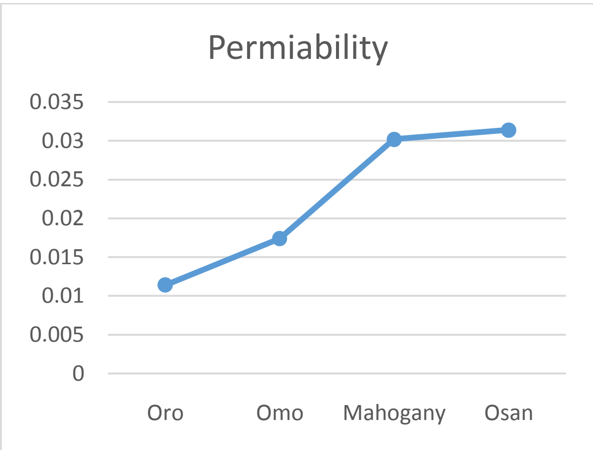

Figure 3: Graph showing the relationship between the Permeability of Species

Mechanical Properties of Timber Species
Modulus of Elasticity (MOE)

The Modulus of elasticity in wood is considered high relative to the compressive strength in wood, compared to the other building materials. Table 4, 5, 6, 7 and 8 show the result of modulus of elasticity for timber species before and after exposure to fire.

Table 4 shows that the average values of modulus of elasticity for tested timber species were 736.39, 385.18, 906.33 and 786.74 N/mm^2 with corresponding coefficient of variables of 8.37, 16.26, 17.39 and 8.02 for Oro, Omo, Mahogany and Osan timbers respectively. However, the highest COV was recorded for Mahogany followed by Omo, Oro and Osan has the least.

Table4: AverageResults ofMOE forTimberSpecies before Exposure

Species	Mean Value	Std.Dev.	C.V
Oro	736.39	61.64	8.37
Omo	385.18	62.68	16.26
Mahogany	906.33	157.70	17.39
Osan	786.74	63.12	8.02

Table5: AverageResults ofMOE forTimbersamples after (0-10minutes) Exposure

Species	Furnace Exposure Time	Modulus of Elasticity (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 10mins	776.43	68.23	8.79
Omo	0 – 10mins	296.93	25.19	8.48
Mahogany	0 – 10mins	669.16	106.37	15.89
Osan	0 – 10mins	663.47	109.06	16.44

The above table shows that the average mean values of modulus of elasticity for tested timber species after being subjected to fire for 10minutes at 300^{0}C were 776.43, 296.92, 669.16 and 663.47 N/mm^2 with corresponding coefficient of variables of 8.79, 8.48, 15.89 and 16.44 for Oro, Omo, Mahogany and Osan timbers respectively. However, Oro has the highest average mean value followed Mahogany, Osan and Omo has the least at the same time the highest COV was recorded for Osan followed by Mahogany, Oro and Omo has the least.

Table6: AverageResults ofMOE forTimbersamples after (0-20minutes) Exposure

Species	Furnace Exposure Time	Modulus of Elasticity (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 20mins	656.59	23.01	3.50
Omo	0 – 20mins	405.77	35.19	8.67
Mahogany	0 – 20mins	929.69	457.95	49.26
Osan	0 – 20mins	989.84	152.55	15.41

The table shows that the average mean values of modulus of elasticity for tested timber species after being subjected to fire for 20minutes at 300^{0}C were 656.59, 405.77, 929.69 and 989.84 N/mm^2 with corresponding coefficient of variables of 3.50, 8.67, 49.26 and 15.41 for Oro, Omo, Mahogany and Osan timbers respectively. However, in this section Osan has the highest average mean value followed by Mahogany, Oro and Omo has the least, at the same time the highest

COV was recorded for Mahogany followed by Osan, Omo and Oro has the least. We can see that there is a changes after we increased the furnace exposure time.

Table7: AverageResults ofMOE forTimbersamples after (0-30minutes) Exposure

Species	Furnace Exposure Time	Modulus of Elasticity (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 30mins	848.22	151.66	17.88
Omo	0 – 30mins	140.17	21.17	15.10
Mahogany	0 – 30mins	1557.88	729.95	46.86
Osan	0 – 30mins	869.72	123.44	14.19

In the table above, the average mean values of modulus of elasticity for tested timber species after being subjected to fire for 30minutes at 300^0C were 848.22, 140.17, 1557.88 and 869.72 N/mm^2 with corresponding coefficient of variables of 17.88, 15.10, 46.86 and 14.19 for Oro, Omo, Mahogany and Osan timbers respectively. In this section, it can be seen that the specie that has highest average mean value is Mahogany followed by Osan, Oro and Omo has the least, at the same time, Mahogany also recorded as the specie that has highest COV followed by Oro, Omo and Osan has the least. There was also a changes after we increased the furnace exposure time to 30minutes.

