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Research Article

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Failure Analysis of Timber (Wood) in Constructional Work for Engineering Application (Afterglow Time and Oven Dry Densities of Some Tropical Timbers)

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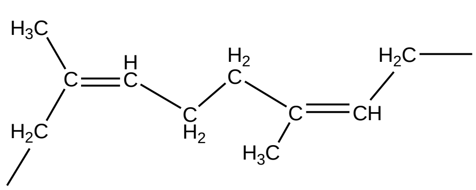
Abstract Timber is an essential raw material needed in constructing one thing or the other in all fields of human endevour. It is combustible. In this research, fire characteristics of fifty-seven (57) tropical timbers were investigated. The characteristics studied are: afterglow time (AGT) and oven dry density (ODD). The tropical timbers with the highest AGT and ODD are *T. africana* and *Manilkara* respectively while the ones with the least of these fire characteristics were *B. nitida* and *B. bonopozense* respectively. Although some tropical timbers with lower ODDs possess high afterglow time, some of the timber with higher ODDs possess lower afterglow time, it can be said that there is neither direct nor inverse relationship between the afterglow time of the tropical timbers and their oven dry densities. Though density is an important factor, in determining the fire characteristics of timber, the cellular structure, molecular composition, orientation of fiber (direction of grain) and timber extractives (e.g. resins) deserve a special attention in explaining the results. The aims and objectives of this work is to identify the timbers that are fire resistant and those that are not; to compare the afterglow time of these tropical timbers with their oven dry densities and to relate these characteristics to failure analysis of timbers in constructional work.

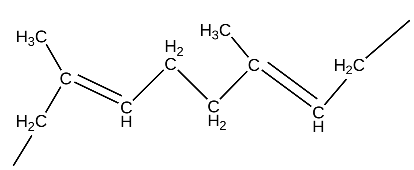
Keywords Tropical timbers, afterglow time, oven dry densities, fire characteristics, fire resistant and non-fire resistant timbers.

Introduction

A tree is a large woody plant with a main stem (trunk) which does not usually branch until several feet from the ground. Trees are perennials and are taller than shrubs. The size of a tree depends on the climate and the type of soil [1]. Many bioactive compounds are derived from trees. These include those compounds that are of biological, industrial, commercial, agricultural and domestic importance had been derived from trees (plants). Indeed, trees are beneficial to man by providing some useful agricultural produce such as rubber, cocoa used for production of stimulants and timbers for construction of buildings for habitation. *Hevea brasiliensis* is a native of the Amazon Region of Brazil but it is nowadays grown in plantations in different parts of the world, e.g. Nigeria, Sri Lanka and Malaysia. Natural rubber is a type of hydrocarbon known as a polyterpene, $(C_5H_8)n$, and exists in two isomeric forms.



Cis Poly (2-methylbuta-1,3-diene)
Cis –Polyisoprene (Elastic form)



Trans - Poly (2-methylbuta-1, 3-diene)
Trans – Polyisoprene (Nonelastic form)

Cellulose is yet another basic constituent of paper. It is obtained from the wood of trees. Wood is used in the manufacture of these materials: various categories of papers. Trees with spongy stoma e.g. palms provide the source for the production of alcohol such as ethanol which is a stimulant in palm wine. Ply wood is made of a number of veneers (laminations) which are glued together with the grain of each at right angles to its neighbor and then placed in a press. A variety of timbers is used in making plywood.

Also, trees are of paramount importance worldwide because they are both biologically and economically important to man. Biologically, plants (trees) and animals (including man) live an interdependent life. This can be seen in the area of: (i) Taking in of carbon (IV) oxide and giving out oxygen, (ii) Synthesis of food, (iii) Animals die and decay to form plant food (manure) [2].

$$\mathbf{6CO_2 + 6H_2O + Energy \longrightarrow C_6H_{12}O_6 + 6O_2}$$

Trees are indispensable sources of both coarse and fine fibres used in the manufacture of cloths or garments. Camphor is obtained from the wood and leaf of *Cinnamomum camphora*, a tall tree of China, Japan and Taiwan origin. It has a characteristic strong but agreeable odour and is widely used in very small quantities in perfumery and medicines [3]. Cinnamon is the dried brown bark peeled off from *Cinnamomum zeylanicum*, a small tree of Ceylon. It is aromatic and tastes sweet. It is extensively used for flavouring foods and vegetables. Cinnamon oil is extracted from the bark and leaf of *cinnanomum* tree. It is used in combination with some drugs as an intestinal antiseptic [4].

