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Fire Resistance Potentials of Structural Timbers

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Abstract: *Fire resistance/endurance potential of structural timbers was investigated. The experiment was carried out as what the case may be under natural burning flame at varying interval of time. From the result obtained and analysed, structural timbers known as hard woods have varying fire resistance capacity under flexural and compression loads. All the species tested submitted to ASTM standard time-temperature control curve. Charring behavior of teak (tectona grandis) is more at 1220c of 60 minutes fire exposure compared to others, thus it's rate of ignition is faster than other species.*
Iroko (milicia excels) demonstrated highest compressive strength at moisture content up to 18% while mahogany proved better in tension (bending) at same moisture content.
Key words*: Timber, moisture content, fire resistance*

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I. Introduction

Timbers are wood prepared for use in construction activities. It is the most variable and adaptable raw material available to man (Chudley, 1987). Wood differs from most other structural materials in that it is made up of cells hollow tubes, many times as long as they are wide. It is comparatively easy to manufacture into useful sizes and shapes. It's high strength to weight ratio, resiliency, pleasing appearance, low heat conductivity.

High ease of fabrication and fastening make wood the best and most economical material for many structural purposes. On this basis, the need for determining the fire resistance status of structural timbers is discovered imperative, that which is the focus of this package.

Wood is naturally highly combustible but non- inflammable and not readily ignited. Certain timbers are classified as fire resistant, having withstood a standard flame test or resisting the passage of flame during a definite arbitrary period (Desch, 1973). Surface condition of exposure of structural wood is another factor that determines rate of ignition. Unprotected/ untreated wood heated to a minimal degree will easily decompose, producing inflammable gases and charcoal. If the inflammable gases are produced in sufficient quantities and ignited, their combustion raises the temperature of wood further inwardly, and the fire kept going until all the wood is ultimately completely consumed. Again the material substances are keen interest for investigation

The approach is purely investigatory; involving material sampling of different available species of hardwood, physical observation, specimen preparation, testing and laboratory determination of stresses.

Obtained results were collected, collated, analyze and compared with standard control fire test for a final comment. The activities of fire endurance methods and requirements as applicable to load- bearing materials and constructions are in accordance with standards in Codes of practice for assessing the fire resistance of flexural tension and compression members of timber, BS 5268 (2003), ASTM (2002) and Standard methods of fire tests of building construction and material. ASTM Standard E. 118, part 14. References were also made to relevant texts and other allied codes for timber structures and properties.

II. Literature Review

2.1 Preamble: According to **Wood Committee on Wood** of the ASCE Structural Division, 1975, fire resistance investigation and treatment is one of the preservative process of wood. Since no timber is immune to deterioration and ultimate disintegration if exposed for a sufficiently long period to the ordinary atmospheric conditions. The principal causes of deterioration of wood in service, as distinct from deterioration during seasoning, are fungal infection, termite and others. The extent of which depends on the plant type and species of the trees that produces the timber.

2.2 Classification of Timber: Commercial timbers fall into two main groups, the softwoods and hardwoods. The tree that produces these two different classes of timber are themselves quite distinct (Desch H. E. 1973).
Softwoods are gymnosperms, i.e. conifers or cone- bearing plants with characteristics of needle- shaped leaves and naked seeds. It is relatively soft and easily worked. The rays that run at right angles to the annual rings are

narrow and scarcely visible even under lens. Again resin in only found in soft wood and usually characterized with turpentine smell.

Hardwoods are dicotyledons, they are broad- leaved plants with seed enclosed in a seed case. In most cases it is physically harder than softwood and denser. Hardwood do not hold resin and the absence of turpentine smell is a prove of useful characteristic over softwood, Herbert L.E, 1969. Thus it is used for load bearing elements.

Generally, all plants consists of three main parts; the roots, stems and leaves. The characteristics that separates trees from other woody plants is that they have a single main stem, the trunk or bole, Desch H. E., 1973.

However, timber users are interested primarily in the trunk or bole.

2.3 Tree Felling And Plank Production: Mechanical large saw is normally used to fell standing trees, cut into logs of wood and transported to saw mill.