Table8: AverageResults ofMOE forTimbersamples after (0-60minutes) Exposure

Species	Furnace Exposure Time	Modulus of Elasticity (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 60mins	635.62	154.59	25.48
Omo	0 – 60mins	193.59	57.63	29.77
Mahogany	0 – 60mins	737.37	0	0
Osan	0 – 60mins	Nil	Nil	Nil

The average mean values of modulus of elasticity for tested timber species shows above after being subjected to fire for 60minutes (1hr) at 300^0C were 635.62, 193.59, 737.37 and Nil N/mm^2 with corresponding coefficient of variables of 25.48, 29.77, 0 and Nil for Oro, Omo, Mahogany and Osan timbers respectively. However, it can be seen that the specie that has highest average mean value is Mahogany followed by Oro and Omo has the least but Osan has turned to charcoal during the test, at the same time, Omo recorded as the specie that has highest COV out of the two species that remained out of all the species after being subjected to fire for 60minutes the rest had turned to charcoal followed by Oro. In this section we discovered that only the Oro and Omo can resist the fire for 60minutes and Mahogany and Osan cannot resist fire for 60 minutes. Since Modulus of Elasticity in Wood is considered high relative to the compressive strength in wood, the results show that Oro has more compressive strength than other species followed by Omo. This is required for preventing gradual deflection in structures loaded continuously over a period of time. Therefore, we concluded that Oro is more suitable for roofing planks than others because of its resistance against fire.

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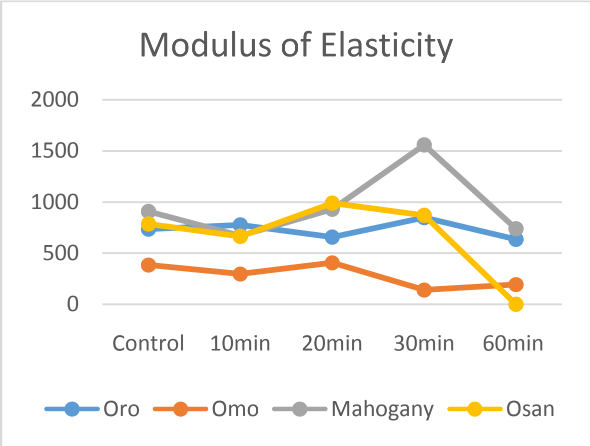

Figure 4: Graph showing the relationship between the average mean values of Modulus of Elasticity of All Species at different Furnace Exposure Time with the Control

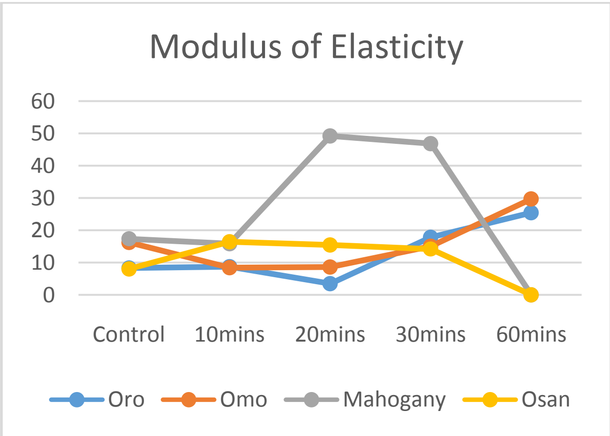

Figure 5: Graph showing the relationship between the Coefficient of Variation of Modulus of Elasticity of All Species at different Furnace Exposure Time with the Control

Modulus of Rupture (MOR)

The modulus of rupture of wood which is representing the tensile strength of this material was calculated and presented in Table 9, 10, 11, 12and 13and show the result of modulus of rupture for timber species before and after exposure to fire.

Table 9 shows that the average values of modulus of rupture for tested timber species were 60.22, 29.87, 60.53 and 35.48 N/mm^2 with corresponding coefficient of variables of 5.86, 28.29, 26.53 and 13.50 for Oro, Omo, Mahogany and Osan timbers respectively. However, the highest COV was recorded for Omo followed by Mahogany, Osan and Oro has the least and Mahogany has highest mean value followed by Oro, Osan and Omo has the least.