There would be nothing like wood and timber if there is no secondary growth in plant. There would be nothing like the use of wood as a source of heat energy and the manufacture of producer gas by the gasification of coke. Invention of biogas as a source of energy would not have been thought of. This includes the fermentation of cellulose that results to the formation of alcohol fuel.

(1) **Gasification of coke**

$$\mathbf{2C + O_2 + N_2 \longrightarrow 2CO_{(g)} + N_{2\,(g)} + Heat}$$

Air

producer gas

$$\mathbf{H_2O_{(g)} + C \longrightarrow CO + H_2}$$

Steam white hot coke .

Water gas

Fermentation of cellulose to produce ethanol Again, there would be nothing like wood and timber. There would be nothing like the use of wood as a source of heat energy and the manufacture of producer gas by the gasification of coke. Invention of biogas as a source of energy would not have been thought of. This includes the fermentation of cellulose that results to the formation of alcohol fuel.

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Steam white hot coke .

Water gas

(i) Fermentation of cellulose to produce ethanol

$$\mathbf{(C_6H_{12}O_6)_n + nH_2O \xrightarrow{\text{dil } H_2SO_4} nC_6H_{12}O_6}$$

Cellulose glucose

$$\mathbf{C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2}$$

glucose ethanol

Fire or flame is a gaseous matter heated to such a degree as to be luminous, or it's a region of hot gases raised to incandescence. It is a chemical phenomenon that involves exothermic process of oxidation and combustion. Physically, flame is defined as rise in temperature of the ambient atmosphere and its pollution with gases. For fire to exist, air and fuel must be in equilibrium. The burning generates heat. Some of the strategies used in the study of fire include: Flame duration (FD), Ignition Time (IT), Flame Propagation Rate (FPR), Afterglow Time (AGT) and Oven Dry Density (ODD).

A fire outbreak is an accidental disaster. Fire disaster is not a new misfortune in the world. Among the African nations, it is quite unfortunate that Nigeria is taking the lead on the constant fire calamities [5]. The government and private institutions are not left out. Think of the Nigerian External Telecommunications Ltd (NET), Lagos and the Cocoa House Building, Ibadan. These national edifices were all successfully raped by the "undesirable element" called fire. On the other hand, only a few large markets within the country could be excluded from all these rampant undesirable occurrences. No State in Nigeria had not experienced fire problems once or twice in the past .The most vulnerable places include markets, personal belongings and government establishments. Among the notable markets affected in the country are Aria (Ogbete), Gwombe, Sabongari, Diobu, Ariaria, Jos, Abakaliki and many others including the famous Onitsha. Although Onitsha markets had been encountering fire occurrences, the 1984 incidents in a year seemed to be more or less mysterious issues [5]. The factor contributing to the attentiveness of the 1984 incidents was that none of the past fire occurrences gutted two giant markets possessed by the town in a day. The conflagration of 17^{th} December, 1984 that occurred at the Ochancha and Main-Markets brought the happiness and joy in the minds of the people of benedicted deportment to what could be described as dumb-founding darkness of the day in the field of the commercial undertaking-showing gigantic “sorry sights”.A case where many people had earlier planned for their Christmass celebrations, though there were fair feelings of the banging austerity, while it remained only eight days before the merriment, the people of the “water city” and the nation at large experienced huge losses resulting from their commercial assets. Honestly speaking, this is a heavy slap to the channels of happiness and joy and management of life. Someone, for instance, who happened to be aware of the past fire incidents in Onitsha might have agreed with me that two huge markets burning down in a day might be more embarrassing and dishearting. This is so, because there were no physical or civil war, yet billions of Naira worth of valuables were lost. On Saturday, October 17, 1998, the thirty-two (32) communities in Idejerhe were thrown into unprecedented mourning when a pipeline carrying fuel exploded and kill over five hundred (500) people. Fire disaster is not peculiar to Nigeria. It also occurs in other nations.Some notable fire disasters that claimed the lives of many students are highlighted as follows:- Lake Vie Grammer School in Collinwood, Ohio, (176 dead). The New London Consolidated School in Texas (294 dead). Our Lady of the Angels School in Chicago (95 dead) [6].

