DEVELOPMENT OF BAOBAB/SISAL REINFORCED LOW DENSITY POLYETHYLENE HYBRID COMPOSITE

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NOVEMBER,2016

Declaration

I hereby declare that this desertation entitled "**Development of Baobab/Sisal Reinforced Low Density Polyethylene Hybrid Composite"** has been carried out by me in the Department Chemical Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project was previously presented for another degree or diploma at this or any other Institution.

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Certification

This is to certify that this dissertationentitled "**Development of Baobab/Sisal Reinforced Low Density Polyethylene Hybrid Composite"** by USMAN, SHEHU with registration number P13EGCE8003 meets the regulations governing the award of Masters of Science (M.Sc) degreein Chemical Engineering of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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Dedication

This research work is dedicated to my parents, Alhaji Shehu Usman and Hajiya Hajara Ibrahim and also to my entire family members especially my elder brothers: Alhaji Mahmud Tauheed Usman and Alhaji Musa Yabagi Muhammed.

May Almighty Allah assist us all in all our endeavours (ameen).

Abstract

In this work, the properties of baobab/sisal fibre reinforced low density polyethylene hybrid composites were studied. The effect of fibre loading and fibre treatment with varying sodium hydroxide (NaOH)concentration on the composite properties was investigated. The developed composites were characterized for tensile strength, modulus of elasticity (MOE), elongation at break, hardness and impact strength.Analysis of the results showed that, for the monolithic composite,10 wt% baobab fibre loading had the bestmechanical property compared to other baobab fibre loadings, with tensile strength and MOEof 8.28 MPa and 127 MParespectively.The result ofNaOH treatment showed that 8 wt% treated fibre composite exhibited the best tensile strength, MOE, impact strength and the least percentage water absorption of 14.54 MPa, 245 MPa, 4.4 J/mm^2 and 1.8% respectively.On hybridization with sisal, it was observed that the100% sisal fibre composite exhibited higher tensile strength and MOEof 12.47 MPa, 262.85 MPa, and the least percentage water absorption capacity of 0.37% but for both the hybrid were higher than the monolithic composite. The result of the NaOH treated hybrid composite showed that 6 wt% NaOH treated sisal/baobab fibre exhibited the best tensile strength, MOE and percentage water absorption of 17.08 MPa, 279.40 MPa, and 0.18% respectively which were higher than that of the monolithic sisal fibre reinforced composites. The fourier transforms infrared spectroscopy (FT-IR) analysis of untreated and treated baobab fibre showed that there was reduction in the hemicelluloses in the NaOH treated baobab fibres as indicated by the band at2277–2274 cm^{-1}representing C=O stretching of hemicelluloses. The scanning electron microscope (SEM) analysis showed that composite produced from untreated fibre had more cracks and voids, possibly due topoor interaction between the fibre and low density polyethylene matrix, resulting in lower mechanical properties.The composite have properties whichsuggest their suitability for application in deck boards, dash board, rear seat barriers and guardrails systemsto replace the hardwood and metals currently used hence, preserving the environment.

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List of Abbreviation and Symbols

LDPE – Low Density Polyethylene

LLDPE – Linear Low Density Polyethylene

HDPE – High Density Polyethylene

NaOH – Sodium hydroxide

SEM – Scanning electron microscopy

FTIR –Fourier transforms infrared spectroscopy

ASTM – American Society for Testing and Materials

MOE – Modulus of Elasticity

MPa – Megapascal

wt% – Weight Percentage

J/mm^2– Joules per millimetre square

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Composites are multifunctional material systems that provide characteristics not obtainable from any discrete materials. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form (Prankash *et al*., 2009). These materials consist of the matrix and reinforcement (Mohini*et al.,* 2011). The constituents can be wholly natural or synthetic and sometimes the combination of the two.

Synthetic-based fibre composites are commercially appealing because they can be used to develop products with known properties to meet a variety of diverse applications. However, these materials represent an environmental liability both in production and upon disposal. In the past years, growing environmental pollution has called for the use of natural materials for different applications. This has been influenced by the ever increasing demand for newer, stiffer, recyclable, fire repellant, less expensive and yet lighter-weight materials in fields such as aerospace, transportation, construction and packaging industries (Duigou *et al*., 2008). Meanwhile, natural fibres reinforced polymer composites represent an opportunity to partially minimize on the environmental impacts by integrating biodegradable fibres such as flax, hemp, sisal, and wood particles in place of synthetic fibres such as glass, carbon or steel in composite materials production (Alabi, 2011).

Natural fibres, such as cotton, flax, hemp, kenaf etc. or fibres from recycled wood or waste paper, or even by-products from food crops are examples of fibres being used for the production of polymer composite materials (Fowler *et al*., 2006). Hence composites made with natural fibres are known as “green composites” (Guduri *et al*., 2006).

In a studyby Ajayi *et al.* (2000), the physical properties of natural cellulose fibres was found inextricably linked to their gross morphological features. It was also reported that when the bast fibres cells were embeddedin a continuous inter-molecular poly-propylene matrix, the molecules were oriented and arranged parallel along the major axis of the fibre to yield high strength and anisotropy (ie. different properties in different direction).

Siddika *et al*., (2013) developed coir/epoxy composite and evaluated their mechanical properties. Scanning electron micrographs obtained from fractured surfaces were used for a qualitative evaluation of the interfacial properties of coir/epoxy and this was compared with glass fibres.Tensiletestof the compositeshowedadecreasingtrendof tensilestrength andincreasing trendof the Young's modulus with increasing fibre content. The flexuralstrength, flexural modulus, impact strengthand hardness were found to increase with increasing fibre loading. Based on the fibre loadingused in the study, 20% fibre reinforced composite gave thebest set of mechanicalproperties.

Reise (2006), stated that the fracture toughness decreased by 22.2% when epoxy composites was reinforced with banana pseudo-stem fibre while fracture toughness increased by 15.7% with coconut reinforcement and 17.8% with sugar cane bagasse reinforcement. This shows that not all natural fibres would increase the fracture toughness of polymer matrix composites.

Thombrel *et al.*, (2014) studied the mechanical properties of hybrid natural fibre composites, here samples of several jute-bagasse-epoxy and jute-lantana camara-epoxy hybrids were manufactured using hand layup method and the weight fraction of the fibre and matrix was kept at 40%-60%.It was found that they have higher tensile strength than glass, good elasticity, excellent resilience and in turn it would not induce a serious environmental problem as would glass fibres.

Jute fibre reinforcedpolyester composites were developed and characterized for friction and sliding wear properties. Effect of fibre orientation and applied load on tribological behaviour of jute fibre reinforced polyester composites was determined. Maximum wear resistance was observed where fibres orientations were normal to sliding direction (Chand*et al.,* 2009). Interest in sisal fibre reinforced composite is particularly higher than other natural fibres, because it has been reported to posses' high impact strength, moderate tensile and flexural properties when compared to other lignocellulosic fibres (Kuruvilla *et al.,* 1999).

Baobab (Kuka in Hausa) is a popular and widely cultivated plant in the surrounding region of West Africa. Its fibres are obtained either from the pod or bark of the tree; these are stripped from the lower part of the trunk and husks. Strong fibres can also be obtained from its root bark (Sidibé and Williams, 2002). Although there are numerous reported works on the use of natural fibres either monolithically or in combination with other fibres in composite development, the use of baobab (*Adansonia-digitata*) in composite production is rare, despite its known high elongation at break. Its use is only limited to making of rope, string, cord for musical instruments, snares, fishing-nets, mats and waterproof hats.

1.2 Statement of Problem

The use of baobab pod fibre as reinforcement in composite development is currently rare in conventional literature. However, data on composite properties based on baobab pod fibre is lacking despite its potentials. Similarly, systematic studies on itscombination with other fibres are not available as far as literature search is concerned. Therefore, the use of baobab pod fibre as monolithic reinforcement in composite making and its hybridization with other well known natural fibre, (sisal in this case for improved physical and mechanical properties) has not been reported.

1.3 Justification for the Research

The research serve as means of obtaining data on baobab pod composites materials and will probably lead to alternative materials in some areas of applications. The developed material willbe more environmentally friendly when compared to conventional composites. More so, alternative use of baobab fibre was established and this lead to more income to the agricultural sector.

1.4 Aim and Objectives

The aim of this research work is to develop baobab/sisal reinforced low density polyethylene monolithic and hybrid composites.

This aim would be achieved by actualizing the following objectives:

1. Mechanical extraction of the fibres.
2. Studies on the effect of fibre loading on the mechanical properties of the composites.
3. Modification of the fibres by chemical method.
4. Studies on the effect of hybridization of the fibres on mechanical behaviour of low density polyethylene.

1.5 Scope of Study

The scope of the research will be limited to the use of baobab and sisal fibres only. The fibres will be extracted from baobab pod and sisal leaves.Fabrication of baobab and sisal fibres reinforced low density polyethylene monolithic and hybrid composite materials will be carried out. Effect of fibre loading and varying concentration of sodium hydroxide treatment of fibre on the properties of the composite materials developed will be studied.

CHAPTER TWO

LITERATURE REVIEW

2.1Composite Materials

Composite results from the combination of two or more distinct constituents or phases, of a stiff, strong material, often fibrous in nature, embedded within a matrix phase which is usually weaker and compliant (Paul *et al.,* 2007). By this combination, materials with enhanced physical or chemical properties are produced. Hence properties better than those of individual constituent are achieved.

The normal way to strengthen a material is to increase the volume and by implication increase its weight. An alternative route is to strengthen the structure with fibre, creating a composite. Emphasis has been on the use of fibres with lower density and improving the strength while reducing the specific weight at the same time (Alabi, 2011).

2.1.1 Basic constituent materials in composites

Although it is undoubtedly true that the high strength of composites is largely due to the fibre reinforcement, the importance of matrix material cannot be underestimated as it provides support for the fibres and assists the fibres in carrying the loads. It also provides stability to the composite material. Resin matrix systemacts as a binding agent in a structural component in which the fibres are embedded. When too much resin is used, the part is classified asresin rich. On the other hand if there is too little resin, the part is called resin starved.A resin rich part is more susceptible to cracking due to lack of fibre support, whereas a resin starved part is weaker because of void areasandthe fact that fibres are not well held together and they are not well supported (Joseph *et al.,* 2002).

2.1.1.1*Matrix phase*

A matrix is also known as binder material. It provides shape to the composite material,makes the composite material generally resistant to adverse environments and protects reinforcement material from adverse environments. The materials which constitute matrix of composite materials are polymers, metals and ceramics (Paul *et al.*, 2006).

I. Polymers:Polymer matrix based composite materials constitute more than 95 percent of composite materials in use today. Both thermosets as well as thermoplastics are used as matrix materials.The most commonly used thermosetting polymers are phenol-furfural, urea-formaldehyde, melamine-formaldehyde, epoxy, unsaturated polyesters and silicones. The most common thermoplastic polymers are cellulose nitrate, low density polyethylene (LDPE), high density polyethylene (HDPE), polyamides, polyvinyl alcohol and poly-iso-butylene (Mitra *et al.*, 2014).

   As thermosets mostly exist in liquid state before cross-linking, it is very convenient to combine reinforcements in the required proportion, shape the product and cure it into solid. Thermoplastics, on the other hand, have to be heated and liquified before adding reinforcements (Basu and Roy. 2007).

II. Metals matrix:Metal matrix composites, as the name implies, have a metal matrix. Examples of matrices in such composites include aluminium, magnesium and titanium. The typical fibre includes carbon and silicon carbide. Metals are mainly reinforced to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased, while large co-efficient of thermal expansion, and thermal and electrical conductivities of metals can be reduced by the addition of fibres such as silicon carbide (Sreekala *et al.*,2002).

III. Ceramic and other brittle matrix: Ceramics have great thermal stability and are resistant to most forms of attack (abrasion, wear, corrosion). Ceramic, carbon and

glass are widely used as matrix in composites materials. The introduction of fibres into ceramics improves tensile strength and toughness. Similarly, carbon glass reinforced with carbon fibres has better toughness.

2.1.1.2 *Low density polyethylene*

Low-density polyethylene (LDPE) is a thermoplastic made from the monomerethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process via free radical polymerization (Dennis, 2010). They are thermoplastic polymers consisting of bound ethylene units (C_2H_4). In low density polyethylene, the ethylene monomeric units are linked in random fashion, with the main chains having long and short side branches. This branching prevents the formation of a closely knit pattern, resulting in material that is relatively soft, flexible and tough, and which will withstand moderate heat (Joseph *et al.*, 1999).

LDPE is part of the polyolefins family witha density ranging from 0.915 to 0.940 g/cm^3. The LDPE and LLDPEvolumes in 2007 account for 35% (roughly 7.8 milliontonnes per year) of Western Europe's total polyolefinsproduction which is 22.1 million tonnes per year. Polyolefinsrepresent 40% of total plastics production in WesternEurope, which is 55 million tonnes per year (Joseph *et al.*, 2002).

LDPE-fibre reinforced composites: Low density polyethylene has been used in hybrid composite formulations because it is the least expensive polyethylene. It was also reported that LDPE has the ability to photodegrade in sunlight and photo-degradation is found to be important in biodegradation (Basu and Roy. 2007).

Joseph *et al.* (2002) studied the effect of chemical treatment on the tensile and dynamic mechanical properties of short sisal fibre reinforced low density polyethylene composites. It

was observed that the cardanol derivative of toluene disocyanate (CTDIC) treatment reduced the hydrophilic nature of the sisal fibre and enhanced the tensile properties of the sisal-LDPE composites. They found that peroxide and permanganate treated fibre-reinforced composites showed an enhancement in tensile properties. They concluded that with a suitable fibre surface treatment, the mechanical properties and dimensional stability of sisal-LDPE composites could be improved.

Prachayawarakorn *et al.* (2010) prepared biodegradable polymer from thermoplastic rice starch (TPRS) plasticized by glycerol. In order to improve on the poor tensile properties and high water absorption of the TPRS, cotton fibre and low-density polyethylene (LDPE) was interchangeably added into the TPRS matrix. The effect of maleic anhydride grafted polyethylene (MAPE) and vinylmethoxy silane (VTMS) compatibilizers on properties of the TPRS and LDPE specimens were also studied. The TPRS and cotton fibre, TPRS and LDPE, TPRS and LDPE/MAPE and TPRS LDPE/VTMS samples were analyzed for tensile and morphological properties. The results showed that the incorporation of either cotton fibre or LDPE into the TPRS matrix caused considerable improvement of tensile strength and young's modulus. Moreover, water absorption of the TPRS samples was clearly reduced by the inclusion of cotton fibre or LDPE.

Majeed *et al.* (2014) investigated the effect of nanoclay [montmorillonite (MMT)] on the mechanical, O_2barrier, and thermal properties of LDPE/RH composite films.XRD patterns revealed the formation of intercalated nanocomposites, confirmed byincrease in the interlayer spacing and substantial reduction in the peak intensity ofMMT. Further, MMT loading did not alter the adhesion features between RH and LDPE,as confirmed by SEM.Tensile and tear properties improved with the addition of MMTand the maximum improvement of 8%in tensile strength and 5% in tear strength wasobserved at 3 wt%MMT. Theunique combination

of O_2 barrier, biodegradation, and mechanical properties for thehybrid filler-filled composite films showed that these hybrid nanocomposite films arepotential candidates for a variety of food packaging.

In another study by Alabi (2011), a comparative analysis of biocomposites from Kenaf and Roselle fibres in virgin and recycled low density polyethylene matrix showed that composites used in packaging industries can be produced from the fibres. The incorporation of these fibres led to increase in moisture absorption of samples while the tensile strength decreases. The result also ascertains the inferiority of recycle plastics when compared to virgin plastics.

2.1.1.3*Functions of a matrix*

In a composite material, the matrix material serves to hold the fibres together, protects the fibres from environment and also distributes the loads evenly between fibres so that all fibres are subjected to the same level of strain. However, it enhances transverse properties of a laminate, improves impact and fracture resistance of a component. It also helps to avoid propagation of crack growth through the fibres by providing alternate failure path along the interface between the fibres and the matrix (Pandey, 2004).

2.1.1.4*Reinforcement*

It is the reinforcement material which basically gives strength, stiffness and other mechanical properties to the composite material.There are a number of reinforcement materials and the selection is based upon the properties to be imparted to the end product.They can come generally in the form of fibres, fabric particles or whiskers. Fibres areessentiallycharacterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibres (Pandey, 2004).

I. Fibre reinforcement: Fibres are the most important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired.

Fibres fall short of ideal performance due to several factors. The performance of a fibre composite is judged by its length, shape, orientation, composition and the mechanical properties of the matrix (Nissen *et al.,* 1985).

The orientation of the fibre in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal direction of fibre. (This doesn't mean the longitudinal fibres can take the same quantum of load irrespective of the direction in which it is applied). Optimum performance from longitudinal fibres can be obtainedif the load isapplied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite (Ahagon *et al.,* 1990).

Basically organic and inorganic fibresare used to reinforce composite materials. Almost all organic fibres have low density, flexibility, and elasticity. Inorganic fibres are of high modulus, high thermal stabilityandpossess greater rigidity than organic fibres (Ahagon *et al.,* 1990).

II. Whiskers reinforcement: Single crystals grown with nearly zero defects are termed whiskers. They are usually discontinuous and short fibres of different cross sections made from several materials like graphite, silicon carbide, copper, iron etc. Whiskers diameter ranges from 0.1 to 1μm, and is thus an order of magnitude below that of ordinary fibres. Their length reaches 0.1-1mm. Whiskers differ from particles in that, whiskers have a definite length to width ratio greater than one. Whiskers can have extraordinary strengths up to 7000 MPa (Mahfuz *et al.,* 2004).Whiskers were grown quite incidentally in laboratories for the first time, while nature has some geological structures that can be described as whiskers. Initially, their usefulness was overlooked

as they were dismissed as incidental by-products of other structure. However, study on crystal structures and growth in metals sparked off an interest in them, so also the study of defects that affect the strength of materials, they came to be incorporated in composites using several methods, including power metallurgy and slip-casting techniques (Mahfuz *et al.*, 2004).

Metal-whisker combination, which strengthening the system at high temperatures, has been demonstrated at the laboratory level. But whiskers are fine, small sized materials not easy to handle and this comes in the way of incorporating them into engineering materials to come out with a superior quality composite system (Mahfuz *et al.*, 2004).

Early research has shown that whisker strength variesinversely with effective diameter. When whiskers of diameterupto 2 to 10μm were embedded in matrices,they yielded fairly good composites (Mahfuz *et al.*, 2004).

Ceramic whiskers have high moduli, usefulstrengths and low densities. Specific strength and specific modulus are very high and this makes ceramic whiskers suitable for low weight structure composites. They also resist temperature, mechanical damage and oxidation more responsively than metallic whiskers, which are denser than ceramic whiskers. However, they are not commercially viable because they are damaged while handling (Nabi and Jog, 1999).

2.2 Classification of Composites

Most composite materials developed have been fabricated to improve the physical and mechanical properties of the resulting composites. However, composite materials may be broadly classified into natural and synthetic composite materials. Figure 2.1 schematically shows the classification of composite materials.

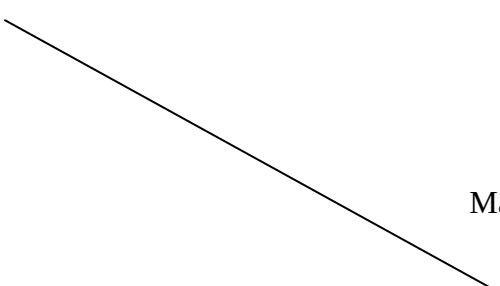


Figure 2.1: Classification of Composite Materials (Mohanty*et al.,* 2005)

2.2.1 Synthetic composite material

Synthetic composite materials are generally prepared by taking the ingredients constituents separately and physically combining them by different techniques (Bledzki*et al.,* 1999). Two ingredients may be composed as:

(i) Layered composition in which layers of ingredient materials are bonded to one another.

(ii) Phase composition in which one ingredient is introduced into the other ingredient. The phase that receives the introduced ingredient in the phase composition is the continuous phase and iscalled matrix.

The purpose of adding the ingredient is generally to improve the mechanical properties of the matrix or to make it cost effective. If the insert is added to improve the mechanical properties, it is called reinforcement but if added to make it cost-effective or to change a property other than mechanical properties, it is called filler (Jochen *et al.,* 2002).

2.2.2 Fibrous composite

Fibres have no direct engineering application because of their small cross sectional dimension. They are therefore embedded in the matrix materials to form fibrous composites (Bhagwan *et al.,* 2006). Fibre reinforcement materials basically give strength, stiffness and other mechanical properties to the composite material. Hence, the use of fibres as reinforcing materials in fibre-reinforced plastics has beenwidely accepted as materials for structural and nonstructural applications (Liu *et al.,* 2011).

2.2.2.1*Hybrid composites*

The word "hybrid" is of Greek–Latin origin and can be found in numerous scientific fields. In the case of polymer composites, hybrid composites are either systems in which onekind of reinforcing material is incorporated in a mixture of different matrices (Thwe and Liao, 2003), or two or more reinforcing and filling materials are present in a single matrix (Fu, Xu, and Mai, 2002; KargerKocsis, 2000) or both. The incorporation of two or more lignocellulosic fibres into a single matrix has led to development of hybrid composites. The behaviour of hybrid composites is a weighed sum of the individual components in which there is more favourable balance between the inherent advantages and disadvantages. While using a hybrid composite that contains two or more types of fibre, the advantages of one type of fibre could complement what is lacking in the other. As a consequence, a balance in cost and performance could be achieved (John *et al.*, 2008). The strength of hybrid composites is dependent on the properties of fibre, the aspect ratio, fibre content, length of individual fibre, orientation of fibre, extent of intermingling of fibres, fibre to matrix interface bonding and arrangement of both the fibres and also on failure strain of individual fibres. Maximum hybrid results are obtained when the fibres are highly strain compatible (Sreekala *et al.*,2002).

The selection of the components that make up the hybrid composite is determined by the purpose of hybridization, requirements imposed on the material or the design and

construction method. The problem of selecting the type of compatible fibres and the level of their properties is of prime importance when designing and producing hybrid composites (John *et al.,* 2008). Much has being done on blending of two fibres to achieve the best utilization of the positive attributes of one fibre and to reduce its negative attributes as far as practicable. Some other reasons for blending natural fibres are to impart imagine effect, reduce cost of the end product, and find out suitable admixture of natural origin to mitigate the gap between demand and supply (Basu and Roy, 2007).

Hybridization of natural fibres provides a method for improving their mechanical properties and applications. A more efficient way to enhance properties ofthese composites is to combine distinct fibres, i.e., to produce a hybrid composite, so that their individual characteristics may be transferred to the final composite, creating a material with desirable properties and wide range of applications.

Ramanpreet Singh *et al.* (2014) investigated the flexural behaviour of hybrid natural fibre reinforced composites in which composites based on recycled high density polyethylene (RHDPE) and natural fibres were developed. The results showed that the maximum Flexural Strength and maximum Specific Flexural strength were obtained from the sample having 20% Sisal fibre + 5% hemp fibre as reinforcement with HDPE as a matrix.

Babuk*et al.*(2014) in their work "Fabrication and Analysis of Hybrid Polymer Green Composite" synthesize hybrid polymer by mixing Cashew Nut Shell extract with general purpose resin in different proportions. It was concluded that the strength of the composite is compromised at the cost of bio-degradation. Sivaraj *et al.*(2014) made a systematic approach to evaluate the effect of process parameters on tensile, flexural and impact strength of coir and bagasse fibre reinforced polyester-based hybrid composites.

Aminu *et al.*(2014) in their work "Effect of chemical modification on mechanical properties of Luffa Gourd, Dum Palm and Baobab Bark Fibre reinforced polyester composites" in

which Baobab fibre composite respond better to chemical treatment and has higher impact strength and extension at break at 5% alkali treatment.

Thimmana *et al.* (2014) used sisal/jute/hemp fibrein their work "A Wear Study on Hybrid Natural Fibre Polymer Composite Materials Used as Orthopaedic Implants". It was found that there was 36% improvement in tribological properties of the hybrid natural fibre polymer composite material when compared with 12% and 24% hybrid natural fibrepolymer composite material.

The utilization of baobab pod fibre and its hybridization with other lignocellulosic fibres in composite development was rare in conventional literatures. Although the reinforcement of baobab bark fibre in polyester was reported, the reinforcement of baobab pod fibre for low density polyethylene was not reported in conventional literature.

2.2.3 Factors influencing the performance of hybrid composites

Several factors combine to affect the properties of a hybrid composite material. How these properties are harnessed to reinforce a hybrid composite material is largely governed by three major factors. These are the fibre geometry, matrix interfaces and treatment (Paul *et al.*, 2006).

Fibre Geometry:Fibre geometry encompasses fibre orientation, packing arrangement and fibre volume fraction which are responsible for the mechanical properties of a hybrid composite (Clyne and Hull, 1996). Of these, fibre volume fraction is said to be the most important factor with most mechanical properties increasing with increase in fibre volume fraction up to a certain level. The maximum fibre volume fraction achievable is controlled by orientation and packing arrangement of fibre (Paul *et al.*, 2006).

The geometry of plant fibres is ultimately controlled by the morphology of the natural tissues and the way in which they are extracted. The 'aspect ratio' is a measure of fibre length

compared to diameter. Fibres with high aspect ratio are long and thin, whereas those with low aspect ratio, especially softwood fibres are shorter and chunky. The usual aim is to retain as much fibre length as possible, since higher aspect ratios give rise to greater reinforcement (Mitra*et al.*, 2014).

In practice however, maintaining a high fibre aspect ratio throughout the manufacturing process is difficult, and in several finished products, the fibre length is frequently short and serves only as fillers, doing little to impart true reinforcement to the composites. Research is currently looking at breaking down natural fibres to form 'cellulose nano fibres', whereby the microscopic defect that cause local stress deformations to develop within the matrix can be eliminated. A hybrid composite performance can also be improved by better alignment of the reinforcing fibres within the matrix (Maya and Sabu, 2008).

Fibre Matrix Interface:The fibre matrix interface is another vital factor that influences the performance of hybrid composite. This is because the interface serves to transfer externally applied loads to the reinforcement through shear stresses over the interface. Therefore good bonding is essential if true reinforcing function is to be provided.

The matrix has several functions in the hybrid composites. It functions as a binder for the fibre reinforcement material and it gives protection against moisture and UV-light. In general, there are three categories of binders that are used in the manufacture of hybrid composites today. These are synthetic polymers, biodegradable polymers, and natural binding substances. Synthetic polymers are the most commonly used binders today, owing to the fact that early research was focused on replacing the synthetic fibres only and not the binders. Both thermosetting resins and thermoplastics have been used as matrix materials. Composites with thermosets are usually stronger, while those with thermoplastics provide greater freedom for complex design shapes (Begum and Islam, 2013).

Treatment of Fibres: One of the major drawbacks associated with the use of natural fibres in composites is their high hydrophilic nature leading to low mechanical properties and delamination. The reduction in mechanical properties may be due to poor interfacial bonding between resin matrices and fibres. Therefore, there is need to modify the fibre surface to make it more hydrophobic and well-suited with resin matrices (Abdelmouleh *et al.,* 2004). To surmount the problems, a surface treatment or compatible agents need to be applied prior to composite fabrication. These treatments (both chemical and biological) help in improving the mechanical properties of the fibre and hence making it more hydrophobic (Munawar *et al.*, 2007).

Rout *et al.* (2009) studied the effect of 2% alkali treatment on coir fibre-polyester composites and reported considerable improvement in tensile properties.Mishra *et al.* (2002) examined the chemical resistance of the treated and untreated cellulose fibres when reinforced in unsaturated polyester resin. Improved fibre matrix adhesion and higher moisture resistance properties were reported for the treated fibre composites.

