# EFFECTS OF FIBRE HYBRIDIZATION ON THE PROPERTIES OF NATURAL FIBRE FILLED EPOXY COMPOSITES

**BY**

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**MAY, 2017**

## DECLARATION

I declare that the work in this dissertation entitled "**EFFECTS OF FIBRE HYBRIDIZATION ON THE PROPERTIES OF NATURAL FIBRE FILLED EPOXY COMPOSITES"** has been carried out by me in the Department of Textile Science and Technology. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Raphael Oluwatoyin OGABI

_____ _____ _____

Name of Student Signature Date

## CERTIFICATION

This Thesis entitled "**EFFECTS OF FIBRE HYBRIDIZATION ON THE PROPERTIES OF NATURAL FIBRE FILLED EPOXY COMPOSITES"** by Raphael Oluwatoyin OGABI meets the regulations governing the award of the degree of Master of Science in Textile Science and Technology of Ahmadu Bello University, and is approved for its contribution to knowledge and literal presentation.

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## ABSTRACT

The problems of low mechanical properties of composites reinforced with fibres of natural origin have been a source of concern for researchers. Also, the insufficient utilization of bagasse fibres due to its moderate strength has further reduced its potentialities in composite production hence the need to hybridize with other fibres.

In this work, the effects of hybridization on the physical and mechanical properties of bagasse/sisal/coir fibre-reinforced epoxy composites have been studied.

Test specimens were prepared with different weight fractions of bagasse/sisal/coir in Epoxy resin using hand lay-up method. The samples were characterized for mechanical properties such as tensile strength, flexural strength, hardness and impact strength using ASTM standards. Physical properties such as density and water absorption were also determined. SEM analysis was done to establish microstructure of the fractured samples after the tensile test.

The highest tensile strength of 53.25 MPa was obtained for bagasse/sisal/coir at a hybrid ratio of 60/10/30 %, this was 70.1% higher than the monolithic bagasse/Epoxy composite.

The composite having composition of 50 %Bagasse/50 % Coir showed aflexural modulus of 3.15 GPa while 60/30/10 % had 4.96 GPa with increase of 50 % over 20% bagasse/Epoxy composite.

Hybridization did not improve the hardness of the composites as the highest value was 8.5 RHF at 5% fibre loading of only bagasse.

The highest impact strength of 65 $J/m^2$ was obtained for bagasse/sisal/coir at a hybrid ratio of 60/20/20 %. Therefore a crash helmet was fabricated at this composition of fibre blend.

The water absorption increases as the fibre loading increases, with the hybrid 60/10/30 % having the highest percentage water absorption value of 10.8 %. This was higher than the bagasse/Epoxy composite with the value of 3.5 % at 20% fibre loading.

The SEM analysis showed more fibre pull out for bagasse/coir at 60/40 % than for other hybrid ratios after tensile test. 60/20/20 % gave the best fibre-matrix interaction since there was no fibre fracture or the presence voids.

Hence, it can be concluded that proper combination of bagasse/sisal/coir Epoxy reinforced hybrid composite material may have a variety of industrial applications especially where strength and water absorption would be the critical parameters in the design.

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## Abbreviations

| | |
|---|---|
| Absorp. | Absorption |
| B/C | Bagasse/Coir |
| BF | Bagasse Fibre |
| B/S | Bagasse/Sisal |
| B/S/C | Bagasse/Sisal/Coir |
| BFRC | Bagasse Fibre Reinforced Composite |
| BSFRC | Bagasse Sisal Fibre Reinforced Composite |
| BCRC | Bagasse Coir Fibre Reinforced Composite |
| BSCRC | Bagasse Sisal Coir Reinforced Composite |
| CF | Coir Fibre |
| Comp. | Composite |
| .bre | Fibre |
| SF | Sisal Fibre |

# CHAPTER ONE

## INTRODUCTION

Composites, the wonder materials are becoming an essential part of today's materials due to the advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly (Thwe and Liao, 2003).

They are extensively used as materials in making aircraft structures, military armors, electronic packaging, medical equipment, space vehicle and home building (Shaw *et al*., 2010).

The predominant useful materials used in our day-to-day life are wood, concrete, ceramics, and so on. Surprisingly, the most important polymeric composites are found in nature and these are known as natural composites. The connective tissues in mammals belong to the most advanced polymer composites known to mankind where the fibrous protein, collagen is the reinforcement. It functions both as soft and hard connective tissue(Siddika*et al*., 2013).

Composites are combinations of materials differing in composition, where the individual constituents retain their separate identities. These separate constituents act together to give the necessary mechanical strength or stiffness to the composite part(Nishino, 2006).

In recent years; there has been growing environmental consciousness and understanding of the need for sustainable development, which has raised interest in using natural fibres as reinforcements in polymer composites to replace synthetic fibres such as glass, graphite and carbon fibres (Netravali and Luo, 1999).

Countries such as Egypt, Cuba, etc. used bagasse fibre in pulp, paper industries and for board materials (Silva and Al-Qureshi, 2010). Thus, these natural residues are not just helping some nations in their economy, but also reducing or eliminating urban waste.

Hybrid composites are made of more than one reinforcing phases and a single matrix or single reinforcing phase and multiple matrix phases.

Hybrid composites can be designed by the combination of a synthetic fibre and natural fibre (biofibre) in a matrix or a combination of two natural fibre/biofibre in a matrix.

Hybrid composite provide greater freedom when it comes to designing composites for specific properties as compared to single fibre reinforced composites.

Recently, natural fibres such as bamboo, jute etc. have been mixed with synthetic fibres such as glass to form hybrid composite which plays important role in the composites with desired properties at low cost. The behavior of hybrid composites is a weighed sum of individual components in which there is a more favorable balance between the inherent advantages and disadvantages. The properties of all the composites are decided by many factors such as fibre content, fibre length, orientation, extent of intermingling of fibres, fibre matrix bonding etc (Siddika*et al*., 2013).

Hybrid composites materials have better all-round combination of properties than composites containing only one single fibre type. Hybrid composites may replace or reduce the utilization of synthetic fibres in applications of automotive, building industries, aircraft, (Jawaid*et al.,* 2012).

Jute-coir hybrid composites find application in railway coaches for sleeper berth backing, for building interiors, doors and windows besides in transportation sector as backings for seat and backrest in buses (Baley *et al.,* 2006).

Most hybrid composites usually contain two reinforcement phases but in this work, three reinforcement phases were considered in the course of the experimentation. The natural fibres: Bagasse (Sugar cane fibres), Sisal and Coir (Coconut fibres) were incorporated into epoxy resin matrix.Bagasse is the fibrous matter that remains after sugarcane is crushed to extract their juice. It is used as a biofuel and in the manufacture of pulp and building materials. These fibres possess moderate strength and stiffness. Easy availability, of these reinforced materials induced the interest and curiosity to take up this work (Chand and Jain, 2003).

## 1.1 STATEMENT OF RESEARCH PROBLEM

Fibre reinforced composite, usually made of glass, aramid, or carbon fibre reinforced with polymer are being used extensively, because of their sustainable high mechanical performance. However, they are:

i. Non-biodegradable,

ii. quite expensive materials, and

iii. Not readily available especially in Nigeria (Cao*et al*., 2006).

Bagasse from various geographical locations in Nigeria is regarded as waste, littering the environment. In other countries like India, it is been burn as bio-fuel thereby releasing gases that are hazardous to nature. Hence, if this waste is made useful, this problem of environmental pollution will be minimized.

Also in Cuba and Egypt, bagasse has been used to make paper and pulp. However, due to its moderate strength it has not yet gained application as engineering material for better industrial use(Silva and Al-Qureshi, 2010).

Finally, to the best of my knowledge, not many works has been researched on hybrid composites that require the use of three natural fibres in a common matrix.

## 1.2 JUSTIFICATION

In recent years, there has been growing environmental consciousness and understanding of the need for sustainable development, which has raised interest in using natural fibres as reinforcements in polymer composites to reduce or replace synthetic fibres such as glass, carbon and graphite fibres (Nishino *et al.*, 2006).

The usage of only one fibre may not satisfy all the needs of the composites interms of performance. Hence the systematic investigation of the use of hybrid fibres to produce compositeswith enhanced mechanical properties.

The following are the specific justifications for carrying out this research.

i. This research will add economic value to the abundant bagasse fibre which in turn will reduce the environmental hazard caused by improper disposal and open burning.
ii. This work is expected to develop a new class of polymer composite that can be used in the production of helmet.
iii. The development of small and medium scale enterprise in Nigeria by the establishment of bagassefibre composite factories which in turn will create jobs and reduce unemployment

## 1.2 Aim and Objectives of the Research

### 1.2.1 Aim

This research work is aimed at producing hybrid of Bagasse/Sisal/Coir fibrereinforced with epoxy resinand to cast a safety helmet based on thebest formulation and results of characterization of the composites.

### 1.2.1 Objectives

The aim is achieved through the following objectives:

i. Extraction ofthe natural fibres using mechanical method.

ii. Alkaline treatment of the natural using sodium hydroxide solution.

iii. Study of the effect of different fibre loadings on the mechanical properties of the hybrid composite.

iv. Optimization of the mechanical properties (based on the highest numerical value) of bagasse composite by utilizing the advantages offered by other supporting fibres (sisal and coir) for the development of the hybridcomposite materials.

v. Evaluation of the composite samples (both the unhybrized and hybridized composites) in terms of tensile strength, flexural strength and flexural, impact strength, hardness, density, water absorption (%) and scanning electronic microscopy.

vi. Development of a crash helmet based on the best formulation and results of the mechanical properties of the hybrid composites.