The important lesson, learnt from American historic catastrophes was that after each fire disaster, they latter developed the firefighting force called a fire department [6]. Having understood the usefulness of trees to mankind and brief historical account of fire incidents, it becomes very glaring that there is the need to study fire or thermal characteristics of tropical timbers since timbers are combustible and many materials used in diverse fields of human endeavor are made of timber.

Some of the usefulness of trees/ timbers- the origin of timber and the historical account of some fire disasters have been highlighted. It is known that a good number of the materials and equipment used in domestic, industrial, commercial, medical and research establishments are made of timber/ wood. This forms the basis for this research work. Some of these materials and equipment as indicated earlier include, tables, stools, chairs, wooden cupboards, cardboard sheets, papers, pencils, test-tube holders, mortars and pistils, spoons, rulers, test- tube racks, reagent bottle racks, doors, windows, saw dust, door and window frames, shelf, wooden hangers and window frames, wooden beds, textile materials used for clothing, mattresses, pillows, ceiling boards, to mention just some. Some part of ships, lorries, garden implements, eg rakes, shovels, hand fork, hoes, machetes, cutlasses and others are all made of wood/timber.

The knowledge one acquires in this work will help one to make wise choice of timbers in anything he/she wants to use them for. If a timber is not fire resistant and has high fire propagation rate, an industrialist may decide to treat it with a fire- retardant or choose another before using it in manufacturing any material or constructing an industry.

For economic purposes, a forester may think of a way of introducing more of fire resistant timbers into the forest. The knowledge acquired in this work will also help the masses to guard against possible fire outbreaks. It is also known that there is scanty baseline data on the tropical timbers

Experimental Procedures

Sample collection and preparation: The fifty-seven (57) tree species samples were collected from eleven states in Nigeria. The states are: Anambra, Imo, Enugu, Sokoto, Katsina, Kano, Kebbi, Yobe, Edo, Zamfara and Gombe. The map showing the states in Nigeria are shown in Fig.1.

Some of the tree species were living trees cut dow. Some were the already felled trees. Dulmer machine was used to cut out part of the tree drunk. Thirty-two timbers were obtained from the timber sheds or saw mills at Onitsha, Nnewi and Awka. The states from where these timbers were collected were ascertained from the timber dealers. The tree species were authenticated by the Forest Officer in each of the State or the Local Government Area where the timbers were collected. The timber dealers or the saw millers were able to say the botanical names of few timbers collected from the timber shed. Most of the timbers collected there were taken to the Forest Officer in that Local Government Area where the tree species were got. By mentioning the local or common name of tree species and by having a look at the parts of tree species, the Forest Officers were able to say the botanical names of the tree or timber species.

Figure 1: Map showing the thirty-six (36) states in Nigeria

After the collection and authentification, they were occasionally conveyed to the saw mill where each timber was cut into two different shapes and sizes; They are:

(i) Splints of dimensions of 30 x 2.5 x 0.6cm

(ii) Cubes of dimensions of 2.5cm x2.5cm x2.5cm i.e. 15.625 cubic centimeter. The splints of timber were dried in an oven at 105^0C for 48hours before the experiment. American Standard for Testing and Materials (ASTM) was employed in the analysis. The picture of the saw mill used is in Figure 2.

Figure 2: Photograph of saw mill at Ihiala

Determination of the After-glow Time (AGT) of the timbers

Three splints of each tree species were clamped vertically. Cigarette lighter was used to ignite the samples. The splint sample was allowed to burn for some time. The flame was then purposefully blown off, if it didn't quench on its own. The time between flame-out and the last visually perceptible glow was recorded as afterglow time. In other words afterglow time is the length of time it takes the glow to disappear after the flame is put off. For the present work, it is measured in seconds.

The average of the three readings taken was calculated and recorded as afterglow time.

