

**EFFECT OF TREATED BORASSUS AETHIOPUM MART
FIBERS ON THE PHYSICAL AND MECHANICAL
PROPERTIES OF HOLLOW BLOCK-MORTAR**

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DECLARATION

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DEDICATION

This thesis study is first of all dedicated to the Almighty God Jesus Christ for imparting me this golden opportunity of life to pursue my Master in good health and my parents: my dear father; Mr. Andre Mabanza, my dear mothers; Mrs. Clementine Babindamana for their unconditional love, care and support through this academic journey.

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Abstract

Borassus aethiopicum mart is a woody monocotyledon plant and a renewable resource that comes from sub-Saharan Africa. In Benin, the transformation of its trunk in strips produces some fibrous waste unused due to the lack of fiber upgrading process in the manufacture of cementitious composite. These wastes cause problems in terms of environmental management. As an illustration, these wastes were also used as household fuels, producing CO₂ which is one of the main greenhouse gases responsible for global warming. In addition, these fibrous wastes were dumped in pits behind Sourou Bayayé's hullers acquired on a subsidy from Millennium Challenge Account Benin.

In order to protect the environment and valorize the availability of this local material, *borassus aethiopicum* mart fiber (BAMF) were used in mortar to produce hollow blocks for hollow-core-slab which the most used in Benin. This present study focused on the effect of treated *borassus aethiopicum* mart fiber on the physical and mechanical properties of hollow block-mortar.

For this purpose, alkaline treatment of BAMF was done using different concentration of NaOH (3%, 5%, and 10%) and at different immersion period (1h and 3h). For this reason, Scanning electronic microscopy (SEM) was employed to examine the effect of NaOH concentration on the surface morphology of BAMF including its effect on the mechanical properties. A change in fiber surface was observed from the untreated to the treated BAMF, as well as an increase in tensile strength of BAMF treated with 3% and 5% NaOH was respectively observed 288.72 MPa and 252.54 MPa as compared to untreated BAMF 210.45 MPa. Then 3% and 5% treated BAMF with

3%, 5%, and 10% NaOH at 1-hour were used in mortar. For this purpose, the mechanical behavior in flexion (three-point by bending) and compression of composites were studied at 28 days of age. The composites offer not only good mechanical performance in three-point bending up to 9.013 MPa but also compressive strengths up to 16.06 MPa as compared to the controls used 5.38 MPa and 12.8 MPa respectively. In addition, the performance of the composites after exposure in H₂SO₄ medium at 90 days using pH3 was evaluated by loss in compressive strength as durability test. Finally, the flexural (three-point) and compressive strength at 7 and 28 days of curing of the hollow blocks used as an application to the mortar were evaluated according to EN 1537-02.

Keywords: Alkaline treatment, tensile strength, flexural strength, compressive strength, durability.

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List of abbreviations and acronyms

NF:	French Standards
BS:	British Standard
BAMF:	Borassus Aethiopum Mart Fiber
ASTM:	American Society for testing and materials
EN:	Mechanical resistance measurement standard
DPF:	Data Palm Fiber
FAO:	Food and Agriculture Organization of the United Nations
W/C:	The Water/Cement Ratio
NaOH:	Sodium Hydroxide
S ₂ SO ₄ :	Sulfuric Acid
CO ₂ :	Carbon dioxide
CSL:	Compressive Strength Loss
SEM:	Scanning Electronic Microscopy
JKUAT:	Jomo Kenyatta University of Agriculture and Technology

Chapter 1: Introduction

1.1 Background to the Study

To achieve sustainable development, the protection of the environment must be an integral part of the development process and cannot be considered in isolation, that states the third principle of the Rio Declaration on the environment and development (United Nations, 2012), which reflects the nations of the world to face the environmental problems that threatens the existence of our planet. The different actors of development are then called to reduce pollutants (in particular the emission of greenhouse gases) related to their respective activities and to preserve natural resources.

Statistical studies reveal that buildings are responsible for more than a third of carbon dioxide (CO₂) emissions, that puts the construction sector the second largest transmitter of CO₂ after industry (Nguyen, 2010). Note that CO₂ is one of the main greenhouse gases responsible for global warming and contributes around 50% of the greenhouse effect. This is why the building sector is often considered as a «golden mine » to reduce this phenomenon. Thus, one of the solutions to minimize the impacts of building on the environment is to seek and develop the use of materials that are renewable, consume very little energy and produce a minimum of pollution and health risks. As a result, at present, there is interest in the use of materials of natural origin such as plants (wood, straw, hemp, flax, borassus aethiopicum mart, etc.) that are renewable, recyclable and sustainable and can help to reduce emissions of greenhouse gases by their capacity of CO₂ imprisonment. In addition, the use of natural materials with innovative constructions also helps reduce the cost of construction.

1.2 Problem statement

Borassus aethiopum mart plant also called Palmyra is a woody «monocotyledon» plant which comes from sub-Saharan Africa. It is a very dense wood fibers and a renewable resource that produces wood and can't get deteriorated. In countries such as Chad, Niger, Senegal and Benin, borassus aethiopum mart plant is widely used as slats in the construction of habitats and as fence posts fields houses. In the republic of Benin, the production of service and work wood generate fibrous waste unused due to a lack of fiber upgrading process in the manufacture of cementitious composites. There will be problems in terms of environmental management of these unused fibrous wastes. As an illustration, these wastes were also used as household fuels, producing CO₂ which is one of the main greenhouse gases responsible for global warming. In addition, these fibrous wastes were dumped in pits behind Sourou Bayayé's hullers acquired on a subsidy from Millennium Challenge Account Benin. Therefore, various fibers and wood particles of various species from agricultural waste recycling/wood industry or grinding have been the subject of several studies relating to the study of cementitious composites. These are residues of sisal, banana and eucalyptus and date palm fibers (Kriker, 2005), coconut fiber, sugar cane and banana (Jannah & Mariatti, 2009), wood chips (Tamba, 2007), diss fibers (Merzoud & Habita , 2008) and flax fiber.

If the idea of using these plant biomasses in their natural form to reinforce cement matrices is welcome in the context of sustainable development and to contribute to the protection of the environment, therefore, there is a need to seek to valorize the use of borassus aethiopum mart fiber in the same purpose to contribute to sustainable

development and to the preservation of the environment. In order to face this major challenge of preserving a healthy and quality environment, this study will be focused on the recycling of borassus aethiopum mart fiber into composite of borassus aethiopum mart fiber-mortar that can be used for manufacturing non-load bearing elements in the building such as blocks and hollow blocks. For that, the order to study its new mechanical properties (flexural and compressive strength) the BAMF-mortar will be investigated.

1.3 Objectives

1.3.1 General Objective

The main objective is to investigate the effect of treated borassus aethiopum mart fiber on the physical and mechanical properties of hollow block-mortar.

1.3.2 Specific Objectives

- 1) To assess the mechanical properties of treated borassus aethiopum mart fibers
- 2) To determine the physical and mechanical properties of treated Borassus aethiopum mart fiber-mortar (cement mixed with sand and the fiber)
- 3) To evaluate the durability of treated Borassus aethiopum mart fiber-mortar before and after exposure in sulfuric acid medium
- 4) To investigate the physical and mechanical properties of hollow blocks as an application to the treated borassus aethiopum mart fiber-mortar composite.

1.4 Research Questions

- a. What is the effect of NaOH on surface and mechanical properties borassus aethiopum mart fiber?
- b. What is the effect of using treated borassus aethiopum mart fiber in mortar on the mechanical properties?
- c. Will the physical and mechanical properties of the composite treated fiber-mortar improve?
- d. How will the formulated mortar react after the exposure to H_2SO_4 at 90 days in terms of structural performance (compressive strength)?

1.5 Justification

The present study carried out was to show and promote the utilization of borassus aethiopum mart wastes in social life which is a threat to the environment, as a way to sustainable development and to contribute to the preservation of the environment by using borassus aethiopum mart fiber waste in mortar to produce hollow blocks and full blocks which are the most used construction material in Benin. The use of borassus aethiopum mart fiber in hollow blocks reduces the weight of the construction material, which contributes to the reduction of hollow-core-slab weight, hence the reduction in foundation cost for a hollow floor building. In addition, borassus aethiopum mart wastes have also been used as fuel in households, which produces CO_2 , which is one of the main greenhouse gases responsible for global warming. Hence, utilization of BAMF contributes to the reduction of Carbon dioxide emitted and hence preserving the environment.

1.6 Scope of the Study

The scope of this study was to investigate the effect of treated borassus aethiopum mart fiber on the physical and mechanical properties of hollow blocks mortar. Use of NaOH treated borassus aethiopum mart fiber was applied. The main study targets were to characterize physical and mechanical properties of both treated borassus aethiopum mart fiber and blocks made from BAMF mortar.

This project research was limited to Africa, and a case study of West Africa was used. All materials that were used in this study apart from BAMF were obtained from suitable sites in Kenya. The borassus aethiopum mart fibers used for this study came from trunk wastes during the transformation of the trunk in slats in Benin. The fibers used were cut in the length of 30mm. The research project was carried out between May 2018 and September 2018.

Chapter 2: Literature review

2.1 Introduction to composite materials

A composite material is a material consisting of the assembly of two or more materials of different classes, complementing each other and making it possible to obtain a material whose overall performance is greater than that of the components taken separately (Yavu , 2008).

A composite material is constituted in the most general case of one or more discontinuous phases distributed in a continuous phase. In the case of several discontinuous phases of different natures, the composite is called hybrid. The discontinuous phase is usually harder with mechanical properties superior to those of the continuous phase. The continuous phase is called the matrix. The discontinuous phase is called the reinforcement or reinforcing material (Figure 2-1). Matrices maybe molten raw materials such as metals, thermosetting resins as well as thermoplastics. On the other hand, the reinforcements may consist of different materials in the form of powder, fibers and even in the form of woven fibers (Soucy, 2007).

The properties of composite materials result:

- i. Properties of constituent materials;
- ii. Their geometric distribution; and
- iii. Their interactions.

The geometry of the reinforcement will be characterized by its shape, its size, the concentration of the reinforcement, its arrangement (its orientation), etc. The concentration of the reinforcement is a determining parameter of the properties of the

composite material. It is usually measured by the volume fraction (fraction by volume) or by mass fraction (mass fraction).

For a given concentration, the distribution of the reinforcement in the volume of the composite is also an important parameter. An even distribution will ensure "homogeneity" of the material: hence an isotropic material.

In the case of uneven distribution of the reinforcement, the rupture of the material will be initiated in areas poor in reinforcement, thus decreasing the strength of the composite.

In the case of composite materials when reinforcement is made of fibers, the orientation of the fibers determines the anisotropy of the composite material. This aspect is one of the fundamental characteristics of composites; the possibility to control the anisotropy of the finished product by a design and manufacture adapted to the desired properties.

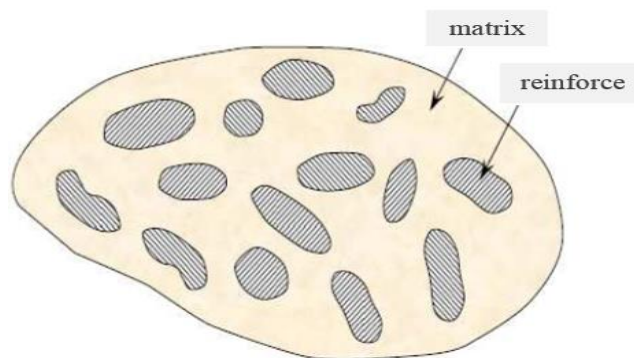


Figure 2- 1: Composite material (*Chowdhury , 2010.*)

2.2 Classification of composite materials

Composite materials can be classified according to the shape of the components or the nature of the components (Chowdhury , 2010.).

2.2.1 Classification according to the form of the components

Depending on the shape of the constituents, the composites are classified into two main classes: fiber composite materials and particle composite materials.

2.2.1.1 Particle composites

A composite is a mixture of two materials with distinct intrinsic properties in order to enhance the resultant combined properties. A particle, as opposed to fibers, does not have privileged dimension.

Particles are generally used to improve certain properties of materials or matrices, such as stiffness, temperature resistance, abrasion resistance, shrinkage reduction, etc. In many cases, the particles are simply used as fillers to reduce the cost of material, without diminishing its characteristics (Edem, 2014)

2.2.1.2 Fiber composites

A composite material is a fiber composite if the reinforcement is in the form of fibers. The fibers used are either in the form of continuous fibers or in the form of staple fibers: cut fibers, short fibers, etc. The arrangement of the fibers and their orientation has an influence on the mechanical properties of the composite materials, to obtain materials ranging from highly anisotropic materials to isotropic materials in a plane (Edem, 2014). The researcher therefore has a type of material that he can modify and modulate the mechanical and physical behavior by playing on:

- i. The nature of the constituents,
- ii. The proportion of constituents,
- iii. The orientation of the fibers.

Thus, fiber composites cover an extended domain in which the development is constantly increasing.

2.2.2 Classification according to the nature of the constituents

Depending on the nature of the matrix, the composite materials are classified according to organic matrix, metal matrix or mineral matrix composites. Various reinforcements are associated with these matrices. Among these composites, we can mention (Edem, 2014):

Organic matrix composites with:

- i. Mineral fibers: glass, carbon, etc.
- ii. Metal fibers: boron, aluminum, etc.
- iii. Natural fibers: sisal, coconut fibres, etc.

Composite organic matrix materials can only be used in the temperature range of not more than 200 to 300 ° C, whereas metal or mineral matrix composite materials are used beyond: up to 600°C for a metal matrix, up to 1000 ° C for a ceramic matrix.

This present study was focused on composite material with natural fibers.

2.3 Natural fibers

Natural fibers are plant based which are lignocellulose in nature and composed of cellulose, hemicelluloses, lignin, pectin and waxy substances. They are also composed of a small amount of organic (extractives) and inorganic (ash) components. The extractives components are composed of cuticle, layer waxes, oils and impurities from the surface of fibers.

At present time, due to simultaneous awareness increases on environment and energy, increased attention is now paid to natural fibers with a view to conserving energy and protecting the environment. The use of this natural fibers in mortar is therefore particularly attractive in the field of engineering materials opines that various innumerable advantages in the use of natural vegetable fibers in mortar or concrete as reinforcement in the matrix, among them the following : increased flexural strength, improved tensile strength, bending strength, low density, thermal insulation, and they act as cracks-arresters, easy handle and renewable resources (Asasutjarit, Development of coconut coir-based lightweight cement board, 2005).

As natural fibers are lignocellulose, therefore they have some problems that cause adverse effects on composite properties due to different chemical constituents such as:

- i. cuticle,
- ii. *layer waxes*,
- iii. *oils*
- iv. *pectin and waxy substances*
- v. *Hemicelluloses and lignin.*

Therefore, these chemical constituents need to be extracted (cuticle, layer waxes, oils, pectin and waxy substances) and for Hemicelluloses and lignin a certain portion needs to be taken out to prevent adverse effects on the composite properties, hence, natural fibers need to chemical modified.

2.3.1 Different types of natural fibers

Natural vegetable fibers are produced in most developing countries and require only a low degree of industrialization for their processing (Gladius, 1979). There are several types of natural fibers; some of them that are the most used as reinforcement in the composites are resumed in the figure 2-2 below.

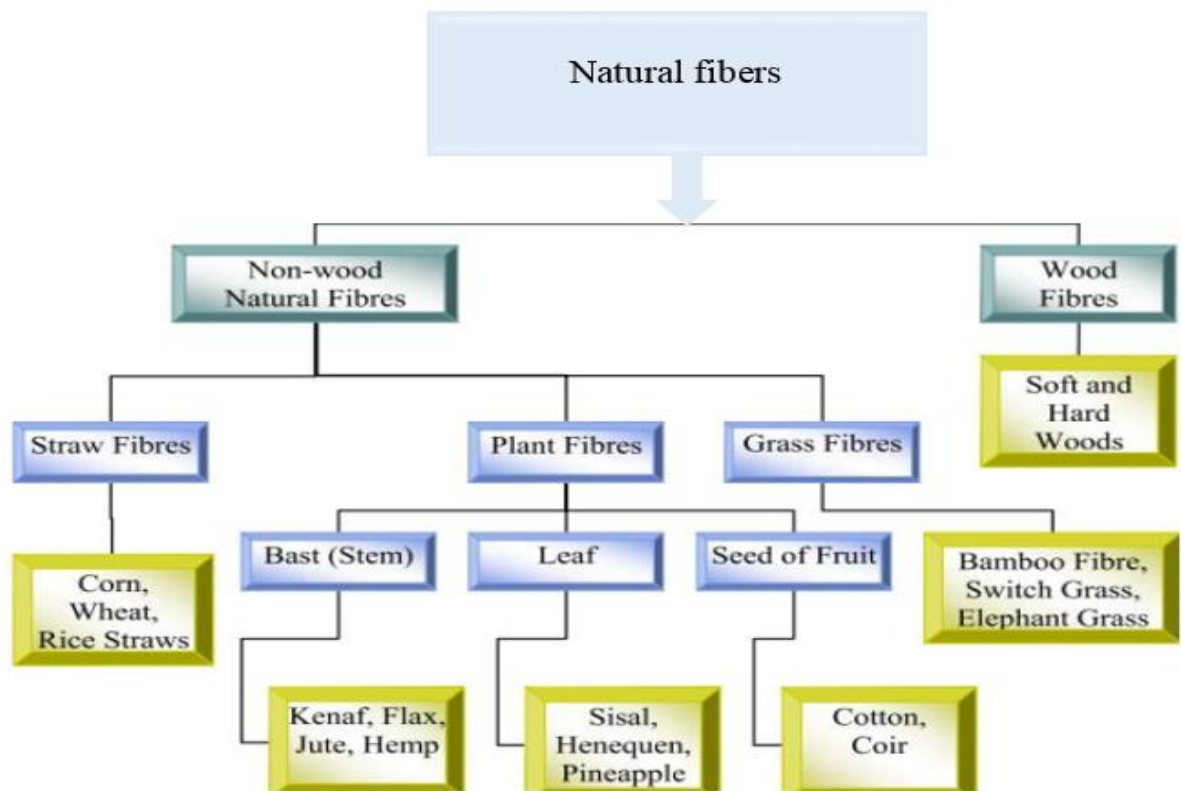


Figure 2- 2: Different types of natural fibers (Gladius, 1979)

2.3.2 Mechanical properties of natural fibers

The mechanical property of natural fibers varies from fiber to fiber. The mechanical properties of fiber depend on type of fiber, origin age, volume fraction physical properties, structure, environmental conditions and processing methods. Different matrix

systems have different properties. Natural fibers have well prospective as reinforcements in polymer composites. Due to high specific properties and low density of natural fibers, composites based on these fibers may have very good implications in industries. Natural fibers also possess good mechanical properties and these fiber composites can also be used in different applications.