In about 1781, Walter Taylor of Southampton in England was the first sawmiller to use circular blades to saw up logs, using the power of water- wheel on the River Itchen.

However, industrial revolution in American and Europe had brought the present vast improvement to sawing technologies and deliveries of different sizes of planks, Herbert L.E. 1969.

2.4 Plank Preparation: Sawn wood inevitably has a rough surface, because the action of saw- teeth breaks the fibres of the timber. Hence, further process of preparation, manually or mechanically are adopted to straightening, cutting, surface smoothening and planning carving, shaping, moulding and wood turning.

2.5 Seasoning Timber: From the moment that the tree is felled, its timber starts to lose moisture, this process of drying or seasoning begins. As the wood loses water air fill the emptying spaces of cells and so becomes lighter in weight, harder and substantially stronger with little shrinkage.

The loss of water, with associated shrinkage and slight change of shape is of serious concern. Hence steps must be taken to reduce it's ill effect using any of the following approaches;

i. Stacking method: this is natural and takes many months
ii. Kiln – seasoning: it is very efficient and satisfactory
iii. Chemical/salt seasoning method: the system involves risk of corrosion on metallic contact and it's depth of penetration not great.

2.6 Strength Characteristics: The following were considered principal to this investigation while others are not taken as unimportant for extensive analysis (Scofield and O'Brien, 1954).

Modulus of Elasticity (E) – Is simply a measure of the stiffness or rigidity of a material.

Compressive – the ability of the wood to resist stresses on compression depending on the direction of the load.

Tensile – this describes the potential of material fibre to withstand bending stresses as to establishing the relationship;

$$f/y = E/R = M/I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, f is stress in N/mm^2, y = centroidal axis, E = modulus of elasticity,

R= radius of curvature of the bending, M = bending moment due to the loading and I = moment of inertia of the material (Ryder, 1985).

2.7 Heat And Fire Resistance: Dry wood is one of the poorest conductor of heat. This characteristic renders it eminently suitable for many of the uses to which it is put every day – as a building materials, handles of cooking utensils etc.

However, wood is highly combustible but not readily ignited. Certain timbers are classed as fire-resistant, having withstand a standard flame test or have shown themselves capable, under certain conditions, of resisting the passage of flame during a definite arbitrary period.

2.8 Fire Retarding Process: Chemical Application-modern research indicates that suitable chemicals acted in one or more of the following ways

- The chemical melts at a temperature below that at which wood decomposes, forming a glaze over the surface and preventing access of oxygen to the wood.
- The chemical decomposes heat, yielding non- inflammable gases that dilute the inflammable gases from the decomposing wood sufficiently to produce a non- inflammable mixture.
- Chemical vaporizes at relatively low temperatures, absorbing sufficient heat to prevent the temperature o the wood rising to the critical decomposing point.

Effective chemical impregnation requires an average penetration to a depth of 25 to 37mm (Desch, 973). It is to be noted also that chemical processes is costly, corrosive, having hygroscopic effect and toxical.

2.9 Fire Retardant Paint Application- This confers some degree of protection. These paints acts as plasters, insulating and reflecting layer. They normally consist of thin mixture of calcium sulphate plaster or sodium/potassium silicate with an inert fillers and should be applied either by two brush coats or by a spray, to give a covering of 1.86 to 2.3m^2 to 4.55 litres

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2.10 **Limitations-** Fire retardant paints practically offer no protection in the event of intense fire, they are not durably under exposed conditions. Again they are not applicable to timber already painted with oil paints.

2.11 **Fire Considerations In Structures:** Losses in building and other structures each year are substantial both in terms of lives and properties. However, the concern to prevent fire and reduce fire losses has resulted in more restrictive building codes over years.
Since no material is immune to damage by prolonged exposure to fire, engineers are therefore confronted with two distinctive fire problems in the design of buildings

1. Fire resistant/endurance problem- this is the ability of the construction to restrict passage of fire through it. This requirement is mainly applicable to load.
ii. Surface inflammability of a material – it is a measure of rate at which flame spreads along the surface. The relevant data are documented in the code of practice.