Determination of Oven Dry Density (ODD):

Three 2.5cm cubes of each timber were randomly selected from one hundred and eighty cubes of the tree species. Each was weighed with Top loading balance, Model: PL 203, Make: Mettler Toledo. After recording the initial weight, the sample was transferred into the drying oven at the temperature of 105°C. The sample was left in the oven for three hours. After the heating, the oven was switched off, and the sample left overnight to cool. The sample was re-weighed after twelve hours. Care was taken to ensure that sample did not absorb moisture before and during weighing. After recording the second weight for each, the samples were taken back into the oven for another 3 hrs at that same temperature. This was repeated until any two subsequent weights were equal i.e. constant weight attained. Three cubes of each tree species were tied together with a copper wire and weighed as a single entity. Cu wire was removed and the three samples re-weighed. The weight of a cube was obtained by calculating the average of the three samples of each tree species. The dimensions of the three 2.5cm cubes were measured and the volume of each was calculated. The average volume of the three samples was recorded as the volume of each sample of the timbers. Finally the oven dry density of each tree species was determined by dividing the average dry weight of the three samples by the average volume of three samples.

$$\mathbf{ODD} = \frac{\text{Average dry wt of samples}}{\text{Average volume of samples}}\ \mathrm{g/dm^3}$$

Result and Discusion

The results of the investigations carried out in this work are given in Tables 1 and 2, and Figures I and 2 .

Discussion:

The thermal characteristics of tropical timbers investigated in this research include; afterglow time **(AGT)** and oven dry density **(ODD)** .

Table 1: Names of the selected fifty-seven (57) tropical timbers from Nigeria

Tree species No	Botanical name	Common name	Vernacular names
1.	*Cola nitida*	Colanut	Ibo - oji, Hausa – goro Yoruba - obi gbanja, Nupe – Chigban'bi
2.	*Newboldia levis*		Ibo – Ogilisi, Hausa – aduruku, Yoruba – akoko,Benin – Ikhimi
3.	*Crysophyllum albidium*	White Star apple	Ibo – udala Yoruba-Agbalumo,Edo-Otien
4.	*Treculia africana*	African bread fruit	Ibo – ukwa
5.	*Psidium guajava*	Guava	**Ibo – gova**
6.	*Citrus sinensis*	Sweet orange	Ibo – oloma
7.	*Dacroydes edulis*	Native pear	Ibo – ube
8.	*Chlorophoro exelsa*	Iroko	Ibo – orji, Hausa – loko, Yoruba – iroko, Benin – uloko Nupe – rook,Ijwa – olokpata
9.	*Gaeis guineensis*	Oil palm tree	Ibo – nkwu
10.	*Cocus nucifera*	Coconut tree	Ibo – aku oyibo
11.	*Persea Americana*	Avocado pear	Ibo – ube oyibo
12.	*Irvingia smithii*		Ibo – ogbono
13.	*Irvingia gabanensis*		Ibo – ugiri, Yoruba – Oro, Benin – Ogwe, Efik – Oyo Nupe – pekpeara,Ijaw – ogboin
14.	*Caesalpina pulcherima*	Pride of Barbadose	