The following table 2-1 show different mechanical properties of some natural fibers that have been carried out by previous studies.

Table 2- 1: Average mechanical properties of common natural fibers

Natural fibers	Tensile strength (MPa)	References
DPF	170 - 275	(Al-Khanbash, 2016)
Kenaf	930	(Ramakrishna, 2010)
Banana	355	(Naveen, 2014)
Sisal	511-695	(Paul, 2014)
Bamboo	290	(Kannan, 2013)
Hemp	550-900	(Sanjay, 2016)

2.3.3. Factor effecting composite properties

Natural fibers have some problems that cause adverse effects on composite properties. As theses fibers consists of different chemical constituents in their structure and undergo different reactivity with the environment and matrix during processing. The following

are the major issues which need to be addressed during fabrication of composite materials.

2.3.4 Plant fiber structure

Cellulose structure is composed of crystalline and amorphous regions as shown in figure 2-3. Therefore, strong intra-molecular hydrogen bonds with large molecules are formed by the crystallite cellulose. Compactness of crystalline region creates cellulose blocks that makes it difficult for chemical penetration to occur.

However, dyes and resins are absorbed by amorphous region easily. In addition to this, plant fibers are highly polar and hydrophilic in character as hydroxyl groups are present in their structures.

For distension of crystalline region, elimination of hydrophilic hydroxyl groups and removal of surface impurities (*waxy substances*), natural fibers needs to be chemically modified.

This figure bellow, presents the schematic view of secondary layer of fiber cell wall in which crystalline and amorphous regions are indicated and where dyes and resins are absorbed.

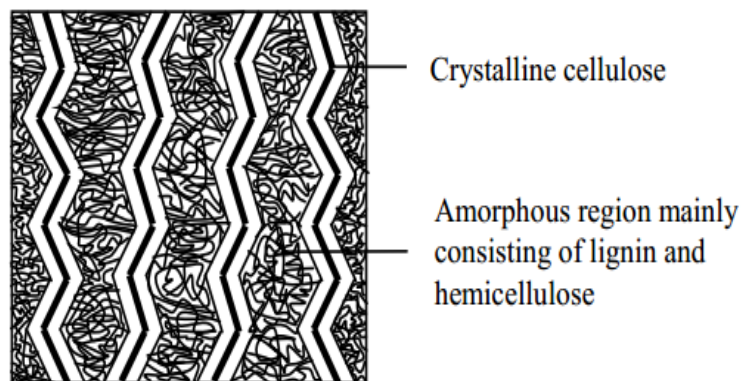


Figure 2- 3: Schematic view of secondary layer of cell wall (*Bledzki & Gassan, 1999*)

2.3.5 Thermal stability of fibers

The natural fiber starts degrading at about 240°C. Structural constituents of the fiber (*cellulose, hemicelluloses, lignin* etc.) are sensitive to the different range of temperatures. It was reported that, lignin starts degrading at a temperature around 200°C and hemicelluloses and cellulosic constituents degrade at higher temperatures. Thermal stability can be enhanced by removing certain proportion of hemicelluloses and lignin constituents from the fiber by different chemical treatment.

2.3.6 Moisture absorption of fibers

The lignocellulose fibers are hydrophilic and absorb moisture. There is a large amount of hydrogen bonds (hydroxyl groups -OH) presents between the macromolecules in the plant fiber cell wall. When moisture from the atmosphere comes in contact with the fiber, the hydrogen bond breaks and hydroxyl groups form new hydrogen bonds with water molecules. The cross-section of the fiber becomes the main access to the penetrating water. As a result, when hydrophilic fiber is reinforced with hydrophobic resin fiber swelling within the matrix occurs. This causes weak bonding between fiber and matrix, dimensional instability, matrix cracking and poor mechanical properties of the composites.

Therefore, the removal of moisture from fibers is an essential step before the preparation of composites. The moisture absorption of natural fibers can be reduced by different chemical treatment such as alkaline, silane, acetylation, benzylation and peroxide treatment on the fiber surface to remove hydrophilic hydroxyl bond (Kabir & Wang, 2011)

2.3.7 Fiber length

The properties of composites material depend on the fiber length, percentage of fiber volume and orientation into the matrix. By controlling factors such as aspect ratio, the dispersion and orientation of fibers, considerable improvements in composites property can be accomplished (Leonard & Nick, 2007).

For this study, the fiber length will be 30mm.

2.3.8 Surface modification of natural fibers

The fiber-matrix interface is the diffusion or reaction zone, in which fiber and matrix phases are chemically and/or mechanically combined. Interfacial adhesion between fiber and matrix plays a predominant part in characterizing the mechanical properties of the composites.

If there is a poor adhesion across the phase boundary, then relatively weak dispersion of force occurs and results in poor mechanical properties of the composite (Wang & Panigrahi, 2007).

For reinforcement of natural fiber in composites, several problems occur along the interface due to the presence of hydrophilic hydroxyl groups on the fiber surface. This hydrophilic nature hinders effective reaction with the matrix. In addition to this, *pectin* and *waxy substance covers* the reactive functional groups of the fiber and act as a barrier to interlocking with the matrix.

To optimize effective interfacial bonding between fiber and matrix, the fiber surface needs to be modified with different chemical treatment, reactive additives and coupling agents. Chemical treatments expose more reactive groups on the fiber surface and thus

facilitate efficient coupling with the matrix. As a result, better mechanical and thermal properties of the composites can be improved (Kabir & Wang, 2011)

Therefore, physical or chemical modification of natural fibers surface is necessary to improve the compatibility and adhesion between fibers and matrices. When the fiber surface is modified by a chemical treatment, there is achievement in interfacial bonding and mechanical properties in composite (Wang & Panigrahi, 2007).

But, if the natural fiber surface is too much modified, that can have an impact on the mechanical properties of the composite.

Several studies have shown the importance of modifying the natural fiber surface and come with improved mechanical properties.

An experimental study carried out (George & Verpoest, 2001), on Surface Modification to Improve the Impact Performance of Natural Fiber Composites which aimed was first based to modify the fiber surface using three different chemical treatments and then the mechanical properties of composite were assessed. It has been shown in their study that when the fiber surface is not modified by a chemical treatment or when it is untreated, it has a lot of fiber pullouts and that make the fiber surface to not to be uniform and give poor interfacial bonding between the fiber and matrix. But when the surface is modified by a given treatment, it gives a better interfacial bonding.

In addition, in their study, photographs of untreated and treated fibers of flax shown in figure 2-4(a and b) were given to see the morphology of the fiber surface before and after the treatment.

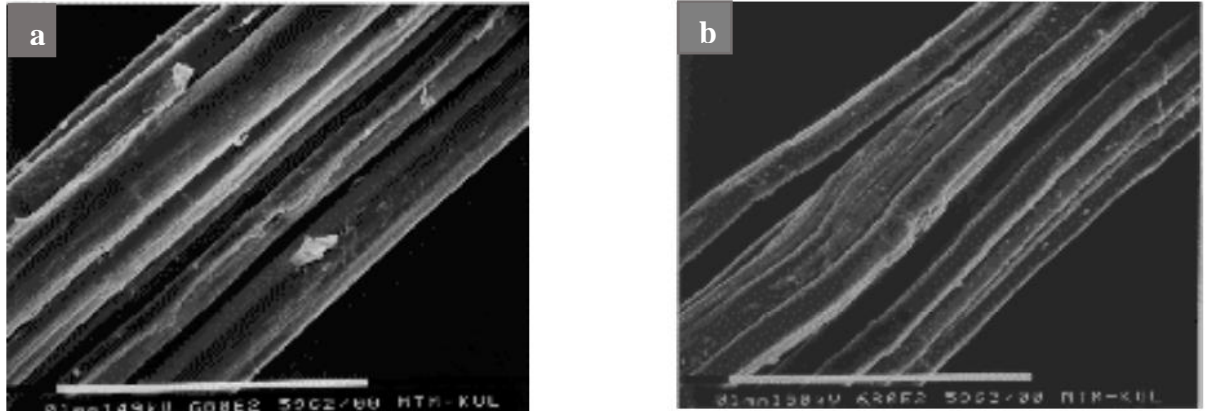


Figure 2- 4: Untreated (a) and treated (b) fiber surface (*George & Verpoest, 2001*)

Fig. (2-4a) which is untreated fibers showed a lot of extractives (*oils, cuticle, pectin and waxy substance covers*) on fibers and make fiber surface not uniform. This suggests a poor adhesion between fiber and matrix.

Fig.2-4(b) which is treated case using NaOH, showed the fibrillar structure of the individual fiber is even more revealed due to the better dissolution of waxy materials and lignin. As a result, the effective surface area available for contact with the matrix increased. Hence the importance of the modification of fiber surface.

For this present study, one of these natural fibers which are Borassus Aethiopum fiber will be used.

2.3.9 Borassus Aethiopum fibers

Borassus aethiopum wood is a wood which belongs to palm trees family. In Chad, Benin and Togo the borassus aethiopum is widely used as slats and beams in the construction of habitats, and as fence posts fields. This is a very dense wood fiber (about 100 fibers per cm²) and compact. Its fibers, brown in color, are very long, very large (area about

1mm²) and very rigid. *Borassus aethiopum* fibers can be extracted manually if the tree is still young or through the machine if old trees. The average density is 124 fibers per cm² for heartwood and 77 fibers per cm² for the sapwood. *Borassus aethiopum* fibers like any other natural fibers are lignocellulose and have the same chemical constituents that other natural fibers have which can result in a problem of the bond between fiber and matrix.

An experimental study carried out on *Anatomical and chemical characteristics of Borassus Aethiopum* by Ngargueudedjim (2016) of Faculty of Exact and Applied Sciences, in the University of N'Djamena (Chad). The chemical part of his study was aimed to determine the contents of cellulose, hemicellulose and lignin in *borassus aethiopum* fibers. In fact, he used Van Soest and Wine method to estimate the contents of the fiber constituents in the Laboratory and the study revealed that *borassus aethiopum* fibers have:

- i. 62.57 % of cellulose
- ii. 10.46 % of hemicelluloses
- iii. 19.52% of lignin and
- iv. 7.45% of extractives

In fact, extractives are composed of oils, cuticle, pectin and waxy substance covers. The following figure2-5 shows a typical structure of untreated cellulose fiber.

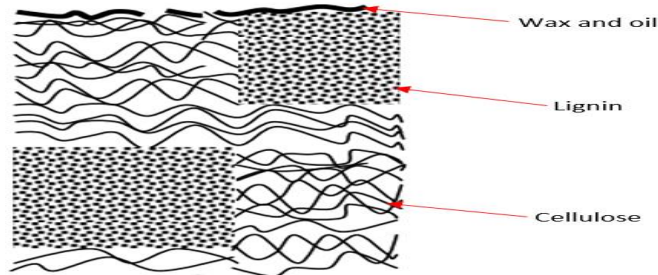


Figure2- 5: Typical structure of untreated natural fiber

(Leonard & Martin, 2002)

According to what has been said above on lignocellulose fibers, and view the rate of the components of this material, *cellulose*, *hemicelluloses*, *lignin* and *extractives* such as: *pectin* and *waxy substance covers, cuticle, and oils*.

It has been showed by researchers that extractives of natural fibers decay resistance of the material and also portion of hemicellulose and lignin must be taken out in order to have a good bond between the fiber and matrix. For, this could be at the origin of several factors that could affect the new composite material, such as there may be a problem of an inherent incompatibility between fibers and matrix, due to the non-uniform surface of fibers which does not allow a very good adhesion, but if there is a poor adhesion across the phase boundary, then relatively weak dispersion of force occurs and resulting poor mechanical properties of the composites (George & Verpoest, 2001).

Borassus aethiopum fibers like other natural fibers are hydrophilic and absorb moisture that could cause weak bonding between fibers and matrix that results in poor mechanical properties of the composites. In addition, the high percentage of these fibers components (hemicelluloses and lignin) could reduce the thermal stability of fibers.

In a nutshell, most of the problems in natural fiber composite originate from the hydrophilic nature of the fiber and hydrophobic nature of the matrix. As a result, chemical treatment on reinforcing fiber can reduce hydrophilic tendency and thus improve compatibility with the matrix by reducing a certain portion of, hemicelluloses and lignin and also removing surface impurities (waxy substances). Therefore, the fiber surface of borassus aethiopum will be modified and facilitate efficient coupling with the matrix.

There are several chemical treatments from which natural fibers can be treated amongst them are:

2.4 Treatment of natural fibers

2.4.1 Alkaline Treatment

Treatment on natural fiber by NaOH is widely used for both thermoset and thermoplastic composites. This treatment changes the orientation of highly packed crystalline cellulose order and forms amorphous region by swelling the fiber cell wall. This provides more access to penetration of chemicals. Alkali sensitive hydrogen bonds existing among the fibers break down and new reactive hydrogen bonds form between the cellulose molecular chains.

Due to this, hydrophilic hydroxyl groups are partially removed and moisture resistance property is improved. It also takes out certain portion of hemicelluloses, lignin, pectin, wax and oil covering materials. As a result, the fiber surface becomes cleaner. In other words, fiber surface become more uniform due to the elimination of micro voids and thus stress transfer capacity between the ultimate cells improves. Composite properties

such as mechanical and thermal behavior can be improved significantly by this treatment. But, If the alkali concentration is higher than the optimum condition, excess delignification of fiber take place, which results in weakness or damage to the fiber (Kabir & Wang, 2011)

Alkaline treatment is done using sodium hydroxide with distilled or portable water; the process consists of dissolving a certain percentage of NaOH in water and then introducing the fibers. The treatment may last one hours, twelve or more depending on the expectation of the researcher, Sodium hydroxide may be either in pellets or in solutions form (Robina & Ankush, 2015).

2.4.2 Silane Treatment

Silane is used as coupling agents to modify fiber surface. It undergoes several stages of hydrolysis, condensation and bond formation during the treatment process with the fiber. It reacts with cellulose hydroxyl group of the fiber and improves fiber matrix adhesion to stabilize composite properties and it also provides the hydrocarbon chains that restrain fiber swelling into the matrix. Silane treated fiber reinforced composite provides better tensile strength properties than the alkaline treated fiber composites. But, silane treatment requires several chemical mixing such as oligo metric siloxane, alcohol solution and methagyloxypropyl trimethoxy silane and also require a qualify technician to make the treatment (Robina & Ankush, 2015).

2.4.3 Acetylation Treatment

Acetylation treatment on natural fiber is generally known as esterification method for plasticizing of cellulose fibers. Fibers are acetylated with and without an acid catalyst to

graft acetyl groups onto the cellulose structure. It reacts with the hydrophilic hydroxyl groups and swells the fiber cell wall. As a result, the hydrophilic nature of the fiber decreases leading to improvement in dimensional stability of the composites. But, this treatment only improves significantly the moisture resistance properties.

In general, acetic acid and acetic anhydride individually do not react sufficiently with cellulosic fibers. For this, to accelerate the reaction, fibers are initially soaked in acetic acid and consequently treated with acetic anhydride between the time periods of 1 to 3 hours with higher temperature (Saha & Adhikari, 2010).

After all that precedes on different treatments, for this present study, the appropriate treatment that was adopted is Alkaline treatment using (NaOH) because it:

- i. Eliminates hydrophilic hydroxyl groups which absorb moisture and improved moisture resistance,
- ii. Takes out a portion of hemicellulose and lignin which form amorphous region that absorbs dyes and resins easily,
- iii. Removes surface impurities on the fibers (waxy substance covers, cuticle, and oils) and the surface becomes clean
- iv. Gives a better adhesion between fiber and matrix,
- v. Enhances thermal stability of fibers by removing certain proportion of hemicellulose and lignin and
- vi. Improve significantly the mechanical properties of the composites.

In addition, it is widely used and many researchers have come with good results when using this treatment.