## 1.4 Scope of the Study

Based on the availability of resources and associated cost, this research work is limited to the following:

i. Extraction of the natural fibres (bagasse, sisal and coir).

ii. Only alkaline treatment of the fibres using Sodium hydroxide solutionwas carried out.

iii. The fabrication of the fibres-reinforced hybrid composites using hand lay-up technique.

iv. Analysis of themechanical and physical properties of the composite samples via:

a. Universal Testing Machine (Tensile).

b. Charpy Impact test (Ability of the composite to absorb shock).

c. Indentec Universal Hardness Testing Machine (Hardness of the composite).

v. Evaluation of the density, water absorption property and the Scanning Electron Microscopic (SEM) studies of the composites.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Fibres

Fibre is a unit of matter that is characterized by high ratio of length to thickness. Fibres can be generally classified into man-made and naturalfibres.

### 2.1.1 Man-made Fibres

A synthetic fibre isformed from a long polymer chain which comprise of small monomeric units joined together covalently. Each small unit is actually a chemical substance. Many such small units combine to form a large single unit called a polymer. The word ‘polymer’ comes from two Greek words; ‘poly’ meaning many and ‘mer’ meaning part/unit. So, a polymer is made of many repeating units (Bledzki *et al.*, 2002). Synthetic or man-made fibres generally come from synthetic materials such as petrochemicals. But some types of synthetic fibres are manufactured from natural cellulose such as rayon, polyester, nylon, acrylics etc.

### 2.1.2Natural Fibres

Fibres are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope.

Natural fibres include those produced by plants, animals and geographical processes. They are biodegradable, abundantly available and very cheap (if not free).

Examples include bagasse, sisal, coir, cotton, hemp, jute, flax, ramie, and pineapple fibre, palm kernel, maize husketc.

Plant fibres are employed in the manufacture of paper and textile (cloth), as reinforcement in composites and dietary fibre is an important component of human nutrition (Chand and Rohatgi, 1994).

### 2.1.2.1Classification of Natural Fibres

Natural fibres can be classified according to their origin.

a. Animal fibre
b. Mineral fibre
c. Plant fibre

***a.Animal Fibres***

Animal fibres generally comprise proteins; examples mohair, wool, silk, alpaca, angora. Animal hair (wool or hair): Fibre taken from animals or hairy mammals. e.g.Sheep's wool, goat hair (cashmere, mohair), alpaca hair, horse hair, etc.

Silk fibre: Fibre collected from dried saliva of bugs or insects during the preparation of cocoons. Examples include silk from silk worms.

Avian fibre: Fibres from birds, e.g. feathers and feather fibre (Dahlke, *et al.*, 1998).

***b. Mineral fibre***

These can be categorized into the following:

Asbestos:example includes wollastnite, attapulgite and hallovsite (Mohanty *et al*., 2008).

Ceramic fibres: for example, Glass fibres (Glass wood and Quartz), aluminum oxide, silicon carbide, and boron carbide.

Metal fibres: such as Aluminum fibres etc

**c. *Plant fibre***

Plant fibres generally comprised mainly of cellulose: examples include cotton, jute, flax, ramie, sisal and hemp. This fibre can be further categorized into the following:

a. Seed fibre: Fibres collected from the seed and seed case e.g. cotton and kapok.

b. Leaf fibre: Fibres collected from the leaves e.g. sisal and agave.

c. Skin fibre: Fibres are collected from the skin or bast surrounding the stem of their respective plants. These fibres have higher tensile strength than other fibres. Therefore, these fibres are used for durable yarn, fabric, packaging, and paper. Some examples are flax, jute, banana, hemp, and soyabean.

d. Fruit fibre: Fibres are collected from the fruit of the plant, e.g. coconut (coir) fibre.

e. Stalk fibre: Fibres are actually the stalks of the plant. E.g. straws of wheat, rice, barley, and other crops including bamboo and grass(Bhuiyan and Sobue, 2001). The natural fibres can be used to reinforce both thermosetting and thermoplastic matrices.

**2.1.3Bagasse**

The sugarcane stalk consists of the upper layers made of a hard fibrous substance called rind while inside is soft material called pith. The pith contains small fibres and the majority of the sucrose, while the rind contains longer and finer fibres, arranged randomly throughout the stem and bound together by lignin and hemicelluloses.

The dry pulpy residue left while extracting the juice from the sugarcane is known asbagasse*(Saccharum Barberi)*. Sugarcane bagasse is a residue widely generated in high proportions in the agro-industry. It is afibrous residue of cane stalks left over after the crushing and extraction of juice from the sugar cane. Bagasse is generally gray-yellow to pale green in colour. It is bulky and quite non uniform in particle size.

The sugar cane residue bagasse is an under-utilized andrenewable agricultural material(Lonsdale and Gosnell, 1972).

### 2.1.3.1Composition of Bagasse

The composition of Bagasse depends on the variety and maturity of Sugarcane as well as harvesting methods applied and efficiency of the Sugar processing(Carrillo *et al.,* 2010).

The main chemical constituents of bagasse are:

a. Cellulose and hemicelluloses; they are present in the form of hollow cellulose in bagasse which contributes to about 70 % of the total chemical constituents present in bagasse.

b. Lignin; It acts as a binder for the cellulose fibres and also serves as an energy storage system.

c. Bagasse consists of water, fibre and small quantities of solids in solution in the followingproportions. Water 46-57 %(mean50%), Fibre 43%-53 %(mean 47%), Solids in solution (sugar)2%-6 % (mean 3%).

Cellulose is a polysaccharide having the general formula $(C_6H_{10}O_6)_n$and the main constituent ofvegetable tissue. Pentosans are a form of hemicellulose which on hydrolysis yield xylose and arabinose and heating with steam is important industrially and can be expressed as follows;

$C_5H_8O_4 \rightarrow C_5H_{10} \rightarrow C_5H_9O_2$…….2.1

(Pentosan) (Pentose) (Furfural)

Bagasse is an essential ingredient for the manufacture of pressed building board, acoustical tile, and other construction materials (Dahlke *et al*., 1998).

### 2.1.3.2Varieties of sugarcane fibre

Sugarcane is an important commercial crop, which is the basic raw material for the manufacture of sugar.

Therefore, it has industrial importance per-hectare yield and percent sugar recovery is the two factors contributing towards production of sugar. Hence while developing new varieties of sugar cane; these two factors get prime importance in the minds of Scientists (breeders). The work of developing new varieties is a continuous process and newer varieties are introduced for cultivation after certain interval. In Maharashtra, sugarcane research is carried out mainly at Padegaon, near Neera in Pune District. This research station has evolved new varieties:

**i. Co 7219 (Sanjeevani)**: This was released in 1982. It is cross between Co.449 and Co 658. The leaves are long and broad and are yellowish green. Cane is of medium size. There is depression on higher side of eye-buds. The variety matures early and is a good yielder. The cane lodges but does not break. It is good for crushing in the early part of the crushing season and is good for pre-season.

**ii. Co.M 7125 (Sampada):** It was released for cultivation in 1982. It is obtained through cross between Co 740 and Co 775. The leaves are of medium size and yellowish green in colour. Cane colour is also yellowish green. It grows tall but does not lodge. It has good sugar content and is also good for gur making. It is suitable for tatooning. The cane and sugar yields are 110 MT and 13.5 MT respectively (Recovery 12.3%). It is tolerant to smut disease.

**iii. Co 8014 (Mahalaxmi)**: It is a cross between Co 740 and Co 6304 and is released in 1994. Leaves are of medium breadth and dark green. The colour of the cane is yellowish white. It tolerates water stress to a certain extent. It gives good yield if harvested after 12 to 14 months. It is recommended for South Satara, Sangli and Kolhapur districts. The yield of cane varies from 98 to 135 MT and that of sugar from 14.11 to 19.48 MT.

**iv. Co 86032 (Nira)** - It is a cross between Co 62198 and Co 671. The sugar content is 19 to 20%. It is also suitable for gur making. Leaves are dark green and flowering is less; it does not lodge and hence yield is good. It is released for cultivation in 1996. Yield of cane varies from 106 to 159 MT in different seasons and that of sugar from 14.55 to 22.42.

**v. Co- S.I.776**: It matures in 11 months and growth is very fast. Size of cane is small, there are cracks on internodes, leaves are thin, green in colour, eye-buds are round and small. Yield potential is 150 MT with recovery 12.5 NR (Lonsdale and Gosnell, 1972).

**2.1.3.4Advantages of Bagasse**

i. Low price

ii. Recyclability

iii. Availability

**2.1.4 Sisal Fibre**

Sisal fibre is obtained from the leaves of the plant (*Agave sisalana)*, which was originated from Mexico and is now mainlycultivated in East Africa, Brazil, Haiti, India and Indonesia(Naik, 1995; Modibbo*et al.*, 2009).

The name "sisal" comes from a harbor town in Yucatan, Maya, Mexico (Devi *et al*., 2003). Agave plants were grown by the Maya Indians before the arrival of the Europeans. It is one of the most extensively cultivated hard fibre in the world and it accounts for half the total production of textile fibres (Bledzki and Gassan, 1999).

The reason for 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 (Khan*et al.*, 2012).

The fibre is extracted from the leaf either by retting, scraping or by mechanical means usingdecorticators.The diameter of the fibre varied from 100mm to 300mm (Mukherjee and Satyanarayana, 1984).

The fibre cells are linked together by means of middle lamellae, which consist of hemicellulose, lignin and pectin.