15.	*Terminalia catappa*	Umbrella tree or Indian Almond	
16.	*Spathodea campanulala*		Ibo – echichii
17.	*Ricinovenvron heudenocii*		Ibo – okwe
18.	*Ficu natalensis*		Ibo – ogbu
19.	*Banbax bonopozense*		Ibo – Akpu ,Yoruba – Puopola,Benin – oboidia Ijaw – idoundu
20.	*Ceiba petandra*	Silk cotton plant	Ibo – akpu ogwu,Yoruba – araba,Benin – okha, Efik – ukem Ijaw – afalafase
21.	*Cola gigantia*		Ibo – ebenebe, Hausa – bokoko, Yorubo – ogugu, Benin – ukpokpo, Efik – dikir, Ishan – abolo
22.	*Acacia nilotica*	Cacia	Hausa – bagaruwa, Kanuri – kangari,Fulani – gaudi
23.	*Nauclea diderrichii*		Ibo – uburu mmiri, Yoruba – opepe, Benin – obiakhe, Ijaw – owoso,Urhobo – urherekor
24.	*Gmelina arborea*	Bushbeech or Meligna	Ibo – malina,
25.	*Pteracarpus soyauxi*		Ibo – oha
26.	*Annoa senegalensis*		Ibo – oghulu, uburu ocha, Yoruba – abo,Hausa – Swandar daji,
27.	*Canarium schwanfurthii*		Ibo – ube okpoko
28.	*Pinus carribean*	Whispering pine	
29.	*Albizia ferruginea*	Albizia	Ibo- Ngwu or ngu Yoruba – Ayinre oga, Benin – uwowe
30.	*Brachystegia Nigeria*		Ibo – ufi, Yoruba – akolodo,Benin – okwen, Ishan – eku Ijaw – akpakpa, Efik – ukung,Boki – kpeunik, Ekoi – etare
31.	*Dialuim guineensis*		Ibo – icheku
32.	*Napoliana vogelii*		Ibo – nkpodu
33.	*Accio bateri*		Ibo – araba
34.	*Brachystigia eurecomya*		Ibo – achi mkpuru,Yoruba – akolodo,Benin – okwen Ijaw – akpakpa,Ishan – eku,Ekoi – etare, Boki – kepuruk Efik – ukung
35.	*Pluneria africana*		
36.	*Walteria americana*		
37.	*Azadirachta indica*	Neem plant	Hausa – dogonyaro
38.	*Khaya senegalensis*	Mahogany	Hausa – madacu

39.	*Manilkara*		Ibo – ukpi
40.	*Alstonia congensis*		Ibo – egbu
41.	*Tectona grandis*	Teak	
42.	*Mansonia altissima*	Mansonia Iron tree	Yoruba-ofun
43.	*Isoberlinia tomentosa*	Berlinia	Ibo – uboba, Hausa – faradoka (white doka) Nupe – baba
44.	*Isoberlinia doka*	Berlinia	Ibo – ububra ibu, Hausa – doka Nupe – babarochii bokun, Tiv – mkovol
45.	*Garcinia kola*	Bitter kola	Ibo – ugolo/adi, Yoruba – orogbo Benin –edun, Efik – efiari, Ijaw – okan Ibibio – efiat
46.	*Garcinia gnetoides*	Wild ugolo	Ibo – ugolo agho
47.	*Baphia nitida*		Ibo – aboshi ojii, Yoruba – irosun,Benin – otun, Efik – ubara Ijaw – abodi, Itsekiri – orosun, Urhobo – arhua
48.	*Baphia gracilipes*		Ibo – aboshi ocha
49.	*Terminalia brownie*	Congo afara	Ibo – edo, Hausa – baushe,Yoruba – idiodan
50.	*Terminalia superba*	Akmond tree (white afara)	Ibo – edo, Yoruba – afara,Benin – egboin nofua, Efik – afia eto,Ijaw – gbarada, Nupe –eji,Urhobo – unwonron
51.	*Terminalia glaucescens*	Black afara	Ibo –edo, Hausa – baushe,Yoruba – idiodan
52.	*Mangifera callina*	Kerosene mango	
53.	*Mangifera banganpalli*	Ordinary mango	Ibo – mango nkiti
54.	*Mangifera indica*	Mango with fibre	Ibo – opiolo mango
55.	*Mangifera indica*	Gernan mango	
56.	*Pentaclethra macrophyllum*	Oil bean tree	Ibo – ukpaka
57.	*Nauclea popeguinii*		Yoruba – opepe

Table 2: Aferglow time and ODD of fifty-seven (57) tropical timbers.

Tree species No	**Botanical name**	**AGT Afterglow Time x 10^1 Sec**	**ODD Oven dry density x 10^{-2} g/cm^3**
1.	*Cola nitida*	18.0	66.6
2.	*Newboldia levis*	83.1	68.1
3.	*Crysophyllum albidium*	48.0	62.7
4.	*Treculia africana*	125.2	58.8
5.	*Psidium guajava*	90.1	**85.5**
6.	*Citrus sinensis*	81.8	86.5
7	*Dacroydes edulis*	20.3	51.1