(George & Verpoest, 2001) Studied the Surface Modification to Improve the Impact Performance of Natural Fiber Composites, have used three different treatments as shown in table 2-2. such as Alkaline (NaOH), silane treatment and isocyanate treatment (phenyl isocyanate) on flax fibers and compared the mechanical properties of the three composites with the non-treated composite, concluded that the composite with alkaline treatment using NaOH improved characteristics about 25% But treatment with coupling agents which is silane and isocyanate did not have much influence on the mechanical performance about 21%, compare to non-treated case.

Table 2- 2: showing the mechanical properties of the composites of the study according to the three treatments

Fibre	Impact Strength (kJ/m ²)	Standard Deviation
Untreated	10.47	± 1.11
NaOH treated	13.09	± 1.59
Silane treated	8.41	± 0.20
Isocyanate treated	8.65	± 0.61

In this study, flax fibers were immersed in 1% sodium hydroxide solution for one hour. Then then fibers were washed thoroughly with water and finally with water. Then the fibers were dried in a hot air oven.

Whereas, flax fibers treated with Silane Treatment (3-amino propyl tri ethoxy silane) were used and Flax fibers were allowed to react with silane by immersing in silane dissolved in a water-acetone mixture for 2 h. The pH of the solution was 9.0. After that the solution is decanted and the fiber is dried.

Another experimental study carried out (Jose & Victor, 2016) on the Effect of Fiber Treatment Condition and Coupling Agent on the Mechanical and Thermal Properties in Highly Filled Composites of Sugarcane Bagasse Fiber/PP (20). In this study sodium hydroxide was used to enhance the mechanical and thermal properties of the composite. In fact, 1% of NaOH was dissolved in distilled water to make the solution of sodium hydroxide; the treatment took one hour (01h). After the treatment of sugarcane bagasse fibers, scanning electron microscopy photographs as shown in figure 2-6 were taken to compare the morphology of the fibers before and after the treatment.

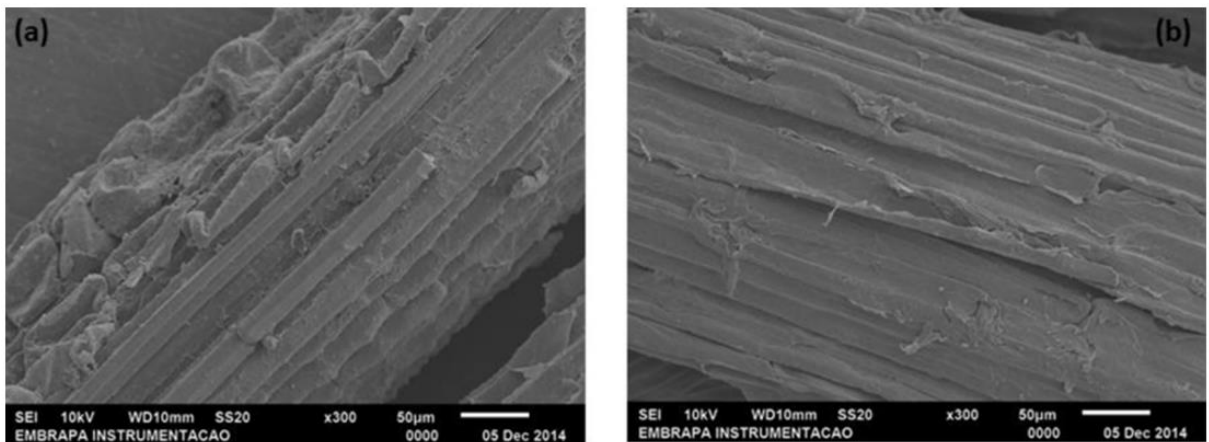


Figure 2- 6: (a) Untreated and (b) treated sugarcane bagasse fiber (*Jose & Victor, 2016*)

According to the study, figure 2-6 (a) shows the fibers with its chemical constituents, cellulose, hemicellulose, lignin and extractives (*waxy substance covers, cuticle, and oils*)

at the point of origin and figure 2-6 (b) shows the removal of extractives and a portion of *hemicellulose* and *lignin* that results to the clean fiber surface and allow them to improve the mechanical properties (Jose & Victor, 2016). Moreover, alkaline treatment is easy to work with, it does not require other solutions and it is easy to get and not very expensive than other treatments. But to come with good result with alkaline treatment on fibers, two important factors must be well optimized such as: the concentration of NaOH and the duration of the treatment. In case these two factors, mainly the concentration of NaOH is not well optimized, precisely when concentration is higher than the optimum condition, this will lead to the weakness or damage to the fiber and then will decrease the mechanical properties of the composite.

For this study, different concentrations of sodium hydroxide will be used at different duration in order to get the optimum treatment for that a scanning electronic microscopy will be used to show the evolution of the treatment on fibers according to the three concentrations of NaOH solution and also to the non-treated fibers state will be taken into consideration. After that phase the fibers will be used for the evaluation of physical and mechanical properties before mixing them in the matrix to evaluate the mechanical properties and then study the durability of the new composite.

2.5 Overview on natural fiber mortar or concrete

2.5.1 Definition

A fiber composite is a material consisting of a set of resistant fibers embedded in a matrix in which the mechanical properties are significantly lower. The fibers play the role of reinforcement while the matrix ensures the cohesion of the composite and the transfer of forces to the fibers (Camille, 2010). Unlike to traditional reinforcement; the fibers are distributed in the mass of the concrete and make it possible to constitute a material which presents a more homogeneous behavior. Fibers, depending on their nature, have a very different behavior of constraint. They may, under certain conditions and for certain applications or processes, replace passive traditional reinforcement. Fiber concretes are subjected to specific design methods for structural applications (slabs, industrial floors, etc.). Methods for optimizing their formulation have been specially developed (Cimbeton , 2006).

2.5.2 Roles of fibers in concrete

Fiber-reinforced concrete is a composite material whose properties depend on the characteristics of the fibers, the quality of the cement matrix and other possible components (other aggregates, plasticizers, etc.). The addition of fibers is intended to ensure the durability of the structure by opposing the appearance, propagation and widening of cracks in concrete. In fact, ordinary concrete is known for its near zero resistance to traction: cracking is often very detrimental to the stability of the structure and there is no control over the evolution of this phenomenon in the material. On the

other hand, the presence of the fibers tends to ensure a seam of the micro-cracks appearing in the concrete, as indicated in Figure 2-7 below.

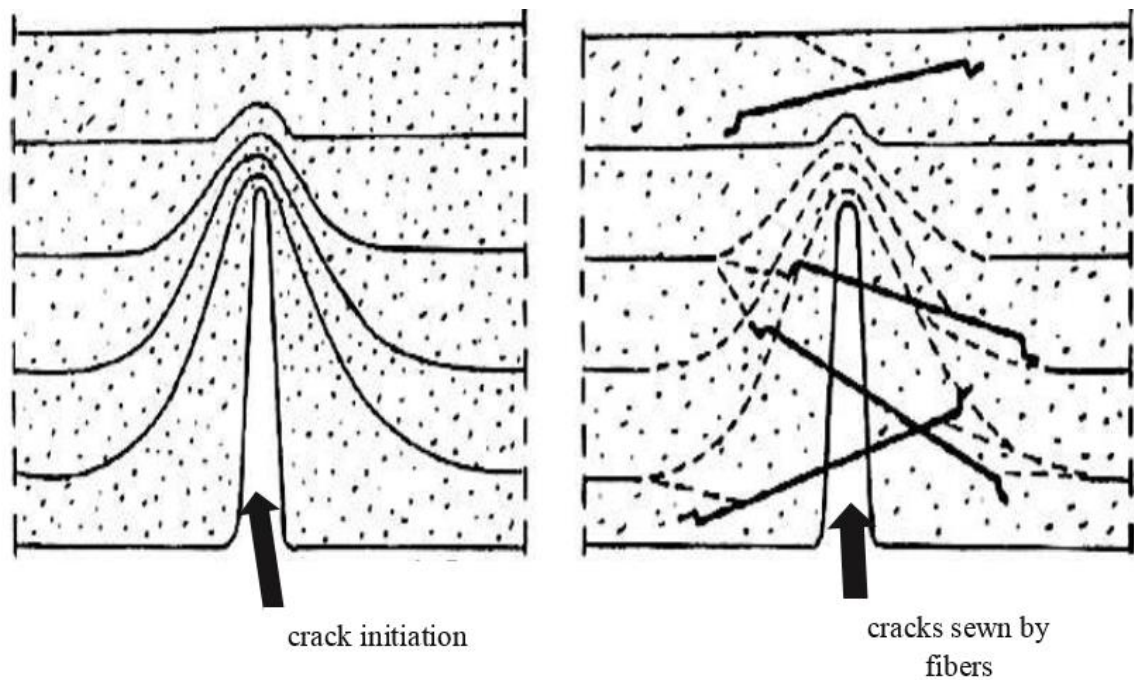


Figure 2- 7: Role of fibers in concrete (*Chergui, 2010*)

2.5.3 Advantages of fiber concrete

This function of the fibers in the concrete gives the fiber-concretes intrinsic characteristics representing significant advantages. Among these features, we can list:

- Control of cracking: with the action of fibers, the break even if it is reached, is no longer brutal. We can therefore determine moments of cracking or rupture allowing the design approach of structures by controlling the risks of cracking and rupture (Nardjes , 2005);

- A multidirectional and homogeneous reinforcement: under the effect of the homogeneous distribution of the fibers, the fiber-reinforced concrete presents, except in certain exceptional cases, the same mechanical properties in all the directions (Nardjes , 2005) Ease and speed of implementation: unlike to reinforced concrete, the implementation of fiber concrete does not require a prior installation of expensive reinforcement in human resources and time (Nardjes , 2005).

2.6 Durability of fiber-mortar composite

Durability of a material, in general is defined as the service life of a material under given environmental conditions. In other words, is its capacity to maintain a minimum performance level over a specified time when exposed to degradation environment.

The above definition holds good for all concrete and cementitious composites (reinforced with artificial fibers like steel etc.). However, in the case of natural fiber composite, not only the (external) environment, but also the internal environment in the matrix (i.e. alkaline medium), play a combined role in determining its durability.

Several investigators have studied the durability of various natural fiber-mortars, such as, sisal, coir, jute etc., in various mediums and exposure conditions which has been summarized in the following table 2-3 below.

Table 2- 3: Durability of different natural fiber-mortar (*Ramakrishna, 2010*)

A	B				C										
	F	T	S	I	1	2	3	4	5	6	7	8	9	10	11
Agava-mortar	√					•	•			•	•	•	•		
Banana-mortar	√						•	•							
Cellulose-cement sheet	√	√											•	•	
	√				•										•
Coir-mortar, concrete	√	√			•	•	•	•							
	√				•		•	•							
	√						•								
		√													
	√						•	•							
Date palm-mortar	√				•										
Jute-mortar	√						•	•							
	√							•							
Ramie-mortar	√						•	•							
	√							•							
Sisal-mortar, concrete	√	√			•	•	•	•							
	√				•		•	•							
	√						•	•							
	√							•							
Wood fibre-cement sheet	√	√		√	•		•								

Note: (A) type of fiber and composite (B) Criterion for evaluating durability (C) aging/exposure

condition (i) F-Flexural strength- Toughness; S- (Compression) Shear; I - Impact strength; (ii) Description of codes for aging/exposure conditions are as under 1-Tap water; 2- Alkaline medium; 3- outdoor environment; 4- Alternate wetting and drying; 5- Na₂SO₄ solution (10%); 6- Alternate elevated and near zero temperature; 7- Alternate elevated and curing in normal water temperature; 8- Alternate freezer and curing in normal water temperature; 9- Cyclic freeze-thaw; 10- Accelerator carbonation and 11- Hot water soak test (ASTM C 1185) (*Ramakrishna, 2010*).

(Ramakrishna, 2010), studied the durability of natural fiber reinforced cement mortar composite- a new approach. In this study, they used sisal fibers in the matrix as reinforcement and the durability evaluation of the composite was done by impact and flexural test: Impact strength at initiation of crack (in Joules), Impact strength at final crack (in Joules) and Residual impact strength; on each slab specimen, the numbers of blows required for the appearance of the first crack and at the failure were noted. The impact energy absorbed by the mortar slab specimens were computed based on the number of blows required to initiate the first crack and the number of blows required to cause ultimate failure using simple projectile test set-up. After exposed the specimens to exposure to alkaline medium.

2.7 Experimental Background on BAMF

A comparative study on physical and mechanical properties of cement matrix composite reinforced with borassus aethiopum mart fibers and rice husk from Benin carried out by Adjovi et al (2013) with a mix design of 1: 3 et 1:4 and 1: 5 using w/c ratio of 0.40 and using 40mm x 40mm x 160mm reported that after 28 days of curing period, the researcher reported that borassus aethiopum mart fibers composite compare to rice husk composite offers good mechanical property (compressive strength) than rice husk as shown is figure 2-7.

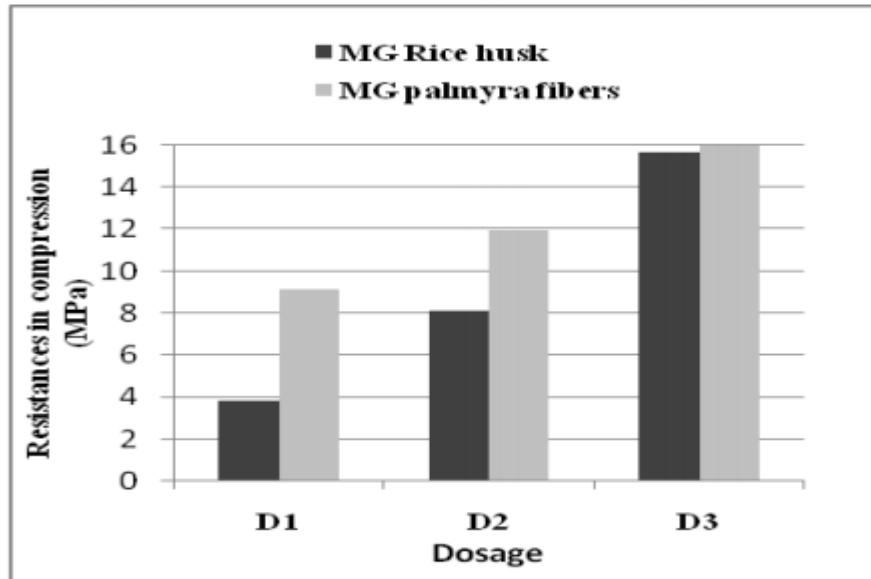


Figure 2- 8: Compressive strength of BAMF cement composite (*Adjovi & Doko, 2013*)

A study carried out by Allarabeye (2015) on mechanical features of the fiber of a male Palmyra (*Borassus aethiopus*. Mart) aimed at determining experimentally the mechanical properties of BAMF (tensile, elongation at break and young's modulus of elasticity). The fibers of *borassus aethiopus* mart tested for this study were taken from the piece of tree 1.5m above the base. The fibers were manually extracted from the heartwood and sapwood. For the determination of tensile strength of BAMF, the researcher used a UTS brand electric machine equipped with a 1.5kN capacity load cell and manual clamping jaws. After testing the fibers, the researcher came up with an average tensile strength of 219 MPa as shown in table 2-4.

Table 2- 4: Mechanical properties of borassus aethiopum mart fibers (*Allarabeye, Mechanical characteristics of fiber palmyra(borassus aethiopum mart), 2015*)

Table.3: Mean values of calculated mechanical characteristics in traction.		
Average value	Sapwood	Heartwood
Cross section S_0 (mm ²)	0.72 ± 0.15	0.72 ± 0.23
Young's modulus E (GPa)	17.0 ± 3.6	16.8 ± 8.8
Rupture stress R_r (MPa)	184 ± 77	219 ± 8.5
Rupture deformation (mm/mm)	1.3 ± 0.5	1.6 ± 0.7

From this experimental study, the researcher concluded that the knowledge of these characteristics of borassus aethiopum mart fibers opens a perspective of the survey of their utilization as reinforcement in composite materials for further studies.

2.8 Research Gap

Many studies have been investigated on the use of natural vegetable fibers in mortar as reinforcement in the way to improve the mechanical and physical properties of the composite in order to produce construction materials, but Borassus Aethiopum Fibers the most available plant in West and Central Africa which has around 400 uses has not yet been used in the same way.

In recent years, some studies investigated the strengthening of reinforced concrete structure by using borassus aethiopum trees as steel reinforcement in beams and others have used its fibers with cement to produce a composite material in order to assess its compatibility. To that, is added some studies on mechanical properties of borassus aethiopum fibers. However, the treatment out of borassus aethiopum fibers and the use of these fibers to reinforce in cement mortar including the evaluation of the durability of borassus aethiopum reinforced cement mortar is completely a new topic in the construction of building materials and it is not fully investigated.