The chemical composition of sisal fibres have been reported by several groups of researchers. For example, (Naik, 1995) indicated that sisal fibre contains 78% cellulose, 8% lignin, 10% hemicelluloses, 2% waxes and about 1% ash by weight. Rowell found that sisal contains 43-53% cellulose, 7-9% lignin, 21-24% Pentosan and 0.6-1.1% ash.

The cellulose and lignin contents of sisal vary from 49.62- 60.95% and 3.7-4.40% respectively, (Chand and Rohatgi, 1994). This large variation in the chemical composition of sisal fibre is as a result of its different source, age, measurement method etc.

**2.1.4.1 Properties of Sisal fibre**

Fibres from natural sources have been considered as the most promising dressing material. Sisal fibre is exceptionally durable with a low maintenance with minimal wear and tear. It is also recyclable.

The physical properties of sisal fibres vary from source to source (Chand *et al.,* 1998).

The length of sisal fibre is between 1.0 and 1.5m and the diameter is about 100-300mm (Bisanda and Ansell, 1992). Sisal fibres are obtained from the outer leaf skin, removing the inner pulp.

Sisal fibre exhibits good sound and impact absorbing properties. Among the various natural fibres, sisal fibre is fairly coarse and inflexible.

It possesses moderately high specific strength and stiffness, durability, ability to stretch, and resistant to deterioration in salt water (Sahoo *et al*., 2007; Jacob*et al*., 2006).

Therefore, it can be used as a reinforcing material in polymeric resin matrices to make useful structural composite materials (Silva and Al-Qureshi, 2010; Singh and Maiti, 1986).

**2.1.4.2 Uses of sisal**

From ancient times, sisal has been the leading material for agricultural twine because of its strength, durability, ability to stretch and resistance to deterioration in salt water. It is commonly used as ropes in marine industries and agriculture (Mukheerjee and Satyanarayan, 1984). Other applications of sisal fibre include twines, cords, upholstery, padding and mat making (Chand *et al.,* 1998). It has also been used to manufacture corrugated roofing panels that are strong and cheap with good fire resistance (Bisandaand Ansell, 1992).

Now sisal has been utilized as an environmentally friendly strengthening agent to replace asbestos and fibre glass in composite materials in various uses including the automobile industry.

**2.1.5Coir fibre**

Coconut fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocos nucifera and Arecaceae respectively.

There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Brown fibres are thick, strong and have high abrasion resistance. White fibres are smoother and finer, but also weaker.

Coconut fibres are commercially available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement. In engineering, brown fibres are mostly used (Yuhazri and Dan, 2007).

Coconut fibres contain cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut fibres. The pre-treatment of fibres changes the composition and ultimately changes not only its properties but also the properties of composites. Some-times it improves the behaviour of fibres but sometimes its effect is not favourable (Dixit and Verma, 2012).

#### 2.1.5.1 Properties of coir fibre

There are many general properties of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean (Bisanda and Ansell, 1992).

Fibre dimensions of the various individual cells are said to be dependent on the type of species, location and maturity of the plant.

The flexibility and rupture of the fibre is affected by the length to diameter ratio of the fibre and this also determines the product that can be made from it.

Coconut fibres contain cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut fibres. The pre-treatment of fibres changes the composition and ultimately changes not only its properties but also the properties of composites(Bhuiyan and Sobue, 2001).

#### 2.1.5.2 Applications of coir fibre

Yuhazri and Dan, (2007) utilized coconut fibres in the manufacturing of motor cycle helmet. They used epoxy resins, a thermoset polymer as the matrix materials and coconut fibres as the reinforcement.

Due to the high strength, low water resistance and resistance to abrasion, coir has also been used to make rope for marine applications among others.

## 2.2 Composites

“Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material.

They are cohesive structures made by physically combining two or morecompatible materials, different in composition and characteristics and sometimes in form (Jawaid *et al*., 2012).

The composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties.

In terms of strength to resistance to heat or some other desirable properties, it is better than either of the components alone or radically different from either of them(Kelly, 1967).

“The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings”, in other to obtain improved materials (Bannister and Herszberg, 1995).

Composite materials are heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale such that any portion of it will have the same physical property (Das and Chakraborty, 2006).

### 2.2.1 Classification of composite materials

Broadly, composite materials can be classified into three groups on the basis of matrix material. They are:

a) Metal Matrix Composites (MMC)

b) Ceramic Matrix Composites (CMC)

c) Polymer Matrix Composites (PMC)

***a) Metal Matrix Composites***

Metal Matrix Composites have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion (Adine *et al*., 2007). Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers etc.

***b) Ceramic matrix Composites***

One of the main objectives in producing ceramic matrix composites is to increase the toughness. Naturally it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of ceramic matrix composites(Raj *et al*., 1989).

***c) Polymer Matrix Composites***

Most commonly used matrix materials are polymeric. The reason for this is two-fold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics.

These difficulties are overcome by reinforcing other materials with polymers. Secondly, the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature.

Also equipment required for manufacturing polymer matrix composites are simpler (Dahlke *et al*., 1998). For these reasons, polymer matrix composites developed rapidly and soon became popular for structural applications.

Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic.

Composites have a greater modulus than the polymer component but not as brittle as ceramics.Two types of polymer composites are:Fibre reinforced polymer (FRP) and Particle reinforced polymer (PRP)

**2.2.1.1Fibre Reinforced Polymer**

Common fibre reinforced composites are composed of fibres and a matrix. Fibres are the reinforcement agents and the main source of strength while matrix glues all the fibres together in shape and transfers stresses between the reinforcing fibres. The fibres carry the loads along their longitudinal directions. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or reduce the product cost(Dahlke *et al*., 1998).

Common fibre reinforcing agents include asbestos, carbon/graphite fibres, beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminium oxide, glass fibres, polyamide, natural fibres etc. Similarly common matrix materials include epoxy, phenolic, polyester, polyurethane, Polyethenetherketone (PEEK), vinyl ester etc. Among these resin materials, PEEK is most widely used. Epoxy, which has higher adhesion and less shrinkage than PEEK, comes in second for its high cost.

**2.2.2 Components of a composite material**

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of:

i. A bulk material (the ‘matrix’) which is the binder.

ii. A reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

iii. The fibre-matrix interface (Chand and Jain, 2003).

### 2.2.2.1Matrix

Many materials when they are in a fibrous form exhibit very good strength property but to achieve these properties the fibres should be bonded by a suitable matrix. The matrix isolates thefibres from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibres in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibres and evenly distributive stress concentration (Maldas and Kokta, 1995). Examples of commonly used matrix are epoxy resin, polyester resin etc.

Thermoplastics (Sinha, 2000) are polymers that require heat to make them processable and after cooling, such materials harden and retain their shapes. In addition, these polymers may be reheated and reformed, often without significant changes in their properties.

The thermoplastics which have been used as matrix for natural fibre-reinforced composites are as follows: High density polyethene (HDPE),Low density polyethene (LDPE) (Raj *et al.,* 1990), Chlorinated polyethylene (CPE) (Maldas and Kokta, 1995), Polypropylene (PP) (Simpson and Selke, 1991; Sain and Kokta, 1994), Polystyrene (PS) (Raj *et al.,* 1989).Only the aforementioned thermoplastics are useable for natural fibre-reinforced composites, because their processing temperatures (temperature at which fibre is incorporated into polymer matrix) do not exceed 230°C. They are mostly polyolefins.

Thermoplastics, like polyamides, polyesters and polycarbonates require processingtemperatures greater than 250°C and are therefore not useable for such composite processing without fibre degradation.

Thermoset is a hard and stiff cross-linked material that does not soften or become mouldable when heated (Sinha, 2000).

Thermosets are stiff and do not stretch the way that elastomers and thermoplastics do. Several of these classes of polymers have been used as matrices for natural fibre composites. Most commonly used thermoset polymers are epoxy resin, unsaturated polyester resins, Vinyl Ester, Phenolic and Novolac (Bledzki *et al.,* 1998; Ramires, *et al.,* 2010).

**2.2.2.2Unsaturated polyester resins**

Unsaturated polyester resins (UPR) are the workhorse of the composites industry and represent approximately 75% of the total resins used (American Composites Manufacturers Association, 2004). Thermoset polyesters are produced by the condensation polymerization of dicarboxylic acids and difunctional alcohols (glycols).

In addition, unsaturated polyesters contain an unsaturated material, such as maleic anhydride or fumaric acid, as part of the dicarboxylic acid component. The finished polymer is dissolved in a reactive monomer such as styrene to give a low viscosity liquid. When this resin is cured, the monomer reacts with the unsaturated sites on the polymer converting it to a solid thermoset structure (Ramires, *et al.,* 2010).

**2.2.2.3Epoxy Resin**

Epoxy resins may be defined as resins in which chain in extension and cross-linking occurs through the reactions of epoxide group.

Epoxy is a copolymer; i.e. it is formed from two different chemicals.

The resin consists of monomers or short chain polymers with an epoxide group at either end (Sinha, 2000).Epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A.

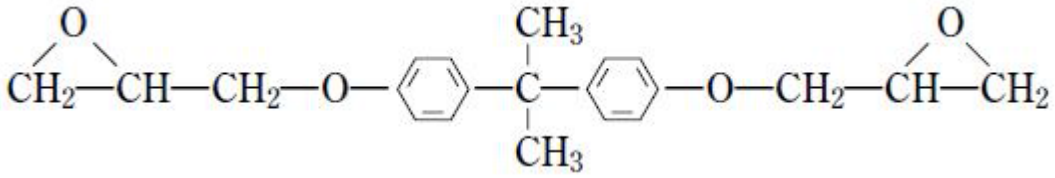


Figure 2.1: Chemical structure of Epoxy resin (Sinha, 2000).