2.3Natural Fibres

As mentioned earlier, natural fibres covers a broad range of vegetable, animal and mineral fibres. However, in the composite industry, it usually refers to wood fibre and agro based bast, leaf, seed and stem fibres. These fibres often contribute greatly to the structural performance of the plant and when used in plastic composites, can provide significant reinforcement.

The major steps in producing natural fibres for use in plastic include harvesting of fibre bearing plants, extraction of fibres and processing of the extracted fibres to meet required purity and performance aspect for use in hybrid composite.

A major drawback of the use of natural fibre is the lower processing temperature permissible due to the possibility of lignocellulosic degradation or of volatile emissions that could affect composite properties. The processing temperature is thus limited to about 200^{o}C although it is possible to use higher temperature for shorter periods (Jayaraman, 2003). This limit the type of thermoplastics that can be used with natural fibres to commodity thermoplastics such as polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), and Polystyrene (PS) (Anandjiwala*et al.,* 1997).

Another drawback of utilizing natural fibre is its high hydroxyl content from cellulose which makes it susceptible to absorb water and consequently affects the mechanical properties of composites adversely (Alamri and Low, 2012). As mentioned by Ray and Rout (2012), this is the natural behaviour of hydrophilic fibres. It also explained that water molecules will tend to attract to hydrophilic groups of fibres and reacts with hydroxyl group (-OH) of the cellulose molecules to form hydrogen bonds.

The moisture absorption of the fibres can be dramatically reduced through chemical modification of some of the hydroxyl groups present in the fibre but this is associated with some increase in the cost of the fibre. Good fibre matrix bonding can also decrease the rate and amount of water absorbed by the composite (Kabir *et al.*, 2012).

However, based on present evidence, it appears that to match the performance and consistency offered by existing reinforcement materials (such as glass), natural fibres may well have to be treated with coatings, which might militate against easy recycling of the base fibre. Automobile companies have studied many materials and have used animal hairs and fibres from flax, sisal, coconut and cotton in upholstery, door panels and rear shelves of cars (Jeyanthi and Janci, 2012).

2.3.1 Advantages of natural fibres

Natural fibres, as reinforcement, have recently attracted the attention of researchers over other established materials. They are environmentally friendly, biodegradable, available, renewable and cheap and have low density. Plant fibres are light compared to glass, carbon and aramid fibres. The biodegradability of plant fibres can contribute to a healthy ecosystem while their low cost and high performance fulfils the economic interest of industry (Prakash*et al.,* 2013). When natural fibre-reinforced plastics are subjected, at the end of their life cycle, to combustion process or landfill, the released amount of CO_2 is neutral with respect to the assimilated amount during their growth. The abrasive nature of the fibre is much lower, which leads to advantages in regard to technical processing and recycling of the composite materials in general. Natural fibre reinforced plastics, using biodegradable polymers as matrices, are the most environmental friendly materials, which can be decomposed at the end of their life cycle (Prachayawarakorn *et al.,* 2010).

Natural fibre composites are used in place of glass mostly in non-structural applications. A number of automotive components previously made with glass fibre composites are now being manufactured using environmentally friendly composites (Seki. 2009).

2.3.2 Disadvantages of natural fibres

Natural fibres and their composites are environmental friendly and renewable (unlike traditional sources of energy, such as coal, oil and gas), these have several bottlenecks. They have poor wetability, incompatibility with some polymeric matrices and high moisture absorption. Composite materials made with the use of unmodified plant fibres frequently exhibit unsatisfactory mechanical properties. To overcome this, in many cases, a surface treatment or compatibilizing agents need to be used prior to composite fabrication. The properties can be improved both by physical treatments (cold plasma treatment and corona treatment) and chemical treatments (maleic anhydride, organosilanes, isocyanates, sodium hydroxide, permanganate and peroxide). Mechanical properties of natural fibres are much

lower than those of glass fibres but their specific properties, especially stiffness, are comparable to the glass fibres.

The performance of hybrid composites depends on the properties of the natural fibres used in them. However, using natural fibres in building materials has also some disadvantages such as low modulus of elasticity, decomposition in alkaline environments or in biological attack, and variability in mechanical and physical properties (Ayrilmis*et al.*, 2011). To understand these problems, it is necessary to study the properties of natural fibres intensively. Generally, cell wall polymers and their matrices are the reason for chemical and physical properties of natural fibres. For instance, dimensional stability, flammability, biodegradability and degradationare attributed to acids, bases and UV radiation that alters the composites back into their basic building blocks (carbon dioxide and water). However, the properties of natural fibres that result from the chemistry of the cell wall components make some main problems in hybrid composites. Therefore, to address these problems, improving the natural fibre properties by modifying the basic chemistry of the cell wall polymers has been recommended (Verma*et al.*, 2013).

2.3.3 Chemical treatment of fibres

The major problem of natural fibre composites originate from the hydrophilic nature of the fibre and hydrophobic nature of thematrix. The inherent incompatibility between these two phases results in weakening the bonding at their interface. Chemical treatments onreinforcing fibre can reduce its hydrophilic tendency and thus improve compatibility with the matrix (Kabir *et al.*, 2012). Several research activities have been conducted to improve fibre adhesion propertieswith the matrix through chemical treatments.

Selective removal of non cellulosic content was the main objective of chemical treatment of fibres. Both the hemicelluloses and lignin content plays an important role in fibre bundle

integration, fibre bundle strength and individual fibre strength as well as water absorbency, swelling, elasticity and wet strength. The production of individual fibre without the generation of twist bands will generate fibre with higher intrinsic fibre strength which is very useful for composite application (Alabi, 2011).

Studies have shown the influence of various type of chemical modification on the performance of natural fibre and fibre reinforced composites. The different surface chemical modifications of natural fibre such as mercerization, isocyanate treatment, acrylation, latex coating, permanganate treatment, acetylation, silane treatment and peroxide treatment with various coupling agents and others, have achieved various levels of success in improving fibre strength, fibre fitness and fibre matrix adhesion in natural fibres composites (Bei, 2004).

2.3.3.1*Mercerization (alkali treatment)*

Alkali treatment of cellulosic fibres, also called mercerization, is the normal method to produce high quality fibres. Alkali treatment improves the fibre matrix adhesion due to the removal of natural and artificial impurities.In addition, alkali treatment leads to fibrillation which causes the breaking down of the composite fibre bundle into smaller fibres. In other words, alkali treatment reduces fibre diameter and hence increases the aspect ratio. Therefore, the development of a rough surface topography and enhancement in aspect ratio offer better fibre matrix interface adhesion and increase in mechanical properties (Li *et al.*, 2007).

The following reaction takes place as a result of alkali treatment according to Joseph *et al.*(2000).

$$\text{Fibre-OH}_{(S)} + \text{NaOH}_{(aq)} \longrightarrow \text{Fibre-O-Na}^{+}_{(S)} + \text{H}_2\text{O}_{(L)} \qquad (2.1)$$

Several other studies were conducted on alkali treatment (Mishra *et al.*, 2002; Joseph *et al.*, 2000). It was reported that mercerization led to the increase in the amount of amorphous

cellulose at the expense of crystalline cellulose and the removal of hydrogen bonding in the network structure.

2.3.3.2 *Silane treatment*

Silane is a chemical compound with a chemical formula SiH4. Silanes are used as coupling agents to let natural fibres adhere to the polymer matrix, stabilizing the composite material. Silane coupling agents may reduce the number of cellulose hydroxyl groups in the fibre matrix interface. In the presence of moisture, hydrolysable alkoxy groups lead to the formation of silanols. The silanol then reacts with the hydroxyl group of the fibre, forming stable covalent bonds to the cell wall that are chemisorbed onto the fibre surface (See Figure 2.2) (Xi *et al.*,2010). Therefore, the hydrocarbon chains provided by the application of silane restrain the swelling of the fibre by creating a cross linked network due to covalent bonding between the matrix and the fibre (Li *et al.,* 2007).

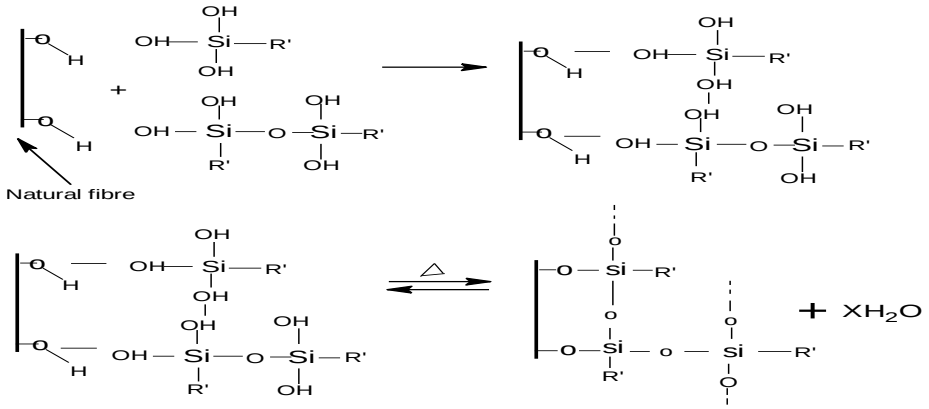


Figure 2.2: Interaction of Silane with Natural Fibres by Chemical Grafting **(**Li *et al.,* 2007).

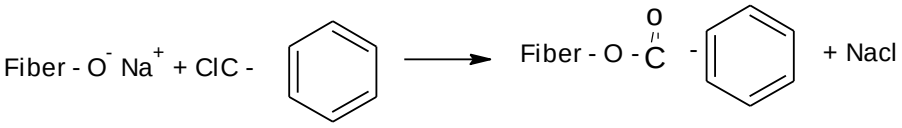
2.3.3.3 *Benzoylation*

In benzoylation treatment, benzoyl chloride is used to decrease hydrophilic nature of the fibre and improves interfacial adhesion, thereby increasing strength of the composite. It also enhances thermal stability of the fibre (Li *et al.,* 2007). During benzoylation treatment alkali

pre-treatment is used. At this stage, extractable materials such as lignin, waxes and oil covering materials are removed and more reactive hydroxyl (OH) groups are exposed on the fibre surface, then the fibres are treated with benzoyl chloride. The OH groups of the fibre are further replaced by benzoyl group and attached on the cellulose backbone. This results in more hydrophobic nature of the fibre and improves adhesion with the matrix. Joseph *et al.* (2000) studied the benzoylation treatment on the surface of fibres. A fixed amount of washed fibre (35g) was soaked in 18% NaOH solution for 0.5h, filtered and washed with water. The treated fibre was suspended in 10% NaOH solution and agitated with 50ml benzoyl chloride.

The reaction between the cellulosic -OH group of sisal fibre and benzoyl chloride is shown in equation (2.2) and (2.3)below according to (Joseph *et al.,* 2000).

$$Fibre - OH_{(s)} + NaOH_{(aq)} \rightarrow FibreO\text{-}Na^{+}_{(s)} + H_2O_{(L)} \quad (2.2)$$



2.3

(2.3)

2.3.3.4Peroxide treatment

Interface properties of fibre and matrix can be improved by peroxide treatment. The peroxide inducegrafting of polyethylene onto the fibre surface. Additionally, peroxide initiated free radicals react with the hydroxyl group of the fibre and with the matrix. As a result, good fibre matrix adhesion along the interface occurs. This treatment also reduces moisture absorption tendency by the fibre and improves thermal stability (Wang *et al.,* 2007). Sapieha *et al.* (1990) indicated that pre-treatment of fibre by benzoyl or dicumyl peroxide showed higher mechanical properties of the composites. The mechanism of peroxide treatment involves alkali pre-treatment on the fibre then coated with benzoyl peroxide or dicumyl peroxide (around 6% concentration) in acetone solution for 30 mins. Complete decomposition of peroxide can be achieved by heating the solution at higher temperature (Li *et al.,* 2007).

Joseph *et al.* (2000) investigated optimum concentration of benzoyl peroxide (6%) and dicumyl peroxide (4%) treatments on short sisal fibre reinforced polyethylene composites and reported improved tensile strength properties. The reaction between the cellulosic -OH group of the fibre and decomposition of the peroxides is given in Equation 2.4 and 2.5 respectively (Sreekala *et al.,* 2000).

$$RO\text{-}OR \longrightarrow 2RO \qquad (2.4)$$

$$RO + Cellulose - H \longrightarrow R - OH + Cellulose \qquad (2.5)$$

R= peroxide functional group

2.3.3.5*Other chemical treatment methods*

Several interface modification method were reported in literature. Acetylation of natural fibre is a well known esterification method to introduce plasticization to cellulosic fibres. Acetyl group (CH_3CO) reacts with the hydrophilic hydroxyl groups (OH) of the fibre and remove the moisture. As a result, hydrophilic nature of the fibre is decreased and improves dimensional stability of the composites (Sreekala *et al.,* 2000). Moreover, this treatment provides rough surface topography with less number of void contents that give better mechanical interlocking with the matrix (Tserki *et al.,* 2005). Rowell *et al.* (1996) investigated acetic anhydride treatment on different types of natural fibres to analyze the effects of equilibrium moisture content and reported improved moisture resistance properties. This was due to the removal of hemicellulose and lignin constituents from the treated fibre.

Another effective method of surface chemical modification of natural fibres is the Isocyanate, which works as a coupling agent for fibre surface modification. The functional group (-N=C=O) of isocyanate reacts with the hydroxyl groups of cellulose and lignin constituents of

the fibres and therefore a urethane linkage is formed. This chemical linkage provides strong covalent bonds between the fibre and matrix (Kaliaa *et al.,* 2009).

Permanganate treatment on natural fibres was another method carried out to improve the bonding at the fibre polymer surface. It requires the use of potassium permanganate ($KMnO_4$) in acetone solution. This treatment makes highly reactive permanganate (Mn^{3+}) ions that react with the cellulose hydroxyl groups to form cellulose manganate for initiating graft copolymerization. This treatment enhances chemical interlocking at the interface and provides better adhesion with the matrix (Rahmann *et al.,* 2007).

Paul *et al.*(2010) reported that during an oxidation reaction,$KMnO_4$ etches the fibre surface and makes it physically rougher to improve mechanical interlocking with the matrix. Flexural strength and modulus properties were increased by 5% and 10% for the treated banana fibre polypropylene composites.

Li *et al.*(2007) reported higher tensile strength properties for acrylic acid treated flax fibre HDPE composites. This also resulted to reduced hydrophilic tendency of the fibre. Patel and Parsania. (2010) studied acrylation on an alkali pre-treated jute fibre reinforced in epoxy-phenolic matrix and reported increased composites tensile and flexural strength by 42.2% and 13.9% respectively.

2.3.4 Baobab and sisal fibres

Many fibres grown in the tropics are used to produce a wide range of materials. Apart from being sources of fibres, sisal and baobab are used locally as source of ropes. Baobab and sisal have been found to be among the species of fibre crops that can grow in temperate regions of the world.

2.3.4.1*Baobab fibre*

Baobab fibre is obtained from the pod and bark of the tree *Adansonia digitata*. Apart from being source of fibre, the fruit pulp, seeds, leaves, bark and root tubers have been studied by scientists for their useful properties. They all have interesting possibilities for use in pharmaceutical, nutritional, cosmetic and veterinary items (Joerg and Mathias, 2005).

Adansonia digitataL. (Bombacaceae family) is a native deciduous tree from the African savannas. The English common name is baobab, probably derived from the Arabic bu hibab, which means "fruit with several seeds". There are many different local names used in southern Africa: Umkhomo and Muuju in Zimbabwe; Muuyu, Mbuyu, Mkulukumba, Mlambe in Zambia (Kurebgaseka, 2005).

It is characterized by an unusual swollen, relatively short, bottle shaped trunk (about 15m in height) in which spongy fibres store water for the dry season. For this reason, it is also called "bottle tree". The matured circumference can exceed 20m; the diameter at chest height is about 10m. The crown is rounded and shows a stiff branching habit. The tree has an extensive lateral root system, which produces tubers at the end. African baobab normally lives for about 500 years, but it is believed that some trees are up to 5000 years old.

Because of its great size and diffusion, *Adansonia digitata* is an extremely impressive tree. It symbolizes the African savannah better than any other plant. Its spongy wood does not burn; therefore the plant is protected from fire. Hollowed out baobab trunks in the vicinity of villages are used for water storage.

In areas where the baobab tree grows, there are traditions that prohibit communities from cutting down the baobab tree and any other fruit bearing trees. Where there has been

extensive deforestation, only baobab and other fruit trees remain standing (Kurebgaseka, 2005).

Baobab fibre have been commonly used in Nigeria by local farmers for making several materials such as rope, basket nets, snares, fishing lines and is even used for weaving. Fibres are also available from disintegrated wood and have been used for packing. Baobab fibres, even though available locally, are presently underutilized in Nigeria due to lack of good marketing system and poor processing (Sidibé and Williams, 2002).Plate 1 shows the pictorial view of baobab pod, open pod and the extracted baobab fibres.

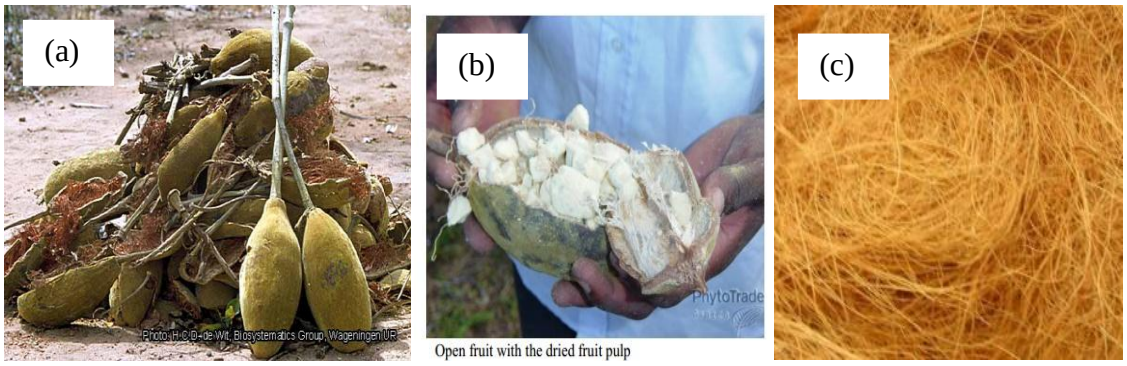


Plate 1: (a) Baobab pod (b) Open pod and (c) Baobab Fibres (Joerg and Mathias, 2005)

2.3.4.2 *Physical properties of baobab fibre*

The mechanical and physical properties of natural fibres vary considerably depending on the chemical and structural composition, fibre type and growth conditions. Baobab fibre as an emerging bio fibre predominantly used in making ropes, string, cord for musical instruments and water proof hat, due to some promising characteristics combined with certain limitations. Like other natural fibres, baobab fibres are lignocellulosic fibres with high percentage extension at break and low density of 5.3% and 1.40 g/cm^3 respectively compared to other natural fibres (Modibbo *et al.*, 2009).

2.3.4.3*Sisal fibres*

Sisal fibre is obtained from the leaves of the plant Agave sisalana, which originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia (Nilsson, 1975; Mattoso *et al.,* 1997). It is grouped under the broad heading of the "hard fibres" among which sisal is placed second to manila in durability and strength (Weindling, 1947). The name "sisal" comes from a harbor town in Yucatan, Maya, Mexico (Nilsson, 1975) and means cold water. Agave plants were grown by the Maya Indians before the arrival of the Europeans.They prepared the fibres by hand and used it for ropes, carpets and clothing. Some clothes were called "nequen", and this is where the present name of Mexican agave, henequen, probably originates.

Global production of sisal fibre in 2013 was two hundred and eighty one thousand tonnes (281 thousand tonnes) of which Brazil, the largest producing country, with one hundred and fifty thousand, five hundred and eighty four tonnes (150,584 tonnes) (www.fao.org). It is one of the most extensively cultivated hard fibres in the world and it accounts for half the total production of textile fibres (Lock, 1962; Wilson, 1971). This is due to the ease of cultivation of sisal plants, which have short renewing times, and is fairly easy to grow in all kinds of environments. A good sisal plant yields about 200 leaves with each leaf having a mass composition of 4% fibre, 0.75% cuticle, 8% other dry matter and 87.25% moisture. Thus a normal leaf weighing about 600g yields about 3% by weight of fibre with each leaf containing about 1000 fibres (Kallapur, 1962). The fibreis extracted from the leaf by retting, scraping or retting followed by scraping or mechanical means using decorticators (Grisha *et al.,* 2012). The diameter of the fibre varies from 100 µm to 300 µm (Mukherjee and Satyanarayana, 1984).

Among different natural fibres, sisal fibres are prominent reinforcing material in fabrication of different types of polymer based composites, due to cost effectiveness, high strength, etc. Sisalfibre have good tensile strength (300-500 MPa) compared with other natural fibres (Cheung*et al.,* 2009). Plate II is a pictorial view of sisal plant and extracted fibres from the leaves.



Plate II: (a) Sisal Plant (b) Sisal Fibre (Grisha *et al.,* 2012).

2.4.4.4*Physical properties of sisal fibre*

Plant-based natural fibres are lignocellulosic in nature. As stated by (Sujan *et al.*, 2013), the specific properties of natural fibres (such as high-stiffness, high-strength, and low-density as compared to synthetic fibres) make the material highly desirable in primary and secondary structures (Cheung*et al.,* 2009). Its mechanical properties are determined by the cellulose content and low micro fibril angles. A high cellulose content and low micro fibril angle are desirable properties of a fibre to be used as reinforcement in polymer composites (Williams and Wool 2000).

The use of sisal fibre as reinforcement has grown substantially in the past decade and as such a considerably large amount of literature has been published on sisal and it uses. Sisal has some promising characteristics combined with certain limitations. As other natural fibres, sisal fibres are lignocellulosic fibres, hence their hydrophilic features and the poor bonding is

expected if sisal fibres are used as reinforcement without any modification of the fibres themselves or of the matrices used (Grisha *et al.,* 2012). Sisal fibre, among the vegetable fibres was analysed for physical properties by Ramesh*et al.,* (2013) as shown in Table 2.1.

Table 2.1 The physicalproperties of sisal fibres

Physical property	**Sisal fibre**
Density (g/cm^3)	1.41
Elongation at break (%)	6–7
Cellulose content (%)	60–65
Lignin content (%)	10–14
Tensile strength (MPa)	350–370
Young's modulus (GPa)	12.8
Diameter (mm)	0.2–0.4
Length (cm)	80-120

Source: Ramesh*et al.*, 2013.

CHAPTER THREE

3.1Materials and Methods

This chapter presents the materials, equipment and experimental procedure used in this work.

3.1.1 Materials and equipment

The materials and equipment used in this work are tabulated in Tables 3.1 and 3.2 respectively.

3.1.1.1*Materials*

Table 3.1: Materials used for the work

Material	**Purity**	**Source**
Baobab pod and Sisal fibre	Standards	NARICT, Basawa, Zaria
Low Density Polyethylene	Virgin	Chemical Vendor
Distilled water	100 %	NARICT, Basawa, Zaria
Sodium Hydroxide (NaOH)	98 %	Chemical Vendor
500 ml Beakers	Standard	NARICT, Basawa, Zaria
500 ml Measuring cylinder	Standard	NARICT, Basawa, Zaria

Table 3.2: Equipment used and their characteristic

Equipment	**Description**	**Domicile**
Weighing machine	Kern and Solm Company Berlingen Germany (Model No D72336).	National Research Institute for Chemical Technology (NARICT) Zaria.
Grinding machine	Locally fabricated	National Research Institute for Chemical Technology (NARICT) Zaria.
Two roll mill Machine	Reliable Rubber and Machinery Company North Bergen New Jersey U.S.A (Model No 5183).	College of Leather Research and Chemical Technology, Zaria
Hydraulic press	Carver Incorporation New Jersey, U.S.A Model No 12000.	College of Leather Research and Chemical Technology, Zaria
Tensile Testing Machine	Instron Machine Model 3369,(CERD) Number 3369K1781,Capacity 50kN, weight 141kg, Maximum speed	Centre for Energy Research and Development (CERD) Obafemi Awolowo University Ile-Ife Osun State.

	500mm/min, Power Requirement 100/120/220/240V, Maximum Vertical Test space 1193mm.	
Flexural Testing Machine	Universal Materials Testing Machine,Norwood Instruments Ltd. Serial Number Cat. Nr 261, 100 kN capacities.	Strength of Material Laboratory of the Department of Mechanical Engineering Ahmadu Bello University Zaria.
Impact Testing Machine	Charpy Impact Testing Machine, Capacity 15J and 25J, Serial Number 412-07-15269C, Manufactured by Norwood Instruments Limited, Great Britain.	Department of Metallurgical and Materials Engineering Ahmadu Bello University Zaria.
Hardness Testing Machine	Indente Universal Hardness Testing Machine. DIN 53505 ISO 868 ASTM D2240, Serial Number 01554, Model 5019.	Collage of Leather Research and Chemical Technology, Zaria.
Fourier Transform Infrared Spectroscopy (FT-IR)	Shimadzu machine (model:FTIR-84005) FT-IR spectrometer	National Research Institute for Chemical Technology (NARICT) Zaria.
Scanning Electron Microscope (SEM)	Phenom tm Prox scanning electron microscope	Department of Chemical Engineering laboratory Ahmadu Bello University Zaria.

3.2 Experimental methods

3.2.1 Extraction of baobab fibres

Ripe and mature baobab pods about 0.635 cm thick, 20 cm high and 10 cm in radius, were collected from baobab tree. They were mechanically sliced open with a knife. Each mature pod holds about 30 g of baobab fibre in combined state with fruit pulp. The fibres were separated from the fruit pulp by hand, which was followed by washing in a running tap water to remove the remaining pulp that gummed the fibres together. Finally the fibres were sun dried for 5 h.

3.2.2 Extraction of sisal fibres

Sisal fibre was obtained from the leaves of the plant *Agave sisalana*, The fibres were extracted from their leaves using the local extraction method known as "decortication", which involves gradual beating of the leaves with subsequent drying in an open space for five minutes enabling the gradual removal of moisture from the leave fibres. The beating is stopped when almost all the water, lignin, wax, pectin and other compounds binding the fibres together has been removed. This was followed by sun drying for about 4 hours to remove moisture from the fibres. Finally the fibres were combed in other to stretch them for better appearance.

3.2.3 Size reduction

The dried baobab fibres of about 20 g by weight were subjected to size reduction by grinding using local milling machine. The ground fibres were sieved through 1mm (1000 μm) size sieve, in order to ensure equal distribution of the fibres. The same process was used to reduce the size of sisal fibres.

3.2.4Step I: Baobab/LDPE composite preparation

The size screened baobab fibre was mixed with low density polyethylene by a way of compounding using two-roll mill. The two-roll mill machine was heated to a temperature of 120^{o}C for 30 minutes, which is the melting temperature of low density polyethylene. At the end of this period, 95 wt% of LDPE was poured into the preheated two-roll mill to melt the LDPE for about 5 minutes, followed by gradual pouring of 5 wt% baobab fibre into the melted LDPE until a complete mixing of the fibre with the matrix was achieved. Finally, the compounded baobab/LDPE was scraped from the mill to form a sheet.

Theresulted compounded sheet was press using hydraulic press. At the start, the machine was heated for 30 minutes at the set temperature of 120^{o}C. After which the compounded sample is placed inside a rectangular mould coated with aluminium foil paper. The arrange mould was taken into the preheated hydraulic press and held under a pressure of 10 kN for a period of 6 minutes. Thereafter, the samples were removed from the press and allowed to cool before removing the composite sample from the mould.

The procedure was repeated for 10 wt%, 15 wt%, 20 wt%, 25 wt% and 30 wt% of baobab fibre with the corresponding 90 wt%, 85 wt%, 80 wt%, 75 wt% and 70 wt% matrices of low density polyethylene.

3.2.5 Step II:Determination of effect of NaOH concentration on baobab fibre

In this step the outcome from step I was used to determine the effect of NaOH concentration on the properties of baobab fibre composites.