2.9 Conceptual framework

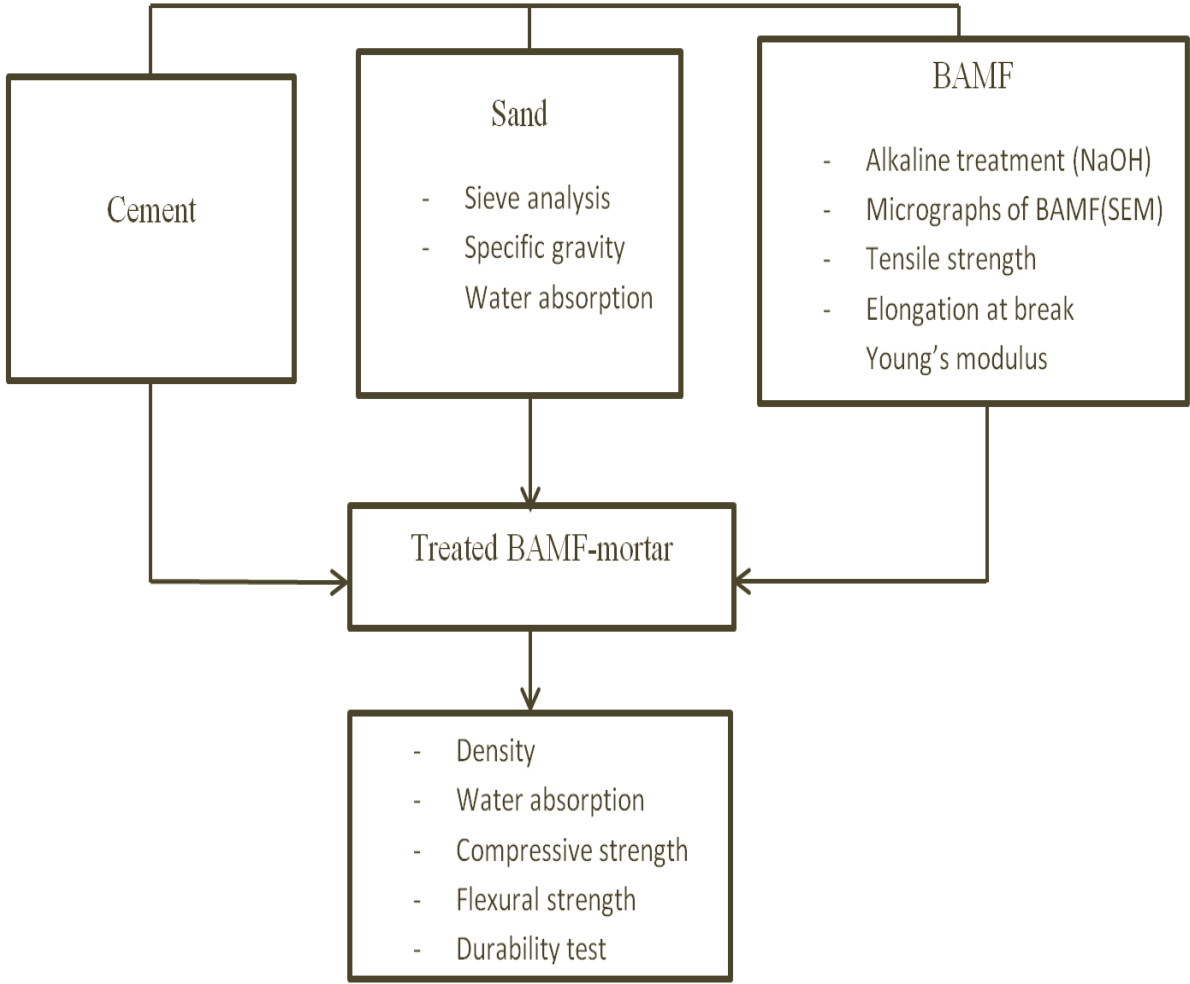


Figure 2- 9: Conceptual frame work used for this study

Chapter 3: Materials and Methods

3.1 Materials

3.1.1 Borassus aethiopum mart fibers

Borassus aethiopum mart fibers come from borassus aethiopum mart plant which belongs to palm trees family. The borassus aethiopum mart fibers used in this study comes from trunk wastes during the transformation of the trunk in slats in Benin. Its fibers can reach 10 to 15 cm.

3.1.2 Sodium hydroxide (NaOH)

Sodium hydroxide is known as caustic soda, is a strong base which occurs at room temperature, in solid form. It is consisted of sodium (Na^+) cations and hydroxide anions (OH^-). For this study, the sodium hydroxide that was used for the alkaline treatment of borassus aethiopum fibers was delivered in pellets form.

3.1.3 Distilled water

Distilled water is water without minerals or organisms. For this study, distilled water was used for the alkaline treatment of borassus aethiopum mart fibers and to wash the fibers after the treatment in order to remove to traces of NaOH on the fibers.

3.1.4 Cement

The type of cement used for this study was ordinary Portland cement 32.5R locally manufactured by Bamburi in Kenya. This cement has a large range of applications from domestic building constructions to large civil engineering projects.

3.1.5 Aggregate (fine aggregate)

River sand was obtained locally from Meru in Kenya. In this study, sand conforming to BS 882:1992 was used. The fine aggregates that passed the 5.0mm BS 410 test sieve and containing no more coarser material were considered as sand for the study. The figure below shows the type sand that was used for this study.

3.1.6 Water

In this study, portable water conforming to BS 1348-2(1980) was used for mixing the materials and curing the fiber mortar samples. The water used in this research was obtained from general supply water system of JKUAT University.

3.1.7 Sulfuric acid(H_2SO_4)

Sulfuric is classified as one of the most aggressive natural threats. when the concrete is exposed to an environment containing sulfuric acid, it undergoes severe deterioration due to neutralization reactions. For this reason, H_2SO_4 was used in this study for durability tests in order to evaluate the chemical resistance on treated BAMF- mortar composite in sulfuric acid environment. The sulfuric acid used was produced by the company with a degree of purity of 97% which is equal to 18.10 mol/l.

3.2 Methodology

3.2.1 Introduction

This part deals with the methodology per objective that was used in this research. This research focused on the effect of treated BAMF on the physical and mechanical characterization of BAMF mortar blocks. The main parameters that were studied are the effect of chemical treatment on the surface of borassus aethiopum fibers by the means of SEM micrographs, tensile strength, elongation at break and modulus of elasticity of untreated and treated fibers and water absorption, density, compressive strength and flexural strength of treated BAM-mortar composite including the density and compressive and flexural strength of hollow blocks were studied. An Evaluation of the durability tests by the determination of loss in weight of the specimens and compressive strength was studied to determine the chemical resistance of treated BAMF-mortar composites.

This study was executed in five (07) steps as followed:

- (a) Chemical treatment of borassus aethiopum mart fiber using 3%, 5%, and 10% NaOH concentration during 1 and 3h;
- (b) Evaluation of the effect of NaOH concentration on the surface of BAMF through SEM;
- (c) Mechanical test on treated BAMF;
- (d) Addition of 3% of BAMF in mortar composites treated with 3%, 5%, and 10% NaOH;

- (e) Addition of 5% of BAMF in mortar composites treated with 3%,5%, and 10% NaOH;
- (f) Study on chemical resistance of treated BAMF-mortar composites;
- (g) manufacturing of hollow blocks made with mortar reinforced with 5% of BAMF treated with 5% NaOH at 1h.

Specific objective 1:

To assess the mechanical properties of treated borassus aethiopum mart fibers;

3.2.2 Pretreatment of borassus aethiopum mart fibers

The fibers of borassus aethiopum mart used in this study, were soaked in water during 3 hours to facilitate the removal of contaminants and adherent dirt before being washed with distilled water. Thereafter, the fibers were dried in the open air for 24 hours at room temperature before being treated.

3.2.3 Alkaline treatment (NaOH) of borassus aethiopum mart fibers

The alkali concentration and immersion period of this study were chosen according to the information collected in the literature review. According to (Dipa & Rana, 2001) if alkaline concentration or immersion period is higher than the optimum condition, excess delignification of the fiber take place, which results in weakness or damage to the fibers. For this reason, Borassus aethiopum mart fibers were treated with sodium hydroxide (NaOH) at different concentration 3%,5% and 10% and during immersion periods of 1 and 3 hours. Alkaline treatment was prepared by dissolving NaOH pellets in distilled water. The mass of NaOH varied depending on the concentration of the solution(3%, 5% and 10%).

The quantity of NaOH used in terms of percentage was calculated based on the following notion:

- i. For 1 Molarity of NaOH to be dissolved in 1000 cm³ of water which is 1liter and as 1M(NaOH= Na= 23g, O= 16g, H= 1g \Rightarrow 23g + 16g + 1g = 40g) which means 40g of NaOH to be dissolved in 1liter;

Equation 3.1 was used to calculate the concentration of NaOH in terms of percentage

$$\%1M(NaOH): \frac{40g}{1000g} \times 100 = 4\%NaOH \dots\dots\dots (3.1)$$

Meaning that for;

- + 3% of NaOH= 30g;
- + 5% NaOH= 50g and
- + 10%NaOH= 100g .

To prepare 3% sodium hydroxide, 30 grams of NaOH pellets were weighed and then dissolved in 1 liter of distilled water in order to form 1 liter solution. Firstly, take the volumetric flask of 1liter capacity and then add sodium hydroxide pellets slowly to distilled water in order to optimize the treatment. Similarly, the other concentrations were measured as 5% NaOH: 50 grams and 10% NaOH: 100 grams. This alkaline treatment was done during 1and 3hours for 3% and 5% NaOH and 1 hour for 10% NaOH only.

After, the treatment the fibers were rinsed five times with distilled water to remove traces of NaOH on the fibers. Thereafter, the fibers were dried under the sun before scanning electron microscopy observation on the morphology of the fibers.

3.2.4. Scanning electron microscopy (SEM)

Study on morphology of the BAMF surface, before and after treatment (at 1-hour immersion period) was carried out using a scanning electron microscopy (SEM). The objective was to characterize the structural changes that have occurred upon treatment and differential by treating with various concentrations.

3.2.5 Tensile strength of untreated and treated borassus aethiopum mart fibers

Tensile tests of untreated and treated borassus aethiopum mart fibers (using 3%, 5%, and 10% of NaOH) were performed using Hounsfield Tensometer machine of 300N capacity based on the standard method for tensile properties of single textile fiber (ASTM D3822-01) at the University of Nairobi in mechanical engineering laboratory. For each treatment of fiber, 3 specimens were tested in order to take the average.

The stresses were calculated using the equation 3.2 and the deformation were calculated using 3.1 respectively.

$$\text{Tensile strength (MPa); } \sigma = \frac{F}{S} \dots\dots\dots (3.2)$$

Where: σ - tensile strength in (MPa)

F- The tensile force in Newton (N) and

S- The cross section of the fiber in cm^2

$$\text{Deformation (in \%); } A(\%) = 100 \times \frac{(L-L_0)}{L_0} \dots\dots\dots (3.3)$$

Where: L_0 - the initial length in (m) and

L – The length after deformation in (m).

The modulus of elasticity was calculated after the calculation of the previous parameters.

Specific objective 2:

To determine the physical and mechanical properties of treated Borassus aethiopum fiber-mortar composite (cement mixed with sand and the fiber)

3.2.6 Physical properties carried out on fine aggregate (ordinary sand) used

3.2.6.1 Sieve analysis and Fineness modulus

Particle size Distribution for fine aggregate (ordinary sand) was determined by Sieve analysis in accordance with BS 812-Part 103-1. Sampling of the aggregates to obtain a representative sample was done in accordance with the procedure described in clause 5 of BS 812:102:1990 using the quartering method. From the finest sieve upwards, the cumulative percentage passing each sieve was calculated and used for plotting the grading curves. The grading curve was plotted on a semi-logarithmic graph showing the cumulative percentage passing on the abscissa while the sieve apertures plotted on a logarithmic scale.

From the sieve analysis tests, fineness modulus was computed for the fine aggregate by dividing the sum of the cumulative percentage retained on the standard sieves divided by 100.

3.2.6.2 Specific gravity and Water absorption of fine aggregate used

Specific gravity of ordinary sand was determined according to ASTM C 128-15 The water absorption and specific gravity were determined using the necessary equipment for the experimental procedure in accordance with the standard.

The water absorption and specific gravity were calculated using equations 3.3 and 3.4 respectively.

$$\text{Water absorption (in \% of dry mass)} = 100 \frac{(C-D)}{D} \dots\dots\dots (3.4)$$

$$\text{Specific gravity} = \frac{D}{C-(A-B)} \dots\dots\dots (3.5)$$

Where: **A**- weight of pycnometer plus sample plus water (g);

B- Weight of pycnometer plus water (g);

C- Weight of sample saturated and surface dry aggregate (g) and

D- Weight of oven dry sample (g).

3.2.7 Formulation of mortar with treated borassus aethiopum mart fibers

For this study, the determination of the composition of mortar with treated borassus aethiopum fibers was done using the same composition as for the conventional mortar according to the French Standard E N 196-1.

The mix design that was adopted in this study was 1:3 for fiber mortar. The following composition was made:

- Cement = 1.0
- Fine aggregate(sand)= 3.0
- Water/ cement= 0.55

The quantity of 3%, 5% and of borassus aethiopum fibers were added by the weight of the cement.

3.2.7.1 Mix proportions

From the adopted mix design below, various calculations were made to find the quantity of the materials to be used. On completion of the initial mix proportion calculations, four (03) controls mix were first made one for a normal weight cement mortar without any additions quantity of the fiber and three ones with the addition of 3% and 5% of the untreated fibers respectively by the weight of the cement. Thereafter, other mixes were conducted using the treated fiber per NaOH concentration used for the treatment and the period of immersion as shown in table.3-5 for this study only the fibers treated during 1 hour were used to formulate the mortar composites the percentage of the BAMF was calculate in terms of the mass of the cement used in each mold.

Table 3- 1: Experimental proportions mixes used

Mix	fiber percentage
Control 1	0%
Control 2	3%
3%NaOH-treated at 1h	3%
5%NaOH-treated at 1h	3%
10%NaOH-treated at 1h	3%
Mix with 5% of BAMF	
Control 1	0%
Control 2	5%
3%NaOH-treated at 1h	5%
5%NaOH-treated at 1h	5%
10%NaOH-treated at 1h	5%

3.2.7.2 Batching and Mixing

In this study, batching was done by weight. The batching procedure first entailed weighing all the individual material fractions as per the mix design calculations which included fine aggregates, cement, BAF and water. The fibers used were cut in the length of 30mm.

The mixing was done as followed:

- The cement and fibers are first mixed to dryness

- The fiber cement mixture is then poured into the mixing water in the mortar mixer by turning on the mixer
- Then the sand is gradually poured into the mixer after homogeneous mixing of the fiber cement.

3.2.7.3 Casting

After mixing, the molds were filled in two layers of fiber mortar and was vibrated using a rod to ensure proper distribution and orientation of the fibers, and finally sharpen and smooth the surface of the mortar. The specimens were made and placed in the open air in the laboratory during 24 hours. The molds used for casting were prismatic steel mold dimensions of $40 \times 40 \times 160$ mm according to E N 196-1 for the following tests:

- Determination of density
- Water absorption
- Flexural strength and
- Compressive strength

3.2.7.4 Curing

Open air curing was done for 24hours, after which the specimens were removed from the molds and then placed in the curing tank containing clean water before 28days mechanical testing.

3.2.8 Tests on hardened treated BAMF-mortar composites

3.2.8.1 Water absorption (%)

The water absorption test was carried out on hardened treated borassus aethiopum fiber mortar prismatic molds casted and cured for 28 days conforming to specification of ASTM C 642-97. The specimens cured at 28 days, were placed in an oven at a temperature of 105°C for 24 hours period. Then, after removal, the specimens were cooled to a temperature of 20°C 24 hours. After cooling, the oven dry mass was determined. After drying, cooling, the specimens were immersed in water in the tank for 48h. After immersion period, the specimens were surface-dry by removing surface moisture with a towel and the surface-dry mass after immersion was determined. Finally, the water absorption was calculated using equation 3.6.

$$\text{Water absorption (in \%)} = \frac{B-A}{A} \times 100 \dots\dots\dots (3.6)$$

Where: **B**- oven-dry mass and

A- Saturated mass after immersion.

3.2.8.2 Determination of density

The density of treated borassus aethiopum fiber mortar was determined according to ASTM C 642-97 on the specimens. The density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic meter as shown in equation 3.6. Density was carried out at 28 days of curing, three runs for each mix were made, and an average density was obtained.

$$\rho = \frac{m}{v} \dots\dots\dots (3.7)$$

Where: m- mass of saturated specimens and

v- Volume of the specimens calculated from its dimensions in (m³)

3.2.8.3 Flexural strength (three points test)

The flexural strength was tested at 28days on prismatic specimens (40x40x160) mm³ in accordance with standard EN 196-1. The test consisted first to determine of the flexural load performed on specimens using testing machine three-point test figure.3-12. After that, the flexural strength of treated borassus aethiopum fiber mortar was calculated using equation 3.8.

$$\sigma_f = \frac{1.5 \times F_f \times L}{b^3} \dots\dots\dots (3.8)$$

Where: σ_f – flexural strength in (MPa);

F_f – Maximum flexural load in Newton (N);

L – The length of the prismatic mold in (mm) or the distance between support, and

b – The width of prismatic mold in (mm)

3.2.8.4 Compressive strength

The compressive strength was tested at 28days on the two half-prism obtained after rupture specimens in accordance with standard EN 196-1. The mechanical properties obtained from tests performed on three specimens the compressive strength of untreated and treated borassus aethiopum fiber mortar was determined using Universal Testing Machine (UTM).

Objective 3:

To evaluate the durability of treated Borassus aethiopum mart fiber-mortar composite before and after exposure in sulfuric acid (H₂SO₄) medium.

3.2.9 Sample preparation for durability test

The samples used for the test were prepared according to the procedures of standards NF EN 196-1 using 40 × 40 × 160 mm molds. The specimens were demolded after 24-hours and then placed in the curing tank containing clean water for 28 days before being subjected to the acid attack.