Epoxy resins contain a reactive oxirane structure:

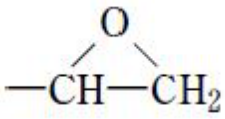


Figure 2.2: Functional group of Epoxy resin

This is commonly referred to as "epoxy" functionality.

Liquid epoxy resins are converted through these reactive epoxy sites into tough, insoluble, andinfusible solids.

This epoxy has outstanding properties which are utilized as the matrix material:

i. Excellent adhesion to different materials.

ii. High dimensional stability.

iii. Excellent mechanical and electrical properties.

iv. Odorless, tasteless and completely nontoxic.

v. Negligible shrinkage.

Now-a-days fibres reinforced composites are in use in a variety of applications ranging from aircraft to building and bridges; this wide use of composites has been facilitated by introduction of new materials (Chandramohan and Marimuthu, 2011).Epoxy resins are one of the most important classes of thermosetting polymers which are widely used as materials for fibre – reinforced composite materials and as structural adhesives (Shangjin*et al.,* 2001).

Epoxy resin is widely used in industrial application because of their high strength and mechanical adhesiveness characteristic.

Curing takes place at room temperature and atmospheric pressure after addition of hardener. Cure shrinkage is generally very less and may be still further reduced by the addition of fillers. Fully cured mixture has excellent mechanical and thermal properties. The castings have good ageing characteristics. Resin can be stored for at least a year if they are kept under cool, dry conditions in the original containers (Ramires, *et al.*, 2010). It is also good solvent and has good chemical resistance over a wide range of temperature.

**2.2.2.4Hardener**

Hardener is a yellowish-green liquid. Due to the versatility of epoxy resins in a wide variety of chemical reactions, epoxy resins can be cured using a range of materials with different types of curing conditions(Harriette, 2004).

The choice of curing agents (also called 'hardener') depends on the curing conditions applicable and the final application of the resin. Epoxy can be cured with amines, thiols, and alcohols. Amines are widely used as hardener for epoxy resins (Sinha, 2009).

**2.2.2.5 Interface**

The interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical, chemical etc. It has characteristics that are not depicted by any of the component in isolation. The matrix material must "wet" the fibre. Coupling agents are frequently used to improve wettability. Well "wetted" fibres increase the interface surfaces area. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibres via the interface. This means that the interface must be large and exhibit strong adhesion between fibres and matrix. Failure at the interface (called debonding) may or may not be desirable (Abdelmouleh *et al*., 2007).

The interface is an anisotropic transition region between the fibre and the matrix. It is considered to be an important region because it provides chemically and physically stable bonding between the fibres and the matrix. If the composite material have low strength and stiffness but will possess high resistance to fracture. Similarly, a composite system with strong interface will have high strength and stiffness but brittle (Tripathy *et al*., 2002).

**2.2.2.6Reinforcement**

The objective of the reinforcement in a composite material is to enhance the mechanical properties of the resin system. All of the distinct fibres that are used in composites have distinct properties and so affect the properties of the composite in different ways(Maldas and Kokta, 1995).

For most of the applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible and the variety of fibreorientations make it possible to achieve different characteristics (Tripathy *et al*., 2002).

**2.2.2.7Hybrid Composites**

When more than one typeis reinforced into a common matrix, the resulting composite is called hybrid composite. Hybrid composite provide greater freedom when it comes to designing composites for specific properties as compared to single fibre reinforced composites. Hybrid composites are made of more than one reinforcing phases and a single matrix phase or single reinforcing phase and multiple matrix phases.

These materials have better all-round combination of properties than composites containing only one fibre type.

Hybrid composites include multiple reinforcing such as natural as well as synthetic fibres. Hybrid composites may replace or reduce the utilization of synthetic fibres in applications of automotive, building industries, aircraft etc.

Jute-coir hybrid composites find application in railway coaches for sleeper breath backing, for building interiors, doors and windows besides in transportation sector as backings for seat and backrest in buses.

Recently, natural fibres such as bamboo, jute etc. have been mixed with synthetic fibres such as glass to form hybrid that plays important role in composites with desired properties at low cost. The behavior of hybrid composites is a weighed sum of the characteristics of the individual components (Tripathy *et al*., 2002). The properties of hybrids are decided by many factors such as fibre content, fibre length, orientation, extent of intermingling of fibres, fibre matrix bonding etc.

The properties of hybrid system consist of two components that can be predicted by the rule of mixtures.

Volume of composite = Volume of fibres + Volume of matrix

Volume fraction of fibres, $V_f$ = Volume of fibres/Volume of composite

Volume fraction of matrix, $V_m$ = Volume of matrix/Volume of composite

$V_f + V_m = 1$ …….. 2.2

$V_m = (1 - V_f)$ ……..…….. 2.3

Thus, density of composite,

$P_c = V_f P_f + V_m P_m$ or $P_c = V_f P_f + (1 - V_f)$ …….. 2.4

Where

$P_c$ = density of composite

$P_f$ = density of fibre

$P_m$ =density of matrix

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

Hybrid effect can be defined and used to quantify any positive or negative deviation of the resistance to external stress of the hybrid composite from the predicted value using rule of mixture equation (Aggarwal*et al*., 2006).

Hybrid composites are classified as follows:

i. Intimately mixed hybrids, where the constituent fibres are mixed as randomly as possible so that no over-concentration of any one type of fibre is present in the material; other kinds of such are those reinforced with ribs, pultruded wires, and thin veils of fibre or combinations of the above.

ii.Sandwich hybrids, known as also core-shell, in which one is sandwich between two layers of another.

iii.Interplay or laminated, where alternate layers of the two (or more) materials are stacked in a regular manner.

iv.Interplay or untwisted bundle of fibres, in which tows of the two or more constituent type of fibres are mixed in a regular or random manner.

## 2.3Technique of Composite Fabrication

There are numerous methods for fabricating composite components. Many were developed to meet specific design or manufacturing challenges. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or application (Siddika *et al.*, 2013).

### 2.3.1 Spray Lay-Up:

Fibre is chopped in a hand-held gun and fed into a spray of catalysed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions.

This process offers a good surface finish on one side and a rough surface finish on the other side. But it is difficult to control the fiber volume fraction as well as the thickness. In this method, this parameter is highly dependent on operator's skill.

### 2.3.2 Autoclave Curing:

An autoclave is used in this process; an autoclave is a closed vessel for controlling temperature and pressure used for curing polymeric matrix composites.

Composites to be cured are prepared either through hand lay up or machine placement of individual laminae in the form of fibers tape which has been impregnated with resin. The components is then placed in an autoclave and subjected to a controlled cycle of temperature and pressure. After curing, the composite is "solidified".

The curing of matrix material is carried out under controlled environment, the resin distribution is better as compared to spray lay-up processes and it has better surface finish. The process has high initial cost of tooling and high running and maintenance cost and not suitable for small products. The process is suitable for aerospace, automobile parts like wing box, chassis, bumpers, etc.

### 2.3.3 Filament Winding:

This process is an automated process. Fibre tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fibre feeding mechanism, and rate of rotation of the mandrel. The wound component is then cured in an oven or autoclave.

Complex fibre patterns can be attained for better load bearing of the structure. However, Fibre cannot easily be laid exactly along the length of a component, and mandrel costs for large components can be high and the external surface of the component is not smoothly finished.

### 2.3.4 Pultrusion

It is a continuous process in which composites in the form of fibers and fabrics are pulled through a bath of liquid resin. Then the fibres wetted with resin are pulled through a heated die. The die plays important roles like completing the impregnation and controlling the resin.

Further, the material is cured to its final shape. The die shape used in this process is the replica of the final product. Finally, the finished product is cut to length. The process is suitable for mass production. However, heated die costs can be high and the process is limited to constant or near constant cross-section components.

### 2.3.5 Hand Lay-up

Hand lay-up technique is the oldest and the simplest open moulding method of the composites fabrication process. It is a low volume, labour intensive method suited especially for large composites, such as boat hull, Glass or other reinforcing mat or woven fabric. The reinforcement material is positioned manually in the opened mould and resin is poured, brushed or sprayed over and into the glass piles. Entrapped air is removed manually with squeegees or roller.

Polyester and epoxy matrix resins are the room temperature curing thermosets commonly used. Curing is initiated by a catalyst in the resin system which hardens the fibre reinforced resin composites. Lubricating grease is first applied to the mould to facilitate easy removal of the fabricated composites.

**Advantages:**

i. The process results in low cost tooling with the use of room-temperature cure resins.

ii. The process is simple to use.

iii. Any combination of fibres and matrix materials are used.

iv. Higher fibre contents and longer fibres as compared to other processes.



Plate 2.1: Cured Composite in the mould (Ogabi *et al.*, 2016)

**2.5 Helmet Description**

A helmet is aprotective gear worn to protect thehead from injuries. Itattempts to protect the user's head by absorbing mechanical energy and protecting against penetration. Their structure and protective capacity are altered in high-energy

impacts.Some helmets have other protective elements attached to them, such as a face visors or goggles or a face cage, or an ear cage or ear plugs and other forms of protective headgear(Jacobs and Dingenen, 2001).

In civilian life, helmets are used for recreational activities and sports; dangerous work activities and transportation.

The helmet shape (design) is one that the Army has developed for its Future Force Warrior (FFW) initiative. Currently, the Army uses helmets of a different design.