2.12 **Ignition And Charring:** Wood surface are observed to char prior to ignition from a flaming source. The time to ignite wood with a small flame varies with environment temperature.
If wood is uniformly heated with hot air, without presence of flame, spontaneous self-ignition may occur in less than an hour at temperature as low as 330^{o}C.
Consequently, the char layer increases in thickness with continued exposure to flame, as more wood is latilized.

2.13 **Fire Resistance Rating:** This is determined by considering the period of time for which a material/construction inhibits passage of fire and/or continues to support structural load (Schaffer, 1967).

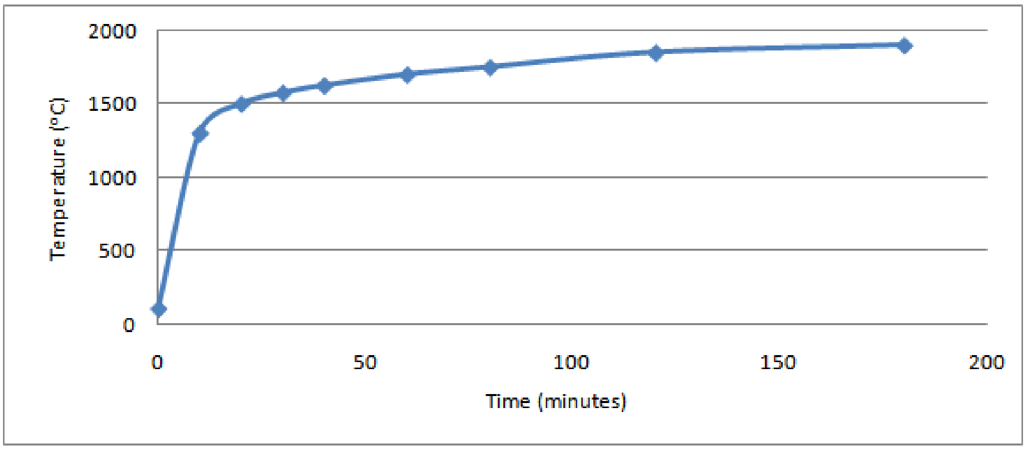

Fig. 1: ASTM Standard Temperature - Time curve for Fire Tests (Source: Schaffer, 1967)

Thus in fire resistance test the subject materials/construction is submitted to a standard fire exposure during which time it's behavior is recorded. This is compared with the ASTM Standard time-temperature curve (Fig. 1) for control of the fire test.

2.14 Surface Flame Spread: Spread of surface flame is known to reduce with an increase in *moisture content* and *surface smoothness*. However, threat of travel of flame along a material under test is compared with asbestos – cement board which does not spread flame, rated zero (0) and red oak flooring which is rated at 100 (ASTME 84 – 68).

III. Methodology

3.1 Introduction: The method involves materials sampling, physical observation, specimen preparation, fire testing and laboratory determination of stresses. Results were collected, collated, analysed and compared with standard control fire test in the discussion.

Material Sampling: Since the focus is on load bearing materials of wood, hardwood of four varying species were obtained at market source. The size considered for the test is 50 x 75 x 3600mm plank as seem commonly used in construction works.

Specimen Sampling: two sizes were obtained for investigation behavior under the two principal methods of loading as follows:

- Compression – 300mm Length
- Tension – 100mm length

Note: Tensile stress was estimated applying stress/strain relationship expression as detailed above.
4N0 specimens were prepared from each of 4species of the hardwood and tested at 5 min, 15min, 30min and 1 hr respectively.

3.2 Equipment/Materials Used: 50 x 75 x 3600mm hardwood of four (4) different species, Incinerator, Fire wood, thermometer, Stop watch, Copper wire, Nail, Plier, Wheel barrow, Matches and Writing materials

3.3 Procedure:

a) Samples were collected at market point
b) Specimen prepared and grouped into four batches of timing; 5 min 10 min 30min 60min.
c) A meter length of copper wire nailed to each specimen for prompt withdrawal.
d) Batched specimen arranged over the wire gauze inside the incinerator.
e) Fire woods were set under the wire – gauze and ignited at the set of a stop watch and temperature.
f) Withdraw of the fired specimens were done at expiration of the set time 5 min, 1 5min, 30min and 1 hr and allowed to cool normally.
g) Samples taken to the laboratory and loaded on tension and compression respectively.
h) Scale reading were taken and recorded accordingly.

