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CHEMICAL COMPOSITION OF BAMBOO (BUMBUSA VULGARIS) AND ITS SUITABILITY AS A ROOF TRUSS MATERIAL IN A SEVERE ENVIRONMENT.

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Abstract:
*This study investigated the chemical composition of the bamboo species (**Bumbusa Vulgaris**) and its suitability as a roof truss material when it is exposed to rainfall environment during roof truss construction stage in building construction works. Exposed and fresh bamboo samples were grinded to powder form then dissolved to solution form using N-ezane solution. Thereafter, injected into MSD scan machine that is connected to a computer that contains files of the known organic compounds. The result shows that exposed bamboo contains chemical compounds which are different from the compounds in fresh samples. Rainfall is capable of attacking some chemical compounds of bamboo and causes reduction in its tensile and compressive strength, ductility, and some other engineering properties of the bamboo. Knowing the chemical composition of the organic compounds of bamboo will facilitate the methods to be adopted to protect bamboo in this severe environment.*

Keyword: *Bamboo, Compressive Strength, Chemical Composition, Tensile Strength, Roof Truss.*

Introduction

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries, a renewable resource that has become one the most important alternatives to tropical hardwood in recent years. It is considered a composite material because it consists of cellulose fibers imbedded in a lignin matrix. Cellulose fibers are aligned along the length of the bamboo providing maximum tensile, flexural strength and rigidity in that direction [Lakkad and Patel 1980]. Over 1200 bamboo species have been identified globally [Wang and Shen 1987]. Bamboo is also one of the oldest building materials used by human kind [Abd.Latif 1990]. Bamboo chips were used to record history in ancient China. The Chinese bamboo is known as the hardest bamboo species in the world and grows on average up to 20m tall and 10cm in diameter. It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs, etc. It has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters and purlins; it is also used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffoldings.

There are several differences between bamboo and wood. In bamboo, there are no rays or knots, which give bamboo a far more evenly distributed stresses throughout its length. Bamboo is a hollow tube, sometimes with thin walls, and consequently it is more difficult to join bamboo than pieces of wood. Bamboo does not contain the same chemical extractives as wood, and can therefore be glued very well [Jassen 1995].

Fibers are of three types: natural fibers which consist of animal and plant fibres, manmade fibres which consist of synthetic fibres and regenerated fibres. The earliest evidence for humans use of fibres is the discovery of wool and dyed flax fibers found in a prehistoric cave in the Republic of Georgia that date back to 36,000 BP (Gram, 1983).

Natural fibers are made from plant, animal and mineral source and classified according to their origin as vegetable fibres and animal fibres. Vegetable fibers are generally composed mainly of cellulose: examples include cotton, jute, flax, ramie, sisal, and hemp (Balter, 2009). Animal fibers generally comprise proteins such as collagen, keratin and fibroin; examples include silk, sinew, wool, catgut, angora, mohair and alpaca. Animal fibres are sub classified thus:

i) Animal hair (wool or hairs) fibre: Fiber or wool taken from animals or hairy mammals. e. g. sheep's wool, goat hair (cashmere, mohair), alpaca hair, horse hair et c.
ii) Silk fiber: Fiber secreted by glands (often located near the mouth) of insects during the preparation of cocoons.
iii) Avian fiber: Fibers from birds, e.g. feathers and feather fiber.(Audu et al.,2015)

Natural fibres are prospective reinforcement material and their use until now has been more traditional than technical. They have long served many useful purposes but the application of materials technology for the utilization of natural fibres as reinforcement in concrete has only taken place in comparatively recent years. (Audu *et al.*, 2015). The distinctive properties of natural fibre reinforced concrete are improved tensile and bending strength, greater ductility and greater resistance to cracking and hence improved impact strength and toughness (Toledo *et al*., 2000).

Vegetable fibres are of different types but Sera *et al.* (1990) broadly classified them into four categories; wood fibres (bamboo, reeds, bagasse and fan palm), bast or stem fibres (jute, flex, hemp, bagasse), leaf fibres (sisal, abaca seed) and fruit fibres (coconut fibre, coir). The properties of some natural vegetable fibres are presented in Table 1.0. It could be observed from the table that bamboo is a probable good natural local fibre that could be used for a structural material or roof truss materials in roofing construction. Bamboo when exposed to rainfall environment during roof truss construction works in building construction pose threat to the roofing members. Therefore, there is a need to study the composition of bamboo: so as to know how to improve the durability before recommending it for use in roof construction works.