Table9: AverageResults ofMORforTimberSpecies before Exposure (Control)

Species	Mean Value	Std.Dev.	C.V
Oro	60.22	3.53	5.86
Omo	29.87	8.45	28.29
Mahogany	60.53	16.06	26.53
Osan	35.48	4.79	13.50

Table10: AverageResults ofMORforTimbersamples after (0-10minutes) Exposure

Species	Furnace Exposure Time	Modulus of Rupture (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 10mins	69.31	2.68	3.86
Omo	0 – 10mins	25.39	7.28	28.66
Mahogany	0 – 10mins	53.58	7.64	14.26
Osan	0 – 10mins	35.48	13.82	38.93

The above table shows that the average mean values of modulus of rupture for tested timber species after being subjected to fire for 10minutes at 300^{0}C were 69.31, 25.39, 53.58 and 35.48 N/mm^2 with corresponding coefficient of variables of 3.86, 28.66, 14.26 and 38.93 for Oro, Omo, Mahogany and Osan timbers respectively. However, Oro has the highest average mean value followed Mahogany, Osan and Omo has the least at the same time the highest COV was recorded for Osan followed by Omo, Mahogany and Oro has the least.

Table11: AverageResults ofMORforTimbersamples after (0-20minutes) Exposure

Species	Furnace Exposure Time	Modulus of Rupture (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 20mins	61.44	3.19	5.19
Omo	0 – 20mins	36.92	3.90	10.57
Mahogany	0 – 20mins	61.19	19.09	31.21
Osan	0 – 20mins	37.20	9.68	26.03

The table shows that the average mean values of modulus of rupture for tested timber species after being subjected to fire for 20minutes at 300^{0}C were 61.44, 36.92, 61.19 and 37.20 N/mm^2 with corresponding coefficient of variables of 5.19, 10.57, 31.21 and 26.03 for Oro, Omo, Mahogany and Osan timbers respectively. However, in this section Oro has the highest average mean value followed by Mahogany, Osan and Omo has the least, at the same time the highest COV was recorded for Mahogany followed by Osan, Omo and Oro has the least. We can see that there is a changes after we increased the furnace exposure time.

Table12: AverageResults ofMORforTimbersamples after (0-30minutes) Exposure

Species	Furnace Exposure Time	Modulus of Rupture (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 30mins	62.83	8.12	12.92
Omo	0 – 30mins	12.95	2.29	17.72
Maho	0 – 30mins	77.83	16.29	20.94

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gany				
Osan	0 – 30mins	30.42	7.61	25.03

In the table above, the average mean values of modulus of rupture for tested timber species after being subjected to fire for 30minutes at 300^{0}C were 62.83, 12.95, 77.83 and 30.42 N/mm^2 with corresponding coefficient of variables of 12.92, 17.72, 20.94 and 25.03 for Oro, Omo, Mahogany and Osan timbers respectively. In this section, it can be seen that the specie that has highest average mean value is Mahogany followed by Oro, Osan and Omo has the least, at the same time, Osan recorded as the specie that has highest COV followed by Mahogany, Oro and Omo has the least. There was also a changes after we increased the furnace exposure time to 30minutes.

Table13: AverageResults ofMORforTimbersamples after (0-60minutes) Exposure

Species	Furnace Exposure Time	Modulus of Rupture (N/mm^2)		
		Mean Value	**Std.Dev.**	**C.V**
Oro	0 – 60mins	40.89	15.07	36.84
Omo	0 – 60mins	18.76	8.67	46.19
Mahogany	0 – 60mins	737.37	0	0
Osan	0 – 60mins	Nil	Nil	Nil

The average mean values of modulus of rupture for tested timber species shows above after being subjected to fire for 60minutes (1hr) at 300^{0}C were 40.89, 18.76, 737.37 and Nil N/mm^2 with corresponding coefficient of variables of 36.84, 46.19, 0 and Nil for Oro, Omo, Mahogany and Osan timbers respectively. However, it can be seen that the specie that has highest average mean value is Mahogany followed by Oro and Omo has the least but Osan has turned to charcoal during the test, at the same time, Omo recorded as the specie that has highest COV out of the two species that remained out of all the species after being subjected to fire for 60minutes the rest had turned to charcoal followed by Oro. In this section we discovered that only the Oro and Omo can resist the fire for 60minutes and Mahogany and Osan cannot resist fire for 60 minutes. Since Modulus of Ruptureof wood is representing the tensile strengthin Wood, the results show that Oro has more tensile strength than other species followed by Omo. The strength in bending is most important for structural applications such as rafters, floor joists and beams. Therefore, it was concluded that Oro is more suitable for structural application than others because of it result after being subjected to fire.