3.2.9.1 Resistance to chemical attack test

The relative acid attack was determined in accordance with ASTM C267-97. The mortar specimens were cured in water at 20°C ± 3°C for 28 days before being subjected to acid attack. Specimens of each mix were immersed in of chemical solution of H₂SO₄ for the required period of 90 days : the acidity of H₂SO₄ solution was followed in order the maintain its degree by using a pH meter. For this study pH 3 was used. Before the test, the attacked specimens were cleaned with tap water and then the acid attack was evaluated by determining the compressive strength loss (CSL%) using equation 3.8

$$\text{CSL (\%)} = \frac{(f_{cr} - f_{cs})}{f_{cr}} \times 100 \dots\dots\dots (3.9)$$

Where *f_{cr}* is the reference compressive strength of specimen before immersion in the acid solutions in MPa and *f_{cs}* is the average compressive strength of the specimens after immersion in solutions for the required period of time 90 days.

Specific objective 4:

To investigate the physical and mechanical properties of hollow blocks as an application to the treated borassus aethiopum mart fiber-mortar composite

3.2.10 Physical property of hollow bricks

3.2.10.1 Density

The density of the hollow blocks used for hollow-core-slab was determined according to ASTM C 642-97 on the specimens. The density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic meter as shown in equation 3.6. Density was carried out at 28 days of curing, three runs for each mix were made, and an average density was obtained.

$$\rho = \frac{m}{v} \dots \dots \dots (3.10)$$

3.2.11 Mechanical properties on hollow blocks

The mechanical characterizations of the hollow blocks were done in accordance with EN 15037-2 standard requirements for hollow blocks used for hollow-core-slab.

3.2.11.1 Flexural strength by bending three-point on hollow blocks

The flexural strength by bending is one of the important tests on hollow blocks. The flexural strength of the blocks was tested at 14 and 28 days using the specimens of 200 × 500 × 160 mm in accordance with EN 15037.

3.2.11.2 Compressive strength of hollow blocks

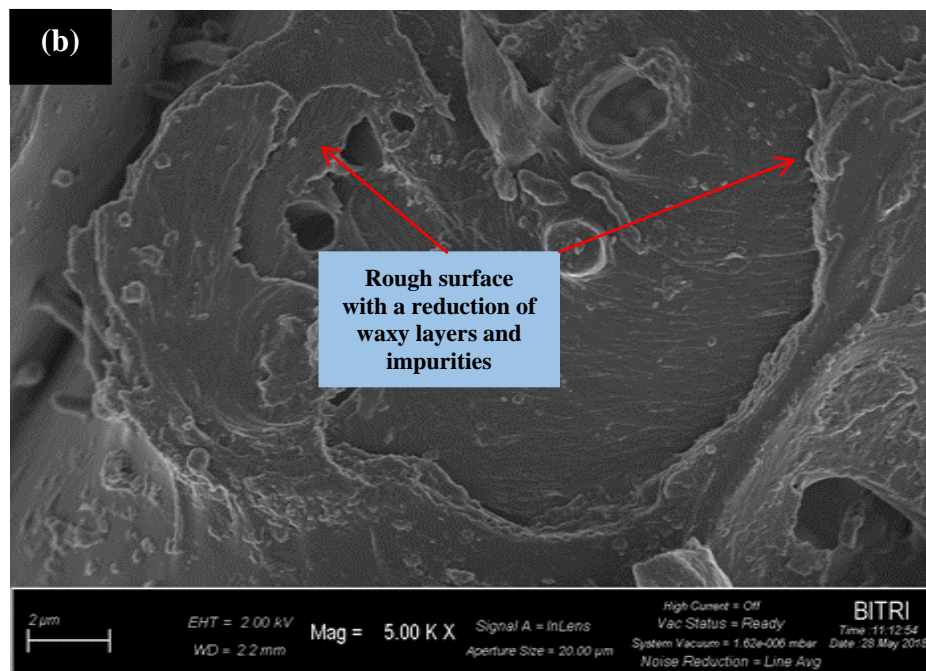
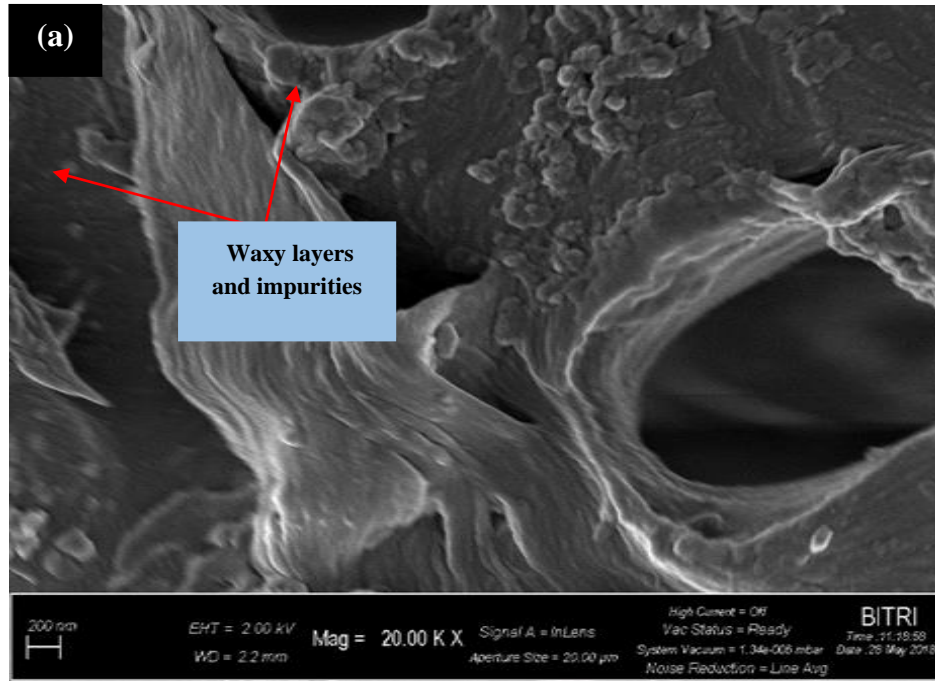
The compressive strength was tested at 14 and 28 days using the specimens of 200 × 500 × 160 mm specimens in accordance with standard EN 15037.

Chapter 4: Results and Discussions

4.1 Chemical treatment of BAMF

4.1.1 Effect of chemical treatment on the surface morphology of borassus aethiopum mart fiber

The alkaline treatment (NaOH) of BAMF resulted in removal of a certain amount of lignin, hemicellulose, waxes, oils, cuticles and impurities that cover the surface of external fibers. Further it allows for ionization of hydroxyl group leading to enhanced bonding. Check the benefit of this ionization from (Xue & Satyanarayan, Chemical treatment of natural fibre for use in natural fibre-reinforced composite: A review, 2007). Figure 4-16(a) shows the SEM of surface morphology of untreated and treated BAMF which allows evaluating the effect of this treatment (NaOH) on the surface morphology BAMF.



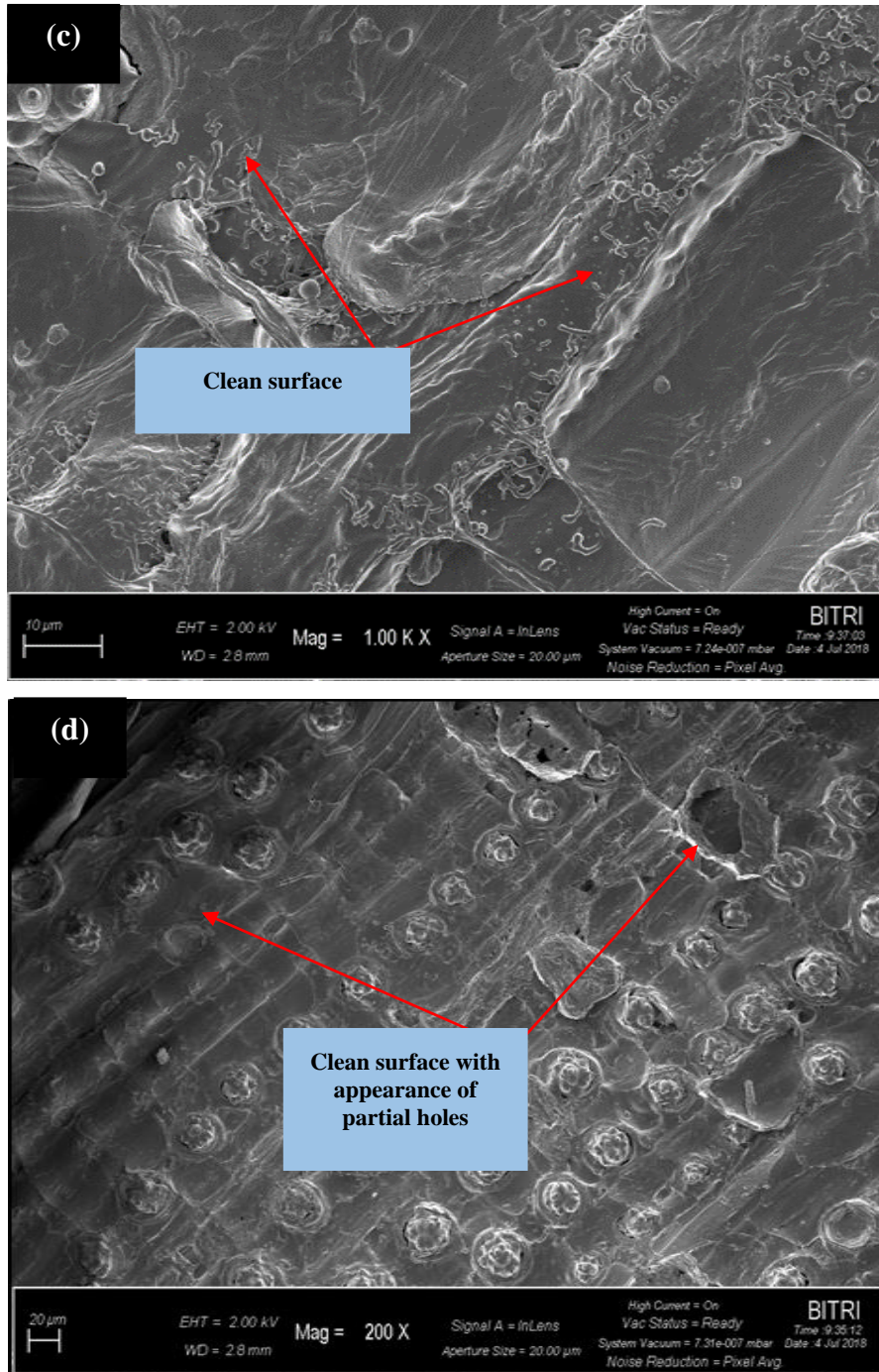


Figure 4- 1: SEM micrographs of (a) untreated BAMF, (b) 3%NaOH-treated BAMF, (c) 5%NaOH-treated BAMF and (d)10%NaOH BAMF (at 1h immersion)

Scanning Electron Microscopy (SEM) provides a better technique for the examination of surface morphology of natural fibers. SEM was employed to examine the surface morphology of untreated and treated BAMF and it was observed that the untreated BAMF differs to the treated BAMF, in terms of their level of smoothness and roughness. Changes in the surface morphology of BAMF throughout the treatment at different concentrations of NaOH are very remarkable through the micrographs above.

Figure 4-1 shows the SEM micrographs of the untreated and treated borassus aethiopicum fiber surface morphology. It showed that, NaOH treatment remove the impurities of BAMF because the impurities were observed on the surface of untreated BAMF figure 4-1(a).

Fig. 4-1 (a), shows the SEM micrograph of the untreated BAMF surface that displays the presence of waxy layers which is a protective layer that lodge in the surface of natural fiber. These layers prevent a good adhesion between the fiber and matrix. By referring to figure 4-1, we can see that from (b) the surface of BAMF started to get clean than that of (a), this is due to effect of NaOH which started to remove a portion of waxy layers and impurities on the surface of BAMF.

Further, from figure 4-1, it was observed that, (c) have smoother surface than (a). This different in surface morphology is due to the increase in NaOH concentration which considerably removed waxy layers and impurities on the surface of BAMF as shown figure 4-1 (c). As researchers reported that increasing the concentration of alkaline treatment leads to the reduction of cementation components(waxy layers, impurities)

which also increases the effective surface of adhesion with the matrix and allows good fiber-matrix bonds (Saha & Adhikari, 2010).

By referring to (c) and (d), we can see that, (d) presents a cleaner surface than (c) but with partial holes and also the fibrils of BAMF can be seen. This is still due, to the increase in NaOH concentration. At this stage, it was observed that the higher concentration of NaOH on BAMF surface has had a considerable effect by weakening the BAMF mechanical properties which can be noticed on Figure 4-2. Based on that, we can refer to what (Faulstich de Paiva & Frollini, 2006) reported the increase in NaOH concentration can lead to the weakness of natural fibers.

4.2 Effect of NaOH concentration on the Mechanical characterization of BAMF

4.2.1 Effect of NaOH on tensile strength of borassus aethiopum mart fibers

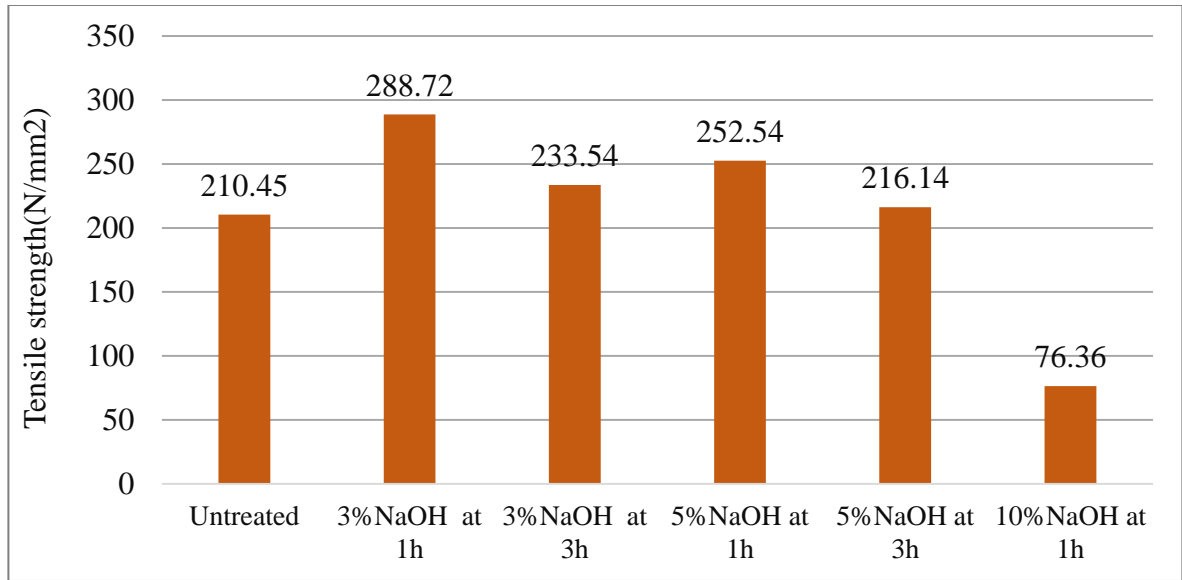


Figure 4- 2: Variation in tensile strength of untreated and treated BAMF at 1-h and 3h immersion period

The results of tensile test showed that alkaline treatment gives change on tensile strength of BAMF. A positive treatment effect was observed with the fibers treated with 3 and 5% NaOH solution when the fibers were treated at 1 and 3h immersion period as compared to the untreated fibers. When the fibers were treated with 10% NaOH solution at 1h, a decrease in tensile strength was observed.

Figure 4-2 shows the variation in tensile strength for untreated and treated fibers at different concentration of NaOH and at different immersion period of 1h and 3h. From the data presented in figure 4-2, it was first observed that, the tensile strength of treated BAMF increased with the lower concentration (3 and 5%) of NaOH and decreased with higher concentration (10%). This increase in tensile strength for 3 and 5% NaOH can be

attributed to the fact, the alkaline treatment result in an improvement of fiber surface by making it uniform due to the elimination of micro voids in the fibers (Kabir & Wang, 2011). Hence, the improvement in tensile strength of the fibers. On the other hand, the decrease in tensile strength of BAMF treated with 10%NaOH at 1h may be attributed to the high concentration of NaOH applied that yielded the main construction components of the fibers to be attacked (Mechedden, 2014). In addition, researchers reported that, the treatment of the fibers can increase or decrease the strength of the latter, that is to say, the alkali concentration must not be higher than the optimum condition (Eichhorn & Baillie, 2001).

Secondly, by referring to figure 4-1 it was observed that, BAMF treated with 3 and 5%NaOH at 1h offered better tensile strength than BAMF treated with 3 and 5%NaOH at 3h. This variation in tensile strength of the fibers treated with the same NaOH concentration but at different immersion period is clearly attributed to the long period of immersion. In fact, as the chemical treatment is to remove the weak boundary layers of natural fibers, the time of immersion could affect the properties of the latter (Usman, 2014). This means the time of immersion must also be optimized in order to come with better tensile strength.