8.	*Chlorophoro exelsa*	77.4	58.4
9.	*Gaeis guineensis*	11.4	59.9
10.	*Cocus nucifera*	22.9	60.1
11.	*Persea Americana*	39.5	43.4
12.	*Irvingia smithii*	32.8	81.7
13.	*Irvingia gabanensis*	94.7	87.8
14.	*Caesalpina pulcherima*	29.9	46.5
15.	*Terminalia catappa*	75.4	65.4
16.	*Spathodea campanulala*	52.5	32.0
17.	*Ricinovenvron heudenocii*	73.5	34.2
18.	*Ficu natalensis*	65.6	48.5
19.	*Banbax bonopozense*	27.1	24.0
20.	*Ceiba petandra*	40.1	35.5
21.	*Cola gigantia*	101.8	54.0
22.	*Acacia nilotica*	73.9	64.6
23.	*Nauclea diderrichii*	67.0	54.1
24.	*Gmelina arborea*	15.2	58.6
25.	*Pteracarpus soyauxi*	35.6	47,5
26.	*Annoa senegalensis*	56.7	37.0
27.	*Canarium schwanfurthii*	51.2	41.3
28.	*Pinus carribean*	21.8	40.7
29.	*Albizia ferruginea*	21.5	66.8
30.	*Brachystegia Nigeria*	76	72.1
31.	*Dialuim guineensis*	31.4	73.1
32.	*Napoliana vogelii*	50.6	74.3
33.	*Accio bateri*	71.5	97.5
34.	*Brachystigia eurecomya*	104.1	77.2
35.	*Pluneria africana*	84.4	60.3
36.	*Walteria americana*	67.2	50.1
37.	*Azadirachta indica*	67.4	79.0
38.	*Khaya senegalensis*	59.8	77.5
39.	*Manilkara*	70.7	109.7
40.	*Alstonia congensis*	21.4	40.1
41.	*Tectona grandis*	5.6	55.1
42.	*Mansonia altissima*	40.7	59.6
43.	*Isoberlinia tomentosa*	25.2	49.6
44.	*Isoberlinia doka*	7.7	45.1
45.	*Garcinia kola*	4.2	92.1
46.	*Garcinia gnetoides*	35.4	68.3
47.	*Baphia nitida*	2.5	88.6
48.	*Baphia gracilipes*	71.4	79.2
49.	*Terminalia brownie*	58.4	69.3
50.	*Terminalia superba*	53.0	55.6
51.	*Terminalia glaucescens*	7.6	56.2
52.	*Mangifera callina*	74.3	60.9

53.	*Mangifera banganpalli*	40.4	65.3
54.	*Mangifera indica*	10.6	74.8
55.	*Mangifera indica*	86.0	44.4
56.	*Pentaclethra macrophyllum*	24.3	78.8
57.	*Nauclea popeguinii*	80.8	63.2