These helmets, called PASGT helmets, are made using a composite comprising aramid fabric (kevla) in a thermoset matrix. One major goal of the FFW helmet is to reduce weight compared to the PASGT helmet (Kulkarni, 2013).

Historically, helmets have been made from a wide range of materials, including various metals, plastics, leather, and even some fibrous materials such as Kevlar. Ancient and medieval helmets were usually made of metals, often bronze, iron or steel. The major factors to be considered in the design of helmet are the strength performance and weight.

Helmets of many different types have developed over the course of human history. Most early helmets had military uses, though some may have had more ceremonial than combat-related purposes.

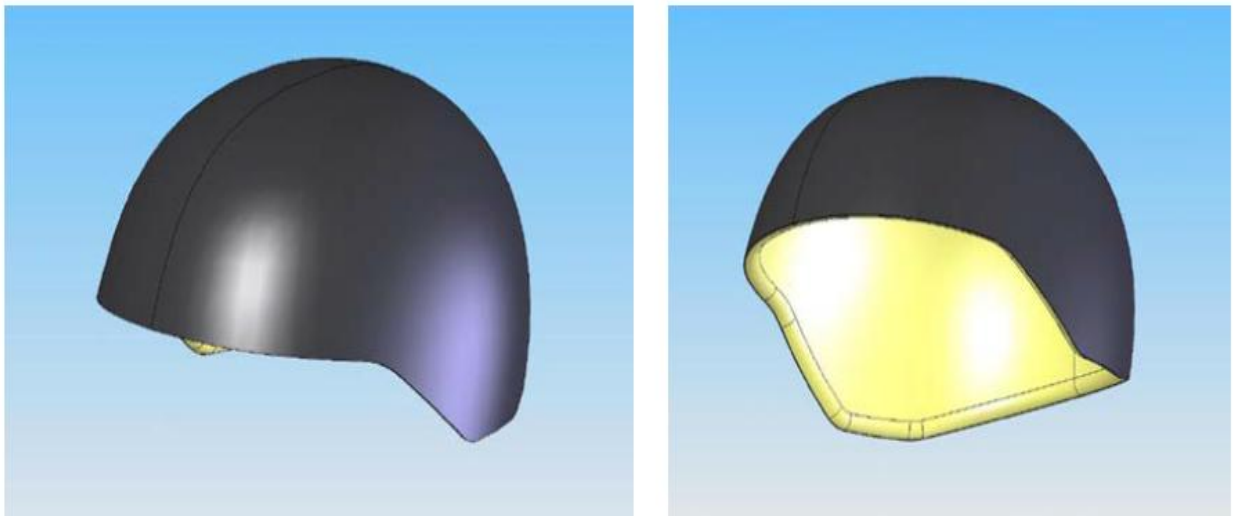


Plate 2.2: Hybrid FFW helmet design (Black, 2010).

## 2.6 Testing of Composites

The assessment of the physical, mechanical and other characteristics of hybrid materialsis a function of the condition of frequent usage.

Andthe purpose may be to establish data for engineering and design control of quality in production, acceptance of testing againstspecification or other end use of economic importance (Siddika*et al.*, 2013).

### 2.6.1Mechanical Tests

These tests determine the strength, stability, bending and the hardness of the materials. However, the literature from material manufacturers and supplier's requirement for incoming inspection of materials often quotes the qualities of plastics in terms of tensile strength, flexural strength, impact strength, hardness, elongation and modulus. These qualities outline the plastics characteristics under tension and its resistance to any change in shape.

The most important mechanical tests are: tensile (ASTM D638), Flexural(ASTMD790), Izod Impact (ASTM D256), Rockwell Hardness (ASTM D785)and Durometer Hardness (ASTM2240), (Hedenberg and Gatenholm, 1995).

### 2.6.1.1Tensile Properties

The force necessary to pull a specimen apart, as well as how the material stretches before breaking indicates how tough or brittle the material may be. Therefore the tensile test measures the maximum stress that a material can withstand while being stretched or pulled.

Plastics materials produce stress-strain curves that offer clear indications of the various points of yielding as the load increased. Thus, there are seven important references that can be derived from a stress-strain diagram (Netravali et and Luo, 1999).

The tensile testing procedure involves placing the test specimen in the testing machine and applying tension to it until it fractures. Stress, strain, young's modulus, yield strength and ultimate tensile strength can be determined from the data obtained(Agrawal*et al*., 2000).

i. Stress

This is the amount of force applied to the test specimen, or the ratio between the forces applied and the cross-sectional area of the specimen. By relating stress to strain, how much the material changes in length, provides information about the rigidity of the material.

Tensile strength = P/A in ($N/mm^2$)……..2.5

Where: P = Breaking load in kN, A = Cross-section area of sample in $mm^2$.

ii. Strain

The strain is the change in length in relation to the applied load. This is recorded at the bottom of the stress-strain curve.

Strain=Elongation/Gauge length.

iii. Elastic limit

This is the point of load on the stress-strain curve where the material under stress can recover its approximate original dimensions. It marks the peak tensile force applied prior to permanent deformation of the material. The elastic limit on the stress-strain curve is the end of the straight line on the first portion of the curve. Below the elastic limit, the applied load (stress) is proportional to the length (strain).If the specimen load does not exceed the elastic limit then the specimen material will return to its original length. Plastic materials are true elastic materials since they do not act like spring when load is applied below their elastic limit. However, they undergo permanent deformation when load is applied.

iv. Yield point

This is the first point beyond the elastic limit where the plastic material begins to lose its ability to resist the force applied to it and begins to stretch.

v. Ultimate strength

This is the maximum force (stress), that a material can withstand. It is the same or higher than the "yield point" for plastic materials (Agarwal *et al*, 2006).

vi.Elongationat break

Elongation is the increase in length of a specimen under a given load (stress). It is the measure of the ductility and can be related plastic toughness in plastic materials.

vii. Modulus of elasticity

This is also referred to as Young's modulus or tensile modulus. It is the ratio of the stress to the strain. It is a measure of a material's stiffness. A material with a higher numerical value of modulus of elasticity is more rigid compared to that with a lower numerical value.

**2.6.1.2Flexural Strength**

The flexural strength represents the stress experienced within the material at the point of rupture. The traverse vertical blending test is mostly employed; in which a specimen having either a rectangular or circular cross-section is bent until fracture occurs. The technique used is either three-point or four-point flexural test. Flexural strength is often measured in mega Pascal (MPa)(Hassan *et al*., 2000).

The flexural strengths were calculated using the following equation:

Flexural strength = $3PL/2bd^2$ ……. 2.6

Flexural modulus = $PL^3/4wbd^3$ …….. 2.7

Where: P= maximum load in kN, L = gauge span of the sample in mm, b = sample width in mm, d =sample thickness in mm, w= deflection

**2.6.1.3Impact Strength**

This is the measure of the work done to break a piece of test sample. It is the ability of a material to withstand shock loading or the work done in fracturing under shock loading. In thepractical terms where the material is to encounter dynamic force such as shock, impact strength may be more important than tensile strength (Chand and Dwivedi, 2006).

### 2.6.1.4Hardness

This test describes the process of surface deformation of a material due to indentation. This test could be employed by the use of two types of durometer hardness machine i.e type A and type D. This is used to measure the hardness of a material ranging from soft rubber to hard rubber and plastic (Sitirabiatull*et al*., 2012).

### 2.6.2Physical Tests

### 2.6.2.1 Density

This is the amount of substance in a specific area. It is also the mass in grams per unit volume of a substance.

Density = mass/volume ($g/cm^3$)……..2.8

### 2.6.2.2Water Absorption

The percentage water absorption of the composites is determined according to ASTM 2842standard.

The samples are weighed and immersed in distilled water for 48hrs and thereafter reweighed. The percentage water absorption was calculated using the equation below:

$$\% \text{ Water absorption} = \frac{(\text{Final weight} - \text{Initial weight})}{\text{Initial weight}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Water absorption leads to the reduction of the fibre-matrix interfacial bond which consequently reduces the mechanical properties of the compositethereby reducing the lifespan of the composite material.All polymeric materials will absorb moisture to some extent which results in swelling and degradation which can causes in loss of mechanical properties of composites material (Arib*et al*., 2014).

### 2.6.2.3Scanning Electron Microscopy (SEM)

Scanning electron microscope is a type of microscope that produces image of a sample by scanning it with a focused beam of electron, the electrons interact with the atoms in the sample, producing various signals which is detected to contain information about the samples surface topography, sub-surface information and compositional difference. SEM is used to determinethe size, distribution and orientation of fibre or particles. It also gives information on the degree of bonding between the matrix and reinforcement.

To prepare samples for SEM, the insulating materials are coated with thin layer of Gold, aluminium or carbon by evaporation or sputtering in order to make the composite conductive. Samples can be viewed with different Voltages and micrographs can be obtained at different magnifications(Warnbua and Verpoest, 2003).

## 2.7Review of Related Past Works

Naveen *et al., (*2016) investigated the mechanical characterization of bagasse/coir hybrid composite. Bagasse composite was prepared with the following fibre loadings: 0%, 5%, 10%, 15%, 20%, and 25%.The ultimate tensile strength was determined having the numerical values of 30.8, 32.52, 33.69, 34.85, 32.32 MPa respectively. At 15%(highest tensile strength), some percentage of coir fibre was added to improve its tensile property with the highest value of 38.45 MPa.