IV. Results And Discussion

4.1 Introduction: Fired specimens were tested in the laboratory for compressive and tensile strength of the material after firing. Another set of unfired specimens for each of the species were also tested for comparative analysis. Detail of the results in the Table 1 below.

4.2 Analysis of Results: Compressive stress, bending stress and density of the specimens were obtained using rational analysis approach and formulae, see detail in Table 2

Compressive stress, f_c = load/Cross sectional area of samples

Bending stress f_b; $$f/y = M/I \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$f_b = M_f\,(y/I) \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where $y = d/2$, $I = bd^3/12$ and $M_f = PL/4$. Considering the self weight of specimen negligible and Incorporating strength reduction factor, η (Andrew, 2001);

$$f_b = \eta M_f\,(y/I) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

If η = 0.115, b = 50mm and d = 75mm,

$$Fb = 6.129 \times 10^{-7} PL \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Table 1: Laboratory Test Results

Timber Species	Time of Fire Exposure Time (min)	Temperature(°C)	Char (mm)	Compression Load at failure (KN)	Specimen Dimension	Bending Load at failure (Kn)	Support Interval (mm)	Mass (g)
Opepe (Naudea-Diderrichii)	0 5 10 30 60	30 92 102 112 122	0 3 5 15 30	165 135 99 44 0	50x75x300	35 32 30 27 17	420	720
Oro/Mahta (Antiaris Taxicaria)	0 5 10 30 60	30 92 102 112 122	0 3 6 16 32	151 148 132 35 27	50x75x300	35 33 31 26 18	420	830

Mahogany (Khaya ovorinsis)	0 5 10 30 60	30 92 102 112 122	0 3 6 17 34	140 135 127 86 36	50x75x300	41 38 32 25 18	420	74 0
Iroko (Milicia Excelsa)	0 5 10 30 60	30 92 102 112 122	0 4 7 19 38	127 99 68 42 39	50x75x300	35 30 26 21 16	420	65 0
Teak (Tectona Grandis)	0 5 10 30 60	30 92 102 112 122	0 4 7 21 42	81 76 60 40 30	50x75x300	33 28 22 18 15	420	83 0

Table 2: Analysis of results

Timber Species	Time (min)	Specimen	Specimen Cross sectional Area (mm²)	Compression Load at Failure (N) x 10^3	Compre-ssive Stress, f_c	Support Interval L (mm)	Bending Load, P at Failure
Opepe	0 5 10 30 60	50x75x300	3750	165 135 99 44 0	44.00 36.00 26.40 11.73 0	420	35 32 30 27 17
Oro/Danta	0 5 10 30 60	50x75x300	3750	151 148 132 35 27	40.27 39.47 35.20 9.33 7.20	420	35 33 31 26 18
Mahogany	0 5 10 30 60	50x75x300	3750	140 135 127 86 36	37.33 36.00 33.87 22.93 9.60	420	41 38 32 25 18
Iroko	0 5 10 30 60	50x75x300	3750	127 99 68 42 39	33.87 26.40 18.13 11.20 10.40	420	35 30 26 21 16
Teak	0 5 10 30 60	50x75x300	3750	81 71 60 40 30	21.60 20.27 16.67 10.67 8.00	420	33 28 22 18 15

Bending Stress, $f_b = 6.13x10^{-7}PL$ (N/mm^2)	Mass (g)	Density (g/mm^3)
9.11 8.23 7.72 6.96 4.38	720	$6.4x10^{-4}$
9.11 8.50 7.99 6.69 4.63	830	$7.4x10^{-4}$
10.55 9.78 8.24 6.46 4.63	740	$6.6x10^{-4}$
9.11 7.72 6.69 5.40 4.12	650	$5.8x10^{-4}$
8.50 7.21 5.66 4.63 3.84	830	$7.4x10^{-4}$