4.2.2 Effect of NaOH on Elongation at break (%) of borassus aethiopum mart fibers

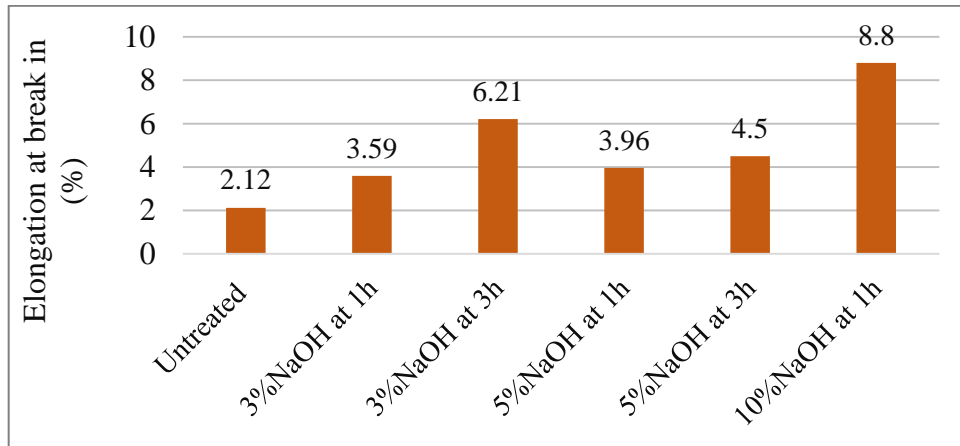


Figure 4- 3: Variation in elongation at break of untreated and treated BAMF at 1-h and 3-h immersion period

Figure 4-3, shows the variation in percentage of elongation at break of the untreated and treated fibers. It was observed that the elongation increased with the increase in NaOH concentration. The maximum elongation at break was observed when BAMF was 10%NaOH at 1h

4.2.3 Effect of NaOH on the Modulus of elasticity (GPa) borassus aethiopicum mart fibers

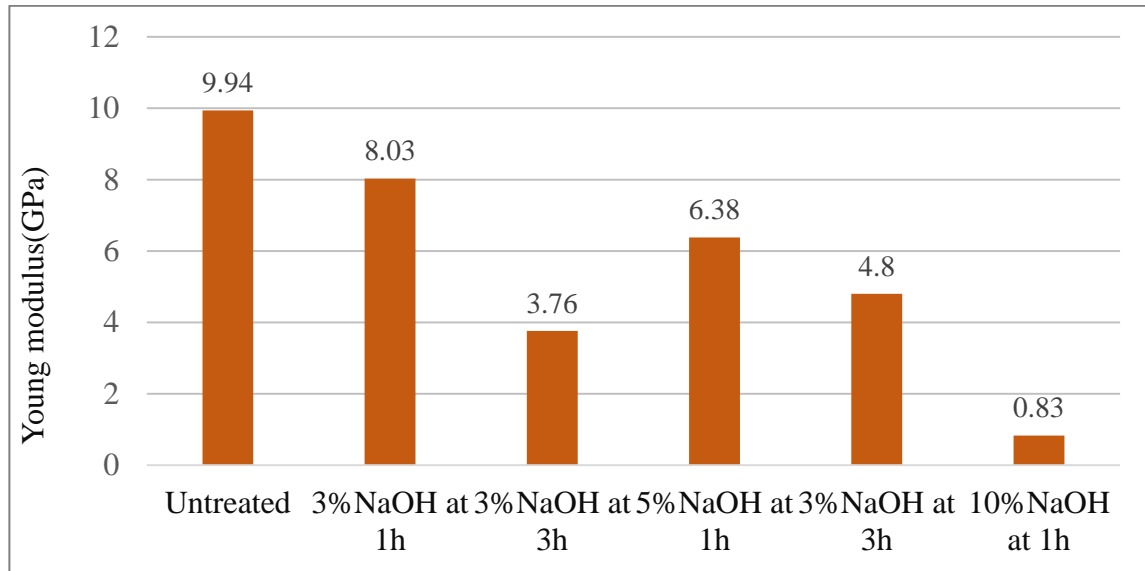


Figure 4- 4: Variation in modulus of elasticity of untreated and treated BAMF at 1-h and 3-h

The above figures indicate the modulus of elasticity of untreated and treated fibers. Firstly, it was observed that the modulus of elasticity was significantly reduced for the increased elongation and increased for decreased elongation. Secondly, it was observed that the modulus of elasticity started to decrease from the untreated to the treated fibers. This decreasing in modulus of elasticity is also due to each concentration of sodium hydroxide/ to the time of immersion used for each treatment. This decreasing in modulus of elasticity makes the fibers of borassus aethiopicum mart to become more flexible, which is good for this kind of material vis-à-vis its utilization in the mortar blocks.

❖ Recapitulation:

From the SEM examination to the mechanical properties, it was observed that the modification of BAMF-surface morphology by alkaline treatment (NaOH) leads to improvement of the fiber- surface because it has removed the impurities and waxy layers that were observed on the surface of untreated BAMF. On the other hand, the improvement in mechanical properties was observed. Therefore, the benefit of BAMF-surface modification can be noticed in the physical and mechanical properties of treated BAMF-mortar composite.

Further, in this study, only the fibers treated with 3, 5 and 10%NaOH at 1h were used to investigate their effect in hollow block-mortar

4.3 Physical properties of fine aggregate

The fine aggregates used in the study was river sand with particle size ranging from 0.15mm to 15m specific gravity of 2.45 and apparent specific gravity of 2.81. The water absorption of the sand was 5.3% and the fineness modulus was 2.64 which meant that the average aggregate size of the sand was between 300µm and 150µm. The physical properties of the fine aggregates are summarized in table 4-1 which show that the geometrical properties of the fine aggregates used.

Table 4- 1: Physical properties of fine aggregate used

Properties	Description
Specific gravity	2.45
Apparent specific gravity	2.81
Water absorption	5.3%
Fineness modulus	2.64

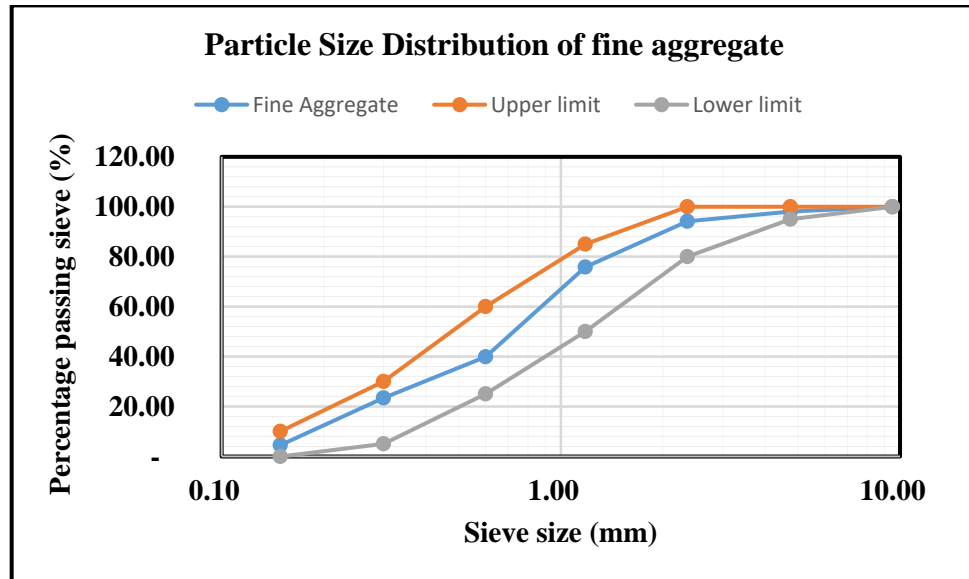


Figure 4- 5: Particle size distribution curve for fine aggregates

The Particle size distribution of the river sand was done using sieve analysis and a graph plotted of percentages passing the standard BS sieve sizes against the sieve sizes as shown in figure 4-5. The envelope (minimum and maximum limits) for the sand as per BS 882 was also plotted on the same graph and as shown the sand was within the envelope hence suitable for use in mortar.

4.4 Chemical composition for Ordinary Portland cement used

The chemical composition for ordinary Portland cement CEM I 42.5N is summarized in table 4 as the cement used in the study was compared with the standard requirement as per EN 197-1. The Chemical composition showed that cement contained 78.76% lime which was available for pozzolanic reaction to form cementitious products in the mortar hence improving the performance of the mortar.

Table 4- 2: Chemical composition of ordinary Portland cement used

parameters	SiO ₂	CaO	Al ₂ O ₃	MgO	P ₂ O ₅	K ₂ O	Fe
From ministry of mining	10.895	78.76	3.43	/	0.53	0.18	2.73

4.5 Effect of treatment of 3% of BAMF on the physical and mechanical properties of BAMF-mortar composites

4.5.1 Physical properties

4.5.1.1 Density

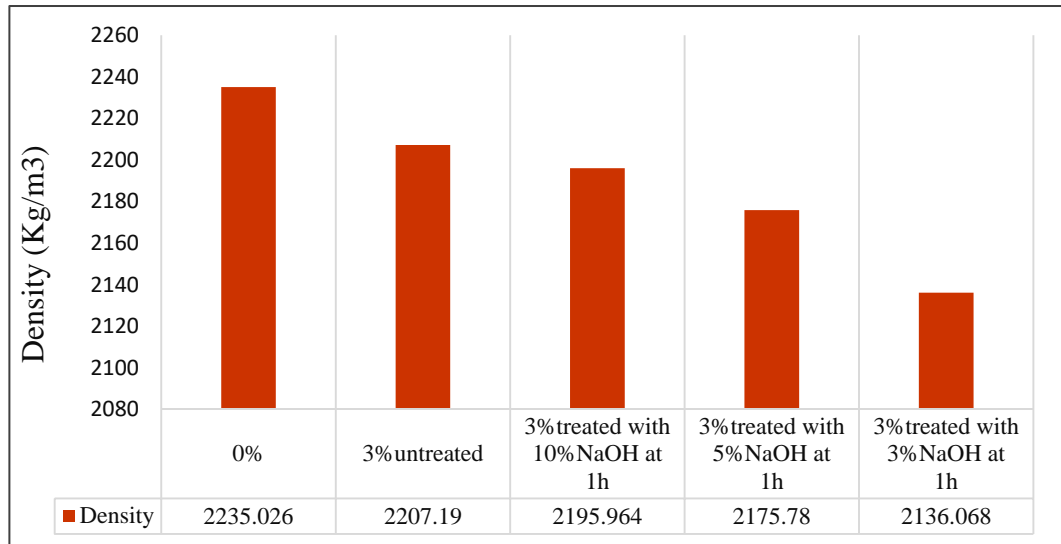


Figure 4- 6: Variation in density of 3%BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig. 4-6 shows the variation in density of 3% untreated and treated BAMF-mortar composite with BAMF treated at different concentration of NaOH. It was observed that the density decreased with the addition of the untreated and treated fibers in the

composite and varies according to each treatment. This can be explained by the increase in the volume of voids created by the incorporation of the fibers (Kriker & Rachedi, 2017). This could be a good result to such a material because it is slightly less dense fiber-mortar.

4.5.1.2 Water absorption

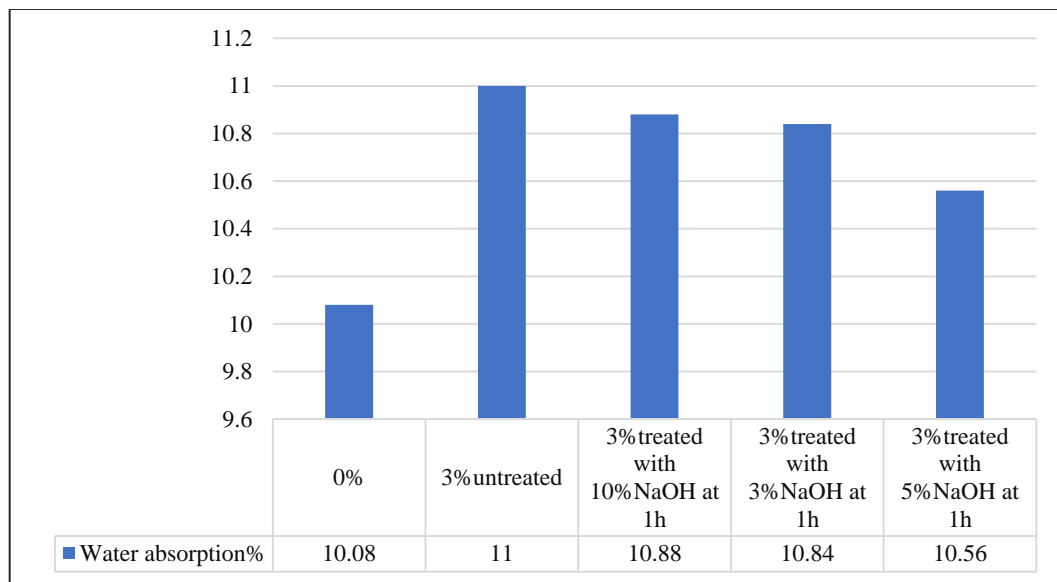


Figure 4- 7: Variation in water absorption of 3% of BAMF-mortar composite in terms of NaOH concentration used for the treatment of BAMF

Fig.4-7 shows the variation of water absorption of 3% of untreated and treated BAMF-mortar composite with the fibers treated at different concentration of NaOH. It was observed that the water absorption capacity of the control with 0% BAMF is lower as compared to BAMF-mortar composites. Further the increased in water absorption of the untreated BAMF-mortar was observed and started to decrease when the fibers were treated with 10% to 5% concentrated NaOH solution. This reduction in water absorption

capacity of the composites with treated fibers could be attributed to the greater adhesion between the fiber and the matrix, that could be possible due to the surface modification (NaOH treatment) of the fibers (Usman, 2014; Sarani & Poh, 2002).

4.5.2 Mechanical properties

4.5.2.1 Flexural strength (three points test)

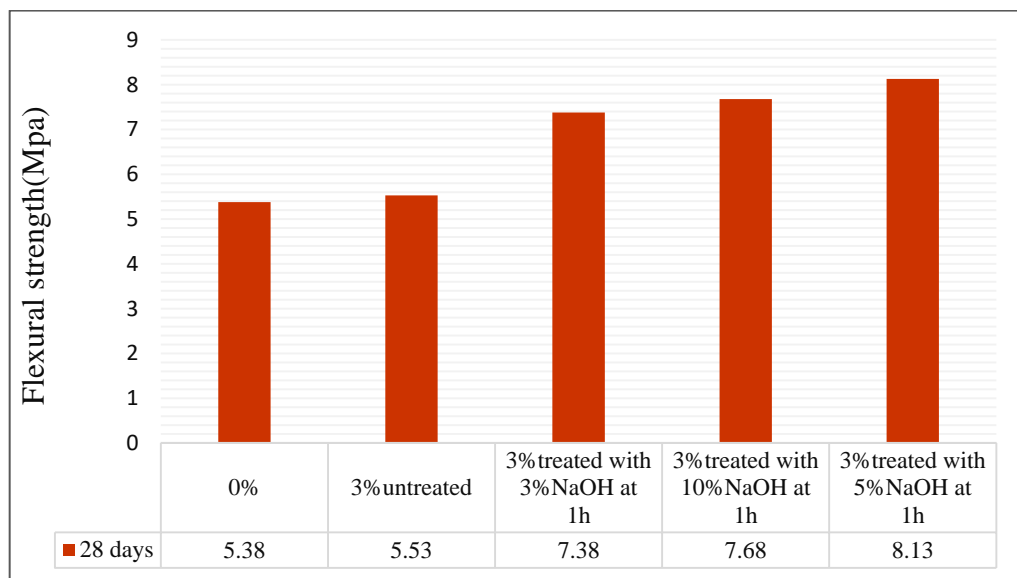


Figure 4- 8: Variation in flexural strength of 3%BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig.4-8 shows the variation in flexural strength (three points test) at the age of 28 days of conventional mortar which is acceptable in the range of [4.41 to 5.88 MPa] according to EN 196-1 and of 3% of untreated and treated BAMF-mortar at different percentage of NaOH. An increase in flexural strength of the composites was observed with the fibers treated with 3%, 5% and 10% NaOH. They exhibited 33.45%, 38.88% and 47.02% increase in the flexural strength of BAMF-mortar as compared to the composite with the

untreated fibers and the control with (0%BAMF). This increase in flexural strength of the composite is due to the fact that, NaOH treatment resulted in an improvement in the interfacial bonding by removing natural and artificial impurities on the fiber-surface and by giving rise to additional sites of mechanical interlocking, hence promoting more adhesion between the fiber and the mortar (Usman, 2014). In addition, this increase in flexural strength for each treatment case can be explained by the concentration of NaOH that had an effect on the surface of the fiber by removing impurities and waxy layers and allowed the fiber to have a good bond with the matrix and acted as crack-arresters which result in the increase in flexural strength. The maximum flexural strength of BAMF-mortar composites was observed with the fibers treated with 5%NaOH at1h.