Table 1. Properties of some natural vegetable fibres.

PROPERTIES	SEED FRUIT FIBRE FIBRE		LEAF FIBRES Sisal	BAST/ STEM FIBRES Jute	WOOD FIBRES		
	Coir	Palm kernel			Bagasse	Bamboo	Fan palm
Length (mm)	37.5	10-25	20-30	180-900	26	2.7	37.5-40.0
Average diameter (mm)	0.241	0.22	0.5	0.1-0.2	0.03	-	-
Specific gravity	1.35	1.25	0.6-0.8	1.02-1.04	1.25	0.6-0.8	1.49
Water absorption (%)	66.50	63.2	30	25-40	78.5	35	19
Moisture content (%)	-	-	18	-	12.1	-	25.92
Ultimate tensile (N/mm^2)	56.0-71.70	44-65.0	449.0	250-350	196.4	47-173	72-134.6
Modulus of elasticity (kN/mm^2)	2.04	19-24.4	14.9	26-32	16.90	8.7-27.7	0.33-1.63
Bond strength (N/mm^2)	-	-	-	-	0.84	0.24-1.47	0.33-1.63

Source: Gram (1983)

Systematic and thorough research of the chemistry of bamboo is important in determining its utilization potential.

Raw bamboo consists of cell+ulose, hemicellulose, lignin, ash and other extractives. The content varies between and within species and is dependent on the age of the culm, as well as the location along the height of the culm and within the culm wall (Li, 2004). From an underground stem arise a hollow woody jointed stem of about 40m high in some species (Carl, 2007). The reinforcement by diaphragms and its physical conditions cause its enormous superiority compared to other building materials, Fig 1.0

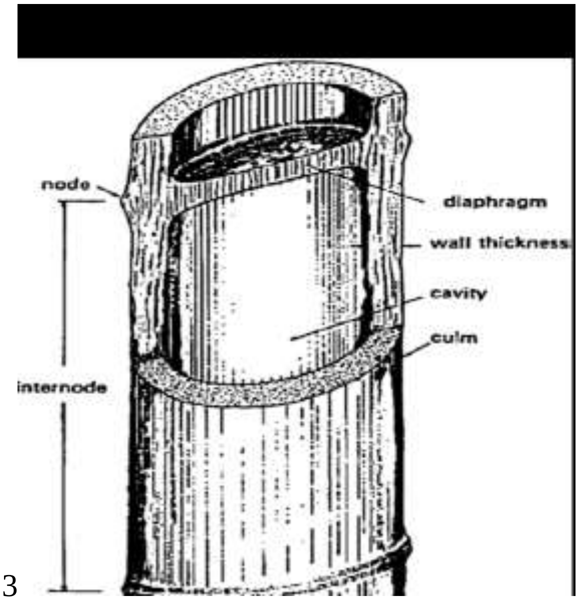

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Figure 1. General features of a bamboo culm

The interaction of Bamboo with water is responsible for several problems. If rain is allowed to fall on the trusses the wet condition causes bamboo to expand especially in transverse direction (i.e. perpendicular to the direction of the culms). . The inability of early completion in this stage gives rise to deterioration of the roofing members. This might be due to non-availability of suitable truss materials or lack of fund since roof truss construction stage is a capital-intensive process. This can cause premature cracks in the trusses. Method of dealing with these problems usually involves treating the bamboo in some ways that are likely expensive. Treatments should also improve the durability of the bamboo which is normally very poor in a wet environment.

There are two species of bamboo commonly found in Nigeria. Oxytenanthera abyssinica exist in the northern part of Nigeria with a minimum and maximum ultimate tensile strength of 52.0N/mm^2 and 400.0N/mm^2 respectively. The second species is Bambusa Vulgaris which is found in the southern part of the country with a maximum ultimate tensile strength of 295.4N/mm^2. From the result of tests by Fapohunda (2000) on bamboo, the characteristic strength, modulus of elasticity, moisture content and factor of safety of the bamboo (Bambusa Vulgaris) are respectively 104.49N/mm^2, 4617.79N/mm^2, 14.2% and 1.14.