3.2.5.1*Treated baobab LDPE composite preparation*

8 g, 16 g, 24 g, 32 g, and 40 g of NaOH pellets were dissolved in 400 ml of distilled water to form 2, 4, 6, 8 and 10 wt% NaOH solution respectively; this was prepared in 500 ml beaker.

15 g of baobab fibre of 1 mm size were soaked in the prepared 2 wt% of sodium hydroxide solution to remove some of the lignin, wax, pectin and other impurities. The soaked fibres were kept on a regulated hot plate at 40°C for 20 minutes, followed by occasional turning with a glass rod to ensure an even treatment. The fibres were removed after 20 minutes and rinsed severally with distilled water until a neutral pH of 7 was attained, followed by drying in an oven at 50°C for 20 minutes. The procedure was repeated using the 4, 6, 8 and 10 wt% of sodium hydroxide for the remaining baobab fibre.

Based on the outcome from step I and the thickness of the composite to similar sample preparation methods explained earlier, the same procedure was adopted to prepare composite using baobab fibre treated with 2 wt% NaOH. The procedure was repeated using 4, 6, 8 and 10 wt% NaOH treated baobab fibres respectively.

3.2.6 Step III: Baobab/sisal LDPE hybrid composite preparation

Based on the 10 wt% fibre loading established from baobab/LDPE composite with the best mechanical property in step I, baobab and sisal fibres were weighed based on the following ratios (90:10, 80:20, 70:30, 60:40, 50:50 and 100 % sisal fibre). The calculated amounts of the various ratios were weighed and kept.

Similar sample preparation methods explained earlier for baobab/LDPE composite was employed. The hybridized fibres (90:10 baobab-sisal fibre ratios) were compounded and pressed using two-roll mill and hydraulic press machines respectively. The procedure was repeated for the other hybridized baobab:sisal fibre ratios of 80:20, 70:30, 60:40, 50:50 and 0:100 respectively.

3.2.7 Step IV:Determination of the effect of NaOH concentration on the hybrid composite

In this step, the result obtained from step IIIwas further used to determine the effect of NaOH treatment on hybrid composite.

3.2.7.1*Treated baobab/sisal LDPE composite preparation*

The same procedure used in section 3.2.5.1 was applied for the baobab and sisal fibres respectively.

Based on the 10 wt% fibres loading established earlier and the thickness of the composite to be moulded, baobab-sisal fibres treated with 2 wt% NaOH were calculated and weighed on 50:50 ratios, being the ratio at which better properties were achieved.

Similar sample preparation methods explained earlier in step I and II was followed for the compounding and pressing using two-roll mill and hydraulic press respectively. The procedure was repeated using the 4, 6, 8 and 10 wt% NaOH treated baobab-sisal fibres respectively.

3.3 Material Characterization

Three samples each were tested from the composites made of the untreated and treated baobab fibre, hybridized baobab/sisal and treated baobab/sisal fibre composites. The mean values of the properties, standard deviation and standard error were calculated respectively.

3.3.1 Tensile test

The tensile test was conducted according to ASTM D638 using the Instron universal testing machine. The dimensions, gauge length and cross-head speeds are chosen according to the ASTM D638 standard. The tensile strength was calculated by dividing the maximum load by cross sectional area of the sample. The modulus of elasticity was expressed as the ratio of the

applied stress to the resulting strain while the percentage elongation at break was expressed as percentage of change of the original length for each specimen between grips at the break.

The same procedure was followed for all the samples, the results obtained are in Appendix A, B, C and D.

3.3.2 Flexural test

Flexural strength was measured under a three-point bending approach using a universal testing machine according to ASTM D790. The dimensions and gauge length are chosen according to the ASTM D790 standard. The samples were machined into 100 x 20 x 10 mm rectangular strips.The distance between the spans was 100mm, and the strain rate was 5 mm/min.The flexural strength (MPa) was calculated by using Equation (3.1).

$$\mathrm{MOR} = \frac{3\mathrm{PS}}{2\mathrm{bt}^2} \tag{3.1}$$

S is the length of support span (measured in mm)

P is the load applied (kN)

b is the width of the specimen (measured in mm)

t is the thickness of specimen (measured in mm)

3.3.3 Impact test

The impact test was conducted according to ASTM D256 using the charpy V-notch impact testing machine. The dimensions, gauge length and V-notch were chosen according to the standard. The specimen was placed between a special holder with the notch oriented vertically and towards the origin of impact. The specimen was struck by a “tup” attached to a swinging pendulum. The specimen breaks at its notched cross-section upon impact, and the upward swing of the pendulum was used to determine the amount of energy absorbed in the process.

3.3.4 Hardness test

The hardness test was performed according to ASTM D2240 using Shore Duro-meter testing machine. The dimensions and gauge length are chosen according to the standard. The sample was cut into 25 x 25 x 10 mm square strips for the test that was performed by gradual pressing of a presser foot of diamond-tipped indenter which penetrate to a certain depth on the specimen. The hardness value depends on the depth to which the indenter penetrated the sample.

3.3.5 Water absorption test

The samples to be tested were placed in an oven at a temperature of 60^{o}C for 4 hrs. The samples were removed and placed in desiccators for 4 hrs so as to maintain a constant weight. They were removed, weighed and submerged in a 250 ml beaker containing water for 24 hrs. On expiration of the 24 hrs, the samples were taken out of the water, dried and weighed according to ASTM D570-98. The percentage water absorbed was calculated using Equation (3.2)

$$\frac{W_f - W_i}{Wi} \times 100 \qquad (3.2)$$

Where,

W_f is the weight of the sample after immersion in water.

Wi is the weight of the sample before immersion in water.

3.3.6 Fourier transforms infrared spectroscopy (FTIR)

The functional groups of the untreated and treated baobab fibres were determined using Shimadzu machine (model: FTIR-84005) FT-IR spectrometer. The samples were dried in an oven at 60ºC to remove the moisture. About 0.2 mg of the specimens were placed on a Kbr plate and inserted into the infrared barrel. The infrared spectra of these samples were measured in the transmission of a wavelength number range between 4500 and 500 cm^{-1}.

3.3.7 Scanning electron microscope (SEM) analysis of composites samples

SEM analyses were carried out using a Phenom tm Prox scanning electron microscope. To achieve this, all the samples were coated with a thin gold layer with a Quick Coater Metalizer Sanyu Electron SC-701 in order to transform the composite into conductive material. The scanning barrel was vacuumed to prevent interference of scanning picture due to the presence of air. Magnification, focus, contrast and brightness of the result were adjusted to produce the best micrographs at 50 and 200 µm.

CHAPTER FOUR

4.1 Results and Discussion

This chapter present the results and discussion of the experimental work.

4.1.1 Baobab and sisal fibres

The results obtained after the extraction of baobab and sisal fibres was presented in Table 4.1.

Table 4.1: Weight of baobab pod, sisal leave and extracted fibres.

Fibre	Initial Weight of pod and leave (g)	Weight of extracted fibre (g)
Baobab pod	60	7
Sisal plant	600	18

4.2 Physical andmechanical properties of the various composites

The analysis of the results here is to establish whether significant differences exist between the values of the mechanical properties of the various composites including water absorption as a result of variation in some parameters. The results were also discussed in relation to previous works.

4.2.1 Effect of the fibre loading on the mechanical and water absorption of untreated monolithic baobab fibre reinforced composites

4.2.1.1*Effect of fibre loading on tensile strength of the composites*

Figure 4.1 presents the results of the effect of varying fibre loading on the tensile strength of untreated baobab fibre composite; raw data is presented in Appendix A.

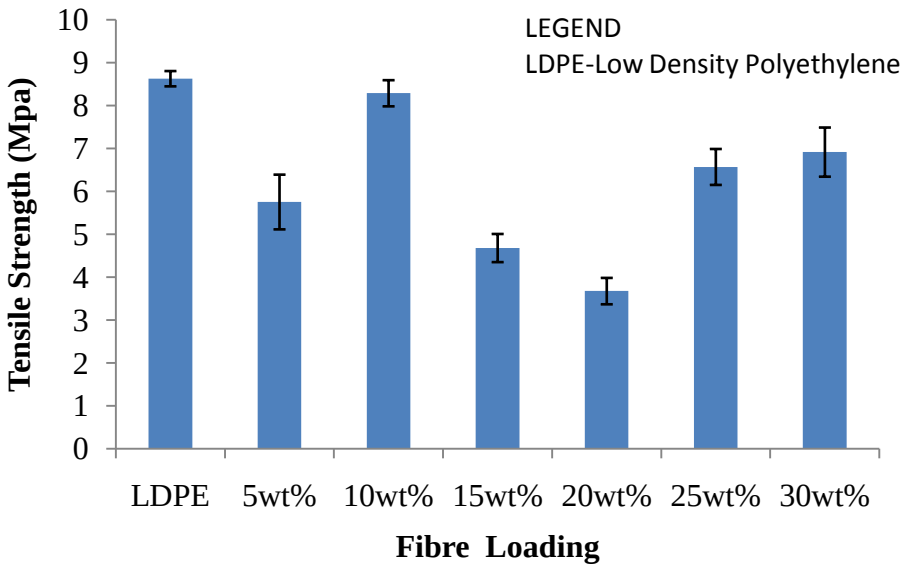


Figure 4.1: The Effect of Fibre Loading on the Tensile Strength of Untreated Baobab Fibre Reinforced Low Density Polyethylene Composite

As shown in Figure 4.1 above the unreinforced low density polyethylene (LDPE) has the highest average tensile strength, when compared to the reinforced LDPE. The decrease in the tensile strength between the reinforced and unreinforced LDPE might be due to the weak compatibility between fibre and matrix. However, 10 wt% baobab fibres reinforced LDPE had the highest tensile strength among the reinforced LDPE, which decrease on increasing the fibre loading to 15 wt% and 20 wt%. The 8.28 MPa obtained for 10 wt% was lower when compared with optimal value of 10.4 MPa for Dum palm fibre-polyester composites(Aminu*et al.*, 2014) and also less than the 9.5 MPa for luffa-polyester composite (Sunmonu *et al.*, 2014). The variation could be as a result of the differences in the strength of the fibres or matrix used in their works, because polyester is known to have higher strength than LDPE.

Also in Figure 4.1, there was increase in tensile strength from 6.5 MPa to 6.9 MPa as fibre loading increased from 25 wt% to 30 wt%. This trend may not be unconnected with fibre-fibre interaction with increase in fibre content.

Despite the differences in the values indicated in the plot, there was overlapping of the error bars of pure LDPE and LDPE reinforced with 10 wt% baobab fibre, indicating that

statistically there was no difference in their values. Also, at 25 wt% and 30 wt% overlap was found to exist between the two fibre loadings.

4.2.1.2*Effect of Fibre loading on modulus of elasticity (MOE)*

The modulus of elasticity values of baobab fibre reinforced low density polyethylene composites for different fibre loadings is shown in Figure 4.2.

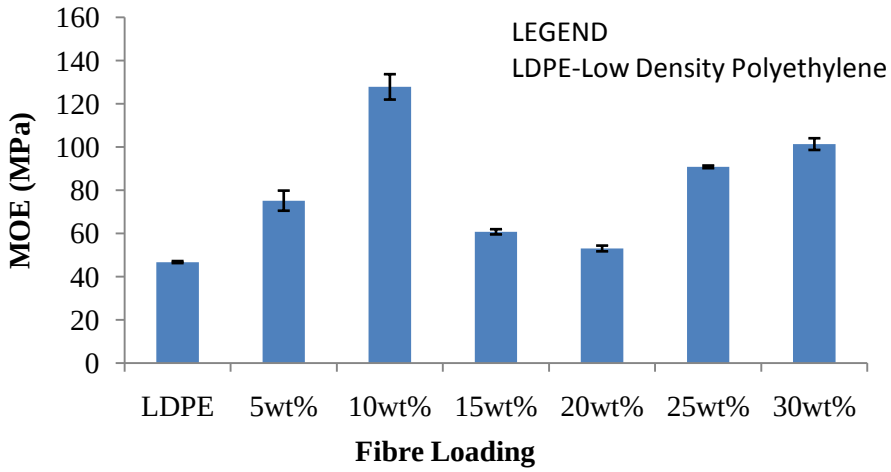


Figure 4.2: Effect of Fibre loading on Modulus of Elasticity (MOE)

The 10 wt% fibre loading exhibited the highest modulus of elasticity of 127.8 MPa. This suggests that the 10 wt% fibre loading composite exhibit higher degree of stiffness within the fibre loadings investigated. The observed increase in MOE with increase in fibre loading is consistent with Nara *et al.*(2012) were it was reported that the tensile modulus, which is an indication of load bearing capacity, increases with fibre weight fraction. At this fibre content the stiffer component of the fibre in the composite was observed, resistance towards deformation increases with increase in fibre content, which expectedly increased the stiffness of the composite. However, the drop in MOE after 10 wt% loading might be attributed to poor dispersion of fibre in the matrix at higher loading in addition to poor fibre-matrix interaction as established by Salma *et al.* (2010).

The result obtained at 10 wt% baobab fibre loading in this work was higher than the optimal MOE of 64.15 MPa for Dum-palm fibre polyester composite (Aminu *et al.,* 2014). The result was in agreement with the worksreported by Abdul *et al*. (2001) and Ismail *et al*. (2011) who showed that the incorporation of starch with coir fibre improved the stiffness of the composite materials. Hence the specific differences in the modulus of elasticity observed in the various researches could be attributed to the property differences of the matrices, weight fractions and the nature of the fibres used as corroborated by Sreekala *et al.* (2002).

The non-overlap in the error bars of the composites suggests that there was significant difference between the modulus of elasticity of the composites.

4.2.1.3*Effect of fibre loading on elongation at break of the composites*

Figure 4.3 presents the effect of fibre loading on the elongation at break of the composite.

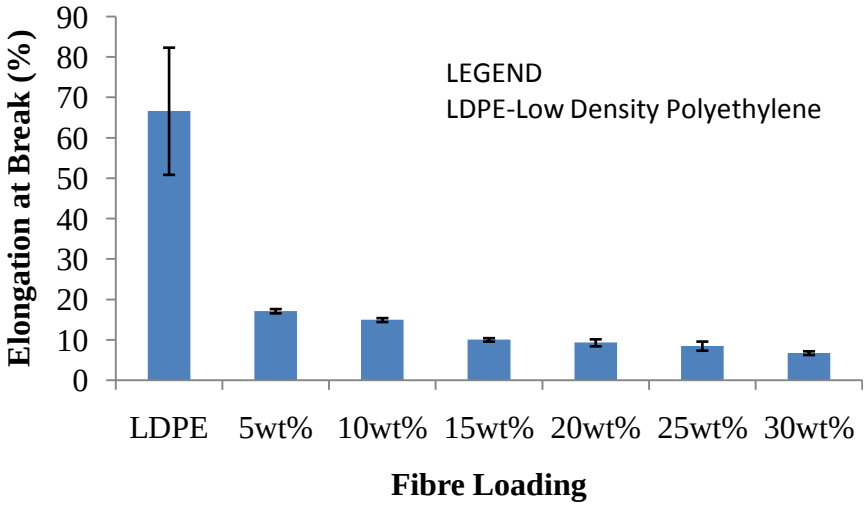


Figure 4.3: Effect of Fibre Loading on Elongation at Break of Composite.

The elongation at break of the unreinforced composites was clearly higher than any of the reinforced baobab fibre composites. As indicated inFigure 4.3, elongation at break decreased with increased in fibre loading,this indicates that the elastic nature of the LDPE decreases with the addition of the baobab fiber. The highest elongation at break of 17.13% obtained at 5 wt% baobab fibre loading was lower than 20% elongation obtained for raw saw dust-LDPE

composites according to Sultana *et al.*(2012), but higher than 1.98% and 0.94% elongations for Dum palm and luffa fibre reinforced polyester composites respectively as reported by Aminu *et al.*, (2014).

The maximum elongation at breakof 17.13%was in line withthe requirement of ASTM D638Mfor utilization in dashboard assemblies and automotive housing (Stereolithography, 2015).

The overlap in the error bar values of 20 wt% and 25 wt% fibre content suggests that there was no significant difference in the average percentage elongation at break of the individual composites.

4.2.1.4*Effect of fibre loading on impact strength of composite.*

Figure 4.4 presents the effect of fibre loading on the impact strength of the composites. The test confirmed that the composites were more brittle compare to virgin LDPE. In fact, a lower energy was required for breaking the composites materials.

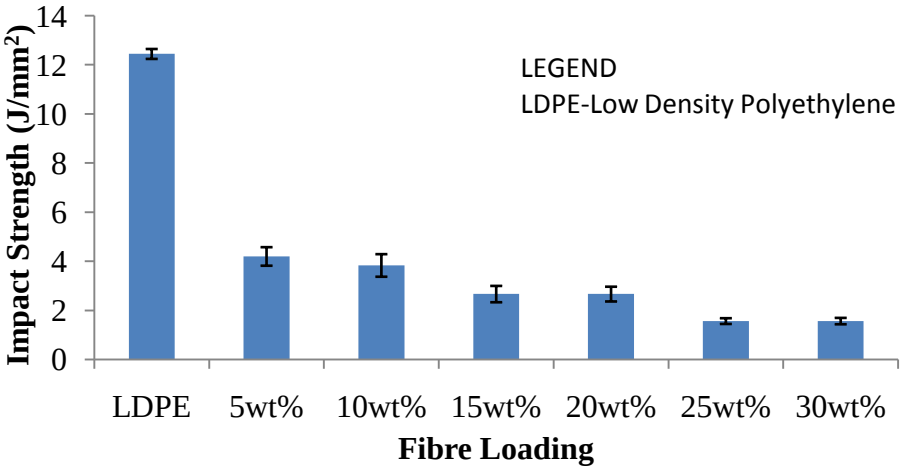


Figure 4.4: Effect of Fibre Loading on Impact Strength of Composite.

It can be seen from Figure 4.4 that the impact strength decreased with increase in fibre content, the strength decreased from 4.20 J/mm2 to 1.57 J/mm2 this showed increase in brittleness of the composite.

The highest impact strength of 4.20 J/mm^2 obtained on reinforcing with 5 wt% fibre content is low when compared favourably with the optimal value of 4.50 J/mm^2 at 5 wt% fibre loading for PALF-polyethylene composite as (Munirah *et al.*, 2007). Adil *et al.* (2010) reported 4.80 J/mm^2 at 5 wt% fibre content for palm-epoxy composite and 5.6 J/mm^2 at 5 wt% fibre loading in jute-coir fibre reinforced hybrid polypropylene composite as indicated by Sidika *et al.* (2013). These could be as a result of the difference in the strength of the fibres or the matrix used.

The overlap in the error bar between 5 wt% and 10 wt% fibre content, suggest that there was no significant difference in the impact strength of the two composites.

4.2.1.5*Effect of fibre loading on flexural strength of composite*

Figure 4.5 shows the variation of flexural strength with fibre loading.

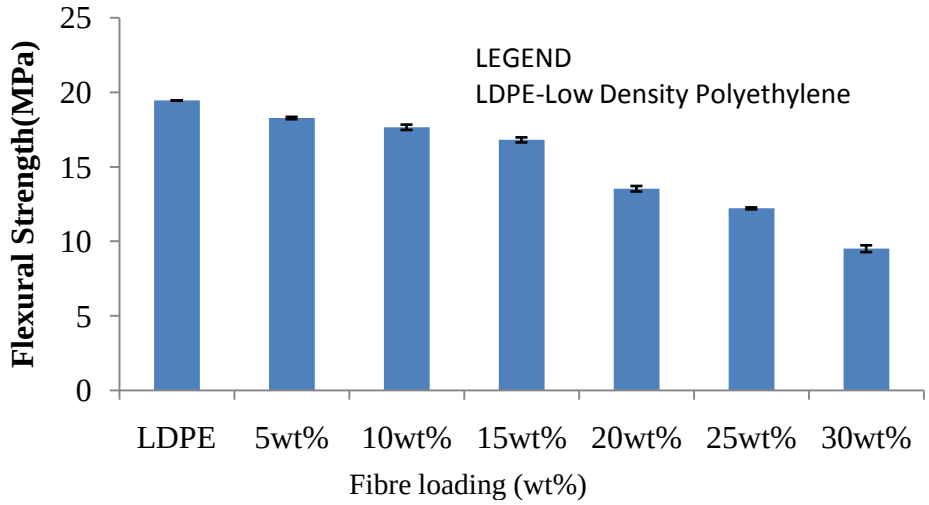


Figure 4.5: Effect of Fibre Loading on Flexural Strength of Composite.

It was observed that the unreinforced low density polyethylene has the highest flexural strength of 19.45 MPa. On reinforcement, the flexural strength decreased with increase in baobab fibre content. The reason for this drop might be based on the basis of unfavourable entanglement of the polymer chain due to weak fibre-matrix adhesion with increasing fibre content (Siddika *et al.*, 2013).

It wasobserved from Figure 4.5 that the highest values of 18.27 MPa flexural strength obtained at 5 wt% fibre loading was greater than 10.00 MPa at 5 wt% fibre loading for raw sawdust-LDPE composites but lower than 45.77 MPa for luffa fibre reinforced polyester composite as reported by Aminu *et al.*(2014) and Sultana *et al.* (2012). The nature of the reinforcement, variation on loading, fabrication, matrix type and fibre-matrix interaction could be responsible for the observed variations in the results (Sreekala *et al.*,2002). The maximum value of flexural strength (18.27 MPa) satisfied the requirement of ASTM D7032 for utilization in deck board and guardrail system.

The non-overlap in the error bars shows that there was significant difference between the flexural strengths of the composites.

4.2.1.6*Effect of fibre loading on hardness of the composite*

The result of effect of fibre loading on the hardness of the composite is presented in Figure 4.6.

15 wt% fibre content exhibit the highest average hardness strength of 86.33 shore D as compared to the other composites reinforced with 5 wt%, 10 wt%, 20 wt%, 25 wt% and 30 wt% respectively.This might be as a result of better dispersion of the fibres in the matrix with minimization of void between the matrix and the fibre as reported by Mishra *et al.* (2000).

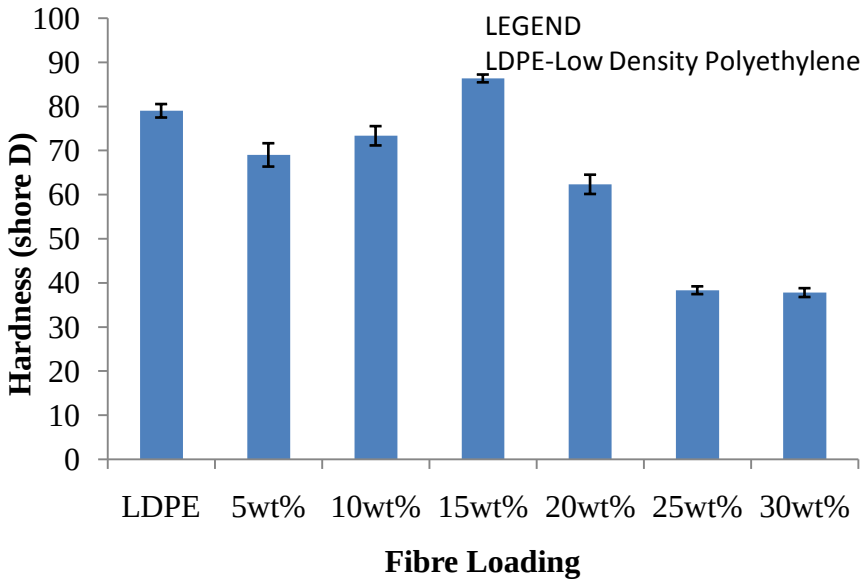


Figure 4.6: Effect of Fibre Loading on Hardness of Composite.

The highest hardness strength of 86.33 shore D obtained at 15 wt% baobab fibre loading was higher than the optimal 53.13 shore D hardness at 15 wt% for luffa fibre reinforced polyester composite reported by Sunmonu *et al.* (2014), but lower than 96.53 shore D hardness at 15 wt% for jute-coir fibrereinforced hybrid polypropylene composites as established by Salma *et al.* (2010). The maximum value of hardness (86.33shore D) satisfied the requirement of ASTM D2240for utilization in automotive housing and dash board assemblies.

The overlap in the error bars values obtained suggests that there was no significant difference in the hardness value of the composites made with 25 wt% and 30 wt% of fibre loading respectively.

4.2.1.7*Effect of fibre loading on water absorption of the composites*

The result of the effect of fibre loading on the water absorption behaviour on the composite is presented in Figure 4.7.

It can be observed that the unreinforced (virgin) low density polyethylene absorbed the minimal percentage of moisture due to it hydrophobic nature. When reinforced with the

baobab fibre, the capacity to absorb moisture increases as a result of the introduction of the hydrophilic baobab fibres.

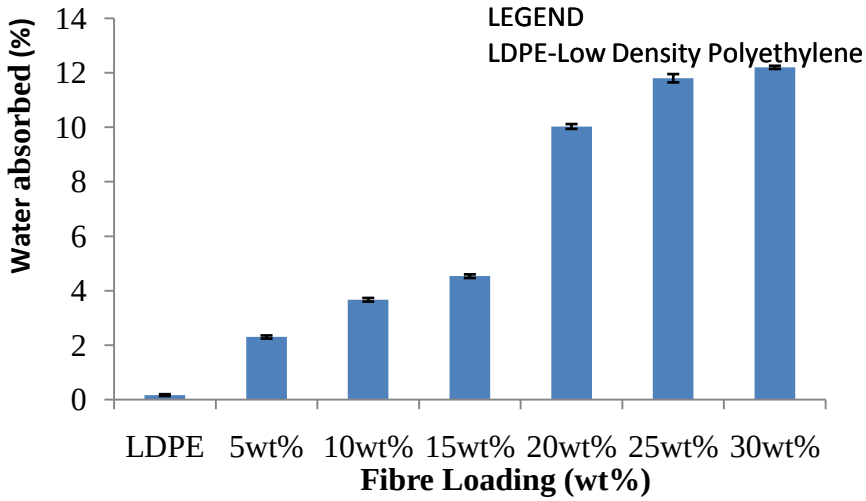


Figure 4.7: Effect of Fibre Loading on Water Absorption Capacity of Composite.

It was observed that there was an increase in the percentage water absorbed by the composite with an increase in baobab fibre content up to 30 wt% loading.Theoretically, the existence of LDPE in the composite could dramatically restrain the water absorption and reduce water sensitivity due to the hydrophobic characteristic of non-polar LDPE. However, the observed rise in water absorption capacity is highly dependent on baobab fibre content.

The minimum water intake reported for the 5 wt% fibre loading composite is five times lower than 12.20% water absorption at 30 wt% fibre loading. Incorporation of lignocellulosic fibre into polymer matrix in polymer composites generally augments the rate of water absorption ability by forming hydrogen bonding between water and hydroxyl groups of cellulose and hemicellulose in the cell wall (Cao *et al.*, 2011).Thus, the rise of water uptake is attributed to the hydrophilic nature of baobab fibre by virtue of the presence of abundant hydroxyl groups, which are available for interaction with water molecules.

It is also worth noting that, higher fibre loading content resulted in higher voids entrapped, resulting in higher water accumulation at the interface between fibre and matrix. This could

be due to low degree of adhesion between hydrophobic LDPE and hydrophilic natural fibres creating cracks and voids between them, allowing easy penetration of the moisture and storage of water in the voids (Tajeddin*et al.*, 2010).

4.2.2 Effect of NaOH treatment on the properties of baobab LDPE composites

In this section 10 wt% baobab fibre was used, at this baobab content, Tensile strength and Modulus of elasticity were highest from earlier results. The baobab fibre was treated at different concentrations of NaOH and used for the composite development.

4.2.2.1*Effect of fibre treatment on the tensile strength of baobab composite*

Figure 4.8 shows the effect of varying NaOH concentration on the tensile strength of the composite; raw data is presented in Appendix B.