4.5.2.2 Compressive strength

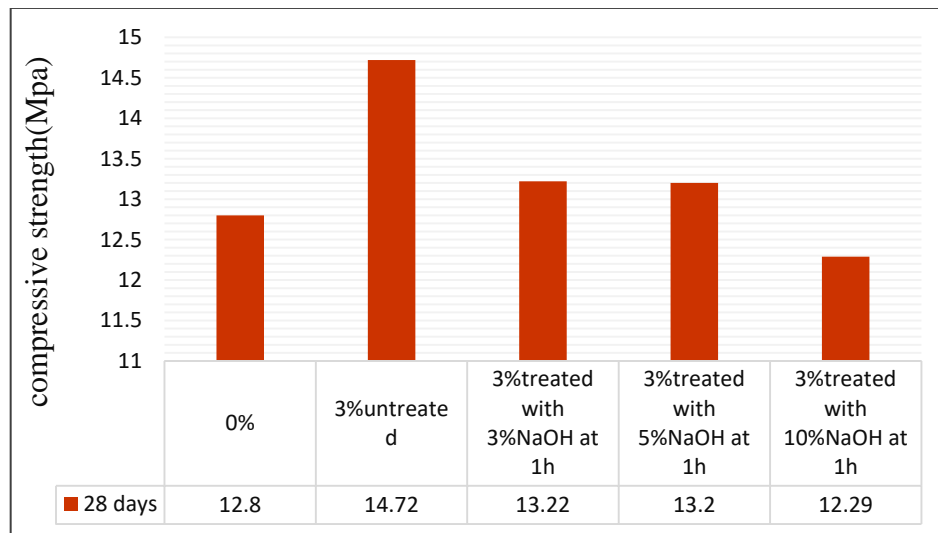


Figure 4- 9: Variation in compressive strength of 3%BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig.4-9 presents the variation in compressive strength results of 3% of untreated and treated BAMF-mortar composite with different concentration of NaOH. The results show that the compressive strength of BAMF-mortar composites with untreated fibers is higher compared to the conventional mortar (with 0% of BAMF) and to the treated BAMF-mortar that started to decrease with composite with treated fibers with 10%NaOH at 1h and from that decreasing then increased slightly at the composite with treated fibers with 5%NaOH at 1h and 3%NaOH at 1h. This decrease in compressive strength for the composite can be explained by the presence of voids inside the paste by increasing its porosity hence the decrease in strength (Kriker & Rachedi, 2017).

4.6 Effect of treatment of 5% of BAMF on the physical and mechanical properties of BAMF-mortar composites
4.6.1 Physical properties

4.6.1.1 Density

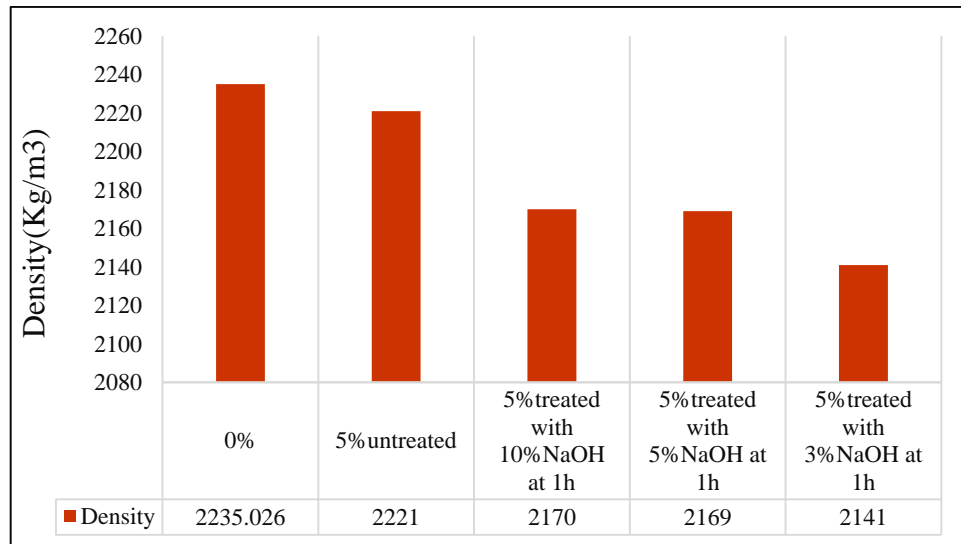


Figure 4- 10: Variation in density of 5% BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig.4-10 shows the variation in density of BAMF-mortar composites with 5% untreated and treated BAMF with different concentration of NaOH. It was observed that the density decreased with the addition of the untreated and treated fiber in the composite and varies according to each treatment. This can be explained by the increase in the volume of voids created by the incorporation of the fibers. This could be a good result to such a material because it is slightly less dense.

4.6.1.2 Water absorption

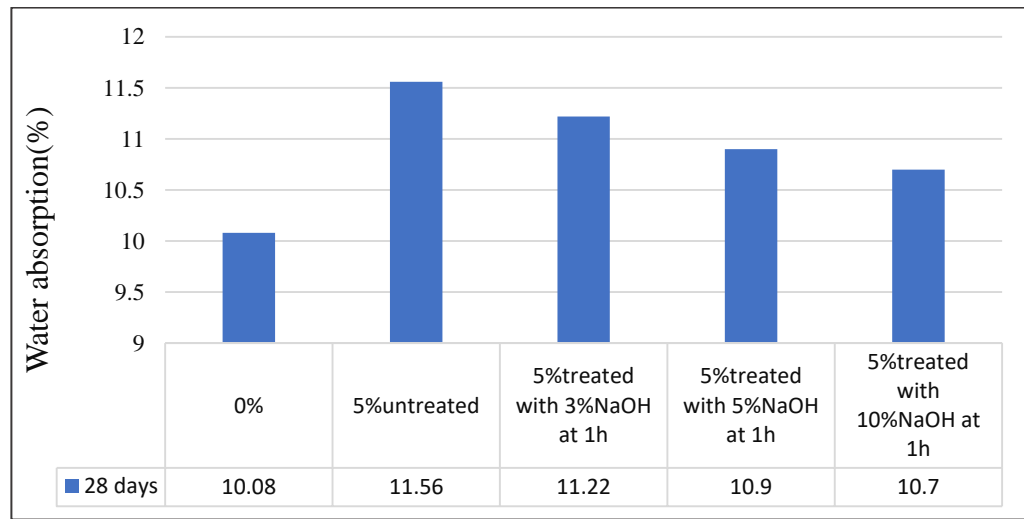


Figure 4- 11: Variation in water absorption of 5% BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig. 4-11 shows the variation in water absorption of BAMF-mortar composites with 5% untreated and treated BAMF with different concentration of NaOH. The result has shown that the water absorption first increased at the composite with untreated BAMF compared to the control (0% of BAMF). From the composite with untreated to the

treated BAMF the water absorption decreased respectively. This reduction in water absorption capacity of the composites with treated fibers could be attributed to the greater adhesion between the fiber and the matrix that could be possible due to the surface modification. It can also be due to the concentration of NaOH used for each treatment of the fibers that reduced the moisture absorption of the fibers (Sarani & Poh, 2002). This is a good factor to consider because the treated BAMF-mortar composite will be used to produce hollow block.

4.6.2 Mechanical properties

4.6.2.1 Flexural strength (three points test)

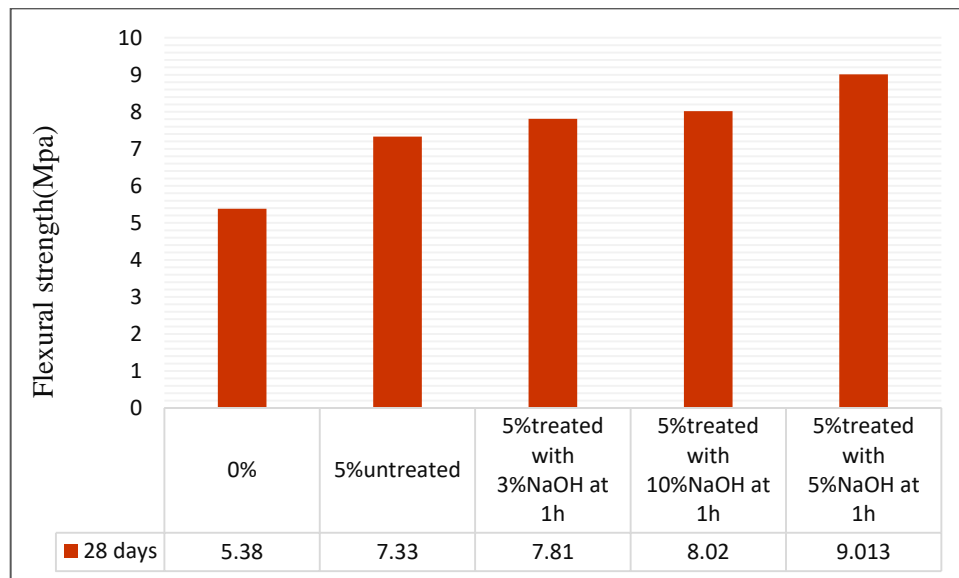


Figure 4- 12: Variation in flexural strength of 5% BAMF-mortar composite in terms of NaOH for the treatment percentage used of BAMF

The above figure 4-12, shows the variation in flexural strength of cement mortar reinforced with 5% of untreated and treated BAMF with different concentration of

NaOH. From the test results, it was first observed that 5% of the fiber in the composite increased the flexural strength for both untreated and treated BAMF-mortar composites compared to the results on figure 4-9. This increase in flexural strength is due first to the increase in percentage of the fiber in both case that allowed a good dispatching in the mortar and assists resistance to crack propagation in tension. And secondly the variation in flexural strength for the composite with the treated fibers is due as mentioned earlier to the improvement in the interfacial bonding by removing natural and artificial impurities on the fiber-surface and by giving rise to additional sites of mechanical interlocking, hence promoting more adhesion between the fiber and the mortar (Usman, 2014). Therefore, the maximum flexural strength of BAMF-mortar composites was observed at 9.013 MPa with fiber treated with 5%NaOH at 1h.

4.6.2.2 Compressive strength

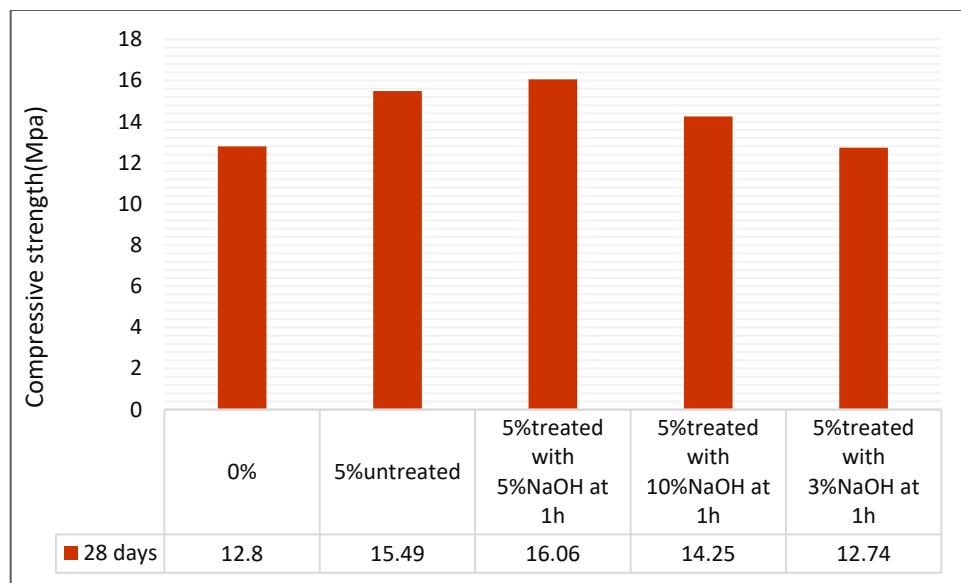


Figure 4- 13: Variation in compressive strength of 5%BAMF-mortar composite in terms of NaOH percentage used for the treatment of BAMF

Fig. 4-13 shows the variation in compressive strength of cement mortar reinforced with 5% of untreated and treated BAMF with different concentration of NaOH. The results show that the compressive strength of composite with untreated fibers increased compared to the conventional mortar (with 0% of BAMF). Further, an increase in compressive of the composite with the fibers treated with 5%NaOH was observed and decrease considerably with composite with the fibers treated with 3%NaOH and 10%NaOH. Variation in compressive strength is due to the dispatching of the fiber inside of the matrix that plays de role of coarse aggregates in ordinary concrete and decrease in compressive strength.

4.7 Recapitulation

After a quick review on the previous graphs and curves on the effect the treatment on the above properties of BAMF-mortar composite, it can be observed that the treatment of BAMF has played a significant role in the physical and mechanical properties of the composite. the composite incorporates with BAMF treated with 5%NaOH at 1h has given best results compared to other treated BAMF-mortar from the point of view flexural and compressive strength. These results allowed coming up with the optimum treatment of BAMF by alkaline treatment. This can be explained by the surface modification of BAMF treated with 5%NaOH at 1h which offers good adhesion with the matrix than 3% and 10%NaOH at 1h. Hence this increase in mechanical properties. This result will help formulating BAMF-mortar for the production of hollow blocks mainly flexural strength which is the most important characteristic required in such a material.

4.8 Sulfuric acid (H₂SO₄) attack

4.8.1 Compressive strength loss (CSL %)

Compressive strength loss is considered to be a more reliable measure to judge the performance of mortar/concrete subjected to acid attack. The above figures present the comparison in compressive strength and variation in compressive strength loss before and after immersion in H₂SO₄ acidic solution for 90 days.

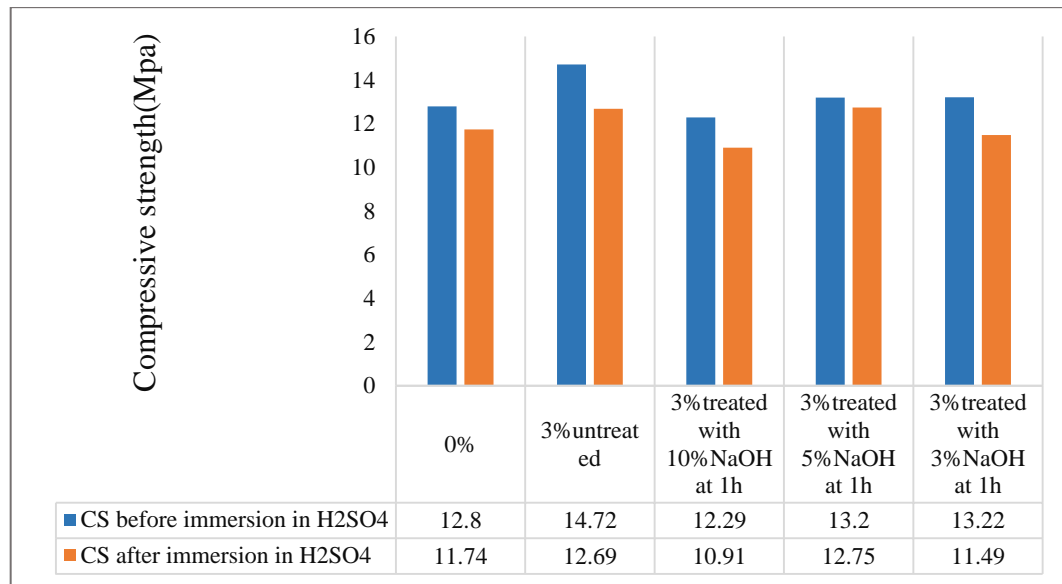


Figure 4- 14: Comparison in compressive strength of 3% treated BAMF-mortar composite before and after 90 days of immersion in H₂SO₄ solution

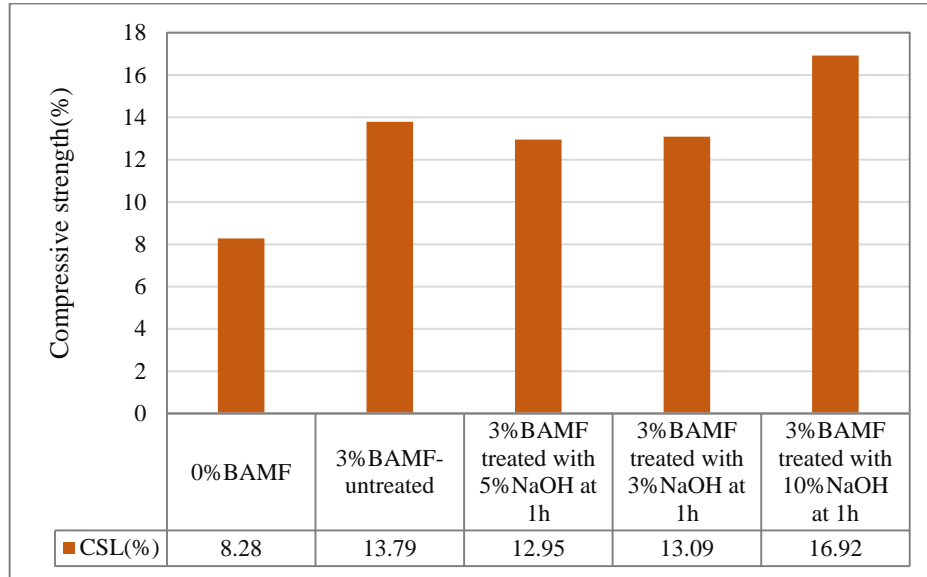


Figure 4- 15: Variation in compressive strength loss of 3% BAMF-mortar composites under H₂SO₄ solution exposure at 90 days