Cook *et al*. (1978) reported the use of randomly distributed coir fibre reinforced cement composites as low cost materials for roofing. The studied parameters were fibre lengths (2.5 cm, 3.75 cm and 6.35 cm), fibre volumes (2.5, 5, 7.5, 10 and 15%) and casting pressure (from 1 to 2 MPa with an increment of 0.33 MPa).

Different properties like bending, impact, shrinkage, water absorption, permeability and fire resistance were investigated.

They concluded that the optimum composite was a composite with a fibre length of 3.75 cm, a fibre volume fraction of 7.5 % and cast at pressure of 1.67 MPa. Cost comparison revealed that this composite was substantially cheaper than the locally available roofing materials.

According to the research carried out byCao *et al*., (2006), the effects of alkali treatments (1, 3, 5%) of bagasse fibres on the tensile strength was examined.

The tensile strength of the 5% sodium hydroxidetreated fibre composites at 20% fibre loading was 18.6 MPa against 16.5 MPa for the untreated fibre composites. This shows that treated fibres give better tensile strength than untreated fibres.Therefore fibre modification improves the adhesion between the fibre surfaces.

Similarly, from the results of the experiment carried out by Khan*et al.,* (2012), it was observed that with increase in fibre content from 10 to 20 % both tensile and flexural strength increases and thereafter with further increase of fibre content both properties tend towards lower value beyond the optimum point due to low wettability.

Natsa *et al.,* (2015) worked on Coconut fibre reinforced polymer composite was used for the production of crash helmet. The coconut fibre, otherwise known as the coir fibre was used as the reinforcement while epoxy resin (bisphenol-A-diglycol) served as the matrix. Seven specimens were produced having 20%, 40%, 50%, 60%, 70%, 80% and 85% coir fibre content in the composite and their mechanical properties (tensile strength, impact strength, flexural strength and hardness strength) were evaluated.

Specimen helmets were formed from blanks that were produced by simple hand lay-up technique adopting the formulation that offered the most acceptable combination of mechanical properties.

Specimen E, having a fibre content of 70% in 28% resin offered remarkable combination of properties: impact strength of 8.733J/mm², hardness strength of 30.03HRF, tensile strength of 13.81N/mm² and a flexural strength of 31.88N/mm². Since impact test result is the most critical test in this research, and specimen E offered the highest, it was adopted for the production of the sample military helmets in this work. The impact strength showed by specimen E (70% coir fibre in 28% resin), which was 8.733J/mm² clearly implies that the composite material can be used for the production of military protective helmets.

They concluded that, coir fibre can be used comfortably as reinforcement in polymer matrix composite for the production of Military helmet.

Murali *etal.*,(2014)concluded based on his findingsthat hybridizedcomposites gavehigher impactstrength,lowerweightandcostthan acrylonitrilebutadienestyrene(ABS)plastics.

AdemohandOlanipekun,(2015) Produced a helmet with20%weightof treatedhybridcompositefrom treatedoil palm male flowerbunch stalkfibreandoil palmfrondfibrein the ratio of 3to 1 wereusedin reinforcingunsaturatedpolyesterresin tofabricateanti-crash helmetshell using handlay-upmethod.Themechanical performanceof thehelmetshellwas determinedandthe results obtainedwerecomparedwithpastliteratures.

From theresult,hybridcompositeofoilpalmmaleflowerbunch stalkfibrehybrid andoil palm frondfibrewithunsaturatedpolyesterhasgoodmechanicalattributesandcan replaceABS plasticcommonly usedin conventionalhelmet productions.

Characterizedfibresofmaleflowerbunchstalkand frondof oil palm (*Elaeisguineensis*)forpolymerreinforcementandconcludedthatthematerialstreatedwith NaOHwere suitableforstructuralstrengtheningof polymercomposites.They successfully producedprototypehelmetsfrom bio-compositesreinforcedwithfibreofoil palmmaleflowerbunchstalk.

Dixit and Verma, (2012) investigated the mechanical properties of composites reinforced with hybrid Palms Kevlar fibers were evaluated. The incorporation of both fibres into a single matrix which is epoxy resin stabilized the mechanical properties. Impact strength, tensile strength, flexural strength and hardness were studied for composite material reinforced with hybrid fibers for Palms and Kevlar as a woven roving.

These fibers were mixed with epoxy resin LY 556 in different reinforcement percentage (10%, 20%, 30%, 40%, 50%, 60%, 70%, and 80%) and the effect on the above mechanical properties was studied. It has shown an enhancement in these mechanical properties after reinforcement by fibres the value of mechanical properties increasedwith increasing percentage of reinforcement.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Materials

i. Bagasse(Chopped average length of 7.5 mm)

ii. Sisal fibre (Chopped average length of 7.5 mm)

iii. Coir (Chopped average length of 7.5 mm)

iv. LiquidEpoxy resin (purchased from Tony Chemical Enterprise, Ojota Lagos)

v. Hardener,Tetraehylenepentaamine(purchased from Tony Chemical Enterprise, Ojota Lagos)

vi. Distilled water

### 3.1.1 Equipment

i. Measuring cylinder

ii. Analytical balance (Sartorius. Model; ED2245)

iii. 200x120x6 (mm) glass mould

iv. Tensometer type “w” (Monsanto, UK)

v. Universal Material Testing Machine. (Cat Nr. Model: 261)

vi. Charpy Impact Testing Machine using Cat Nr.412; 15J capacity

vii. Indentec Universal Hardness Testing Machine (model:8187.5) LKV “B”

viii. Scanning Electron Microscope. Phenon Pro-X by Phenon-World Eindhoven Netherland.

## 3.2 Methods

### 3.2.1 Extraction and Treatment of the Natural Fibres

The natural fibres used were extracted by mechanical method and treated using sodium hydroxide solution to prepare them for use in the composite production.

#### 3.2.1.1 Bagasse

Chewed Sugarcane was collected from Sabon Gari environs of Zaria metropolis.

The bagasse samples were then cleaned withhot water ($60^{o}C$) for about one hour. This procedure removes fine bagasse particles, sugar residues and organic materials from the samples. A drying time of 40 min was established to provide sufficient drying of the fibre.After approximately two weeks, the long bagasse fibres (rind portion only) were shortened into a lengthrange of 6-10mm (average value of 7.5mm) with a pair of scissor.

In order to obtain maximum strength, the bond between matrix and fibres needs to beimproved by alkali treatment. The bagasse was dipped in 5% sodium hydroxidesolutionfor 2hrs at room temperature based on the liquor ratio used. The fibres were further washed with distilled water including 2% acetic acid. Then the fibres were washed with fresh distilled water again until sodium hydroxide was removed. During thealkaline treatment, the OH groups present in the fibres will react with sodium hydroxide toform a metallic compound which will then make the fibre compactible with the polymer matrix for better adhesion.

#### 3.2.1.2 Sisal

Sisal fibre obtained from NARICT, Zariawas extracted by a process called decortication, where leaves were crushed and beaten manually by a smooth edged stick so that only fibres will remain.

Extracted fibres were washed in plenty of water to remove excess wastes such as chlorophyll, leaf juices and adhesive solids (hemicelluloses).

The fibres were then dried in an open air and brushed. The lustrous strands are creamy white in colour.

Sisal fibres were soaked in 5% sodium hydroxide solution for 2 hrs at room temperature. These fibres were further rinsed in water followed by neutralization in 2% acetic acidsolution, finally rinsed in water and dried at the room temperature.

**3.2.1.3 Coir**

The husk of coconut fruit fibre was obtained from Ifo Local Government area, Ogun State. The fibrous layer of the fruit was extracted from the hard shell (husk) manually by driving the fruit down onto a spike to split it (dehusking). The coir was dipped in 5% sodium hydroxide solution, washed with distilled water followed by 2% acetic acid. Finally, the fibres were washed with fresh distilled distilled water and dried.

**3.2.2 Mould Fabrication**

Glass moulds were designed and constructed with the dimension of 200mm x 120mm x 6mm based so as to produce composite slabs that could be cut into various specifications according to ASTM standards.

The plane glass was joined together using silicon gum. A glass cover was also made which enhances smooth surface.The mould fabricated and used is shown in plate 3.1



Plate 3.1: Glass Mould for fabricating various samplesfor characterization.

### 3.2.3 Design of experiment (Formulation)

The formulation below revealed that bagasse composite was prepared first to know at what percentage of weight fraction the composite gives the ultimate tensile strength from that percentage some Sisal is added (i.e 60/40, 60/50, 40/60, 70/30 of the optimum point of bagasse) to enhance its tensile property. Finally, Coir fibre was also added to further increase the property (i.e 60/30/10, 60/20/20 60/10/30 at the optimum Bagasse/Sisal).