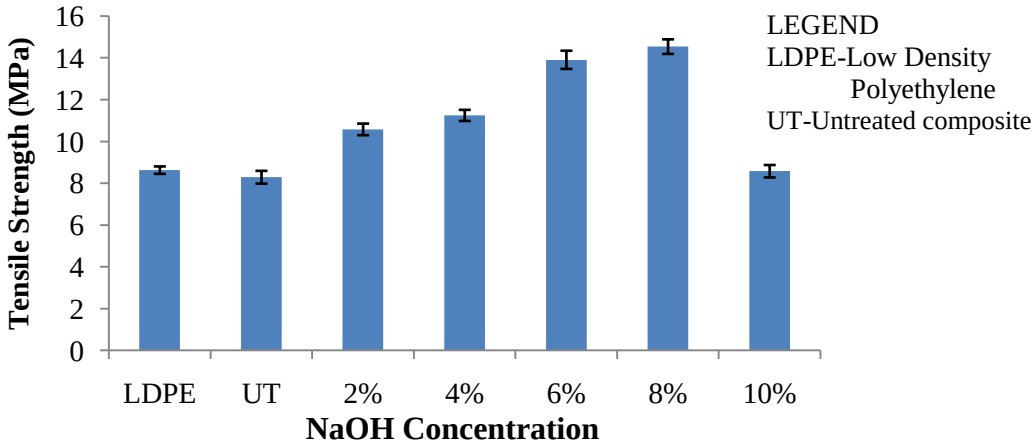


Figure 4.8: Effect of Fibre Treatment on the Tensile Strength of the Composite

As can be seen, a positive treatment effect was noticed on treating the fibre with of NaOH solution, except at 10 wt% concentration. The composite resulting from 8 wt% concentration of NaOH solution treated baobab fibre exhibited the highest tensile strength of 14.53 MPa, which was 43% higher than the untreated baobab fibre composite and also 40% higher than the tensile strength of unreinforced LDPE as shown in the figure.

The positive treatment effect observed with 2 wt%, 4 wt%, 6 wt% and 8 wt% concentrated NaOH solution may be attributed to the increased adhesion at the fibre-LDPE interface after the fibre was chemically modified (Shajan*et al.*, 2012).

The alkali treatment improves the surface adhesive characteristics by removing natural and artificial impurities, thereby producing a rough surface topography. If the alkali concentration is higher than the optimum condition, excess delignification of the fibre can take place, which results in weakening or damaging the fibres (Kabir *et al.*, 2012), as observed for the 10 wt% alkali treated fibre composites.

The highest tensile strength (14.43 MPa) at 8 wt% (NaOH) treatment obtained in this work was higher than 12 MPa at 10 wt% optimal treatment concentration reported by Shajan*et al.*, (2012) for coir reinforced polyestercomposites at 10 wt% total fibre loading. The variation in the results may be attributed to the nature of the fibres and matrix used.

The overlap in the error bars of the composites treated with 6 wt% and 8 wt% NaOH concentration suggests that there was no significant difference in the tensile strength values of the individual composites.

4.2.2.2*Effect of fibre treatment on the modulus of elasticity of baobab composite*

Figure 4.9 presents the effect of baobab fibre treatment on the MOE of the composite.

It can be observed that the highest MOE of 246 MPa was obtained for at 8 wt% NaOH treatments, while with further increase in the concentration of NaOH, to 10 wt% the MOE decreased to 153.88 MPa.

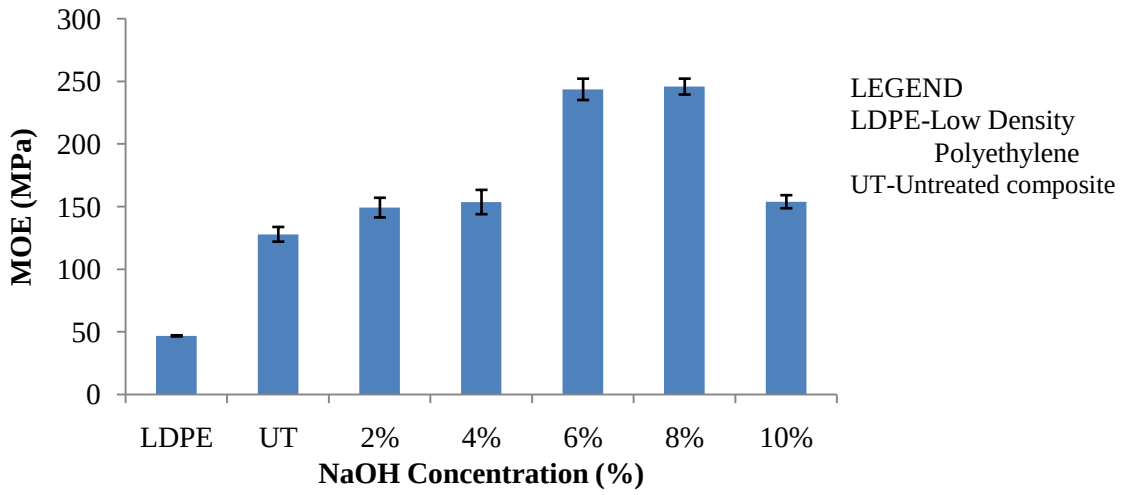


Figure 4.9: Effect of NaOH Treatment on MOE of the Baobab Fibre Composite.

An improvement of about 14%, 16%, 47%, 48% and 17% in MOE respectively were recorded with 2 wt%, 4 wt%, 6 wt%, 8 wt% and 10 wt% concentration of NaOH treated fibre composites when compared to the untreated baobab fibre reinforced composite.

The enhancement in the MOE of the alkali treated fibre reinforced composite could be attributed to the fact that alkali treatments increased the effective surface area and percentage crystallinity index of the fibres due to the removal of the natural cementing materials, which leads to a better packing of the cellulose chains, in most cases impacting positively on the mechanical properties of fibre reinforced composite (Santos *et al.*,2011).

The decreasing MOE value observed after the optimal 8 wt% concentration of NaOH may be attributed to the fibres losing their characteristics, which leads to damaged fibre surface as a result of high concentration of alkali treatment (Li *et al.,* 2007).

An optimal treatment concentration of 5 wt% NaOH was reported by Santos *et al.,* (2011) for sisal-polyester composite and 10 wt% NaOH optimal treatment condition for short sisal polyethylene composite (Joseph *et al.,* 1999). The variation in the results in comparison with the present work may be attributed to the nature of the fibres used. Since composition varies for individual fibres, it will also affect the level of treatment required for a particular fibre.

The overlap in the error bars of the composites for 2 wt% and 4 wt% NaOH treated fibres suggest that there was no significant difference in the MOE values of the individual composites.

4.2.2.3*Effect of fibre treatment on the elongation at break of baobab composite*

Figure 4.10 presents the effect of baobab fibre treatment on the elongation at break of the composite.

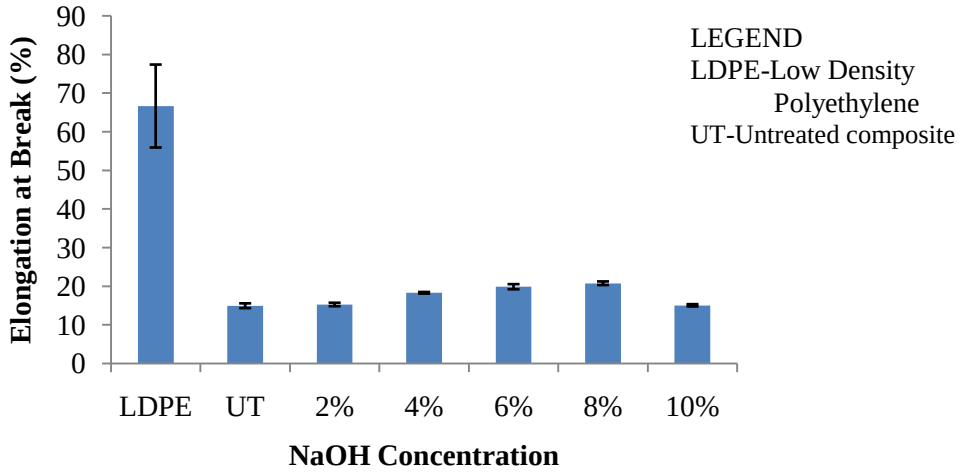


Figure 4.10: Effect of NaOH Treatment on the Elongation at Break of the Baobab Fibre Composite

A positive treatment effect can be observed on treating the fibres with 2 wt%, 4 wt%, 6 wt% and 8 wt% NaOH solution, except for the 10 wt%. The composite resulting from 8 wt% concentration of NaOH solution treated baobab fibre exhibited the highest percentage elongation at break of 20.75% corresponding to 28% increase over the untreated baobab fibre reinforced composite.

The enhanced percentage elongation on treatment was due to the fact that more hemicelluloses, lignin, wax and pectin were removed as a result of the treatment, providing a more effective surface area for contact with the matrix, as well as an increase in the percentage of crystallinity index of fibres (Santos *et al.*, 2011).

However, at very high alkali treatment concentration of 10 wt%, a decrease in the elongation at break of the composite was observed. This may be due to excess delignification of the fibres, which results in weakening or damaging the fibres (Kabir *et al.*, 2012).

An optimal (10 wt% NaOH) treatment condition was reported by Joseph *et al.* (1999) for randomly arranged sisal-polyethylene composites with 27% elongation at break, which was greater than the 20.75% elongation at break observed in this work at the 8 wt% NaOH optimum treatment condition.

The overlap in error bars of untreated fibre composites, 6 wt% and 8 wt% treated composites suggest that there was no significance difference in the elongation at break of the composites.

4.2.2.4*Effect of fibre treatment on the impact strength of baobab composites*

Figure 4.11 presents the effect of baobab fibre treatment on the impact strength of the composite.

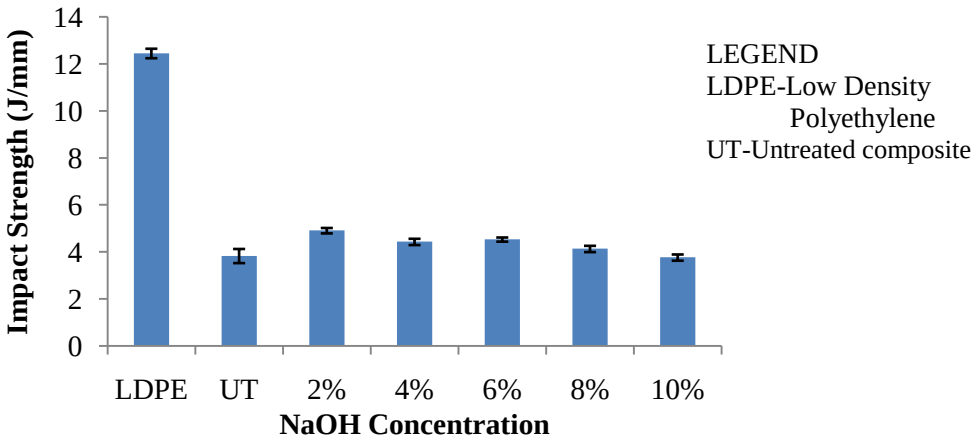


Figure 4.11: Effect of Baobab Fibre Treatment on the Impact Strength of the Composite

A positive treatment effect was observed with the treated fibre composites compare to the untreated fibre composite. There was about 23% increase in the impact strength of the composite made with baobab fibres treated with 2 wt% NaOH solution compared to the untreated baobab fibre composite.

The increase in the impact strength may be attributed to the increase in the fibre surface roughness, resulting in better mechanical interlocking and the increased amount of cellulose exposed on the fibre surface (Bledzki and Gassan. 1999). If the alkali concentration is higher than the optimum condition, the excess delignification of the fibres can take place, weakening or damaging the fibres and consequent decrease in impact strength of the composite (Li *et al.*, 2007), as observed with the composites made with 10 wt% NaOH solution treated fibres shown in Figure 4.11.

The highest impact strength of 4.91 J/mm^2 obtained from 2 wt% NaOH treated baobab fibre was higher when compared with the optimal impact strength value of 0.8 J/mm^2 at 2 wt% NaOH concentration for luffa fibre reinforced epoxy matrix composite represented by Srinivasan*et al.* (2014). The variation could be as a result of the difference in the strength of the fibres or the matrix used.

The overlapped in the error bar between 4 wt% and 6 wt% NaOH treated baobab composites, suggest that there was no significance difference in the impact strength of the two composites.

4.2.2.5*Effect of fibre treatment on the flexural strength of baobab composite*

Figure 4.12 presents the effect of baobab fibre treatment on flexural strength of the composite.

A positive treatment effect was observed with the treated baobab fibre composites when compared to the untreated baobab fibre composite. There was about 23% increase in the flexural strength of the composite made from 8 wt% NaOH treated baobab fibre compared to the untreated baobab fibre composite. As the concentration of the NaOH increased above 8 wt%, a decrease in flexural strength was observed.At higher alkali concentration, excess

delignification of natural fibre occurs, resulting in a weaker or damaged fibre, which decreased the strength of the composite (Mishra *et al.,* 2003).

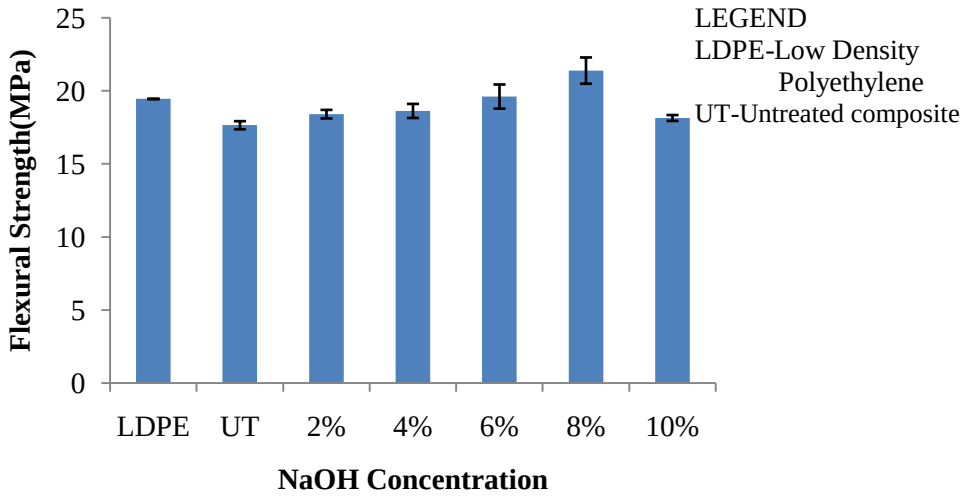


Figure 4.12: Effect of Baobab Fibre Treatment on the Flexural Strength of the Composite

The remarkable increase in flexural strength of the treated fibres composite over the untreated fibre composite may be an indication of better adhesion between the modified fibresand the matrix (Mansour*et al.,* 2011).

Mishra *et al.*(2003) reported an optimal flexural strength of 18 MPa for 5 wt% NaOH treated sisal fibre-reinforced polyester composite, which was less when compared to 21 MPa obtained in this study. While Lassaad *et al.* (2011) reported 37 MPa for 10 wt% NaOH treated luffa-polyester composite at 10 wt% fibre loading, which was higher than 21 MPa the highest flexural strength obtained in this work. The observed differences in the results may be attributed to the type of fibres, matrix or percentage weight of reinforcement used in the various reports mention above.

The maximum value of flexural strength (21.39 MPa) observed at 8 wt% NaOH treatedsatisfied the requirement of ASTM D7032 for utilization in deck boards and guardrail systems. The overlapping in the error bars of the 2 wt% and 4 wt% NaOH treated fibre

composites was an indication that there was no significant difference in their flexural strength at these treatment concentrations.

4.2.2.6*Effect of fibre treatment on the hardness strength of baobab composite*

Figure 4.13 presents the effect of baobab fibre treatment on hardness strength of the composite.

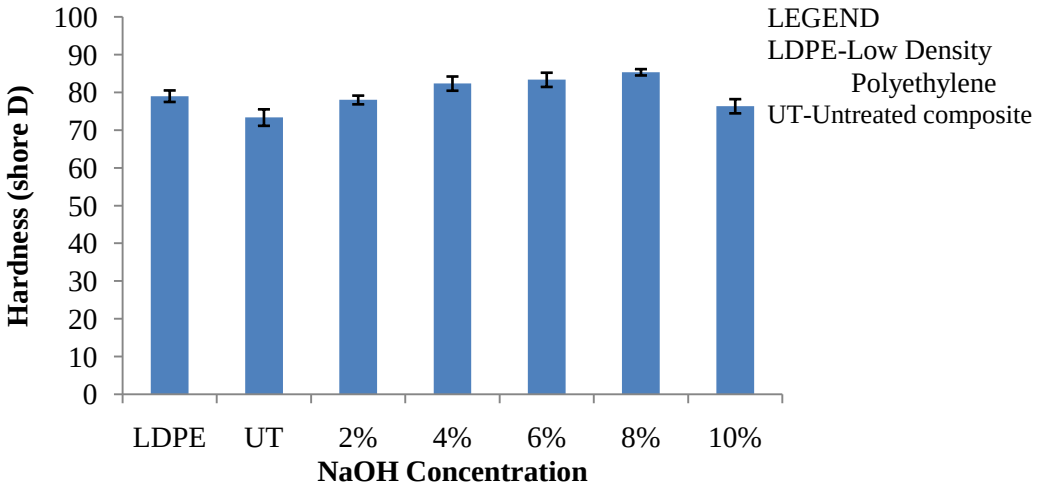


Figure 4.13: Effect of Baobab Fibre Treatment on the Hardness Strength of the Composite

An increase in the hardness value of the composite was observed on modification of the fibre surface with NaOH solution. The highest hardness value (85.33 shore D) obtained at 8 wt% concentration of NaOH lead to about 14% increase in hardness value of the composite compared to the untreated baobab fibre composite and also 7% higher than unreinforced LDPE. The observed increase in hardness value could be attributed to the increase stiffness of the fibres the in matrix as a result of the modification (Kaymakci *et al.*, 2013).

The highest hardness value of 85.33 shore D observed at 8 wt% NaOH treatment was greater than 56 shore D and 68 shore D hardness value reported by Anap (2008) and Khairaih and Khairhul (2006) for flax-HDPE composite and polyurethane-empty fruitbunch blend composites respectively at 10 wt% NaOH treatment concentration.

The overlapped in the error bars between 6 wt% and 8 wt% NaOH treated baobab fibre composite suggest that there was no significant difference in the hardness value of the composites.

4.2.2.7*Effect of fibre treatment on the water absorption of baobab fibrereinforced composites*

Figure 4.14 presents the effect of baobab fibre treatment on water absorption capacity of the composites.

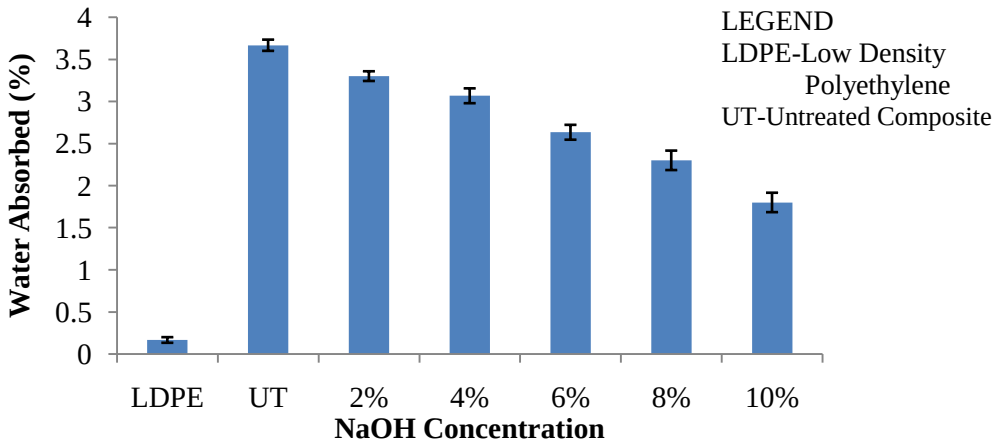


Figure 4.14: Effect of Baobab Fibre Treatment on Water Absorption Capacity of the Composite

It was observed that the water absorption capacity of the composites dropped from 3.7% to 3.3%, when the fibres were treated with 2 wt% concentration of NaOH solution. Further increase in alkali concentration resulted in drastic decrease in water absorption capacity of the treated fibre composites as compared to the untreated baobab fibre composite. The reduction in the water absorption could be possible due to surface treatment of the fibres (Rakesh *et al.,* 2011). Kabir *et al.* (2012) also concluded that alkali sensitive hydroxyl (OH) groups presentamong the molecules are broken down, which then react to give water molecules (H-OH) and move out from the fibre structure. The remaining reactive molecules form fibre-cell-O-Na groups between the cellulose molecular chains. As a result, hydrophilichydroxyl groups are reduced and increase the fibres moistureresistance property.

The least water absorption capacity of 1.8% at 10 wt% NaOH treatment codition experienced in this study was lower than the 2.8% reported by Demir *et al.,* (2006) at optimal treatment concentration of 10 wt% NaOH. Rafael *et al.,* 2010 also reported 6% optimal water absorption capacity for sisal-polyester composite at 10 wt% NaOH concentration which was higher than the 1.8% observed in this work.

The non-overlapping of the error bars indicate that there was significant difference in the water absorption capacity of the composites.

4.2.3 Effect of hybridization ratio on the properties of untreated baobab/sisal reinforced composites

In this section, 10 wt% fibres loading was used, at this loading most of the desired properties were highest.

4.2.3.1*Effect of sisal-baobab fibres hybridization on tensile strength of composite*

The tensile strength result of the untreated sisal-baobab fibre hybridization is presented in Figure 4.15; raw data is presented in Appendix C.

It was observed that the monolithic sisal fibre reinforced (100% sisal fibre) composite exhibited higher tensile strength than the monolithic baobabfibre reinforced composite or any of it hybrids. This could be as a result of sisal fibre having better mechanical properties and better compatibility with the matrix. Modibbo *et al.* (2009) reported that the hydrophilic nature of sisal fibre is less than other fibres on comparison, probably the reason could be that it is more compatible with the matrix than the others. The tensile strength of sisal/baobab fibre hybrid composites is higher than the 100% baobab fibre reinforced composite. The increase in tensile strength of hybrid composite over the monolithic baobab fibre reinforced

composite could be as a result of the sisal fibre content in the hybrid composite in line with the additive rule in composite developed model.

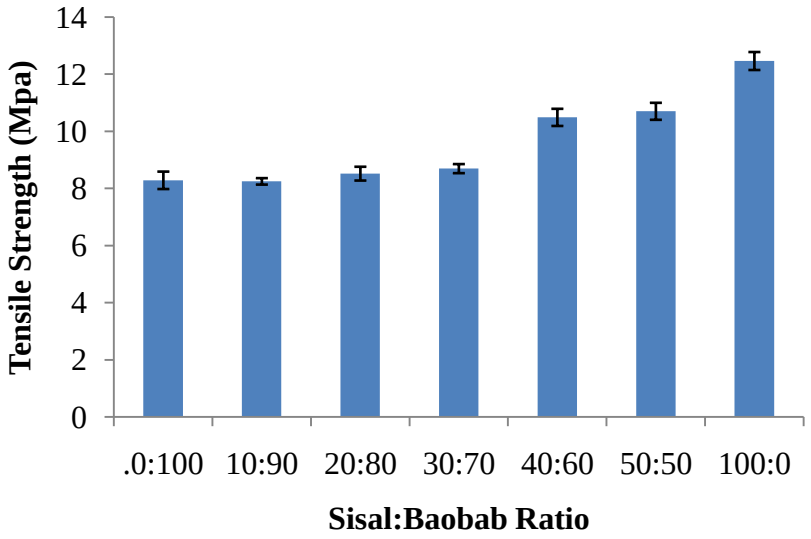


Figure 4.15: Effect of Sisal:Baobab Hybridization on the Tensile Strength of the Composite

Fávaro*et al.* (2010), Sultana *et al.* (2012) and Ramesh *et al.* (2013) reported 16.97 MPa, 14 MPa and 20.1 MPa for sisal/jute fibre, sisal/glass fibres and oxidized and non oxidized sawdust reinforced LDPE composites respectively, which were higher than 10.71 MPa at 50:50 sisal/baobab ratio obtained in this work. The 10 wt% total fibre used in this research as compared to 30 wt% reported elsewhere (Fávaro*et al.*, 2010) and also the low tensile strength exhibited by the baobab fibre are likely responsible for the low tensile strength of the hybrid observed in this study.

The overlapped error bars observed between 40:60 and 50:50 hybridization ratios was an indication that there was no significant difference in the tensile strength of the composites.

4.2.3.2 *Effect of sisal-baobab fibre hybridization on MOE of composite*

The modulus of elasticity result of the sisal-baobab fibre hybridized composite is presented in Figure 4.16.

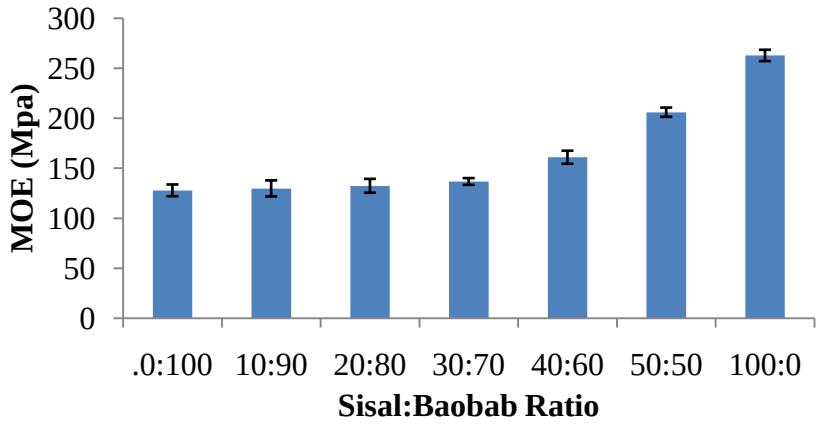


Figure 4.16: Effect of Sisal: Baobab Fibre Hybridization on MOE of the Composite

It was observed that the 100% sisal fibre composite exhibitedhigher modulus of elasticity than the 100% baobab fibre reinforced LDPE composite and any of it hybrids. The MOE of sisal/baobab fibrehybrid composites were higher than 100% baobab reinforced composite. Theincrease in MOE of hybrid composites could be as a result of the incorporated sisal fibre in the hybrid.

As can be seen in Figure 4.16, the maximum modulus of elasticity obtained for the hybrid composite at 50:50 sisal/baobab was higher than that obtained for the unhybridized baobab fibre reinforced LDPE. The increase in modulus of elasticity could be attributed to the stiffness characteristic of sisal fibre introduced into the composite (Sanjeev *et al.*, 2010).

The highest value of 206.03 MPa obtained at 50:50 fibre ratio was less than 380 MPa at 40:60 fibre ratio (Ganzerli *et al.*, 2010) for sisal-jute fibre-reinforced recycled high-density polyethylene composites but higher than 110 MPa at 10 wt% fibre content for jute-coir fibre reinforced hybrid polypropylene composites. The observed variation in the result could be

attributed to the strength and variation of the fibres and the fibre content used in the various works (Salma *et al.,* 2010).

The overlap in error bars of the unhybridized baobab fibre composite and the composites made with 20:80 and 40:60 hybridization ratios indicated that there was no significant difference in the MOE value of the composites. The composite made with the 50:50 hybridization ratios is significantly different from the other composites as indicated in Figure 4.16.

4.1.3.3*Effect of sisal-baobab fibres hybridization on the elongation at break of the composite*

Figure 4.17 presents the effect of sisal-baobab fibre hybridization on the elongation at break of the composite.