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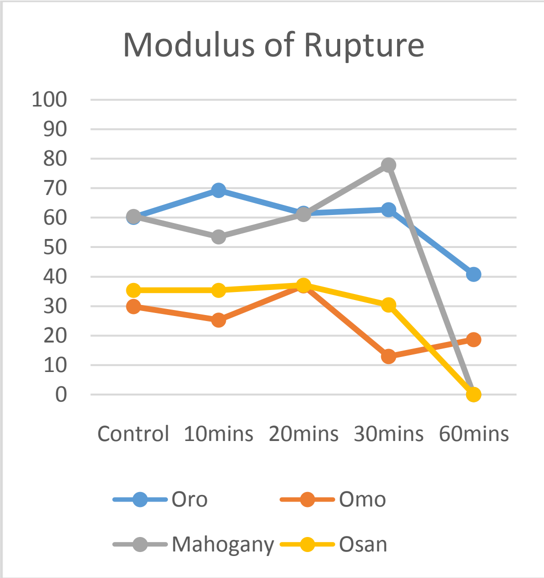

Figure 6: Graph showing the relationship between the average mean values of Modulus of Rupture of All Species at different Furnace Exposure Time with the Control

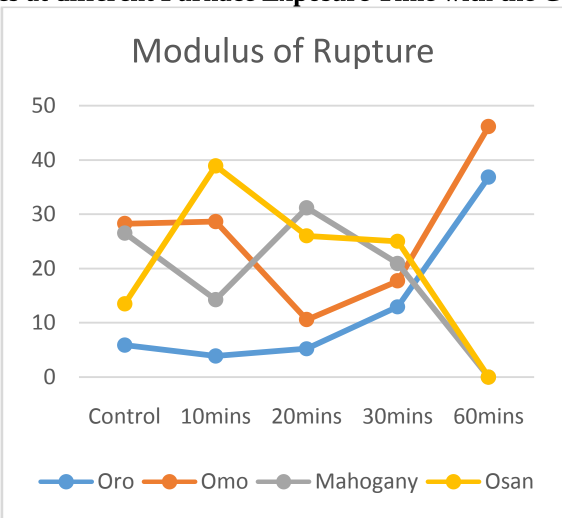

Figure 7: Graph showing the relationship between the Coefficient of Variation of Modulus of Rupture of All Species at different Furnace Exposure Time with the Control

IV. CONCLUSION

Having conducted Laboratory experiments to determine the physical and mechanical properties of four Nigerian timber species, namely: Oro (Antaris Africana), Omo (Cordia Millenii), Mahogany (Khaya ivorensis) and Osan (ChrysophyllumAlbidum). The followings were the conclusions:

Moisture Content: The moisture content of the tested timber species was within the recommended range for air-dried timber specimens, except for Osan, which exceeded the limit slightly. The variation in moisture content among the species was relatively small, indicating consistent data. Oro had the lowest moisture content, while Osan had the highest.

Density: Density is a crucial factor in determining timber strength. Oro exhibited the highest mean density value and the lowest coefficient of variation, indicating that it has greater strength compared to the other species.

Permeability: Permeability influences the processing and impregnation of wood. Osan had the highest average permeability value among the tested species, suggesting that it is more prone to catching fire quickly.

Modulus of Elasticity: After being subjected to fire for 60 minutes, Mahogany had the highest average modulus of elasticity value, followed by

Oro. Omo had the lowest value, while Osan turned into charcoal during the test. Only Oro and Omo were able to resist fire for 60 minutes. Oro exhibited the highest compressive strength among the species.

Modulus of Rupture: Mahogany had the highest average modulus of rupture value, followed by Oro. Omo had the lowest value, and Osan turned into charcoal. Only Oro and Omo were able to resist fire for 60 minutes. Oro exhibited the highest tensile strength among the species.

Fire Resistance: Among the tested species, only Oro and Omo timber exhibited fire resistance for the full 60-minute duration at 300°C. Mahogany and Osan timber turned into charcoal during the test, indicating their inability to withstand fire for 60 minutes. Oro timber demonstrated a higher average mean value of modulus of elasticity and modulus of rupture, indicating its superior strength and resistance against fire.

Based on these findings, it can be concluded that Oro is the most suitable timber species for roofing planks in terms of fire resistance. It demonstrated higher strength, both in terms of compressive strength (modulus of elasticity) and tensile strength (modulus of rupture), compared to the other species. Its lower moisture content and density also contribute to its fire resistance properties.

V. RECOMMENDATION

Based on the conclusion of this study, the following recommendations are made:

1. Oro should be preferred over other timber species for roofing planks due to its superior fire resistance properties. Its use can help enhance fire safety in buildings.
2. Builders, architects, and homeowners in the Southwestern part of Nigeria should consider the fire resistance properties of timber species when selecting roofing planks. Proper attention should be given to moisture content, density, and strength characteristics to ensure optimal fire safety.
3. Further research should be conducted to explore additional factors that may influence the fire resistance properties of roofing planks, such as chemical treatments, coatings, or combinations with other fire-resistant materials. This will help expand the knowledge base and provide more options for fire-safe construction practices.
4. It is essential to adhere to building codes and standards related to fire safety in the construction industry. These codes should incorporate specific guidelines for selecting fire-resistant roofing planks, considering regional factors and timber species commonly available.

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