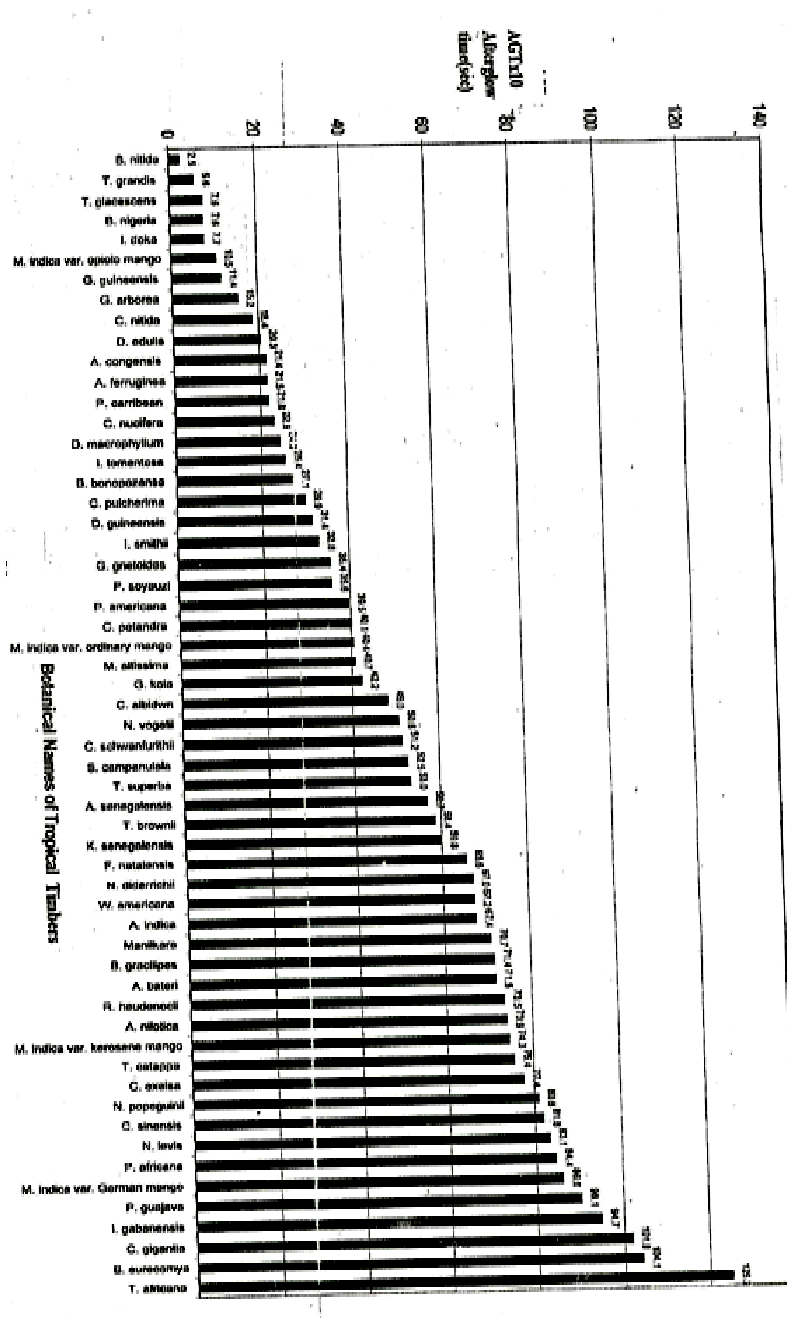

Figure 3: Afterglow time (AGT) of Fifty-Seven Tropical Timbers

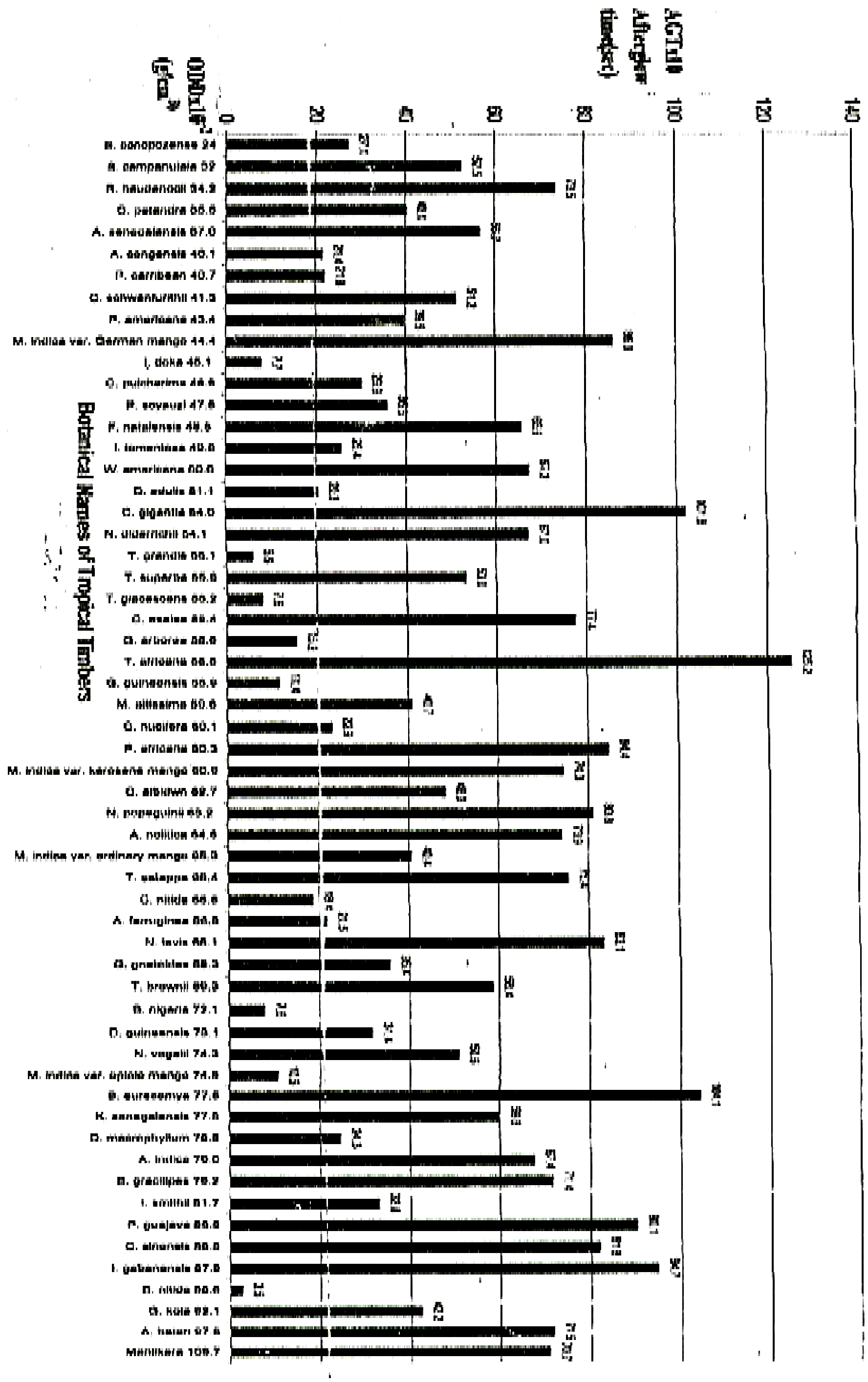

Figure 4: Graph of Afterglow time vs Oven Dry Density (ODD)

Figure 3 depicts the graph of afterglow time (AGT) of fifty-seven tropical timbers. Afterglow time of these tropical timbers were as well represented in their increasing order of magnitude. The tropical timbers, with the least after glow time is *B. nitida* (2.5x10 sec) while the one with the highest after glow time is *T. africana* (125.2x10 sec). The only two tropical timbers with equal after glow time are *T. glacescens and B. nigeria.* Their after glow time is (7.6x10 sec). Afterglow time is a measure of the life time of glow that follows flame out. Glow depends among other things on presence of air or oxygen, air draught and of course on the material or the fuel source. Material that provide greater fuel will enhance glow time and vice versa. Figure 3 makes it clear that only nineteen tropical timbers have low afterglow time which is less than five minutes. This means that these tree species will not glow long enough for rekindling to take place. Thirty-eight tropical timbers have after glow time which is greater than five minutes. *T. africana* have the highest afterglow time of about 20.9 minutes. These tree species with higher AGT will glow long enough that rekindling may occur. Glow was defined as an exothermic surface reaction that radiates heat and light without a flame and usually is favored by an abundance of oxygen.

Figure 4 is the graph of afterglow time vs ODD. The tropical timber; *T.africana* with the highest AGT (125.2x10 sec) had the ODD of ($58.8 \times 10^{-2} g/cm^3$). The tropical timber; *B. nitida* with the least AGT (2.5sx10sec) had the le ODD of ($88.6 \times 10^{-2} g/cm^3$). The tree specie with the highest ODD of ($109.7 \times 10^{-2} g/cm^3$) had the AGT of (70.7x10 sec). It is therefore evident from this figure, that there is neither direct nor inverse relationship between the after glow time and oven dry density of these fifty-seven tropical timbers. This observation is supposed to be the intended outcome bearing in mind the assertion of Horrocks and Brown. Since the percentage composition of fuel in these varied tree species, were not studied, the observation is in order.

Conclusion

There is neither direct nor inverse relationship between the afterglow time of the tropical timbers and their oven dry densities. Afterglow time of tropical timbers should be considered for one to make wise choice of timber for constructional work or for engineering application.

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