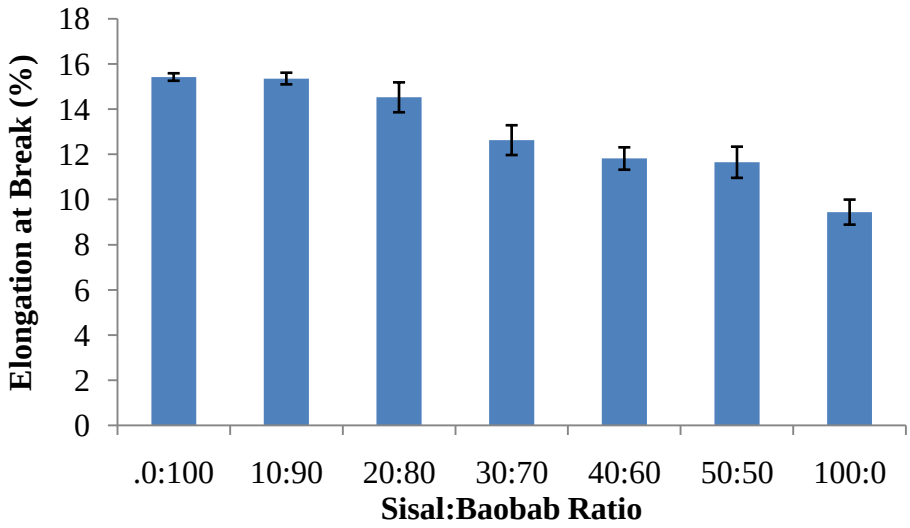


Figure 4.17: Effect of Sisal-Baobab Fibre Hybridization on the Elongation at Break of Composite

It is observed that the baobab fibre composite exhibitedhigher percentage elongation at break than the sisal fibre reinforced LDPE composite. The sisal/baobab fibrehybrid composites exhibited percentage elongation at break lower than baobab reinforced composites but higher than the sole sisal fibre reinforced composite. The decrease in elongation at break of hybrid

composite could be as a result of sisal fibre content, which has lower elongation at break compare to baobab fibre (Modibbo *et al.,* 2009).

Nhlapo (2010) reported 23% as maximum percentage elongation at break on the hybrid of LDPE/sisal-coirfibre composites, which was higher than maximum value obtained at 10:90 sisal:baobab hybrid composite. Prakash *et al.,* (2013) reported 20% optimal elongation at break for coir-sisal reinforced polyester hybrid composite which was higher than the highest value obtained in this study. The variation might be as a result of differences in reinforcement used, matrix or fibre content in the matrix, due to the fact that the actual elongation experienced by low density polyethylene is much higher than that measured for the reinforced low density polyethylene (Georgopoulos*et al.,* 2008).

The overlap in error bars of the unhybridized baobab fibre composite and the composites made with 10:90 hybridization ratios indicate that there was no significant difference in the percentage elongation at break of the composites as shown in Figure 4.17.

4.2.3.4*Effect of sisal-baobab fibres hybridization on the impact strength of the composite*

The effect of sisal fibre hybridization on the impact strength of the composite is shown in Figure 4.18.

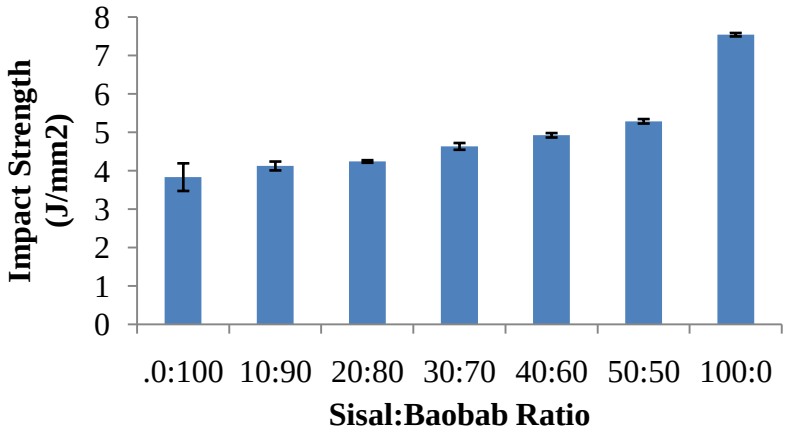


Figure 4.18: Effect of Sisal-Baobab Fibres Hybridization on the Impact Strength of the Composite

It was also observed that the sisal fibre composite exhibitedhigher impact strength than the baobab fibre reinforced LDPE composite. The sisal/baobab fibrehybrid composites exhibited impact strength higher than baobab reinforced composite but lower than the sole sisal fibre reinforced composite. Theincrease in impact strength of hybrid composites result from the sisal fibre content in the hybrid, which has better adhesion compared to baobab fibre which led to better bonding between the fibre and matrix (Kuruvila *et al.,* 1999).

The optimal impact strength of 9.5 J/mm^{2}for sisal/glass fibre reinforced hybrid composites at 5 wt% of sisal fibre content reported by Naga *et al.* (2011) was higher than 5.29 J/mm^2 obtained in this study. While Grisha *et al.* (2012) in their work reported an impact strength of 4.5 J/mm^2 at 10 wt% fibre content of areca-nut husk/tamarind fruit fibres reinforced epoxy hybrid composites. Ramesh *et al.* (2013) reported an impact strength of 12 J/mm^2 for sisal-jute-glass fibre reinforcedpolyester composites at 20 wt% of sisal/jute fibres content. The observed variation in the result is attributed to the type of fibres, matrix used and percentage weight of reinforcement used in the various reports (Wang *et al.,* 2011).

The overlapping in the error bars of the 10:90, 20:80 hybridized ratios and the unhybridized baobab is an indication that there was no significant difference in their impact strength.

4.2.3.5*Effect of sisal-baobab fibres hybridization on the flexural strength of the composite*

The effect of sisal/baobab fibres hybridization on the flexural strength of the composite is shown in Figure 4.19.

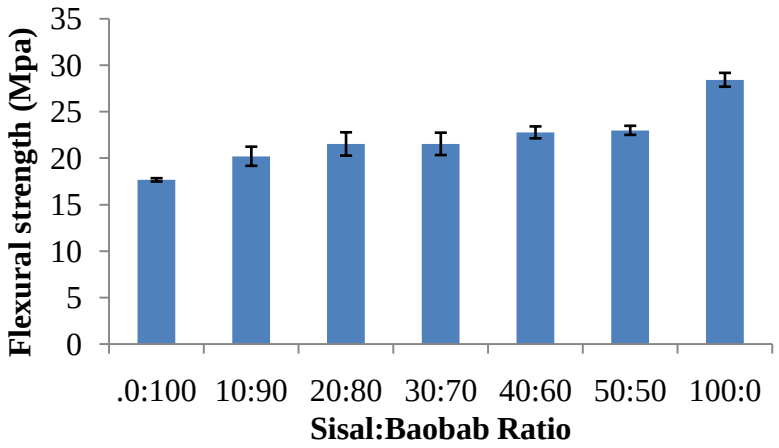


Figure 4.19: Effect of Sisal-Baobab Fibre Hybridization on Flexural Strength of the Composite

It was observed that the 100% sisal fibre composite exhibitedhigher flexural strength than the 100% baobab fibre reinforced LDPE composite. The sisal/baobab fibrehybrid composite had flexural strength higher than baobab reinforced composite but lower than sisal fibre reinforced composite. Theincrease in flexural strength of hybrid composite could be as a result of sisal fibre content in the hybrid.

The highest flexural strength on hybridization at 50:50 sisal/baobab ratios was greater than the unhybridized baobab fibre composite and also the hybrid at 20:80, 30:70 and 40:60 sisal/baobab ratios by 9%, 9.5%, 10%, and 10.5% respectively.

The highest flexural strength of 57 MPa (Grisha *et al.*, 2012) and 46 MPa (Gunti *et al.*, 2012) for sisal/coconut coir fibre ratio at 40 wt% and areca-nut husk/tamarind fruit fibre composites at 50:50 and total fibre weight of 30 wt% respectively were greater than the highest flexural strength of 29.19 MPa on hybridization obtained in this study.

The overlapping of the error bars of the hybridized sisal/baobab reinforce LDPE composite, shows that there was no significance difference in flexural strength of the composites.

4.2.3.6*Effect of sisal-baobab fibre hybridization on the hardness of the composite*

The result of effect of sisal-baobab fibre hybridization on the hardness of the composite is presented in Figure 4.20.

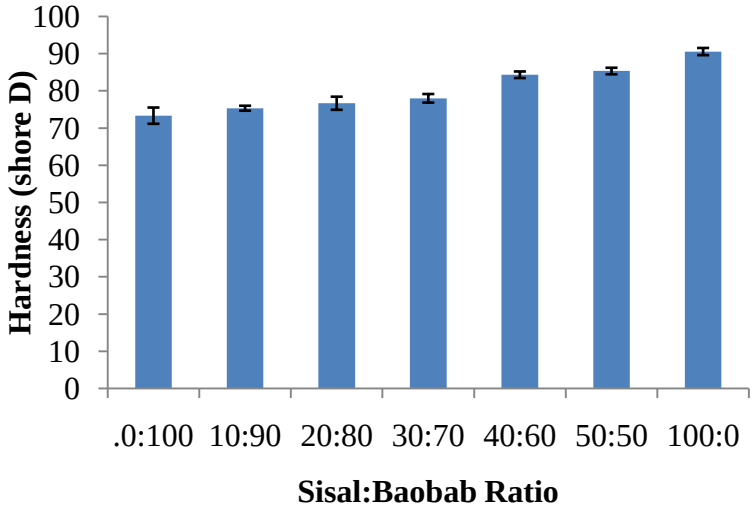


Figure 4.20: Effect of Sisal-Baobab Fibre Hybridization on Hardness Strength of the Composite

It was observed that the 100% sisal fibre composite exhibitedhigher hardness value than the 100% baobab fibre reinforced LDPE composite. The sisal/baobab fibrehybrid composite hardness value washigher than baobab reinforced composite but lower than sisal fibre reinforced composite. Theincrease in hardness value of hybrid composite over the sole baobab reinforced composite could be attributed to the stiffness of sisal fibre in the composite which decreased the penetration of the indenter to the composite material (kuruvilla *et al.*, 1999).

Prakash *et al.,* (2013) reported an increase in hardness with increasing weight percentage of sisal fibres in a sisal/coconut hybrid composite and this could be attributed to the higher strength of sisal fibres compared to the coconut fibres in the composite.

The optimal hardness value of 90 shore D at 50:50 sisal/glass weight percent ratio (Obidiegwu*et al.,* 2012) was higher than the 85.33 shore D obtained at 50:50 sisal/baobab hybrid composite in this work. The observed variation might be attributed to the nature of the fibres. The overlapping of the error bars of the hybrid composite made from 20:80 and 30:70 hybridization ratios shows that there was no significant difference in their hardness values.

4.2.3.7*Effect of sisal-baobab fibre hybridization on the water absorption capacity of the composite.*

Figure 4.21 presents the effect of sisal-baobab fibre hybridization on the water absorption of the composite.

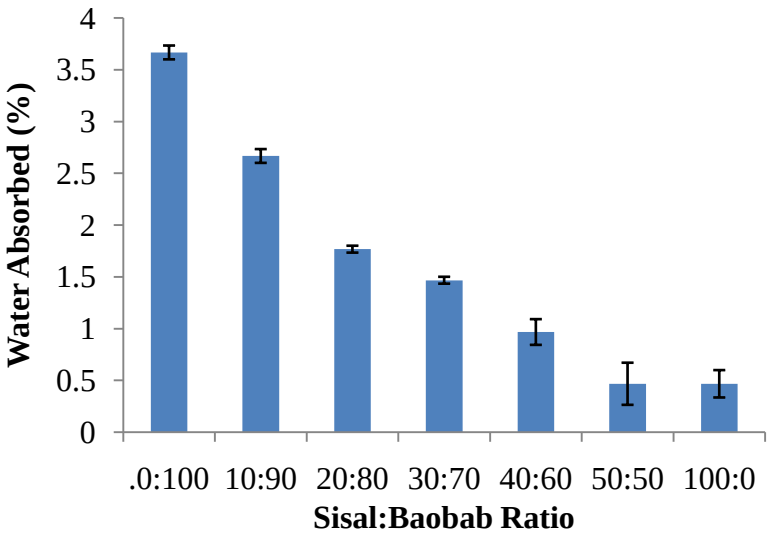


Figure 4.21: Effect of Sisal-Baobab Fibre Hybridization on Water Absorption Capacity of the Composite

It was observed that there was decrease in the percentage water absorbed by the composite on hybridization with sisal fibre content. It was also observed that the sisal fibre composite exhibitedlower water absorption capacity than the baobab fibre reinforced LDPE composite. The sisal/baobab fibrehybrid composite had lower water absorption capacity than baobab reinforced composite, but higher water absorption capacity than sisal fibre reinforced composite. The decrease in water absorption capacity of hybrid composite resulted from the

incorporated of sisal fibre in the composites, sisal fibre is less hydrophilic compared to baobab fibre (Modibbo *et al.,* 2010).

The highest result of 3.6% on hybridization was higher compared to 3.2% at 20 wt% coir/sisal hybrid composites as reported by Grisha *et al.*(2012). Norshida *et al.*(2013) also reported 3.5% amount of water uptake in a blend of starch/kenaf core in low density polyethylene at 10 wt% to 40 wt% of kenaf fibre. The variation of water uptake might be due to different types of natural fibre used.

The minimum percentage water absorption (0.47%) on hybridization at 50:50 sasil/baobab ratios satisfied the requirement of ASTM D570-98for utilization in dash board assemblies.

The overlapping of the error bars of the hybrid composite made from 50:50 and 100% sisal fibre composite indicate that there was no significant difference in the water absorption capacity of the two composites.

4.2.4 Effect of NaOH treatment on sisal/baobab fibres hybrid reinforced LDPE composites

In this section 50/50 baobab/sisal fibres were used, at this combination most of the measured properties were highest. The baobab and sisal fibres were treated at different concentrations of NaOH and used in the hybridization.

4.2.4.1*Effect of fibre treatment on the tensile strength of hybridized composite*

The tensile strength result of the treated baobab/sisal fibre hybridized composite is presented in Figure 4.22; raw data is shown in Appendix D.

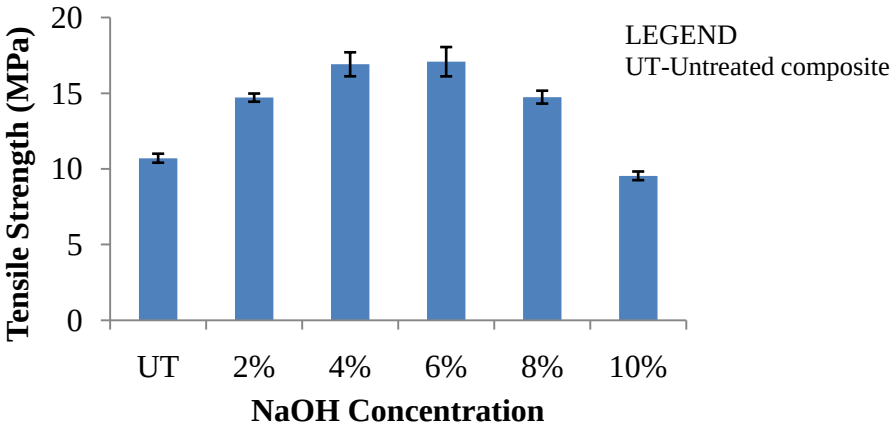


Figure 4.22: Effect of Fibre Treatment on the Tensile Strength of the Hybrid Composite

A positive treatment effect was observed with fibres treated with 2 wt%, 4 wt%, 6 wt% and 8 wt% NaOH solution respectively. They exhibited 30%, 39%, 40% and 30% increase in their tensile strength values respectively as compared to the untreated hybrid composite and 100% sisal fibre composite. As the concentration of NaOH solution was increased to 10 wt%, a negative effect of treatment was observed.

The alkali treatment improves the surface adhesive characteristics by removing natural and artificial impurities thereby producing rough surface topography. This could have resulted to the positive treatment effect observed with the composite treated with 2 wt%, 4 wt%, 6 wt% and 8 wt% concentrated NaOH solution. This treatment resulted in an improvement in the interfacial bonding by giving rise to additional sites of mechanical interlocking, hence promoting more resin-fibre interpenetration at the interface (Bledzki *et al.*, 1999).

If the alkali concentration is higher than the optimum condition, the excess delignification of the fibre can take place, which results in weakening or damaging the fibres, with relative decrease in the tensile strength of the composite (Kabir *et al.*, 2012). Thus for the 8% and 10% alkali treated fibre composites, decrease in strength was observed. Mishra *et al.*,(2003) reported that 5% treated NaOH sisal fibre reinforced polyester composites had better tensile strength than 10% NaOH treated composites. Because at high concentration there is

delignification of natural fibre taking place and as a result damage of fibre surface. The tensile strength of the composite decreased drastically after 6 wt% NaOH concentration.

The highest tensile strength at 4-6 wt% alkali (NaOH) treatment obtained in this work is higher than the 4% optimal treatment concentration reported by Jacob *et al.*, (2004) for sisal/glass hybrid composite at 20% total fibre loading. However, in real application, due to chemical constituent variation among similar or different types of natural fibre, optimal mercerization conditions like the NaOH concentration, time and temperature will vary for each fibre (Fávaro*et al.*, 2010), and this could be responsible for the variation observed in the result. The maximum tensile strength of 17.08 MPa satisfied the requirement of ASTM D638for ethylene vinyl acetate composite, designed to provide economical, non-halogen sound barriers in automotive and industrial applications (Hirabayashi *et al.*, 1993).

The overlap in the error bars of 4 wt% and 6 wt% NaOH treated composites as shown in Figure 4.22 suggest that there was no significant difference in the tensile strength values of the two composites.

4.2.4.2*Effect of fibre treatment on the modulus of elasticity (MOE) of the hybridized composite*

Figure 4.23 presents the effect of fibre treatment on the MOE of the composite.

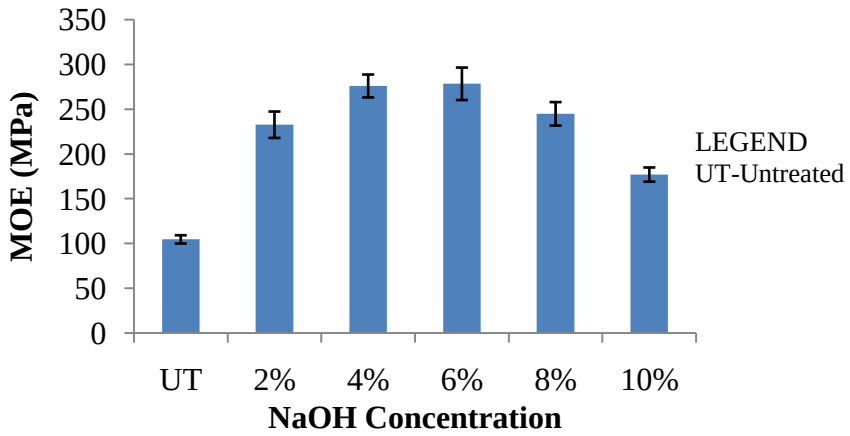


Figure 4.23: Effect of Fibre Treatment on the Modulus of Elasticity of the Hybrid Composite

It was observed that the highest MOE was observed at 4-6 wt% NaOH treatments and with further increase in the concentration of NaOH the MOE decrease up to 177.08 MPa at 10 wt% NaOH concentration. An improvement of about 54%, 62%, 63% and 58% respectively were recorded with 2 wt%, 4 wt%, 6 wt% and 8 wt% NaOH treated fibre composites compared to the untreated hybrid composite, while the maximum MOE obtained at 4-6 wt% NaOH treatment was higher than the MOE of 100% sisal fibre composite.

The enhancement in the MOE of the alkali treated composite could be attributed to the fact that alkali treatment improves the adhesive characteristics of fibre surface by removing natural and artificial impurities, thereby producing a rough surface topography. It also leads to fibrillation, creating more available surface area on the fibre to interact with the matrix (John *et al.,* 2008). The increase in tensile modulus for the treated fibres was due to reduction in the surface deposits in the fibres. At 6 wt% NaOH concentration, better compatibility and adhesiveness was achieved (Aminu *et al.,* 2014).

The decrease in MOE value observed after the optimal 6 wt% concentration of NaOH, possibly as a result of the fibres losing their characteristics which leads to damaged fibre surface at high concentration of alkali (Li *et al.,* 2007).

An optimal treatment concentration of 10 wt% NaOH was reported by Cyras *et al.,* (2004) for sisal-polycaprolactonecomposite, 5 wt% optimal treatment concentration for jute-vinylester composite (Sever *et al.,* 2010) and 4 wt% optimal concentration for sisal reinforced polymer composite (Jacob *et al.,* 2008). The variation in these results in comparison with the present work may be attributed to the nature of the fibres used. Since composition varies for individual fibres, it will also affect the level of treatment required for a particular fibre.

The overlap in the error bars of 4 wt% and 6 wt% NaOH treated composites as shown in Figure 4.23 suggest that there was no significant difference in the MOE values of the two composites.

4.2.4.3*Effect of fibre treatment on the elongation at break of the hybridized composite*

Figure 4.24 presents the effect of fibre treatment on the elongation at break of the hybridized composites.

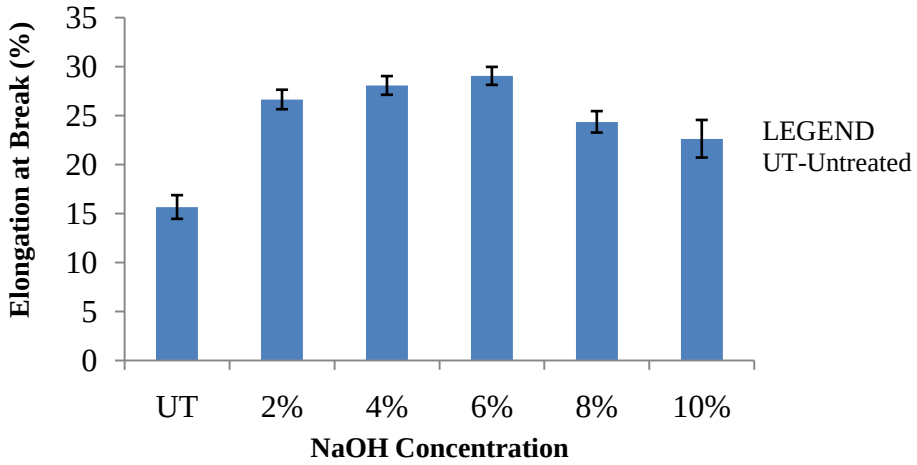


Figure 4.24: Effect of Fibre Treatment on the Elongation at Break of the Hybrid Composite

A positive treatment effect was noticed on treating the fibres with 2 wt%, 4 wt% and 6 wt% concentration of NaOH solutions, thereafter a negative effect set in. The composite resulting from 6 wt% concentration of NaOH solution treated fibre exhibited the highest percentage elongation at break of 29% corresponding to 48% higher than the untreated fibre composite. The enhanced percentage elongation on treatment was due to the fact more hemicellulose, lignin and pectin were removed as a result of treatment provide more surface roughness, hence giving rise to better compatibility with the matrix reported by Kabir *et al.,* (2012). However, at very high alkali treatment concentration of 8% and 10%, deterioration in the strength of the composite was observed. This may be due to excess delignification of the fibres, which results in weakening or damaging of the fibres (Wang *et al.,* 2007).

An optimal 5% treatment concentration was reported by Ku *et al.*, (2013) for Flax/Jute HDPE composite with 30% elongation at break, which compared favourably with the 29% optimal percentage elongation at break observed in this work at 6 wt% NaOH treatment concentrations.

The maximum percentage elongation at break (29%) observedat 4-6 wt% NaOH treated sisal/baobab composites satisfied the requirement of ASTM D638Mfor utilization in rear seat barrier in automotive and electronic housing.

The overlap in error bars of 2 wt% and 4 wt% NaOH treated fibre composites and the overlapped of 4 wt% and 6 wt% NaOH treated fibre composites suggest that there was no significant difference in the elongation at break of the composites.

4.2.4.4*Effect of fibre treatment on the impact strength of the hybridized composite*

Figure 4.25 present the effect of fibre treatment on the impact strength of the hybridized composite.

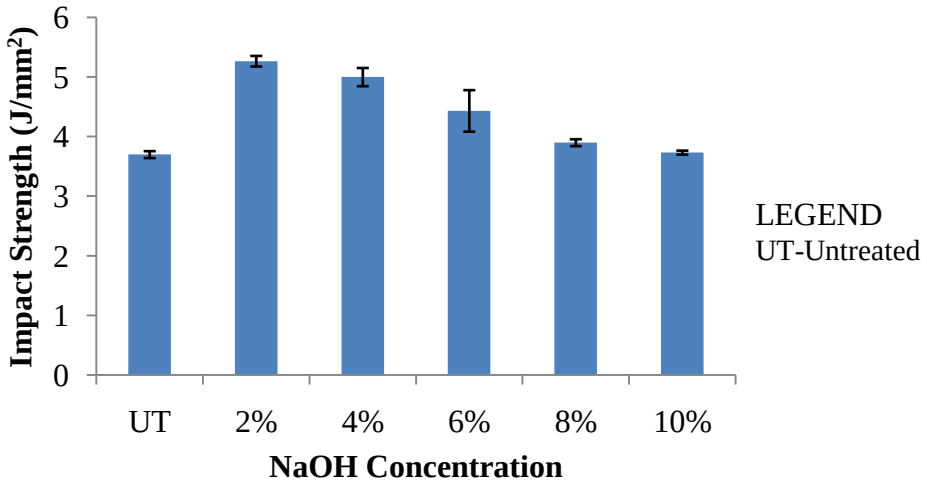


Figure 4.25: Effect of Fibre Treatment on the Impact Strength of the Hybrid Composite

A positive treatment effect was observed with the treated fibre hybrid composites compared to the untreated fibre hybrid composite. There was about 28.8% increase in the impact

strength of the hybrid composites made with fibres treated with 2 wt% NaOH compared to the untreated hybrid fibres composite. Thereafter, decreasing impact strength was observed with increasing concentration of NaOH solution.

However, the entire treated NaOH hybrid composites exhibit a higher impact strength compare to the untreated hybrid composite. The increase in impact strength may be attributed to the increase in the fibre surface roughness as a result of treatment, resulting in better mechanical interlocking (Bledzki and Gassan.1999).

In other words, the fibresurface becomes more uniform due to the elimination of microvoids and thus the stress transfer capacity between the ultimatecells improves. In addition to this, surface treatment reduces fibre diameter andthereby increases the aspect ratio (length/diameter). This increases effective fibre surface area for good adhesion with the matrix (Joseph *et al.,* 2002). If the alkali concentration is higherthan the optimum condition, the excess delignification of the fibrecan take place, which results in weakening or damaging the fibres and subsequent decreased in impact strength of the composite (Li *et al.,* 2007), as observed with the composites made with the 8 wt% and 10 wt% concentrated NaOH solution treated fibres as shown in Figure 4.25.

Siddika *et al.,* (2013) and Zaman*et al.,*(2012) made similar observation for jute-coir fibre reinforced hybrid polypropylene and banana fibre reinforced polypropylene composite. It was concluded that 5 wt% was the optimum NaOH treatment concentration. The strength of the individual fibres used in the studies could be responsible for optimum treatment concentration reported as compared to the 2 wt% NaOH concentration obtained in this work.

The maximum impact strength (5.26 J/mm^2) observedat 2 wt% NaOH treated sisal/baobab composites satisfied the requirement of ASTM D256Afor utilization in wheel-well covers (Stereolithography, 2015).

The overlap in the error bars of 2 wt% and 4 wt% NaOH treated composites as shown in Figure 4.25 suggest that there was no significant difference in the impact strength values of the two composites.

4.2.4.5*Effect of fibre treatment on the flexural strength of the hybridized composite*

Figure 4.26 presents the effect of varying treatment concentration on the flexural strength of the hybridized composite.