Despite the advantages that a bamboo building offers, it has not gained popularity in the building industries in Nigeria. People are skeptical about the strength, durability and safety of buildings built with bamboo, hence there is a need for a reliability optimal design of such building. There has not been a well-developed building design code specific for bamboo building in Nigeria which can serve as a guide. To eliminate flaws associated with poorly designed or a constructed bamboo building there is need for proper design and construction. There is a strong relationship between insect attacks, humidity content and starch of bamboo. Bamboo with low humidity is less prone to mould attacks, with a very low risk when humidity is less than 15% .The physical and mechanical properties increases when bamboo has low humidity content (Chew.et al, 2000)

During construction, trusses are subjected to stresses in the form of tensile and compressive forces. Theses stresses tends to reduce the reliability of the truss with time. Reliability is a function of the constituent strengths; operating conditions and environment where the material is being put to use. The sudden change in temperatures, repeated drying and wetting all have effects on the reliability of the truss. Three categories of loads on trusses can be distinguished as follows according to Basin (1999):

(i) Dead load (G_k): Dead loads for roof structures are basically the own weight of the materials used. These forces act vertically.

(a) Own weight of truss**:**

(b)Weight of purlins / battens

(c)Weight of roof cover

(ii) Live load (Q_K): This is due to foot traffic and maintenance, typically 0.8kN. The man load is usually discarded when analysing the truss as a whole. However, for sizing battens, the man load is the most important life load.

(iii) Wind load (W_K): The magnitude of the wind load depends on the roof shape, wind direction and location of the building. For lightweight roof structures and cover materials, the wind load is the most important load.

Methodology

The determination of chemical compositional elements involves air drying, grinding, dissolving into solution state and analysing. Bamboo samples were procured from Agbaku village in Kwara state. The bamboo samples were air dried in the kiln at room temperature for about ten days until a constant weight (+ 0.01g) is obtained after which the sample was then ground. The grinded particles were obtained while sawing the bamboo log repeatedly.

The ground sample (now in powdered form) was dissolved into solution form using N-ezane solution. A small proportion of the prepared bamboo solution was then put in a test tube to about 2/3rd full. A small proportion (0.01 mg) of the bamboo solution from the test tube was injected into the injection source of molecules scan displaying, MSD, (Agilent 19091s-433Hp-5MS) machine which has been pre-set to the parameters. The machine was connected to a computer that contains files of chemical compounds whose molecular weight have been determined. The machine was turned on and allowed to run for 45.75 minutes after which the values of molecular weights of the chemical compounds were displaced in spectra forms on the monitor of the connected computer. The computer automatically compares the values of molecular weights of the scanned compounds with the molecular weights of the stored compounds in head to tail spectra forms. The processes were repeated for exposed bamboo samples at 9 months.

Results and Discussions

Figure 2 and 3 displayed the spectral of the detected compounds of the fresh and exposed bamboo from MSD machine. Figure 2 and 3 showed the compared spectral of the molecular compounds of the fresh and exposed bamboo with the molecular compounds of the known organic compounds in the library of the MSD machine.

Bamboo is a hard wood fibre and like other hard woods, it is composed essentially of cellulose, hemi-cellulose, lignin and extractives. Table 2 and 3 shows the chemical compound and percentage by proportion of the chemical compounds of fresh and exposed bamboo as obtained from the spectra display on the computer of the MSD machine **(Agilent 19015-433hp-5MS model).** Table 4 shows the computed composition by proportion of the cellulose, hemi-cellulose, lignin and extractives of bamboo obtained from chemical compound of bamboo in Table 2. The main compositions as obtained from Table 4 are discussed further. Cellulose is an organic compound with formula, (C6H10O5**)n ,**a polysaccharide consisting of linear chain of several hundred to over ten thousand β(1, 2, 3, 4) linked D-glucose unit (Crawford, 1981). Table 4, The shows that bamboo contains organic compounds with cellulose 73.83%, hemi-cellullose 12.49%, lignin 10.50% and extractives 3.18% It could be seen that the cellulose compound of the bamboo constitute the highest, at **73.83%.** It contains compounds such as Phenol, 2,6-dimethoxy, Benzofuran, 2,3-dihydro,5-Hydroxymethylfurfural, 4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol. Klemn *et al*. (2005) and Ignetyve *et al*., (2011) reported that cellulose has a strong tendency to form intra. While Table 3 showed chemical compound of the exposed bamboo samples such as n-Hexadecanoic acid, Oleic Acid, Octadecanoic acid; and n-Hexadecanoic acid, ethyl ester.