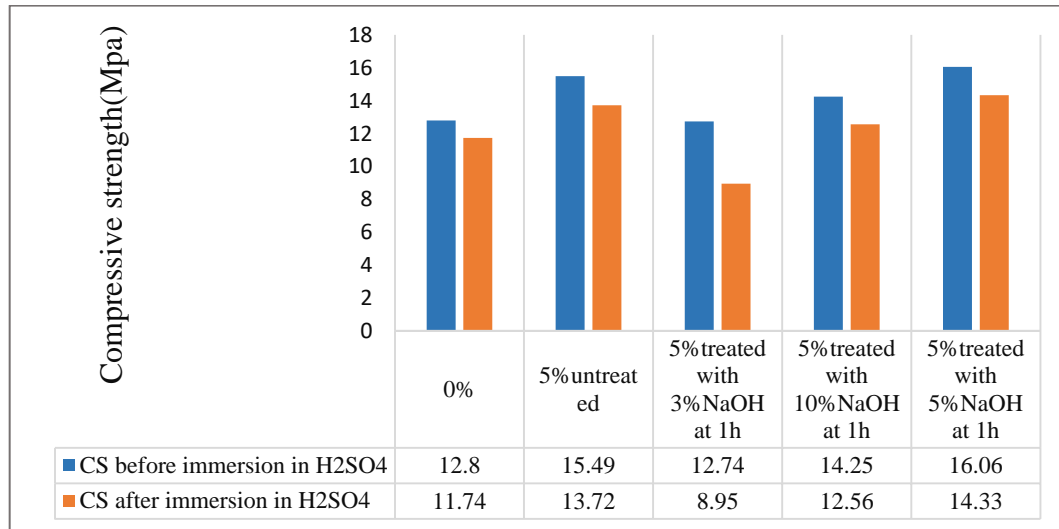


Figure 4- 16: Comparison in compressive strength of 5% treated BAMF-mortar composite before and after 90 days of immersion in H₂SO₄ solution

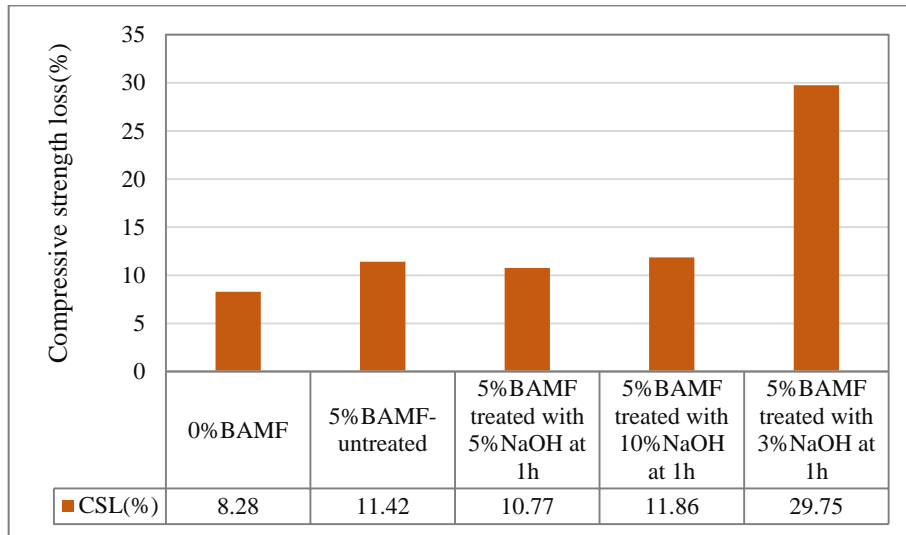


Figure 4- 17: Variation in compressive strength loss of 5% treated BAMF-mortar composite under H₂SO₄ solution exposure at 90 days

Compressive strength is considered to be a more reliable measure to judge the performance of mortar/concrete composite subjected to acid attack (Siad & Mesbah, 2010). Comparison in compressive strength figure 4-14 and 4-16 before and after 90 days' immersion of specimens in H₂SO₄ acidic solution was done for this study to evaluate the performance of BAMF-mortar composite exposed to acid medium in order to evaluate compressive strength loss figure 4-15 and 4-17.

Figure.4-15 and 4-17 present the results of compressive strength loss (CSL) of the mixes at 90 days in H₂SO₄ acid concentration of pH3 solutions. The results indicate that the resistance to H₂SO₄ acid attack of all the composites was reduced by 8.28%, 13.79%, 12.95%, 13.09% and 16.92% respectively for the composite with 3% of BAMF and 8.28%, 11.42%, 10.77%, 11.86% and 29.75% respectively for the composite with 5% of BAMF. So, these results are confirmed by the change of surface

samples figure 4-18 after immersion in the aggressive solutions. This loss in compressive strength is due to sulfuric acid that causes a heavy deposition of gypsum that acts as a protective layer; this surface protection is verified by the unchanged hardness beyond a depth of 2 mm, however, it is noted that gypsum is deposited at depths of up to 2 mm in fissures and voids. In this case the mechanism of attack is caused by the production of the expansive gypsum, this expansive effect being responsible for the progressive opening of the material structure by dislocation of surface material (Rendell & Jauberthie, 1999).

4.8.2 Visual Inspection

Figure 4-18 shows a clear evidence of H_2SO_4 attack on the specimens. For this H_2SO_4 attack, the damaged of BAMF-mortar composite was selected as an example to observe the macrostructure of deterioration.

A visual inspection of specimens as shown in Figure 4-18(j) revealed the deterioration of the samples, immersed in sulfuric acid. These specimens kept their rectangular forms more or less. In fact, the first sign of attack was the deterioration of the corners of specimens, followed by cracking along the edges. Progressively, expansion and spalling took place on the surface of specimens.



Figure 4- 18: Specimens (i) before, (j) after exposure to H₂SO₄

4.9 Application to hollow borassus aethiopum mart fiber blocks

The development of a new material is only envisaged to solve specific problems or to anticipate possible future needs. In either case, it should be clarified whether the designed material is likely to be used for practical purposes. Also, it is essential to make a comparison of the material with the existing conditions to identify the additional advantages and disadvantages that could result from its use.

This part is concerned with the mechanical tests on the hollow blocks of borassus aethiopum mart fiber-mortar composite.

4.9.1 Formulation adopted for applications

The previous mechanical tests have shown that treated BAMF-mortar with 5% fibers treated with 5%NaOH at 1hour has given good mechanical properties; they have a mechanical strength in compression up to 16.06 MPa and 9.013 MPa in flexion. The purpose of this work being to use the composites for the manufacture of hollow blocks for the construction of hollow-core-slab, we thus opted for the choice of the mixture 1: 3 which is 350kg / m³ with the fibers treated with 5%NaOH at 1hour.

4.9.2 Mechanical and physical properties of treated BAMF-mortar blocks

4.9.2.1 Physical property: density

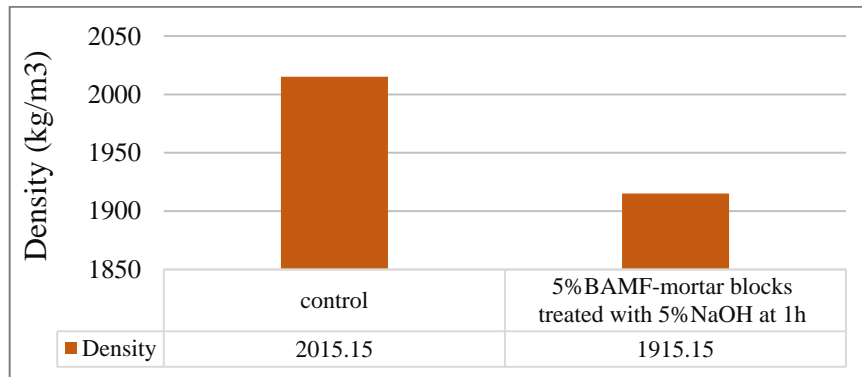


Figure 4- 19: Density of treated BAMF-mortar blocks at 28 days

Figure 4-19 shows the density of ordinary blocks and of blocks made of 5% BAMF-mortar blocks with BAMF treated with 5% NaOH at 1h. It was observed that the density of blocks made from ordinary mortar was higher than those made from 5% treated BAMF as shown in figure 4-20.

This reduction in density of the blocks made from treated BAMF-mortar could be explained with the presence of the fibers that created voids in the blocks and allowed the blocks to have a reduction in density.

4.9.1.2 Flexural strength (by bending tree-point) of hollow bocks

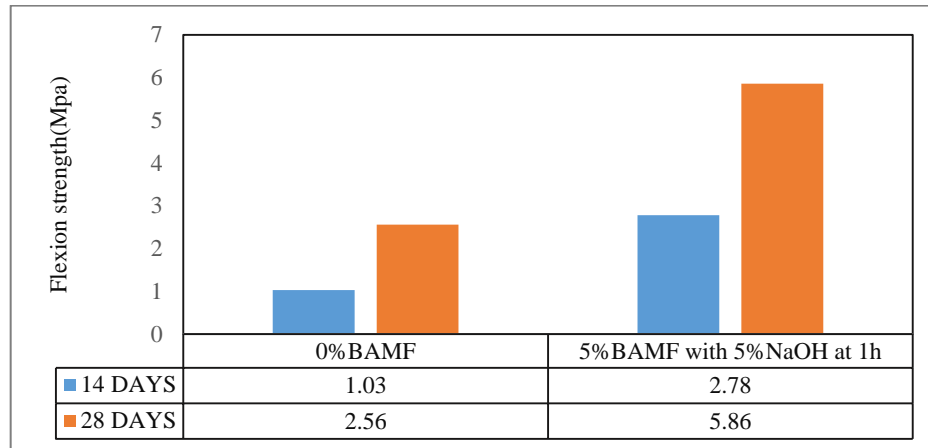


Figure 4- 20: Evolution of flexural strength of treated BAMF-hollow blocks

Flexural strength by bending figure 4-20 is known as one of the most important test on hollow blocks. This test allows determining the strength of hollow blocks during the implementation phase, they must resist to horizontal and vertical efforts. In addition, it allows simulating the walk of a man on hollow blocks in order to take into count the conditions of building site: clamping hollow blocks, roughness of the beams and size of the soles of the shoes.

The above figure 4-20 shows the evolution of flexural strength by bending at 14 days and 28 days of age. It was observed that, the hollow blocks with fibers have given good resistance to flexural by bending compared to the blocks made from normal mortar, this is due to the presence of the fibers that have played the role of cracks-arresters in the blocks. These results are important because hollow blocks are subjected to bending efforts due to human activities during the implementation of the slab. These results at 28 days are in accordance with the results obtained by (Edem, 2014).

4.9.1.3 Compression strength of hollow blocks

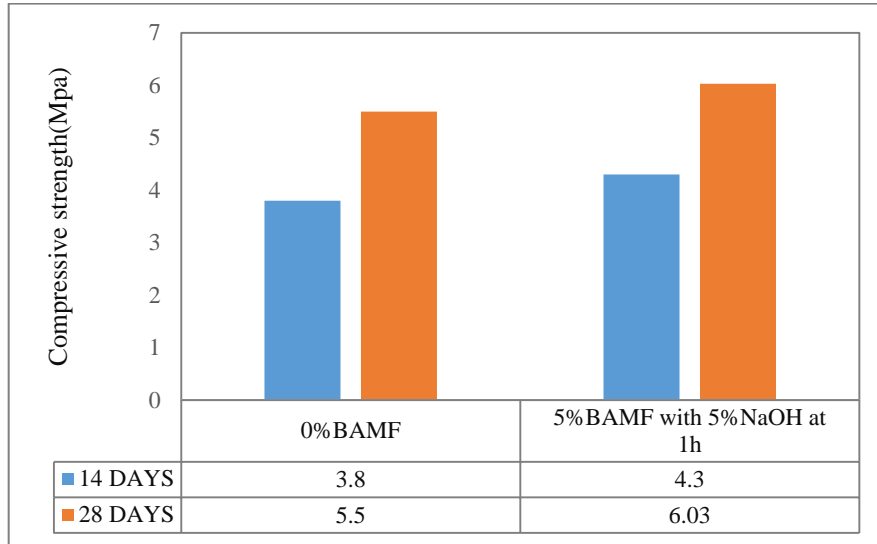


Figure 4- 21: Evolution of compressive strength of treated BAMF-hollow blocks

The above figure 4-21 shows the evolution at 14 and 28 days of the compressive strength of the hollow blocks produced with 5% BAMF-mortar with the fibers treated with 5%NaOH at 1hour. The results have shown an increase in compressive strength from 4.3 MPa at 14 days to 6.03 MPa at 28 days. It was observed that the minimum value in compression is 4.3 MPa which is higher than to the minimum compressive strength of 4 MPa required according to EN 135037.

Based on these results, the hollow blocks made from treated BAMF-mortar can be used after 14 days of curing which is the minimum period of curing of hollow blocks for the construction of hollow-core-slab, but for security reasons 28 days of curing would be better because the resistance has increased.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The general objective of this study was to investigate effect of treated borassus aethiopum mart fiber on the physical and mechanical properties of hollow blocks mortar, the following conclusions can be made:

- (a) Borassus aethiopum mart fibers can be treated with NaOH solution and improve the tensile strength of the fibers at 3% and 5%NaOH and also improve the fiber surface.
- (b) The alkaline treatment of borassus aethiopum mart fiber with 3%, 5% and 10% of NaOH leads to the improvement of the borassus aethiopum mart fiber surface through the removal of waxy layer and impurities which has resulted to the improvement of interfacial adhesion between the fiber and mortar composite.
- (c) Treated borassus aethiopum mart fiber using 3%, 5% and 10%NaOH increase the tensile strength of BAMF-mortar composites and the maximum tensile strength was observed from the composite with treated fiber with 5%NaOH at 1h, the compressive strength of treated BAMF-mortar composite reduced as compared to the untreated BAMF-mortar composite but increased from the composites with treated fiber with 5%NaOH at 1h. Therefore, alkaline treatment using NaOH on BAMF can be used to enhance both the mechanical properties of the fibers as well as for BAMF-mortar composites.

- (d) The incorporation of treated BAMF in mortar also has an impact on the physical property of the composite, a reduction in density which is an important fact to consider particularly for hollow bricks during the implementation of the slab.
- (e) From the composites with treated BAMF, an increase in water absorption was observed with the increase in fiber percentage.
- (f) When treated BAMF-mortar composites were exposed to H_2SO_4 acid with PH3 of acidity, a reduction in compressive strength was observed but not considerably. Therefore, as the composite was exposed to the higher acidity medium, it can be noticed that the materials of construction that is made from this mortar could resist to an aggressive environment.
- (g) The increase in compressive and flexural strength of the hollow blocks formulated with the optimum treated BAMF-composite was observed in accordance EN. Therefore, treated BAMF-mortar can be used as a mortar for the production of hollow bricks for hollow-core slab.

5.2 Recommendations and further research

From this work and its findings, the following recommendations will be suggested for eventual future study to ascertain the use of borassus aethiopicum mart fiber in construction materials:

- (a) To choice other percentages of NaOH for alkaline treatment of BAMF;
- (b) To do a comparative study between two different treatments such as silane and benzoylation treatment on BAMF to investigate they effects.
- (c) To study a cost reduction when using treated BAMF in hollow bricks

(d) To study the behavior of treated BAMF-mortar composite in shear strength as it is also one the efforts that hollow bricks for hollow slab are subjected to.

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Appendix A:

Photographs of the materials used for this study:



Figure A- 1: borassus aethiopicum mart fibers used for this study



Figure A- 2: Sodium hydroxide pellets used for this study

Appendix B:

Photographs taken during different tests in the laboratory



FigureB-1: flexural strength tree-point



Figure B-2: Compressive strength using a UTM machine



Figure B-3: Specimen with BAMF after flexural test



Figure B-4: Specimen with 0% BAMF after flexural test



FigureB-6: flexural strength tree-point



Figure B- 3: Compressive strength of hollow blocks



Figure B- 8: Flexural strength test hollow blocks

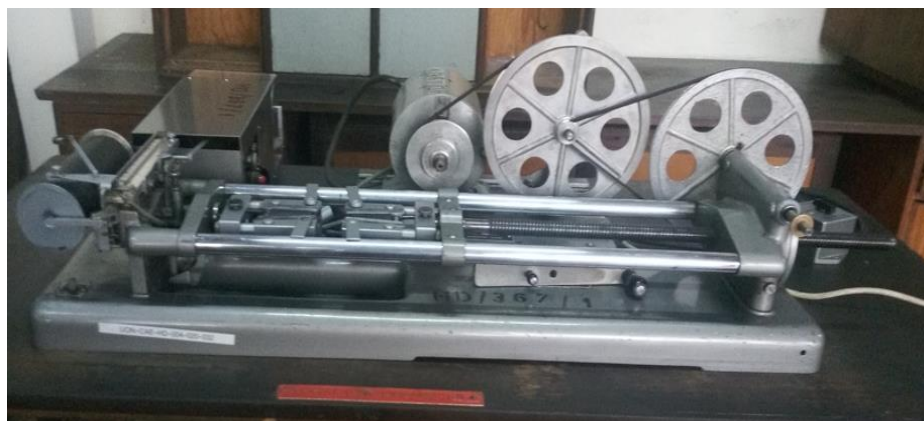


Figure B- 9: Tensile strength test machine for the determination of tensile force of fiber



Figure B- 10: Tensile strength test machine



Figure B- 11: Weight of NaOH pellets per percentage and measurement of water



Figure B- 43: borassus aethiopicum mart slats were the fibers were extracted



Figure B- 12: Hollow blocks tested for this study