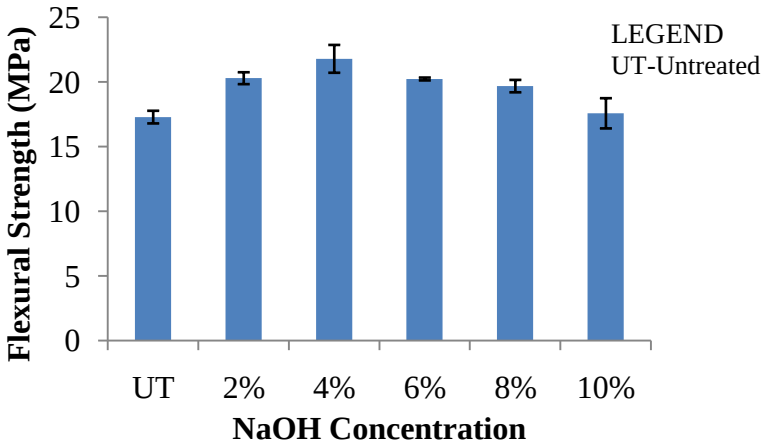


Figure 4.26: Effect of Fibre Treatment on the Flexural Strength of the Composite

A positive treatment effect was observed with the treated fibre composites compared to the untreated fibre composite. There was about 15% and 19% increase in the flexural strength of the composite made with 2 wt% and 4 wt% NaOH treatment compared to the untreated fibre composite. After the highest 4 wt% treatment concentration, decreased in flexural strength was then observed with increasing concentration of NaOH solution. The increase in flexural strength may be attributed to the increase in the surface roughness as a result of the treatment, resulting in better mechanical properties (Oladele *et al.*,2010).

Naga *et al.* (2011) made similar observation for sisal/glass fibre hybrid composite, and concluded that 6 wt% was the optimum NaOH treatment concentration. Mansour *et al.*

(2011) reported 12% increase in flexural strength of Jute-vinylester composites at 5 wt% NaOH treatment compared to the untreated Jute-vinylester composite.

The overlapping of the error bars in 6 wt% and 8 wt% NaOH treated fibre composites as observed in Figure 4.26 indicates that there was no significant difference in the flexural strength of the composites.

4.2.4.6*Effect of fibre treatment on the hardness strength of the hybridized composite*

Figure 4.27 shows the effect of varying treatment concentration on the hardness of the hybrid composite.

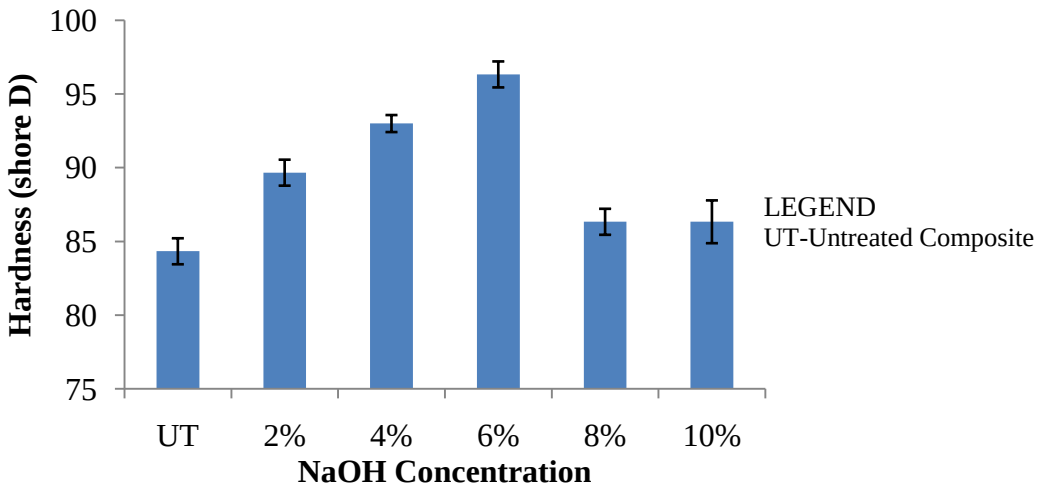


Figure 4.27: Effect of Fibre Treatment on the Hardness Strength of the Composite

An increase in the hardness value of the composite was observed on modifying the fibre with 2 wt%, 4 wt% and 6 wt% concentration of NaOH solution and drastically decrease at 8 wt% and 10 wt% NaOH treated fibre composite.

The modification lead to a 5.6%, 9.6% and 12.5% increase in hardness value of the composite compared to the untreated composite when 2 wt%, 4 wt% and 6 wt% NaOH solutions respectively were used. The observed increase in hardness value could be attributed to strong interface and closed packing arrangement in the composite. This could also be

attributed to the increase in stiffness and the dispersion of the fibres into the matrix as a result of the treatment as reported by Kaymakci*et al*. (2013).

The highest hardness value of 96 shore D obtained at 6 wt% NaOH concentration observed was greater than 85 shore D at 10 wt% NaOH concentration reported by Khalil *et al.*, (2013) and Raghavendra*et al*. (2013) for their works rice husk ash modified, marble sludge loaded natural rubber hybrid composites and short banana fibre reinforced natural rubber composites respectively.

The maximum hardness of 96.33 shore D observedat 6 wt% NaOH treated sasil/baobab composites satisfied the requirement of ASTM D2240for utilization in machine covers, impellers and dashboard assemblies (Stereolithography, 2015).

The overlap of the error bars of 8 wt% and 10 wt% NaOH treated hybrid sisal/baobab composite as shown in Figure 4.27 indicate that there was no significant difference in the hardness of the two composites.

4.2.4.7*Effect of fibre treatment on the water absorption of the hybridized composite*

The effect of treatment on the water absorption capacity of the hybridized composite is presented in Figure 4.28.

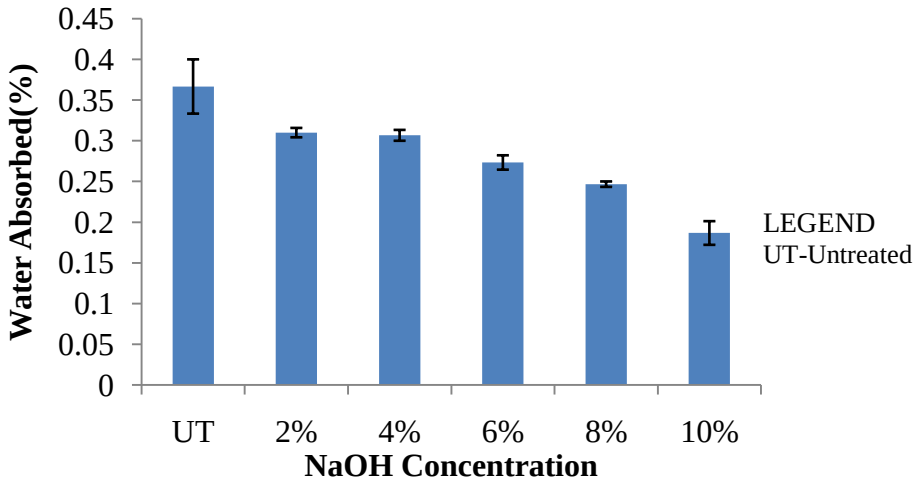


Figure 4.28: Effect of Fibre Treatment on the Water Absorption Capacity of the Composite

It was observed that the water absorption capacity of the untreated fibre composite dropped from 0.4% to 0.3%, when the fibres were treated with 2 wt% NaOH solution.

It can be observed from Figure 4.28, as the treatment concentration of NaOH increases, the water absorption capacity of the composite decreases. This shows that excessive alkali treatment had take out a certain portion of hemicelluloses, lignin, pectin, wax and oil covering materials (Mwaikambo *et al.*, 2000).

The highest water absorption capacity of 0.31% observed in this study was less than 5% reported by Panthapulakkal *et al.*, (2007) at optimal treatment concentration of 10% NaOH concentration. Grisha *et al.* (2012) also reported 12% optimal water absorption capacity for sisal/coconut coir natural fibres-epoxy composites at 4 wt% NaOH fibre treatment concentrations, which was much higher than 0.3% observed in this work.

The minimum water absorption (0.18%) observedat 10 wt% NaOH treatment for sisal/baobab composites satisfied the requirement of ASTM D570-98for utilization in wheel-well covers and dashboard assemblies.

The overlap of the error bars of the composite made from 2 wt% and 4 wt% NaOH treated fibre composites indicate that there was no significant difference in the water absorption capacity of the two composites.

4.2.5FTIR spectra

In this section the FTIR spectra of the untreated and treated baobab fibres of varying NaOH concentration of 2 wt%, 4 wt%, 6 wt%, 8 wt% and 10 wt% were presented and discussed.

4.2.5.1*Fourier transform infrared spectroscopy (FTIR) of untreated and treated baobab fibre.*

Figure 4.29 shows the FT-IR spectra of unmodifiedand alkali treated baobab fibres. The band positions and the possible assignments are given in Table 4.1. From Figure 4.29, it was observed that in the case of untreated baobab fibre, there are well defined bands at around 4382, 3850, 3736, 3634, 2277, 1683, 1528 and 391 cm^{-1}in the spectra. The broad peak at 4382 $cm^{-1}$is due to the bonded OH groups in cellulose. The peak at 3850 $cm^{-1}$is due to C-H stretching in cellulose and hemicelluloses. From the peak assignments in Table 4.1, it can be seen that the bands around 4382 cm^{-1} and 3850 cm^{-1}correspond to α–cellulose, whereas the remaining bands correspond to lignin. Compared with the peaks of unmodified baobab, the spectra of alkali treated cellulose have several differences in the intensity of the peak at 2030 cm^{-1}characteristic of the carbonyl groupstretching and the disappearance of 1550 cm^{-1} which correspond to lignin in the treated baobab fibres.It can be seen that the intensity of the peak at 2030 cm^{-1}characteristic of the carbonyl groupstretching of the untreated baobab is continuously reduceduntil it disappeared completely at 10 wt% NaOH treatment curve.

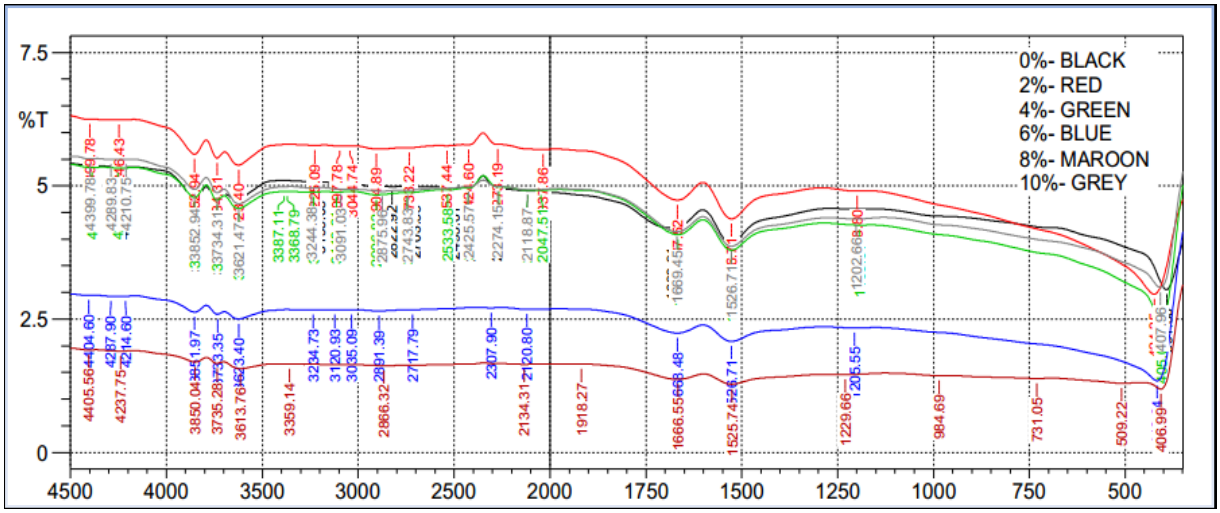


Figure 4.29: FT-IR spectra of untreated and NaOH treated baobab fibre

After the alkali treatment process, the band at 1202 cm^{-1}, attributed to the stretching vibrations of C-O groupsdisappeared.This kind of group is present in lignin and hemicellulose structures. The hemicelluloses contain groups thatabsorb in the carbonyl region and ester group on surface of the fibre. This was due to the removal of the carboxyl or carbonyl groups present in the fibres as a trace of fatty acid present in absorbed oils as found in (Oladele *et al.*,2010; Mwaikambo *et al.*, 1999; Ouajai *et al.*,2004).

Further, for the alkali treated fibres, the intensity of the bands corresponding to α–cellulose increased as shown in the figure.The other spectral change was an increase of the 406 cm^{-1}band attributed to the symmetric in-phase ring-stretching mode. This observation showed that the crystalline structure of the fibres was changed from cellulose I to cellulose II after NaOH treatment. This suggests that the formation of amorphous cellulose and cellulose II took place after alkali treatment.

The enhancement in mechanical properties including tensile, modulus, flexural and impact stress in alkali treated baobab fibres composites was attributed to improved wetting of alkali treated fibres with the matrix. The removal of impurities and waxy substances from the fibre surface and creation of rougher topography after alkalization which resulted in enhancement

of the quality of the fibre and also decrease the hemi-cellulose and lignin content, thus, bringing about an increment in the effectiveness of oriented cellulose fibres. Alkali treatment improved dispersion of baobab fibre in matrix which resulted in increase in fibre aspect ratio which increased fibre reinforcement effectiveness.

Table 4.2: Infrared transmittance peaks (cm^{-1}) and possible assignments of chemical groups in untreated and alkali treatedbaobab fibre

Wave number (cm^1)		
Untreated fibre peak	**Alkali treated fibre peak**	**Peak assignment**
3850	3621	O-H stretching of α–cellulose
2916	2875	Alkyl CH stretching
2277	2274	C=O stretching ofhemicelluloses
1683	1669	CH_2symmetric bending
1367	-	-C-H Bending
-	1202	C-O Stretching
1193	984	Symmetric C-OH stretchingof lignin

4.2.6Scanning electron microscope (SEM)morphology of the composites

In this section the morphology of the untreated baobab fibre composite, 50:50 sisal/baobab hybrid composite and the treated hybrid sisal/baobab fibres composites of varying NaOH concentration of 4 wt%, 6 wt% and 10 wt% are presented and discuss.

4.2.6.1*Surface morphology of untreated and 8 wt% NaOH treated baobab fibre composite.*

Plate III shows the surface morphology of untreated and 8 wt% NaOH tread baobab fibre composite.

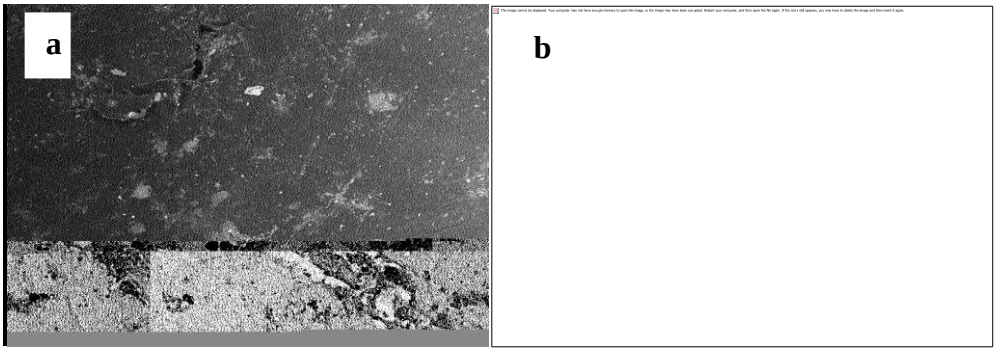


Plate III: Scanning electron microscope (SEM) of untreated and 8 wt% NaOH treated baobab fibre composite.

The micrographs show a significant difference in the surface condition between the untreated and the NaOH treated baobabfibre composite.It can be observed that NaOH treated baobab fibre composite had smooth surface, whereas the untreated baobab fibre composites showed a specific morphology, rough surface with many crack and voids, although treated baobab fibre seemed to be well embedded in the LDPE matrix. The surface roughness tends to be associated with fibrecontent. The cracks visible in the untreated baobab fibre composites may be due to less interfacial adhesion between the fibre and matrix due to the presence surface deposits mostly composed of lignin, hemi-cellulose, and other non-cellulosic substances that cover the cellulose aspect of the fibre. These surface deposits reduced the interactions between the baobab fibres and Polyethylene matrix as represented by Deka *et al.* (2013). On the other hand, Plate III (b) shows the reinforced composite with treated baobab fibre which has less rough surfaces withbetter compatibility of fibre with the polyethylene matrix. A good fibre-matrix binding leads to a resistant interface and also reinforcing the matrix (Fowler *et al.*, 2006). The role of the alkali treatment of baobab fibres is mainly to decrease their hydrophilicproperties. It is clear from the comparison of the SEM Plates III (a and b) that alkali treated baobab fibres improvesthe physical structural properties by smoothing cell wall surface of treated fibres than untreated fibres. The poor interactions between the untreated fibres and matrix and also poor fibre compatibility with the matrix lead to reduction in tensile properties as indicated in Figure 4.1.

4.2.6.2*Surface morphology of50:50 untreated and the treated sisal/baobab hybrid composites*

Plate IV show the surface morphology of 50:50 untreated and 4 wt%, 6 wt% and 10 wt% treated hybrid sisal/baobab composite.

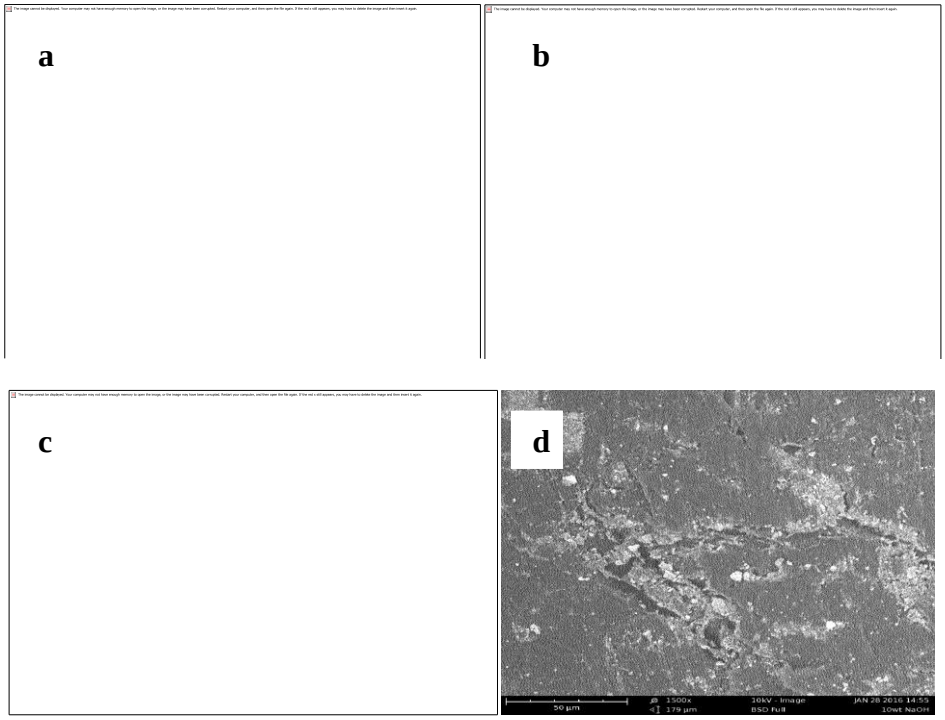


Plate IV: Scanning electron microscope (SEM) of (a) 50:50 untreated, (b) 4 wt% NaOH, (c) 6 wt% NaOH and (d) 10 wt% NaOH treated hybrid sisal:baobab fibre composite.

The SEM micrographs represent a significant difference in the surface condition between the untreated and the NaOH treated hybrid sisal/baobabfibre composite. It was observed that 4 and 6 wt% NaOH treated hybrid composite has less cracks and voids, whereas the untreated hybrid composite showed surface with many cracks and voids,although 10 wt% NaOH treated hybrid composite showed aspecific morphology with rough surface. The surface cracks and voids may be associated with poor interfacial adhesion between the fibre and matrix as reported by Araga *et al*, (2011).

Plates IV (b and c) illustrates the surface morphology of the composites reinforced by 4 and 6 wt% of NaOH treated sisal/baobab fibres hybrid composites. It can be observed that there was smooth surface which might be due to better dispersion of the fibres in the matrix. The

fibres seemed to be well dispersed in the polyethylene matrix. The good dispersion corroborates good stress transfer from matrix to fibres and the reinforcing effect of the fibres. It is an evidence of better compatibility which yielded better tensile strength (Gupta *et al.*, 2008). The surface micrographs in Plate IV (a) show many cracks and voids which are formed as a result of poor compatibility between the fibres and matrix, in which fibre agglomeration become more prominent in the composites as established by Deka *et al.* (2013).

On the other hand, Plate IV (d) illustrates the surface morphology of 10 wt% NaOH treated sisal/baobab hybrid composite. It was observed that there was more cracks and voids in the morphological surface. The surface cracks and voids tends to be associated with high delignification of the fibres at higher concentration of NaOH concentration which lead to surface damage to the fibres and non uniform distribution of the fibre in the matrix. Moreover, the fibres were strongly damaged and the occurrences of some de-bonding phenomena indicated poor adhesion between fibre and matrix (Avella *et al.*, 2008).The non-uniform distribution of fibre gave rise to the formation of stress concentration points as corroborated by Fabunmi *et al.* (2007).This situation is reflected in the mechanical properties of the composites. The mechanical properties of the composites already discussed also support these findings.

CHAPTER FIVE

5.0 Conclusions and Recommendations

5.1 Conclusions

The mechanical properties of baobab/sisal fibres reinforced low density polyethylene composites was investigated in this work, by varying baobab fibre loading from 5 to 30 wt%, hybridization ratio (0:100,10:90, 20:80, 30:70, 40:60, 50:50 and 100:0 sisal) and treatment conditions of NaOH (2, 4, 6, 8 and 10 wt%). Based on the results obtained from the study, the following conclusions were made:

1. Baobab and Sisal fibres were successfully used as reinforcement for low density polyethylene composites.
2. The highest mechanical properties obtained for sole baobab fibre and hybrid baobab/sisal composites were:

a. 10 wt% sole baobab fibres loading exhibited the best tensile strength and MOE of 8.28 MPa and 127.8 MPa respectively.
b. 8 wt% NaOH treatment of sole baobab fibre composites exhibit 43% and 40% tensile strength higher than untreated baobab fibre composite and unreinforced LDPE.
c. On hybridization 50:50 baobab/sisal fibres hybridization ratio exhibited the highest mechanical properties, with tensile strength, MOE and water absorption capacity of 10.70 MPa, 206 MPa and 0.46% respectively.
d. 4-6 wt% NaOH treated baobab/sisal fibres hybrid composites exhibited higher tensile strength and MOE with 96.33 shore D of in terms of hardness.

3. The FT-IR analysis of untreated and treated baobab fibre showed that, there was reduction in the hemicelluloses in the NaOH treated baobab fibres as indicated by the band at 2277 – 2274 cm^{-1}representing C=O stretching of hemicelluloses.

4. The scanning electron microscope analysis indicatedthat the surface of the treated baobab fibre and treated hybrid sisal/baobab composites had little cracks and voids whereas the untreated baobab fibre composite and untreated hybrid sisal/baobab fibres composite showed surfaces with many cracks and voids, this resulted to the observed low values of properties in the untreated fibre composites.

5. Furthermore, composites produced in this study satisfied the requirements of ASTM D7032 in relation to flexural strength for utilisation in deck boards and guardrail systems. On the other hand, the minimum water absorption capacity obtained in the hybrid composite satisfied the requirement of ASTM D570-96 for utilization in dash board and rear seat barriers.

5.2 Recommendation

The following recommendations are made upon the conclusion of this research.

1. The utilization of other natural fibres/synthetic fibres should be employed in hybridization with baobab fibre.
2. Other treatment options should be employed to determine how much modification will be achieved using other chemicals.
3. Live articles should be produced using the composite samples that met ASTM standards in automotive and other applications.

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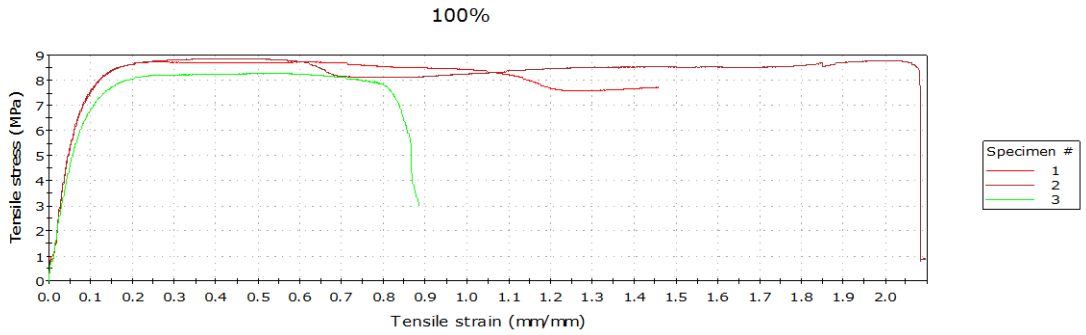
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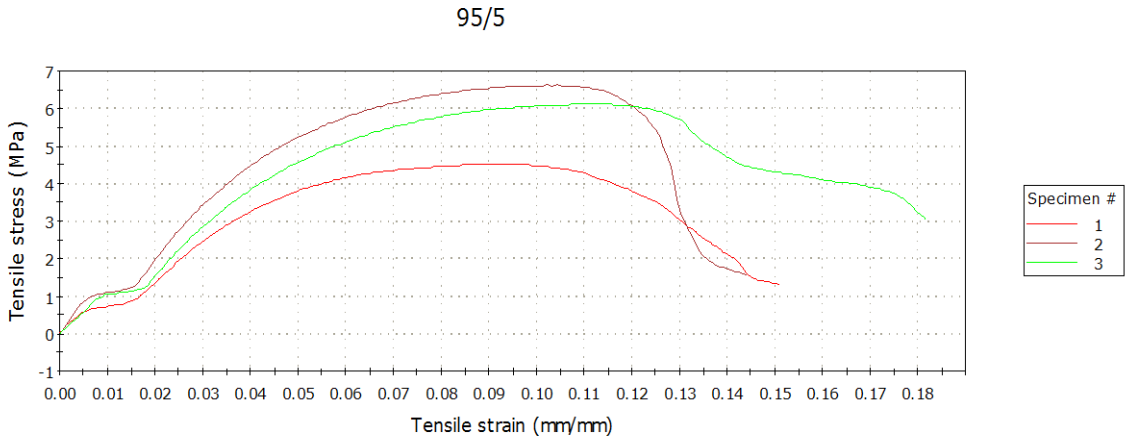
APPENDIX A

Raw Plots obtained from CERD, IFE OSUN STATE.