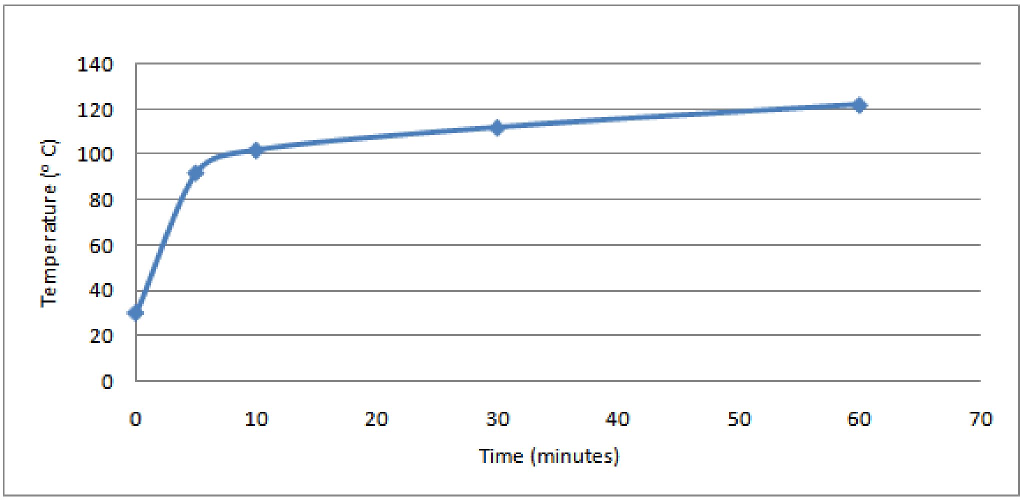

Fig. 2: Time- Temperature curve

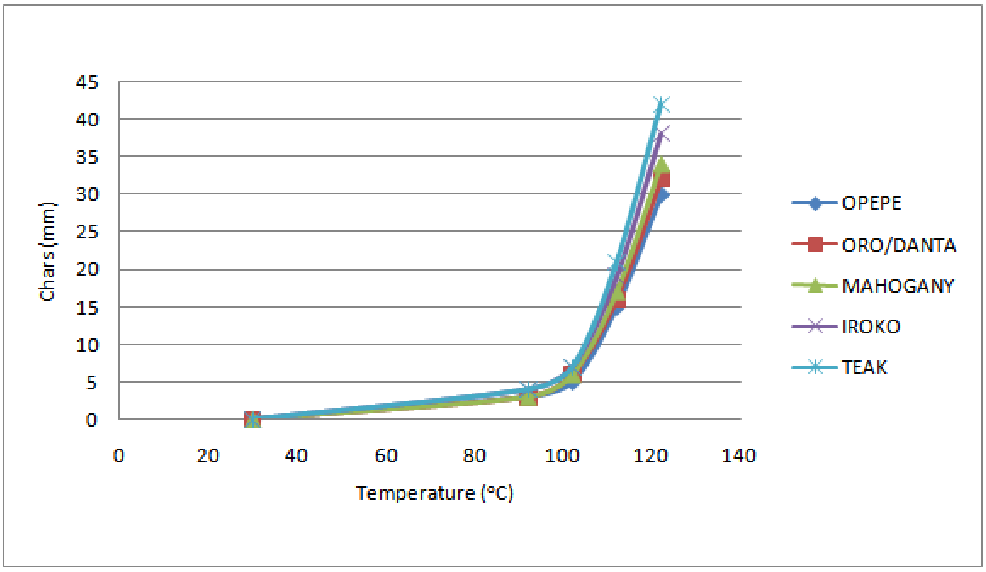

Fig. 3: Chars - Temperature curve

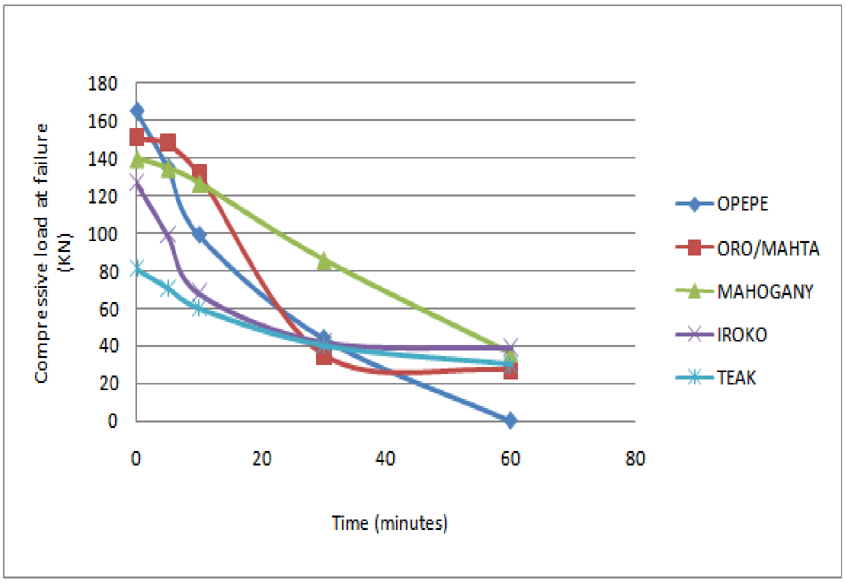

Fig. 4: Compressive load at failure - Time

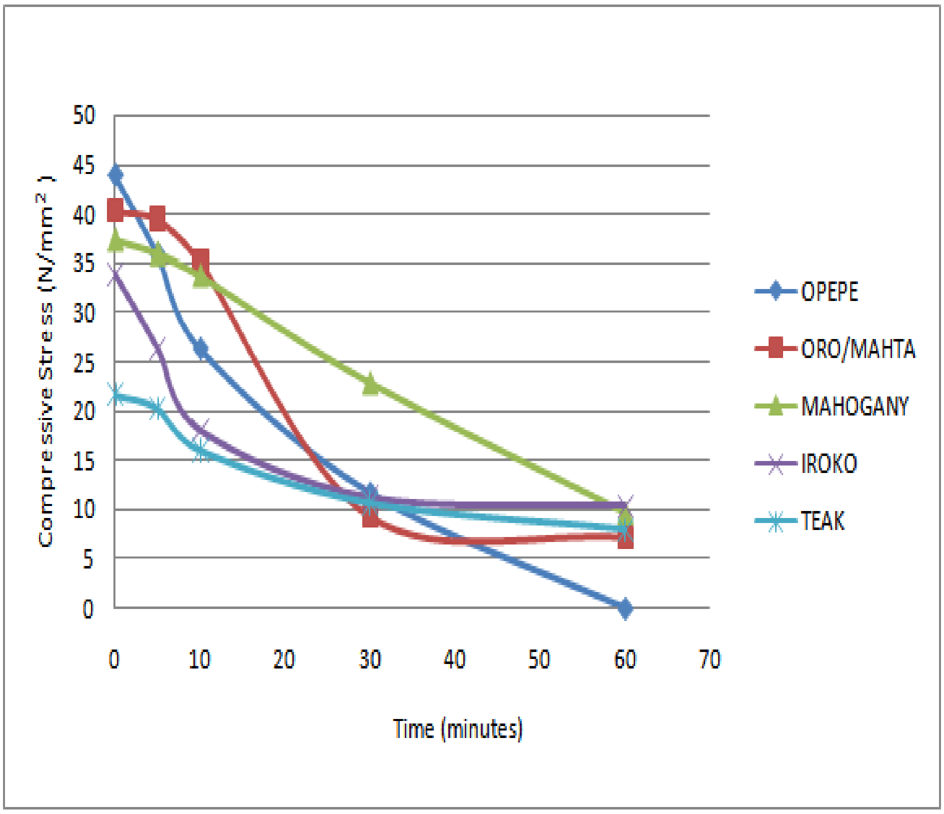

Fig. 5: Compressive stress - Time curve

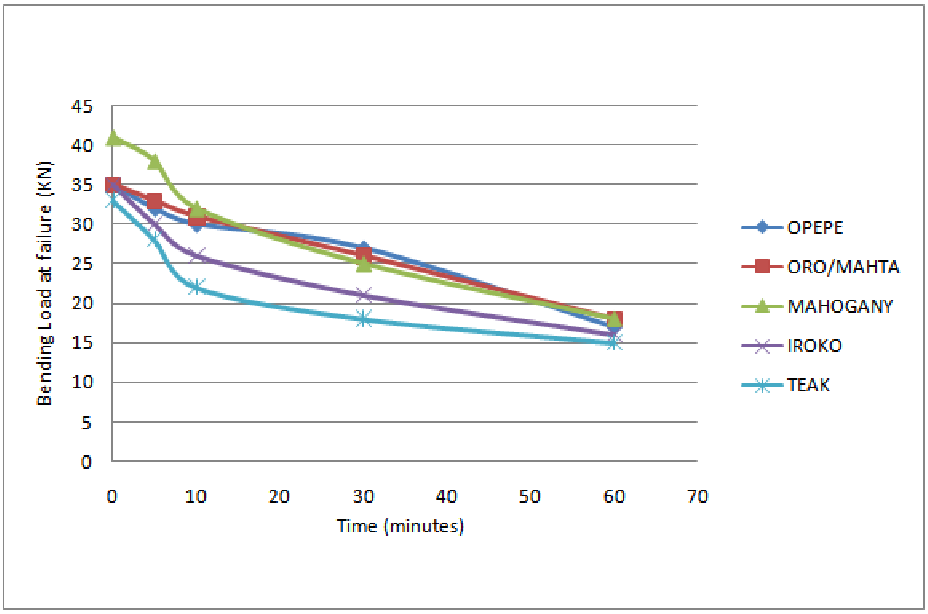

Fig. 6: Bending Load at failure - Time curve

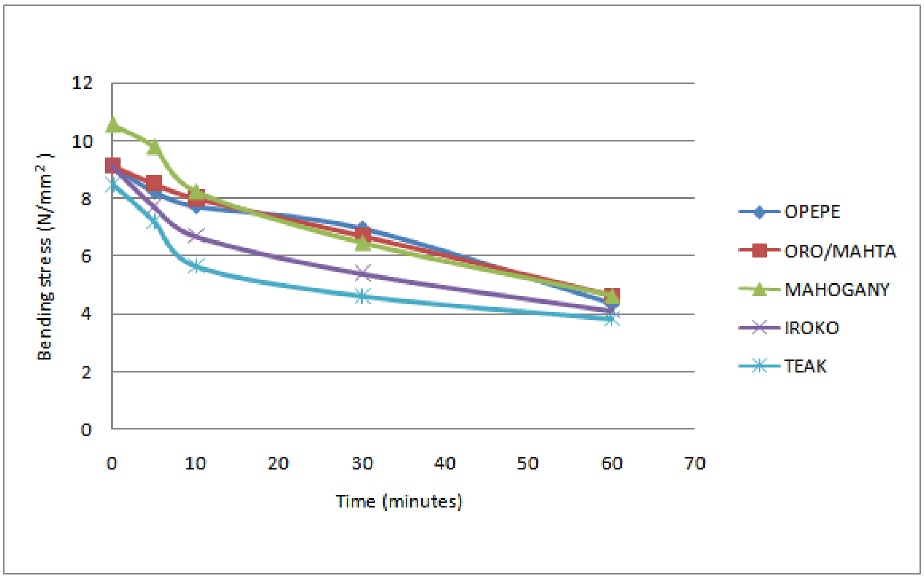

Fig. 7 Bending stress - Time curve

V. Discussion

Like any other materials, wooden elements of structures are susceptible to lost of strength by prolonged exposure to fire, while the surface flammability of timber had been discovered to be a measure of the rate at which charring occur prior to ignition from the flame source.

Considering Fig. 2 the time – temperature relationship corresponds with the ASTM standard in Fig. 1. The results also in Tables and Figures 3-7 above are true behavior of structural timber exposed to fire in order of the period of exposure. In this investigation, highest char was recorded for teak, followed by iroko and mahogany respectively. These were also seen to correspond with the rate of lost in strength of the tested timbers.

VI. Conclusion

The choice of a particular structural timber during design must also put into consideration the intended use of the structure or the locations proximity to fire hazard. Teak had been known to be of keen interest for choice when aesthetic plays priority, but it is weak in fire resistance potential. Hence this characteristic must also be considered before a final decision is taken. Otherwise adequate fire retardant treatment must be observed.

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