Inter- molecular hydrogen bonds by the hydroxyl groups on the linear cellulose chains, which stiffened the straight chain and promotes aggregation into crystalline structure and give cellulose a multitude of partially crystalline fibre structures and morphologies.

Cellulose molecules are bond strongly to each other. It is difficult to break down the polysaccharides of the cellulose compounds .

Table 2.0: Chemical Compounds of Fresh Bamboo (Bambusa Vulgaris).

PK #	R.T. min	COMPOUNDS	% COMPOSITION
1	6.175	Furan, 2-methyl-	0.455
2	7.245	2-Furanmethanol	0.586
3	8.127	4-Cyclopentene-1,3-dione	0.616
4	9.503	2H-Pyran, 3,4-dihydro-	0.604
5	9.947	1,2-Cyclopentanedione	2.978
6	12.675	Phenol	3.321
7	12.881	Oxirane, [(2-propenyloxy)methyl]-	8.742
8	14.195	1,2-Cyclopentanedione, 3-methyl-	0.836
9	15.089	2-Methoxythiophene	1.030
10	15.821	2,5-Dimethyl-4-hydroxy-3(2H)-furan	1.590
11	16.597	Phenol, 2-methoxy-	5.332
12	16.765	1-Pentanol, 4-methyl-2-methylene-	1.115
13	17.541	4-Fluoro-2-methylphenol	0.415
14	18.586	2-Propanamine, N-methyl-N-nitroso-	0.575
15	18.755	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	0.769
16	20.575	Diallylmethylsilane	0.665
17	21.182	Cyclopentanecarboxylic acid, 4-tridecyl ester	0.731
18	21.770	Benzofuran, 2,3-dihydro-	10.620
19	22.020	5-Hydroxymethylfurfural	3.029
20	24.291	Hydroquinone	0.521
21	24.791	2-Methoxy-4-vinylphenol	4.752
22	26.061	Phenol, 2,6-dimethoxy-	11.032
23	26.755	Benzaldehyde, 4-hydroxy-	0.969
24	27.581	Vanillin	1.476
25	29.189	Phenol, 2-methoxy-4-(1-propenyl)-,	1.184

26	31.672	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)-	0.936
27	32.698	4-Methyl-2,5-dimethoxybenzaldehyde	5.110
28	35.563	3,4-Dimethoxy-5-hydroxybenzaldehyd	4.411
29	36.295	Phenol, 2,6-dimethoxy-4-(2-propenyl)-	0.459
30	36.632	3-Methoxytyrosine	0.635
31	36.739	2-Propenal, 3-(4-hydroxy-3-methoxyphenyl)-	1.221
32	36.801	4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol	12.701
33	37.208	2-Pentanone, 1-(2,4,6-trihydroxyphenyl)	1.254
34	37.633	Benzenepentanoic acid, 3,4-dimethoxy-, methyl ester	0.469
35	37.758	5H-Indeno[1,2-b]pyridin-5-one	0.789
36	38.872	2-Pentanone, 1-(2,4,6-trihydroxyphenyl)	0.986
37	38.972	Ethyl tridecanoate	1.263
38	39.034	3-Phenylbicyclo(3.2.2)nona-3,6-dien-2-one	5.825