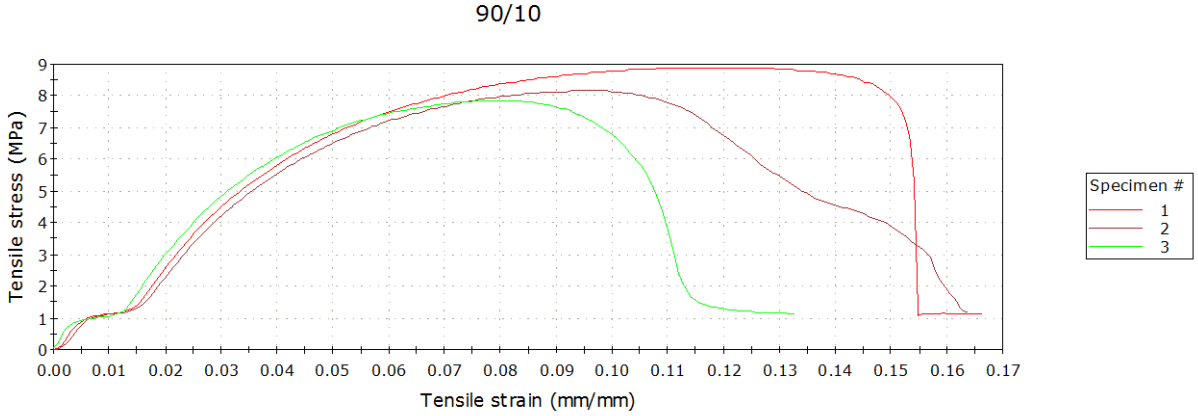
Tensile Test to Determine the Mechanical Properties of Unreinforced Virgin Low Density Polyethylene and Reinforced LDPE with 5, 10, 15, 20, 25 and 30 wt% baobab fibre Composites Materials



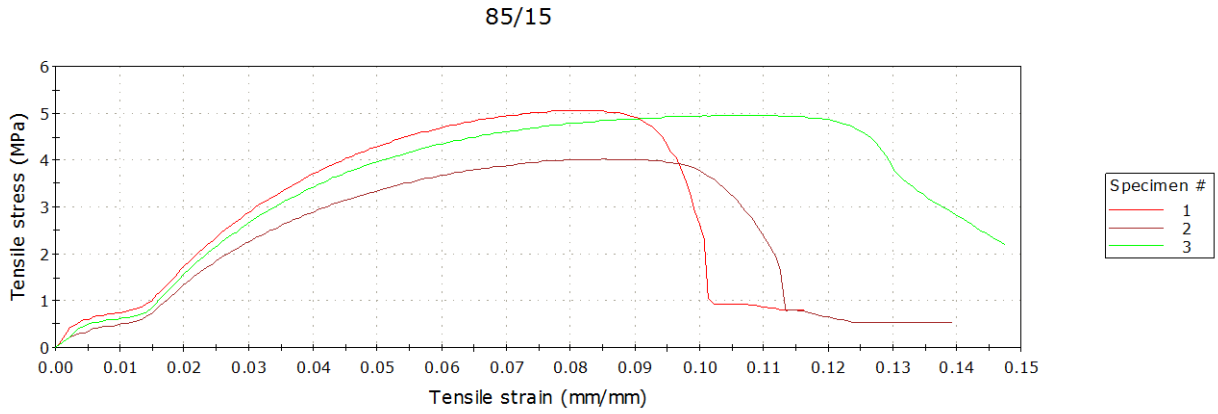
Stress-strain curve for the virgin Low Density Polyethylene Composite



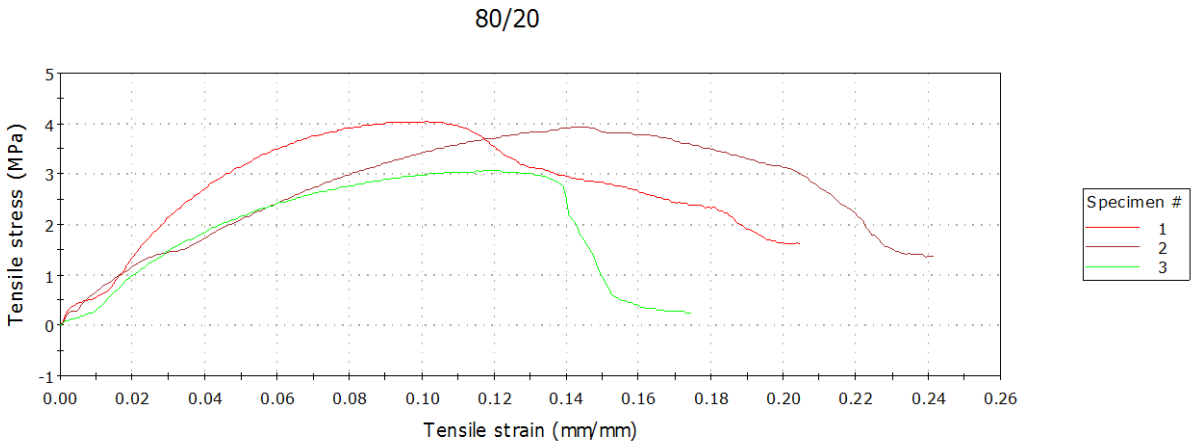
Stress-Strain Curve for 5 wt% fibre loading composite.



Stress-Strain Curve for 5 wt% fibre loading composite.

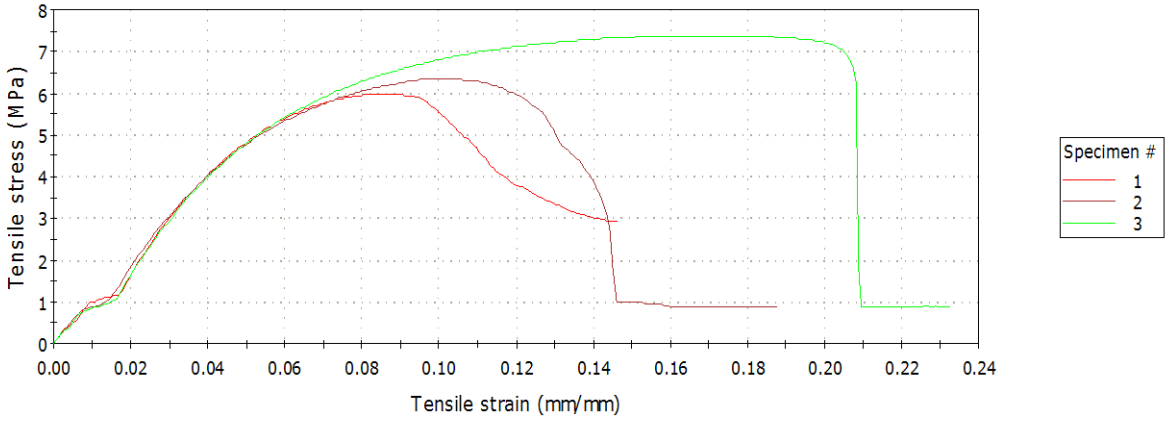


Stress-Strain curve for 15 wt% baobab fibre loading



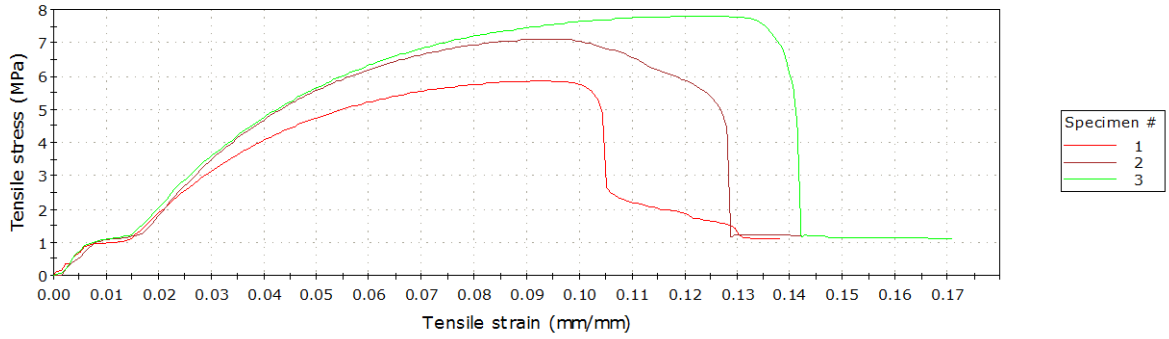
Stress-Strain curve for 20 wt% baobab fibre loading

75/25



Stress-Strain curve for 25 wt% baobab fibre loading

70/30



Stress-Strain curve for 30 wt% baobab fibre loading

100% LDPE	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	8.72451	
2	45.00000	3.13000	19.78000	8.87549	
3	45.00000	3.13000	19.78000	8.28108	
mean	45.00000	3.13000	19.78000	8.62702	
Standard Deviation	0.00000	0.00000	0.00000	0.30896	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	540.14642	0.26741	12.03344	5.23330	7.73151
2	549.49406	0.43037	19.36656	9.27520	0.86891
3	512.69308	0.54223	24.40018	11.12445	3.00147

Mean	534.11118	0.41333	18.60006	8.54432	3.86730
Standard Deviation	19.12841	0.13820	6.21890	3.01282	3.51228

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	478.66888	1.45852	65.63337	32.88505	8.72451
2	53.79536	2.09703	94.36655	48.44872	8.87549
3	185.82529	0.88593	39.86668	18.44990	8.28108
Mean	239.42984	1.48049	66.62220	33.26122	8.62702
Standard Deviation	217.44991	0.60585	27.26339	15.00295	0.30896

95/5	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	3.13000	19.78000	4.51043
2	45.00000	3.13000	19.78000	6.62564
3	45.00000	3.13000	19.78000	6.12182
Mean	45.00000	3.13000	19.78000	5.75263
Standard Deviation	0.00000	0.00000	0.00000	1.10488

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	279.24711	0.09185	4.13337	0.77424	1.31875
2	410.20270	0.10222	4.60000	1.28036	1.59235
3	379.01031	0.11037	4.96675	1.27065	3.06465
Mean	356.15338	0.10148	4.56671	1.10842	1.99192
Standard Deviation	68.40447	0.00928	0.41768	0.28945	0.93904

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	81.64552	0.15037	6.76669	1.32641	4.51043
2	98.58464	0.14370	6.46669	1.82604	6.62564
3	189.73700	0.18148	8.16675	2.21226	6.12182
Mean	123.32239	0.15852	7.13337	1.78824	5.75263
Standard Deviation	58.13698	0.02016	0.90741	0.44413	1.10488

90/10	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	3.13000	19.78000	8.87355
2	45.00000	3.13000	19.78000	8.14224

3	45.00000	3.13000	19.78000	7.84752	
Mean	45.00000	3.13000	19.78000	8.28777	
Standard Deviation	0.00000	0.00000	0.00000	0.52827	

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	549.37364	0.11556	5.20000	1.99038	1.12154
2	504.09776	0.09704	4.36669	1.45584	1.14917
3	485.85092	0.08074	3.63325	1.16386	1.12670
Mean	513.10744	0.09778	4.39998	1.53669	1.13247
Standard Deviation	32.70573	0.01742	0.78391	0.41915	0.01469

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	69.43613	0.16619	7.47875	2.95021	8.87355
2	71.14673	0.16370	7.36662	2.47650	8.14224
3	69.75546	0.13273	5.97269	1.81846	7.84752
Mean	70.11277	0.15421	6.93935	2.41506	8.28777
Standard Deviation	0.90956	0.01865	0.83903	0.56837	0.52827

85/15	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	3.13000	19.78000	5.05458
2	45.00000	3.13000	19.78000	4.02540
3	45.00000	3.13000	19.78000	4.95740
Mean	45.00000	3.13000	19.78000	4.67913
Standard Deviation	0.00000	0.00000	0.00000	0.56823

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	312.93633	0.08296	3.73337	0.75632	0.80445
2	249.21792	0.08518	3.83319	0.61349	0.52654
3	306.91985	0.10963	4.93337	1.06296	2.19572
Mean	289.69136	0.09259	4.16665	0.81092	1.17557
Standard Deviation	35.17989	0.01480	0.66588	0.22966	0.89434

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)

			(mm)		
1	49.80461	0.11556	5.20000	1.01307	5.05458
2	32.59902	0.13933	6.27000	0.92659	4.02540
3	135.94030	0.14740	6.63319	1.47438	4.95740
Mean	72.78131	0.13410	6.03439	1.13801	4.67913
Standard Deviation	55.36968	0.01656	0.74508	0.29450	0.56823

80/20	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	4.03524	
2	45.00000	3.13000	19.78000	3.92717	
3	45.00000	3.13000	19.78000	3.06378	
Mean	45.00000	3.13000	19.78000	3.67540	
Standard Deviation	0.00000	0.00000	0.00000	0.53242	

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	249.82756	0.10148	4.56675	0.77403	1.62143
2	243.13664	0.14296	6.43331	1.00783	1.36311
3	189.68303	0.12000	5.40006	0.69771	0.25229
Mean	227.54907	0.12148	5.46671	0.82652	1.07894
Standard Deviation	32.96317	0.02078	0.93506	0.16159	0.72746

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	100.38529	0.20445	9.20006	1.57501	4.03524
2	84.39196	0.24148	10.86656	1.82601	3.92717
3	15.61947	0.17482	7.86675	0.93776	3.06378
Mean	66.79891	0.20691	9.31112	1.44626	3.67540
Standard Deviation	45.03829	0.03340	1.50299	0.45791	0.53242

75/25	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	5.98531	
2	45.00000	3.13000	19.78000	6.34211	
3	45.00000	3.13000	19.78000	7.38136	
Mean	45.00000	3.13000	19.78000	6.56959	
Standard Deviation	0.00000	0.00000	0.00000	0.72529	

	Load at Maximum	Tensile strain at Maximum	Tensile extension at	Energy at Maximum	Tensile stress at Break

	Tensile stress (N)	Tensile stress (mm/mm)	Maximum Tensile stress (mm)	Tensile stress (J)	(Standard) (MPa)
1	370.55889	0.08518	3.83331	0.88427	2.91540
2	392.64890	0.09778	4.40006	1.10817	0.88453
3	456.99039	0.17259	7.76669	2.62376	0.88732
Mean	406.73273	0.11852	5.33335	1.53873	1.56242
Standard Deviation	44.90398	0.04725	2.12630	0.94631	1.17172

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	180.49653	0.14593	6.56675	1.62207	5.98531
2	54.76237	0.18741	8.43337	1.93144	6.34211
3	54.93536	0.23262	10.46806	3.41017	7.38136
Mean	96.73142	0.18865	8.48939	2.32123	6.56959
Standard Deviation	72.54276	0.04336	1.95126	0.95566	0.72529

70/30	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	3.13000	19.78000	5.84375
2	45.00000	3.13000	19.78000	7.10206
3	45.00000	3.13000	19.78000	7.80124
Mean	45.00000	3.13000	19.78000	6.91568
Standard Deviation	0.00000	0.00000	0.00000	0.99197

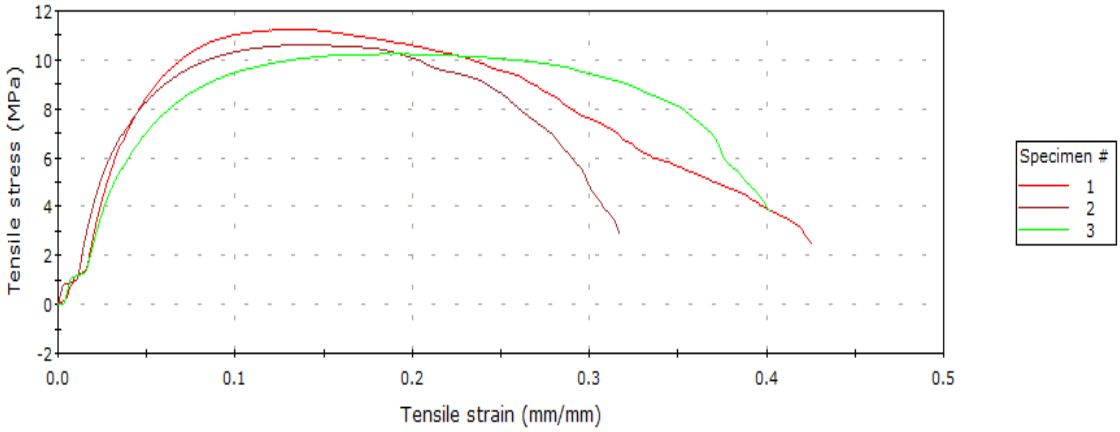
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	361.79449	0.09185	4.13331	0.98554	1.11582
2	439.69876	0.09407	4.23337	1.19214	1.19986
3	482.98584	0.12074	5.43344	1.80520	1.11715
Mean	428.15970	0.10222	4.60004	1.32763	1.14428
Standard Deviation	61.41416	0.01608	0.72347	0.42629	0.04814

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	69.08181	0.13778	6.20006	1.35176	5.84375
2	74.28504	0.14224	6.40069	1.84560	7.10206
3	69.16450	0.17037	7.66669	2.33009	7.80124
Mean	70.84379	0.15013	6.75581	1.84248	6.91568
Standard Deviation	2.98050	0.01767	0.79519	0.48917	0.99197

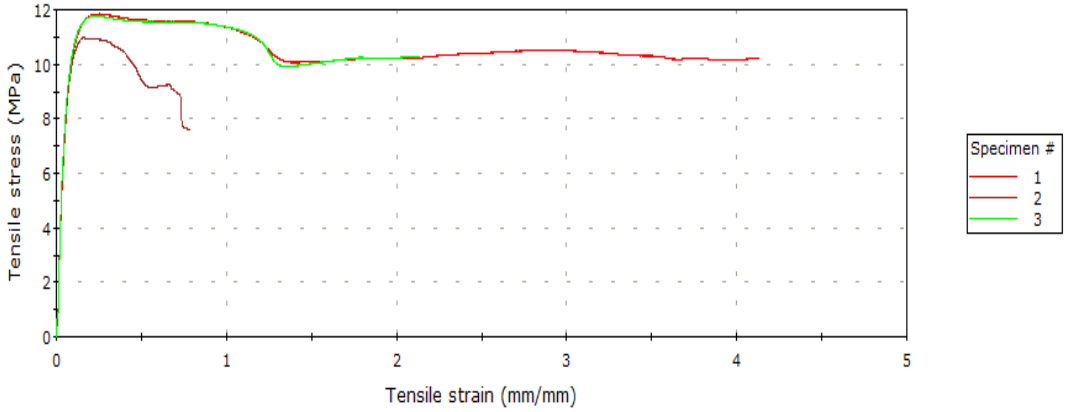
APPENDIX B

Raw Plot obtained from CERD, IFE OSUN STATE.

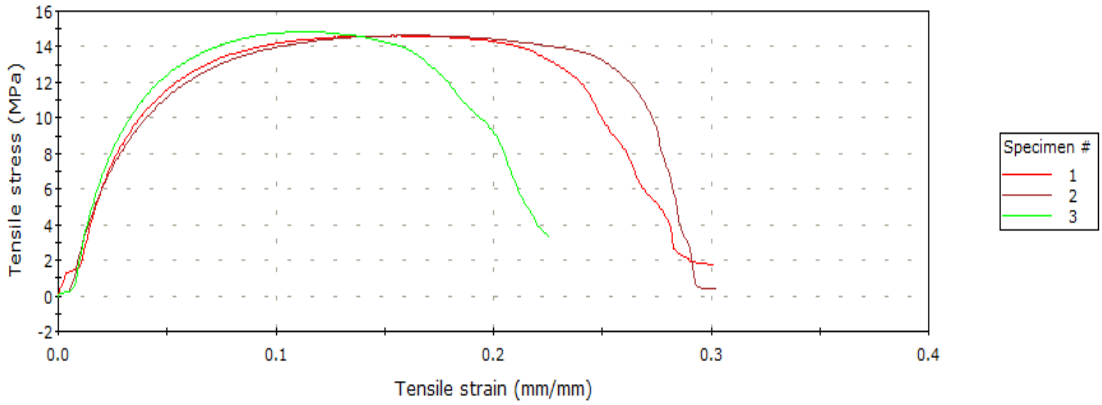
Tensile Test to Determine the Mechanical Properties of 2, 4, 6, 8 and 10 wt% NaOH Treated Baobab Fibre Reinforced Low Density Polyethylene Composite



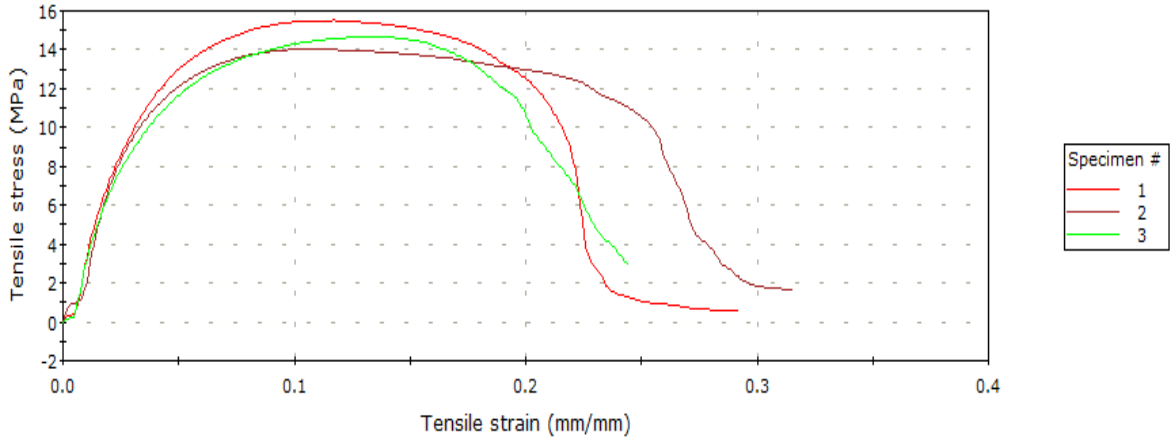
Stress-Strain curve for 2 wt% treated baobab fibre LDPE composite



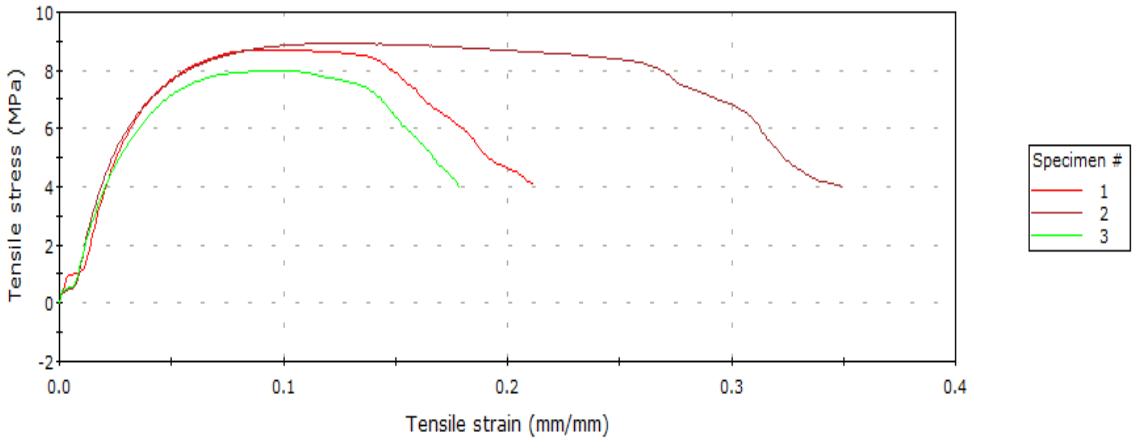
Stress-Strain curve for 4 wt% NaOH treated baobab fibre LDPE composite



Stress-Strain curve for 6 wt% baobab fibre treated LDPE composite



Stress-Strain curve for 8 wt% baobab fibre treated LDPE composite



Stress-Strain curve for 10 wt% treated baobab fibre LDPE composite.

2 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	11.12024	
2	45.00000	3.13000	19.78000	10.41383	
3	45.00000	3.13000	19.78000	10.20172	
Mean	45.00000	3.13000	19.78000	10.5786	
Standard Deviation	0.00000	0.00000	0.00000	0.51538	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	697.13728	0.13407	6.03331	3.04018	2.52369
2	657.11695	0.13482	6.02669	2.99096	2.97626
3	634.07947	0.18963	8.53337	4.18112	3.80559
Mean	662.77790	0.15284	6.87779	3.40409	3.10185
Standard Deviation	31.90778	0.03186	1.43387	0.67338	0.65011
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	156.24521	0.42519	19.13337	9.50147	11.26024
2	184.26469	0.31704	14.26675	7.37422	10.61383
3	235.60957	0.40148	18.06668	9.37363	10.24172
Mean	192.03982	0.38124	17.15560	8.74977	10.70526
Standard Deviation	40.24941	0.05685	2.55804	1.19298	0.51538
4 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	11.05305	
2	45.00000	3.13000	19.78000	10.91341	
3	45.00000	3.13000	19.78000	11.77406	
Mean	45.00000	3.13000	19.78000	11.87684	
Standard Deviation	0.00000	0.00000	0.00000	0.48091	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	733.83902	0.25333	11.40006	6.73513	10.24012

2	679.99843	0.15630	7.03337	3.51049	7.60396
3	728.94832	0.22889	10.30000	5.99622	10.28798
Mean	714.26192	0.21284	9.57781	5.41395	9.37735
Standard Deviation	29.77365	0.05047	2.27116	1.68934	1.53599

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	633.98005	4.13738	186.18204	121.37548	11.85305
2	470.77164	0.78741	35.43337	20.73590	10.98341
3	636.94296	2.14371	96.46673	63.80680	11.77406
Mean	580.56489	2.35616	106.02738	68.63940	11.53684
Standard Deviation	95.09528	1.68506	75.82773	50.49353	0.48091

6 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	2.00000	18.68000	14.22891
2	45.00000	2.00000	18.68000	14.44557
3	45.00000	2.00000	18.68000	13.04693
Mean	45.00000	2.00000	18.68000	13.70714
Standard Deviation	0.00000	0.00000	0.00000	0.12135

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	546.53599	0.15630	7.03337	3.03756	1.74579
2	547.15849	0.16370	7.36669	3.16561	0.38111
3	554.68143	0.11556	5.20006	2.15460	3.37869
Mean	549.45863	0.14519	6.53337	2.78592	1.83520
Standard Deviation	4.53377	0.02593	1.16665	0.55048	1.50079

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	65.22289	0.30148	13.56669	5.63202	14.62891
2	14.23845	0.30222	13.60006	5.88905	14.64557
3	126.22784	0.22519	10.13337	4.28020	14.84693
Mean	68.56306	0.27630	12.43337	5.26709	14.70714
Standard	56.06936	0.04427	1.99193	0.86428	0.12135

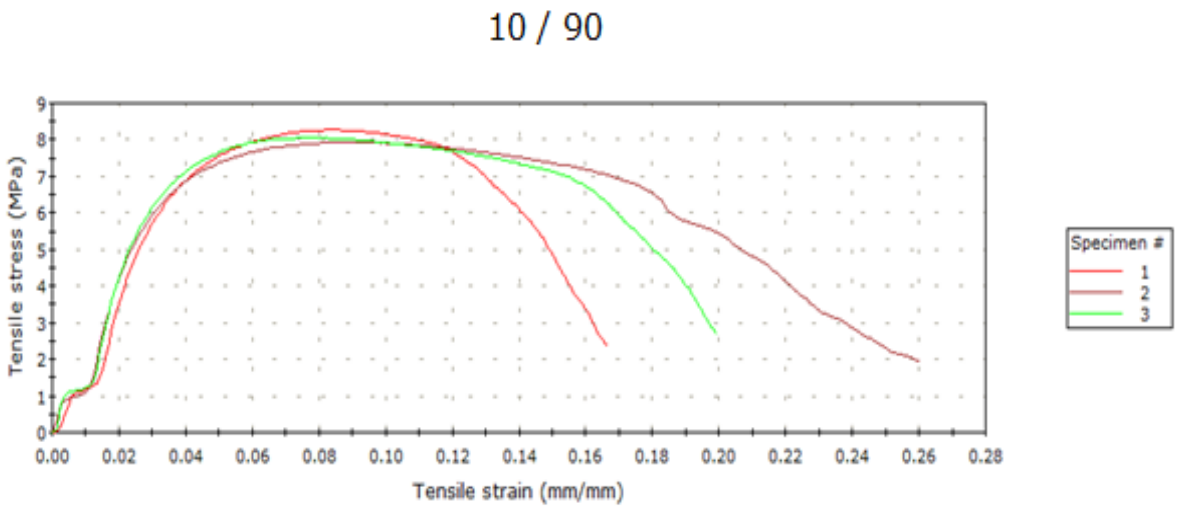
Deviation					
8 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	2.00000	18.68000	15.21340	
2	45.00000	2.00000	18.68000	14.04266	
3	45.00000	2.00000	18.68000	14.36245	
Mean	45.00000	2.00000	18.68000	14.53950	
Standard Deviation	0.00000	0.00000	0.00000	0.73840	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	579.58076	0.11704	5.26669	2.30933	0.60275
2	524.63361	0.10445	4.70006	1.83156	1.66455
3	547.78904	0.13111	5.90006	2.45459	3.00256
Mean	550.66780	0.11753	5.28894	2.19849	1.75662
Standard Deviation	27.58646	0.01334	0.60031	0.32597	1.20255
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	22.51879	0.29188	13.13469	4.91273	15.51340
2	62.18745	0.31482	14.16669	5.52905	14.04266
3	112.17562	0.24370	10.96669	4.51333	14.66245
Mean	65.62729	0.28347	12.75602	4.98504	14.73950
Standard Deviation	44.92729	0.03629	1.63326	0.51171	0.73840
10wt%NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	2.00000	18.68000	8.80829	
2	45.00000	2.00000	18.68000	8.93284	
3	45.00000	2.00000	18.68000	7.98415	
Mean	45.00000	2.00000	18.68000	8.56176	
Standard Deviation	0.00000	0.00000	0.00000	0.49579	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)