Table 3.1: Percentage fibre loading of Bagasse/Epoxy Composites.

| S/N | % of Bagasse (g) | % of Epoxy | Mass of BF (g) | Mass of Epoxy (g) | Total mass (g) |
|---|---|---|---|---|---|
| 1 | 0 | 100 | NIL | 90.72 | 90.72 |
| 2 | 5 | 95 | 4.50 | 86.22 | 90.72 |
| 3 | 10 | 90 | 9.07 | 81.65 | 90.72 |
| 4 | 15 | 85 | 13.61 | 77.11 | 90.72 |
| 5 | 20 | 80 | 18.15 | 72.57 | 90.72 |

Table 3.2: Percentage fibre loading of Bagasse/Sisal Reinforced Epoxy Composites

| S/N | % of BF | % of SF | Massof fibre blend (g) | Mass of Epoxy (g) | Total mass (g) |
|---|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 81.65 | 90.72 |
| 2 | 60 | 40 | 9.07 | 81.65 | 90.72 |
| 3 | 50 | 50 | 9.07 | 81.65 | 90.72 |
| 4 | 40 | 60 | 9.07 | 81.65 | 90.72 |

Table 3.3: Percentage fibre loading of Bagasse/Coir Reinforced Epoxy Composites.

| S/N | % of BF | % of CF | Mass of fibre blend (g) | Mass of Epoxy (g) | Total mass (g) |
|---|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 81.65 | 90.72 |
| 2 | 60 | 40 | 9.07 | 81.65 | 90.72 |
| 3 | 50 | 50 | 9.07 | 81.65 | 90.72 |
| 4 | 40 | 60 | 9.07 | 81.65 | 90.72 |

Table 3.4: Percentage fibre loading of Bagasse/Sisal/Coir Reinforced Epoxy Composites.

| S/N | % of BF | % of SF | % of CF | Mass of optimum fibre (g) | Mass of Epoxy (g) | Total mass (g) |
|---|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 81.65 | 90.72 |
| 2 | 60 | 20 | 20 | 9.07 | 81.65 | 90.72 |
| 3 | 60 | 30 | 10 | 9.07 | 81.65 | 90.72 |

N.B: Where BF= Bagasse fibre, SF= Sisal fibre, CF= Coir fibre

### 3.2.4 Production of Hybrid Composites

Bagasse composite is prepared first to know at what percentage of weight fraction the composite gives the ultimate tensile strength from that percentage some percentage of Sisal is added to enhance its tensile property. Finally, Coir fibre was then added to further increase the property according to the design of the experiment.

First, some sample preparation calculation was done before preparing the composite. The calculated amount of the epoxy resin thoroughly mixed withamine (2:1)was poured into the mould and allowed to cure at room temperature for about 24 hrs and once the composite is completely cured then it's ready for machining according to ASTM standard for testing, the procedure was repeated by adding5, 10, 15, 20% wt of bagasse fibre to the resin using hand lay-up technique. At optimum percentage (10% i.e 9.07g),Sisal fibre was added and a repeat of the same procedure was carried out to get the Hybrid of Bagasse/Sisal/Coircomposite and is tested for mechanical properties.



Plate 3.2: Some Casted Composites slabs ready for Cutting.

### 3.2.5 Cutting of the Composites

The prepared composite samples were then cut into different shapes in accordance to standard specifications for various ASTM tests using hack saw.



Plate 3.3: Some Composite Samples for various Mechanical Property test.

### 3.2.6 Helmet Fabrication

In this research, a helmet composite material was fabricated with bagasse/sisal/coir epoxy reinforced hybrid composite using hand lay-up technique.

Firstly, a mould was designed in the shape and dimension of a helmet model (obtained from Nigeria Defence Academy, NDA) using a Plaster of paris (calcium sulphate hemihydrate) after which clay was applied across the edges of the mould designed in other to avoid undercut (irregularities) that may affect the shape of the material.

The fibres were then mixed in proportion according to their weight percent blend ratio at the best formulation. The epoxy resin and the hardener were also mixed thoroughly in the required ratio.

A mould releasing agent was applied to the interior of the mould and then the composite was casted in the mould to a thickness of about 6mm. Casting was done in such a way that the first thin layer was pure epoxy after which the mixture of fibres (bagasse, sisal and coir) and matrix was laid. The composite was allowed to cure at room temperature for 24 hrs after which it was successfully removed from the mould in the form of a helmet. The hedges of the helmet was trimmed using a rotating saw to a perfect shape and also the interior way laid with upholstery as shock absorber. For aesthetic purpose, the shell was sprayed.

### 3.3 Characterization of the Composites

The characterizations were carried out according to ASTM standards for testing materials. Tensile strength (ASTM D638), flexural strength ASTM (D790), hardness (ASTM2240) and impact strength (ASTM D256).

#### 3.3.1 Mechanical Tests

The composite samples were conditioned for 24hrs after which they were subjected to the following mechanical tests:

Tensile strength, flexural strength, elongation at break, hardness and impact strength.

#### 3.3.1.1 Tensile Strength

The tensile strength of the composite samples depends on the strength of the fibre, length of fibre and the fibre matrix interaction.

The test specimens in dumb-bell shape of the required standard dimensions according to ASTM D638 were cut and clamped between the upper and lower jaws of the type "W" Monsanto tensometer and the machine was loaded.

The samples were stretched in the vice until the sample ruptured. The values of the breaking load and elongation were taken accordingly. The test was repeated three times for each sample of the composite and the average value was recorded.

#### 3.3.1.2 Flexural Strength

Flexural strength is also known as modulus of rupture or bend strength. Three-point bending test was conducted according to ASTM D790. At least three rectangular beam samples were tested at a support span of 70mm, the width and thickness correctly using a Vanier caliper. Load was applied on the sample with the help of a hydraulic lever until the material failed. The load of deformation and corresponding deflection was recorded from the display of the device.

#### 3.3.1.3 Impact Strength

The test was conducted according to ASTM D256. Composite samples were cut into length not less than 10cm. The composite sample was placed on the machine and held tightly with the help of knots, while the end was observed to be of equal length.

The harmer of 15 Joules energy capacity was released to hit the sample, which led to the breaking of the composite sample. The work done in breaking the sample was recorded. This test was then repeated three times for all the samples and the average values were recorded accurately.

### 3.3.1.4 Hardness

The “Indentec Universal Hardness Testing Machine used in measuring the hardness using the shore scale according to ASTM2240. It consist of an indenter, a graduated circular tube and a flat surface which the sampleto be tested are mounted or laid on. The sample was placed on the flat surface and the indenter was made to make an impression on the specimen material, the load was maintained at a minimum time of 10 to 15 seconds. The test was repeated for about three times and the averagevalues were obtained.

### 3.3.2 Physical Tests

The physical tests carried out are density and water absorption of the composites.

### 3.3.2.1 Density

The densities of the composite samples were determined according to ASTM D792-13. A measuring cylinder (250ml) was rinsed thoroughly and a measured quantity of distilled water was poured into the cylinder. The composite samples were cut to a specific dimension (of about 1x2cm each) and immersed completely in the distilled water. The displacement of the water volume was observed and the density was calculated using the equation below:

Density = Mass of composite/volume of water displaced ($g/cm^3$).

### 3.3.2.2 Water Absorption

Water absorption was conducted according to ASTM 2842. Thecomposite samples were cut to a specific size (3x4 $cm^2$) and weighed using electronic weighing balance.

The weighed samples were placed in a disposable plastic container and completely immersed in distilled water. The composites samples were left in the water for 24 hrs.

Thereafter, the samples were removed, cleaned with a soft cloth to remove surface moisture and reweighed. The same procedure was repeated for thirty (30) days and the percentage water absorption examined.

### 3.3.3 Scanning Electron Microscopy

Polymer composites are non-conductive, to make themconductive therefore, a sputter machine (model Q150R ES made by Quorum) was usedwith specification of 5nm gold to coat the surface of the sample before the micrographs were taken.

The coated samples were viewed through a navigation camera; proper adjustments were made to view the samples clearly before the machine was transferred to electronic mode. The viewing voltage was set using 10kV, themagnifications were increased and the sample morphology was stored in the electronic mode. Micro structures were obtained at various magnifications of 770X, 1000X and 1500X.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Mechanical Test Results

The mechanical test carried out on the composite samples whichinclude: tensile strength, flexural strength and modulus, elongation at break, impact strength and hardness strength are shown in this section.

### 4.1.1 Effect of fibre loading on Tensile Strength of the compositesamples

From Figure 4.1, it can be observed that the tensile strength of the bagasse/epoxy composite increases as the fibre loading increases until optimum value was obtained at 10% fibre loading; there after thestrengthdecreases.

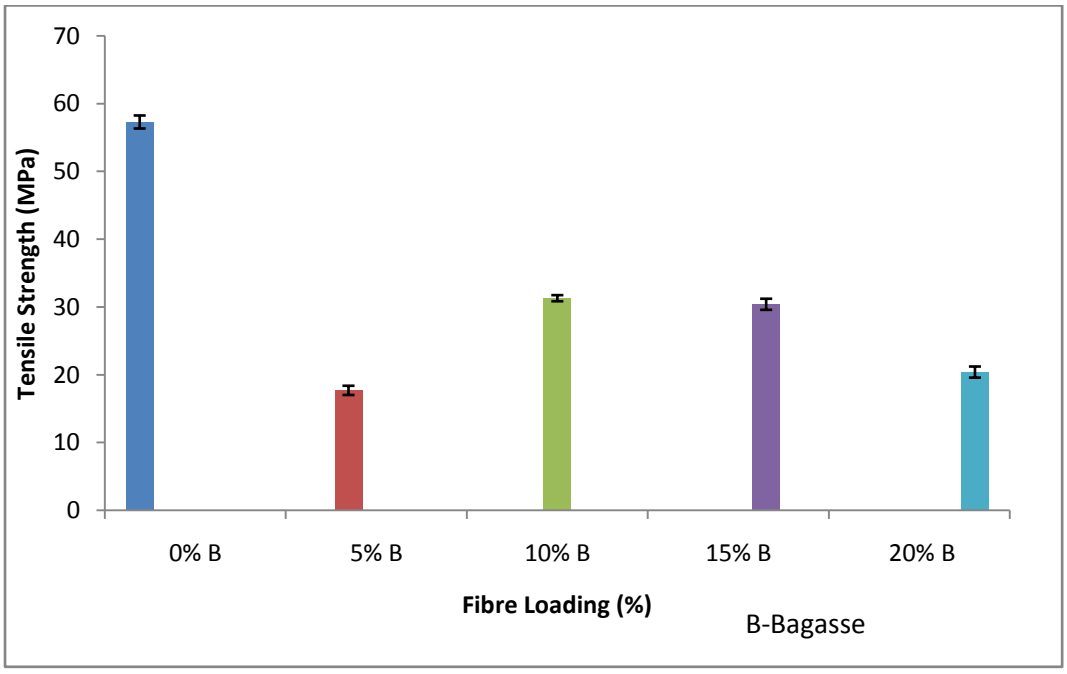



Figure 4.1: Effect of Fibre loading on the Tensile Strength of Bagasse/Epoxy Composites.