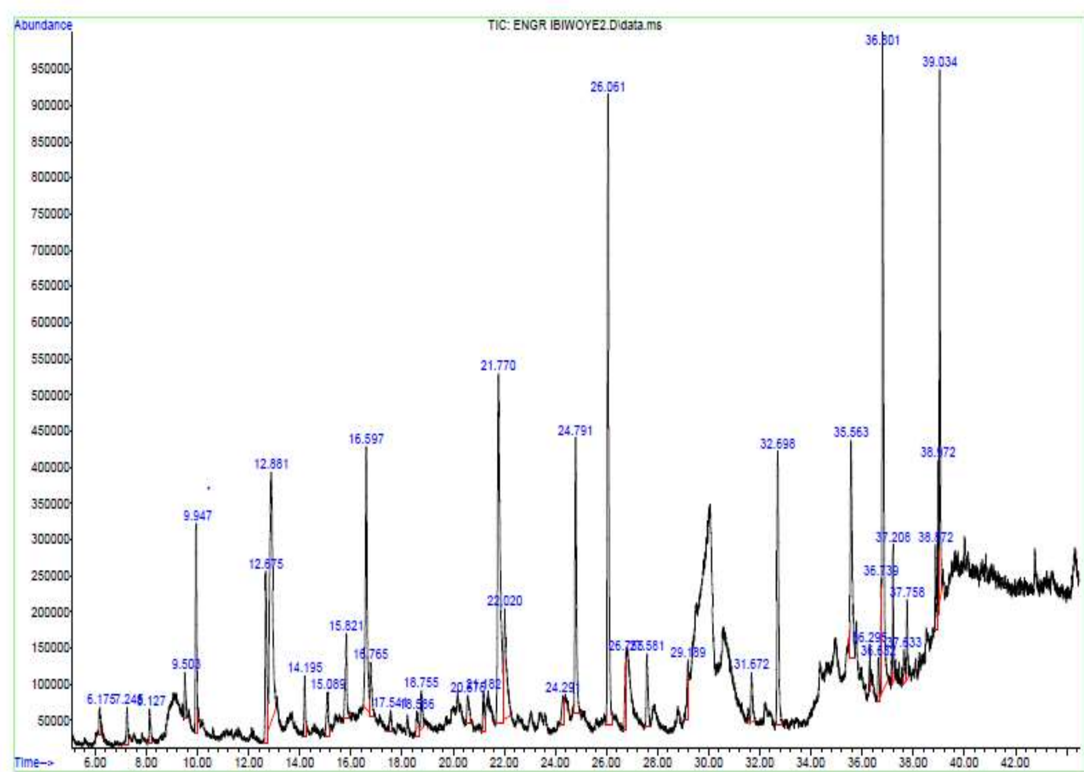

Figure 2.0: Spectral of Detected Compounds of Fresh Bamboo (Bambusa Vulgaris) Samples.

Table 3.0: Chemical Compounds of Bamboo (Bambusa Vulgaris) Exposed to Rainfall for 9 months.

PK #	R.T. min	COMPOUNDS	% COMPOSITION
1	26.999	Pyrazol-3 (2H) -one, 4 - (2-furfurylid enamino) -1, 5-dimethyl -2 -phenyl-	3.503
2	31.810	Cyclopentasiloxane, decamethyl -	1.881
3	35.356	Heneicosane	1.432
4	37.383	n-Hexadecanoic acid	39.476
5	37.583	n-Hexadecanoic acid, ethyl ester	9.403
6	38.565	Oleic Acid	23.808
7	38.697	Octadecanoic acid	16.203
8	39.360	Piperidine -1- acetamide, N - (3-cyano-1-methyl-2-indolymethyl) -N- pheny	4.295

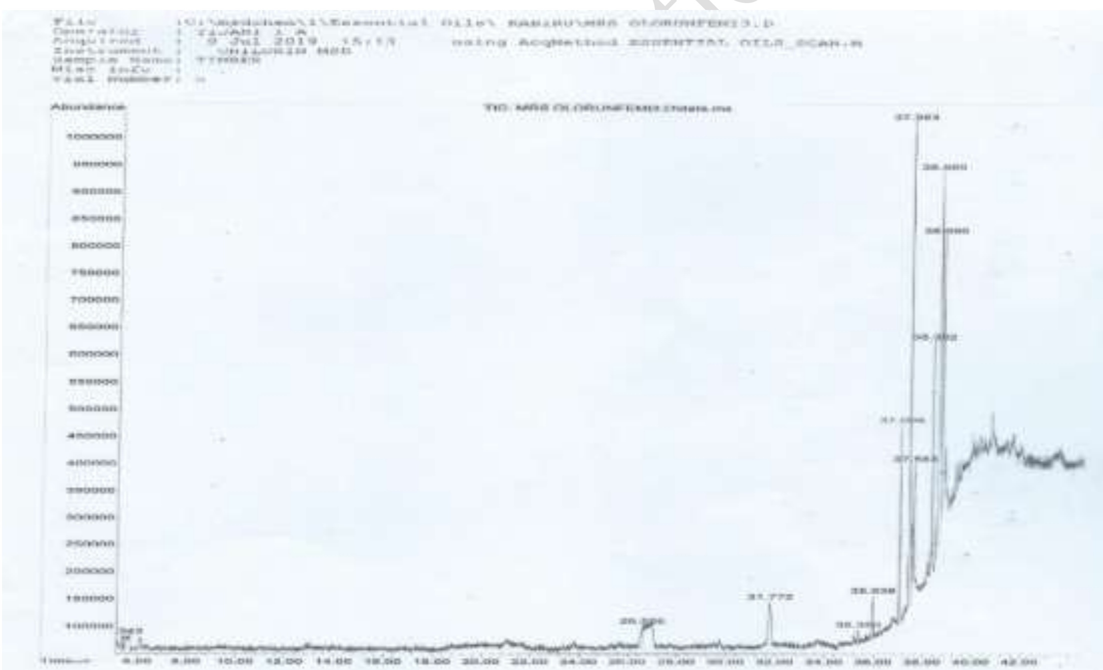

Figure 3.0: Spectral of Detected Compounds of Exposed Bamboo (Bambusa Vulgaris) Samples.