			(mm)		
1	325.34173	0.09259	4.16669	0.96830	4.10493
2	333.73097	0.13556	6.10006	1.62170	4.01600
3	298.28772	0.10297	4.63344	1.04549	4.01387
Mean	319.12014	0.11037	4.96673	1.21183	4.04493
Standard Deviation	18.52261	0.02242	1.00886	0.35705	0.05197
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	153.36027	0.21111	9.50000	2.39875	8.70829
2	150.03775	0.34889	15.70000	4.36638	8.93284
3	149.95818	0.17852	8.03337	1.89194	7.98415
Mean	151.11874	0.24617	11.07779	2.88569	8.54176
Standard Deviation	1.94163	0.09043	4.06956	1.30711	0.49579

APPENDIX C

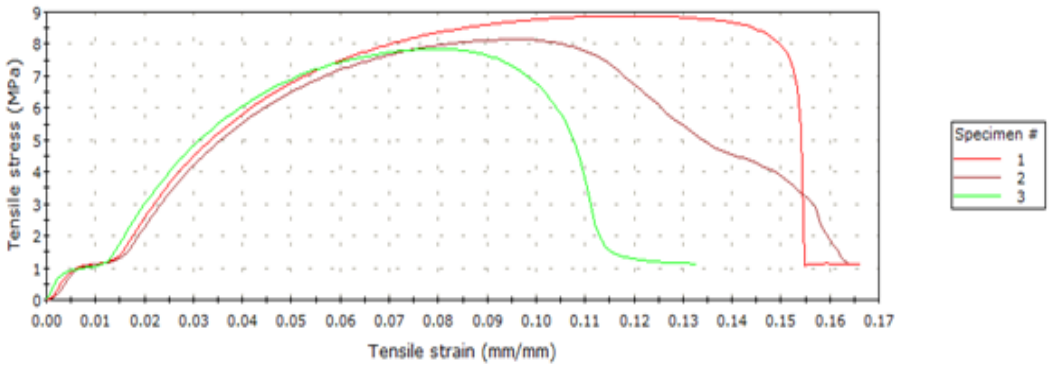
Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile Test to Determine the Mechanical Properties of 10:90, 20:80, 30:70, 40:60, 50:50 and 100:0 Sisal:Baobab hybridized Reinforced Low Density Polyethylene Composite



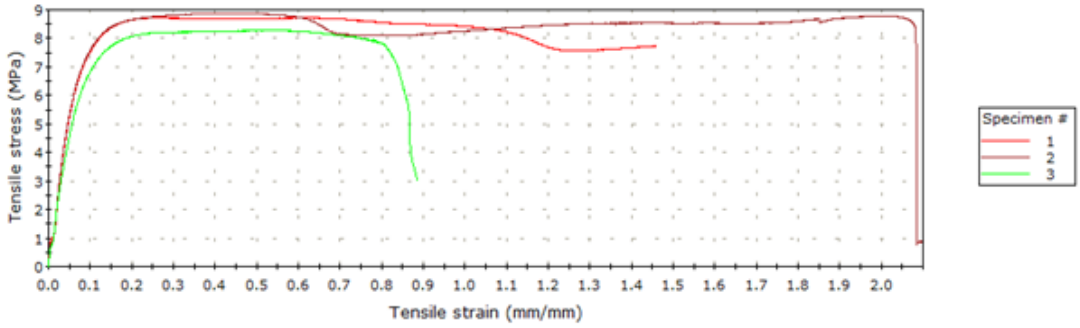
Stress-Strain curve for 10:90 sisal:baobab fibre ratio composite

20 / 80



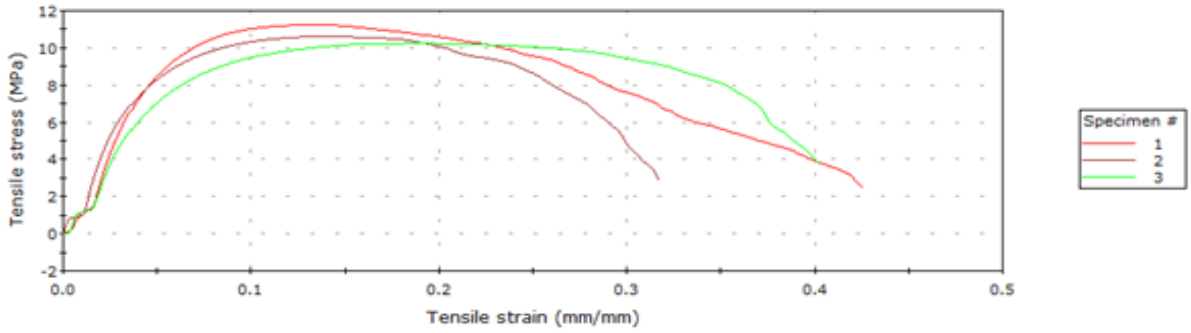
Stress-Strain Curve for 20:80 sisal:baobab fibre ratio composite

30 / 70

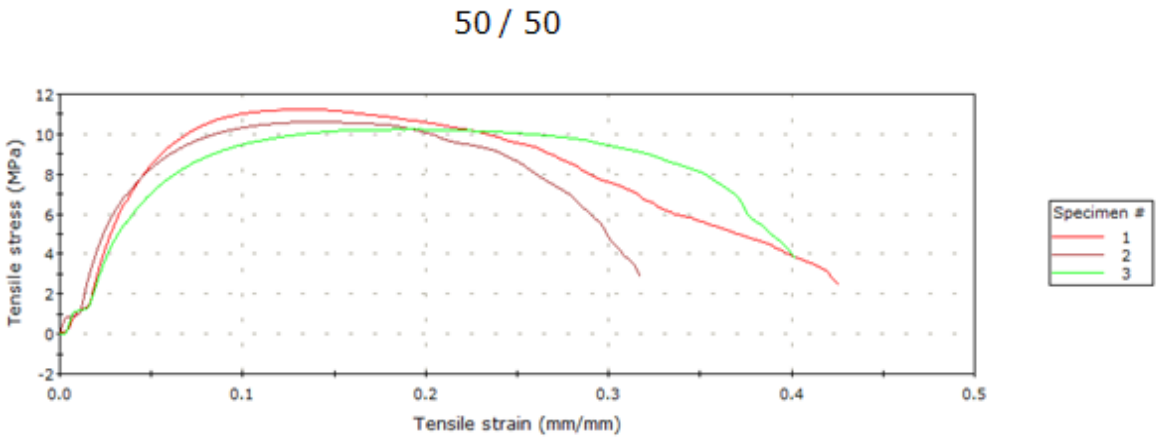


Stress-Strain curve for 30:70 sisal:baobab fibre ratio composite

40 / 60



Stress-Strain curve for 40:60 sisal:baobab fibre ratio composite.



Stress-Strain curve for 50:50 sisal:baobab fibre ratio composite.

10:90 sisal:baobab	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	8.47646	
2	45.00000	3.12000	19.78000	8.12533	
3	45.00000	3.13000	19.78000	8.14937	
Mean	45.00000	3.13000	19.78000	8.25039	
Standard Deviation	0.00000	0.00000	0.00000	0.19615	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	528.16076	0.06333	2.53337	0.83914	3.17607
2	236.59195	0.02583	1.03337	0.11512	0.59649
3	428.79344	0.04000	1.60006	0.34768	2.19517
Mean	397.84872	0.04306	1.72227	0.43398	1.98924
Standard Deviation	148.22710	0.01894	0.75743	0.36964	1.30206
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	222.47741	0.09417	3.76681	1.33540	7.53998
2	41.78288	0.13917	5.56669	0.47242	3.37757

3	153.76719	0.07000	2.80006	0.70281	-----
Mean	139.34249	0.10111	4.04452	0.83688	5.45878
Standard Deviation	91.20681	0.03510	1.40406	0.44684	2.94327
20:80 sisal:baobab	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	8.97355	
2	45.00000	3.13000	19.78000	8.44224	
3	45.00000	3.13000	19.78000	8.14752	
Mean	45.00000	3.13000	19.78000	8.52110	
Standard Deviation	0.00000	0.00000	0.00000	0.41862	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	457.32772	0.08667	3.46675	1.04247	1.14889
2	567.94100	0.13833	5.53337	2.34417	1.03456
3	563.29076	0.13417	5.36675	2.24345	1.03921
Mean	529.51983	0.11972	4.78896	1.87670	1.07422
Standard Deviation	62.56342	0.02870	1.14809	0.72422	0.06471
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	80.47731	0.14167	5.66669	1.86909	6.52878
2	72.46893	0.21667	8.66662	3.64141	8.10788
3	72.79454	0.23305	9.32206	4.01310	8.04150
Mean	75.24692	0.19713	7.88512	3.17453	7.55939
Standard Deviation	4.53257	0.04872	1.94897	1.14572	0.89315
30:70 sisal:baobab	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	8.83541	
2	45.00000	3.13000	19.78000	8.87549	
3	45.00000	3.13000	19.78000	8.38113	
Mean	45.00000	3.13000	19.78000	8.69734	
Standard Deviation	0.00000	0.00000	0.00000	0.27458	
	Load at	Tensile strain	Tensile	Energy at	Tensile stress

	Maximum Tensile stress (N)	at Maximum Tensile stress (mm/mm)	extension at Maximum Tensile stress (mm)	Maximum Tensile stress (J)	at Break (Standard) (MPa)
1	481.51757	0.19500	7.80006	2.94959	0.90316
2	460.92137	0.13167	5.26669	1.74548	2.98984
3	495.69728	0.15750	6.30006	2.28125	1.04432
Mean	479.37874	0.16139	6.45560	2.32544	1.64577
Standard Deviation	17.48634	0.03185	1.27383	0.60327	1.16613

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	63.26438	0.31952	12.78069	4.96054	6.87411
2	209.43228	0.21917	8.76669	2.87742	6.58008
3	73.15237	0.22500	9.00000	3.10833	7.07654
Mean	115.28301	0.25456	10.18246	3.64877	6.84357
Standard Deviation	81.68542	0.05633	2.25315	1.14188	0.24963

40:60 sisal:baobab	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	3.13000	19.78000	11.05142
2	45.00000	3.13000	19.78000	10.40263
3	45.00000	3.13000	19.78000	10.02151
Mean	45.00000	3.13000	19.78000	10.49185
Standard Deviation	0.00000	0.00000	0.00000	0.52072

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	559.40407	0.15167	6.06669	2.57257	0.41122
2	484.04508	0.10167	4.06669	1.33201	2.22104
3	482.85844	0.08833	3.53337	1.11031	2.64068
Mean	508.76920	0.11389	4.55558	1.67163	1.75765
Standard Deviation	43.85510	0.03339	1.33555	0.78807	1.18477

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)

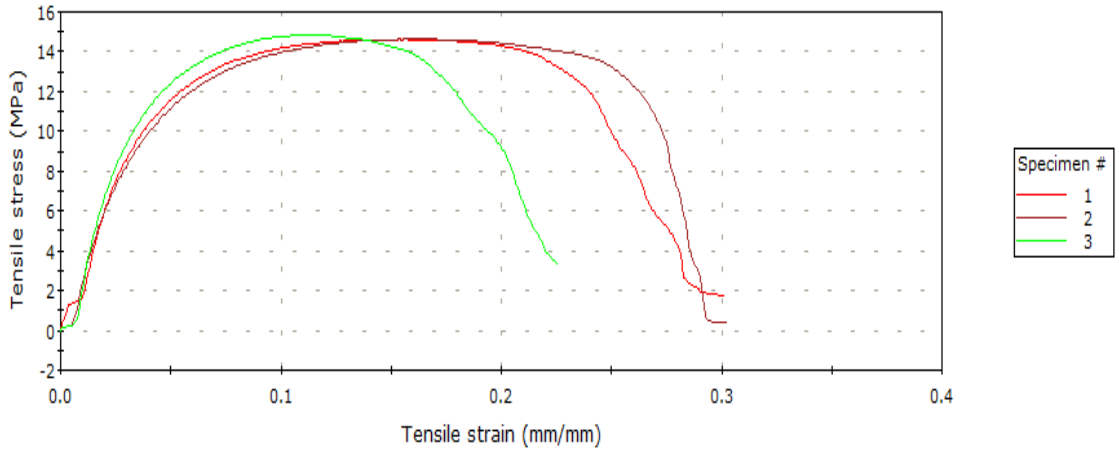
1	28.80522	0.23750	9.50000	3.74896	7.98601
2	155.57916	0.17417	6.96669	2.39143	6.91019
3	184.97461	0.15583	6.23337	2.16414	6.89325
Mean	123.11966	0.18917	7.56669	2.76818	7.26315
Standard Deviation	82.99056	0.04285	1.71397	0.85695	0.62607
50:50 sisal:baobab	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	3.13000	19.78000	11.26024	
2	45.00000	3.13000	19.78000	10.61383	
3	45.00000	3.13000	19.78000	10.24172	
Mean	45.00000	3.13000	19.78000	10.24172	
Standard Deviation	0.00000	0.00000	0.00000	0.51538	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	393.19717	0.09417	3.76669	0.99109	0.60077
2	581.40215	0.15083	6.03337	2.65427	0.87195
3	395.38052	0.07667	3.06675	0.77141	0.91144
Mean	456.65995	0.10722	4.28894	1.47226	0.79472
Standard Deviation	108.03543	0.03877	1.55073	1.02952	0.16912
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	42.08261	0.17000	6.79994	1.63493	5.61325
2	61.07822	0.22185	8.87406	3.51454	8.30005
3	63.84485	0.13632	5.45269	1.29463	5.64442
Mean	55.66856	0.17606	7.04223	2.14803	6.51924
Standard Deviation	11.84682	0.04309	1.72351	1.19560	1.54231
100% Sisal					
1	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
2	45.00000	3.13000	19.78000	12.72451	
3	45.00000	3.13000	19.78000	12.87549	
Mean	45.00000	3.13000	19.78000	11.68108	
Standard Deviation	45.00000	3.13000	19.78000	12.46670	

	0.00000	0.00000	0.00000	0.30896	
1	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
2	540.14642	0.26741	12.03344	5.23330	7.73151
3	549.49406	0.43037	19.36656	9.27520	0.86891
Mean	512.69308	0.54223	24.40018	11.12445	3.00147
Standard Deviation	534.11118	0.41333	18.60006	8.54432	3.86730
	19.12841	0.13820	6.21890	3.01282	3.51228
1	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
2	478.66888	1.45852	65.63337	32.88505	8.72451
3	53.79536	2.09703	94.36655	48.44872	8.87549
Mean	185.82529	0.88593	39.86668	18.44990	8.28108
Standard Deviation	239.42984	1.48049	66.62220	33.26122	8.62702
	217.44991	0.60585	27.26339	15.00295	0.30896

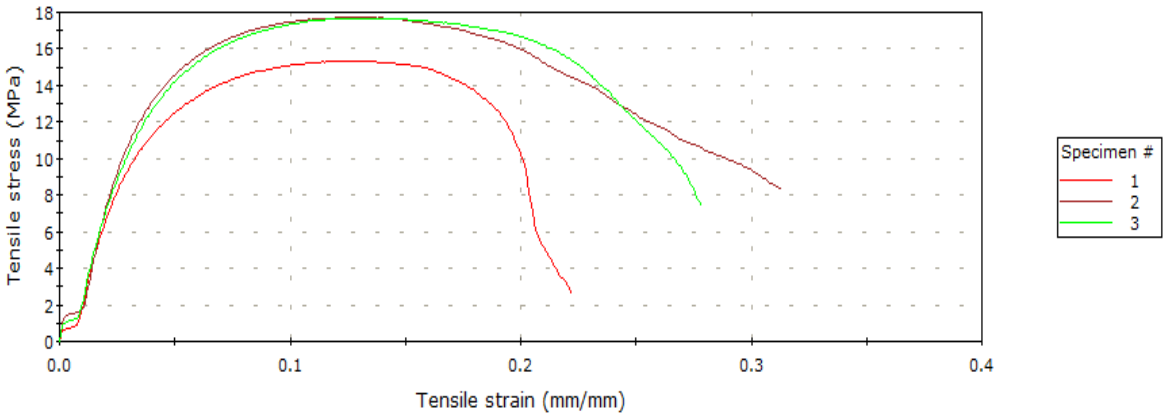
APPENDIX D

Raw Plot obtained from CERD, IFE OSUN STATE.

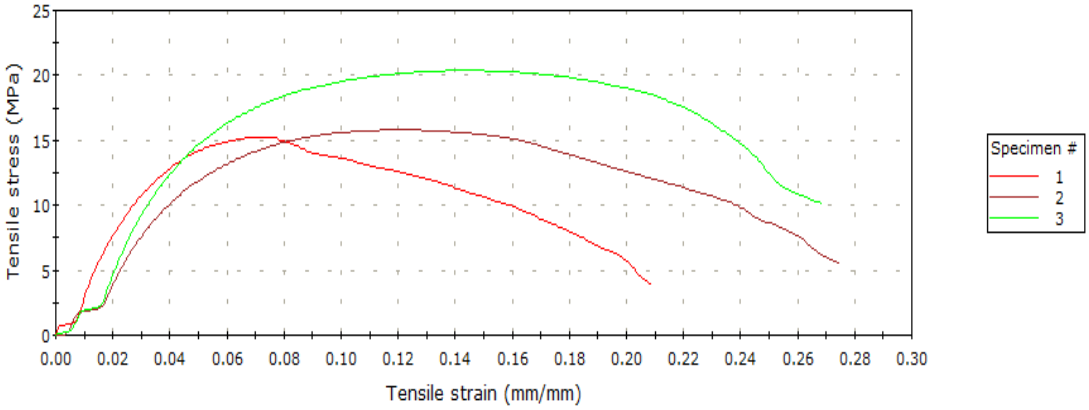
Tensile Test to Determine the Mechanical Properties of 2, 4, 6, 8 and 10 wt% Concentration of NaOH Treated Sisal:Baobab Hybridized Reinforced Low Density Polyethylene Composite



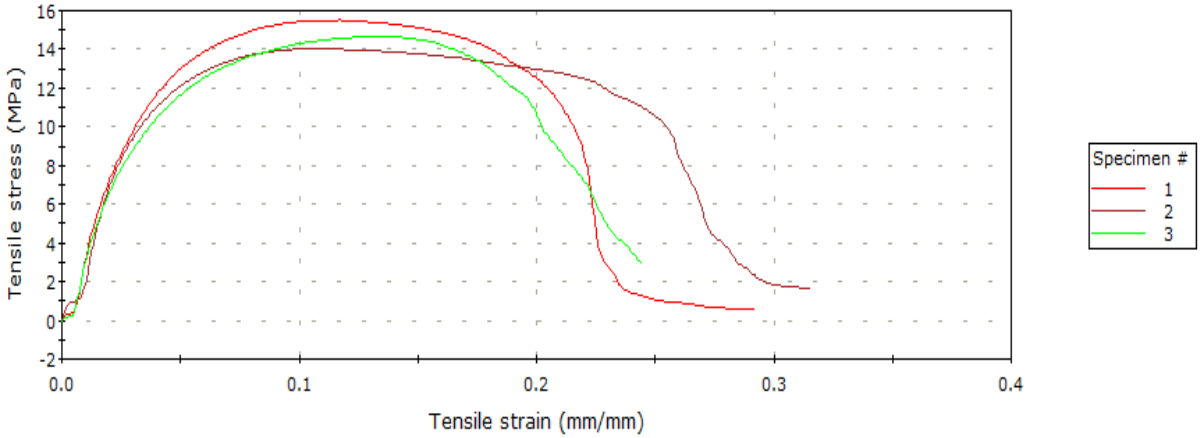
Stress-Strain Curve for Fibre Treated with 2 wt% concentrated NaOH



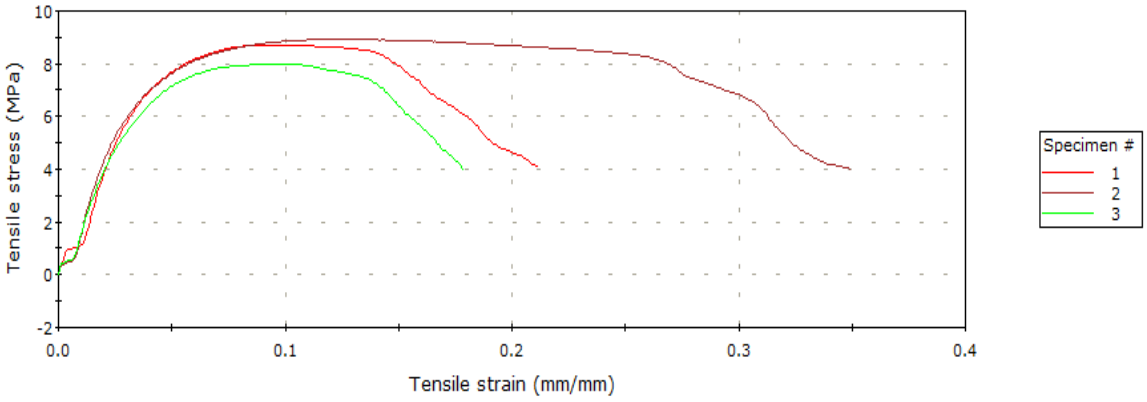
Stress-Strain Curve for Fibre Treated with 4 wt% Concentrated NaOH



Stress-Strain Curve for Fibre Treated with 6 wt% Concentrated NaOH



Stress-Strain Curve for Fibre Treated with 8 wt% Concentrated NaOH



Stress-Strain Curve for Fibres Treated with 10 wt% NaOH

2 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	2.00000	18.68000	14.62891	
2	45.00000	2.00000	18.68000	14.64557	
3	45.00000	2.00000	18.68000	14.84693	
Mean	45.00000	2.00000	18.68000	14.70714	
Standard Deviation	0.00000	0.00000	0.00000	0.12135	
	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	546.53599	0.15630	7.03337	3.03756	1.74579
2	547.15849	0.16370	7.36669	3.16561	0.38111
3	554.68143	0.11556	5.20006	2.15460	3.37869
Mean	549.45863	0.14519	6.53337	2.78592	1.83520
Standard Deviation	4.53377	0.02593	1.16665	0.55048	1.50079
	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	65.22289	0.30148	13.56669	5.63202	14.62891

2	14.23845	0.30222	13.60006	5.88905	14.64557
3	126.22784	0.22519	10.13337	4.28020	14.84693
Mean	68.56306	0.27630	12.43337	5.26709	14.70714
Standard Deviation	56.06936	0.04427	1.99193	0.86428	0.12135

4 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	2.00000	18.68000	15.32460	
2	45.00000	2.00000	18.68000	17.73068	
3	45.00000	2.00000	18.68000	17.67427	
Mean	45.00000	2.00000	18.68000	16.90985	
Standard Deviation	0.00000	0.00000	0.00000	1.37316	

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	572.52706	0.12296	5.53325	2.37788	2.79998
2	662.41818	0.13111	5.90006	2.99124	8.36337
3	660.31087	0.14148	6.36662	3.25430	7.53328
Mean	631.75204	0.13185	5.93331	2.87447	6.23221
Standard Deviation	51.30115	0.00928	0.41768	0.44973	3.00124

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	104.60707	0.22148	9.96669	4.42549	15.32460
2	312.45549	0.31259	14.06669	7.26864	17.73068
3	281.44324	0.27778	12.49994	6.67941	17.67427
Mean	232.83527	0.27062	12.17777	6.12451	16.90985
Standard Deviation	112.12623	0.04598	2.06890	1.50060	1.37316

6 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)	
1	45.00000	2.00000	18.68000	15.22527	
2	45.00000	2.00000	18.68000	15.60827	
3	45.00000	2.00000	18.68000	20.40997	
Mean	45.00000	2.00000	18.68000	17.14784	
Standard Deviation	0.00000	0.00000	0.00000	2.84009	

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	568.81607	0.07037	3.16662	1.20307	3.99640
2	590.59695	0.11926	5.36675	2.19518	5.53961
3	762.51645	0.14444	6.49994	3.57599	10.15573
Mean	640.64316	0.11136	5.01110	2.32475	6.56392
Standard Deviation	106.10573	0.03766	1.69488	1.19176	3.20487

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	149.30569	0.20815	9.36662	3.72237	15.22527
2	206.95997	0.27482	12.36669	5.40954	15.80827
3	379.41795	0.26815	12.06669	7.16713	20.40997
Mean	245.22787	0.25037	11.26666	5.43301	17.14784
Standard Deviation	119.73403	0.03672	1.65231	1.72250	2.84009

8 wt% NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	2.00000	18.68000	15.51340
2	45.00000	2.00000	18.68000	14.04266
3	45.00000	2.00000	18.68000	14.66245
Mean	45.00000	2.00000	18.68000	14.73950
Standard Deviation	0.00000	0.00000	0.00000	0.73840

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	579.58076	0.11704	5.26669	2.30933	0.60275
2	524.63361	0.10445	4.70006	1.83156	1.66455
3	547.78904	0.13111	5.90006	2.45459	3.00256
Mean	550.66780	0.11753	5.28894	2.19849	1.75662
Standard Deviation	27.58646	0.01334	0.60031	0.32597	1.20255

	Load at	Tensile strain	Tensile	Energy at	Tensile stress

	Break (Standard) (N)	at Break (Standard) (mm/mm)	extension at Break (Standard) (mm)	Break (Standard) (J)	at Yield (Zero Slope) (MPa)
1	22.51879	0.29188	13.13469	4.91273	15.51340
2	62.18745	0.31482	14.16669	5.52905	14.04266
3	112.17562	0.24370	10.96669	4.51333	14.66245
Mean	65.62729	0.28347	12.75602	4.98504	14.73950
Standard Deviation	44.92729	0.03629	1.63326	0.51171	0.73840

10wt%NaOH	Length (mm)	Thickness (mm)	Width (mm)	Maximum Tensile stress (MPa)
1	45.00000	2.00000	18.68000	8.70829
2	45.00000	2.00000	18.68000	8.93284
3	45.00000	2.00000	18.68000	7.98415
Mean	45.00000	2.00000	18.68000	8.54176
Standard Deviation	0.00000	0.00000	0.00000	0.49579

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	325.34173	0.09259	4.16669	0.96830	4.10493
2	333.73097	0.13556	6.10006	1.62170	4.01600
3	298.28772	0.10297	4.63344	1.04549	4.01387
Mean	319.12014	0.11037	4.96673	1.21183	4.04493
Standard Deviation	18.52261	0.02242	1.00886	0.35705	0.05197

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	153.36027	0.21111	9.50000	2.39875	8.70829
2	150.03775	0.34889	15.70000	4.36638	8.93284
3	149.95818	0.17852	8.03337	1.89194	7.98415
Mean	151.11874	0.24617	11.07779	2.88569	8.54176
Standard Deviation	1.94163	0.09043	4.06956	1.30711	0.49579