The high proportion of cellulose also accounted for the high tensile strength of bamboo and high modulus of rupture of bamboo reinforced sections as compared to other wood reinforced sections. The Crystalline cellulose has a very limited accessibility to water and chemicals (Klemn *et al.*, 2005). Chemical attack on bamboo can therefore be expected to occur on amorphous cellulose and crystalline surface of the bamboo. The hydroxyl group (^{-}OH) of cellulose can be partially or fully reacted with various reagents like organic acid, [acotic acid, aceticanhydride, propenol acid, cellulose acetate, cellulose triacetate, Cellulose Acetate Propriate (CAP), cellulose acetate butyrate (CAB)]. The percentage composition of the cellulose compounds of bamboo is about 73.83%,

Hemi-cellulose is a polysaccharide related to cellulose. But unlike cellulose, hemi-cellulose is derived from several sugars in addition to glucose. It consists of shorter chain compared to cellulose chain (Klemn *et al.,* 2005). In hardwoods, the main hemi-cellulose consists of compounds that contain glucuronoxylan compounds. In bamboo glucuronoxylan compound such as β, α, 4-0 methyl and acetate group are present. The percentage composition of the hemi-cellulose compounds of bamboo is about 12.49%, which consists of chemical compounds such as cyclohexen, acetate, α-terpine, y-terpine, β-terpine, bicyclo and 3-carene.

Lignin consists of 10.50% of the chemical composition of the bamboo. The chemical compounds in the lignin of bamboo are hysopulegol, benzene, trimethylbenzyl alcohol, o-cymene, α-terpanol, carveol, D-limonene and β-ocymene. Lignin is a complex polymer of aromatic alcohol called monolignals (Klemn *et al.,* 2005). Lignin is hydropholic and conduct water in plant stem (Piotrowski and Carus, 2011). This could have been the reason why the moisture contents and the strength of bamboo vary from the outer core (cellulose) to inner core as recorded by earlier researchers on the properties of bamboo (Fache, 1983; Jimoh, 2006 and Omotosho, 1988). The fairly high content of lignin in bamboo must have been responsible for its durability and high strength when compared with other woods. The decomposition of lignin and hemi-cellulose due to alkaline pore water reacting with chemical compound of hemi-cellulose and lignin thereby breaking links (bonds) between the fibres will consequently reduce the strength of the bamboo.

The extractive compounds in bamboo constitute about 3.18%. These chemical compounds are: caryophyllene and caryophyllene oxide. These extractives are reactive to chemical compound such as nitric acid, propanoic acid. It is also very reactive to alkaline solutions (Mohanty, *et al., 2000*).

There are 38 chemical compounds present in fresh samples of bamboo as shown on Table 2.0 where 4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol, is 12.701%, Phenol, 2,6-dimethoxy-,11.032%, Benzofuran, 2,3-dihydro-, is 10.62%, Oxirane, [(2-propenyloxy) methyl]- is 8.742, Phenol, 2-methoxy-, is 5.33% by composition with other compounds less than 5%, majorly in the methyl, furan and phenol compounds.

In the exposed samples, fatty acidic and ester compounds are predominated with n-Hexadecanoic acid; 39.476%, Oleic Acid; 23.808%, Octadecanoic acid; 16.203% and n-Hexadecanoic acid, ethyl ester ,9.403%. (Table 3.0)

CONCLUSION AND RECOMMENDATIONS

From this study, the chemical compounds found in fresh bamboo samples differ from the ones in samples exposed to rainfall for 9 months. There is a change in chemical compounds as such a change in the chemical composition of the bamboo. The breakdown in the chemical compounds causes reduction in its tensile and compressive strength, ductility, and some other engineering properties of the bamboo which is responsible for the deterioration effect of the exposed bamboo. It is recommended that blocking agents and water repellents agents as a method of reducing or eliminating the attack of the bamboo fibres be examined.

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