As the fibre loading increases, the tensile strength also increases as a result of the incorporation of stiffer fibres into the epoxy matrix.

The decrease in tensile strength could be attributedto low wettability of the fibreby the matrix beyond the optimum point. It could also be inferred that since thetensile strength arelower compared to the 100% epoxy matrix (control), therefore there is need to hybridize the bagasse fibre.

**4.1.2Effect of hybrid composition on Tensile Strength of the composite samples**

Result in Figure4.2 showed the effect of hybridization of bagasse and sisal, bagasse and coir on the tensileproperties of the composites.

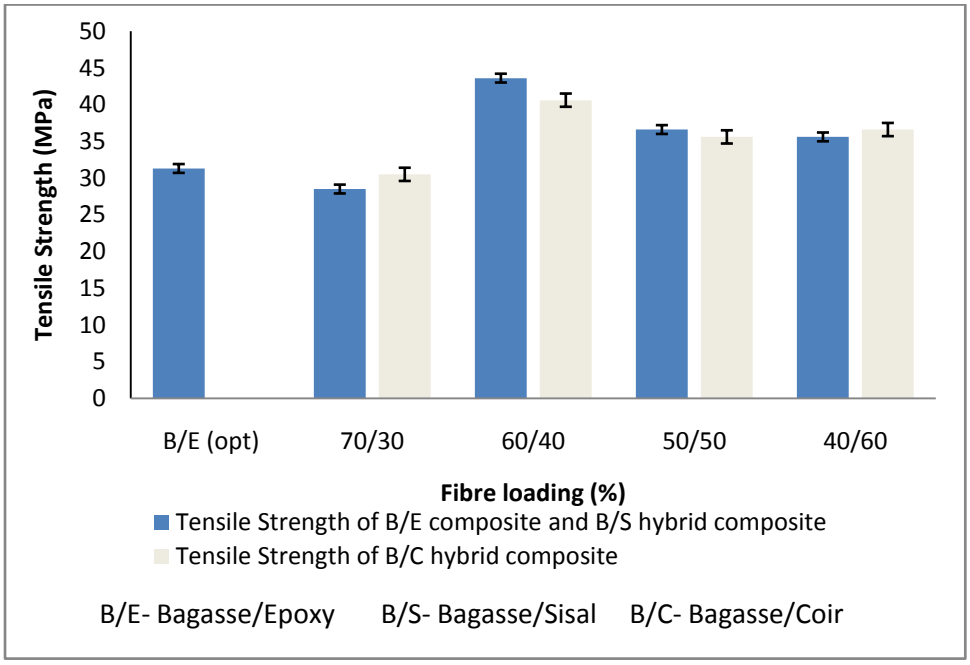



Figure 4.2: Effect of hybrid composition on the tensile strength of bagasse/epoxy composite.

The compositehaving composition of 60% Bagasse/40%Sisal had the highest tensile strength of 43.60 MPa with an improvement of about 39.3 % over the 10 % Bagasse/Epoxy composite.

The composite having a similar composition of 60 %Bagasse/40% Coir shows slightly lowertensile strength than 60% Bagasse/40%Sisal having a numerical value of 40.6 MPa and 29.7 % improvement over the 10% Bagasse/Epoxy composite.

This indicates that there was negative synergy at those compositions where there was decrease in numerical values due to lack of good interaction among the fibres.

### 4.1.3 Effect of hybrid composition on Tensile Strength of the composite samples

The characterization of the composites composition at 60B/10S/30C reveals that hybridization has significant effect on the mechanicalproperties of composites. Havingthe highest tensile strength of 53.25 MPa with an improvement of about 70.1 % over the 10 % Bagasse/Epoxy composite while 60%B/30%S/10%C showed the lowest tensile strength of 46.2 MPa.

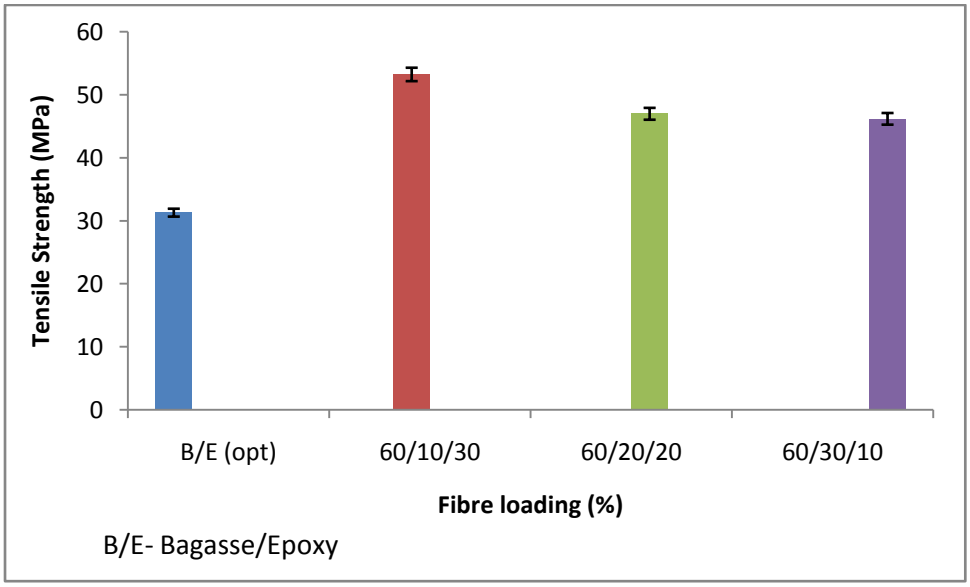



Figure 4.3: Effect of hybrid composition on the tensile strength of bagasse/epoxy composite.

Thus, there is a considerable improvement in the tensile properties of bagasse/epoxy when blended with sisal and coir fibresin two and three-fibre reinforced epoxy hybrid compositesystem respectively.

The improvement in tensile strengthis as a result of the incorporation of stronger sisal and coirfibres into the bagasse/epoxy composite.

The trend of the tensile strengthresult is similar to that obtained byAbbasi and Sarfraz, (2003).

**4.1.4Effect of fibre loading on flexural Strength of the composite samples**

From Figure 4.4a, it can be observed that the flexural strength of the bagasse/epoxy composite increases as the fibre loading increases until optimum value was obtained at 10% fibre loading; there after the flexural modulus decreases.The flexural strength of 5%, 10%, 15% and 20% bagasse/epoxy composite are: 55.6MPa, 89.6MPa, 73.1 MPa and 28.9MPa respectively.

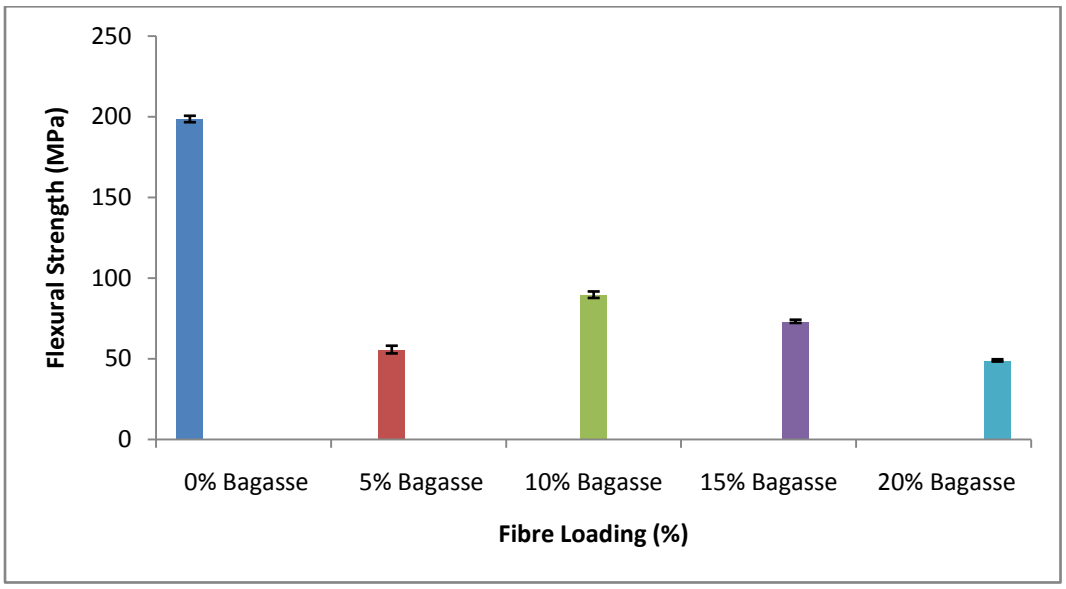



Figure 4.4: Effect of Fibre Loading on the Flexural Strength of Bagasse/Epoxy Composites.

### 4.1.5Effect of hybrid composition on Flexural Strength of the composite samples

Figure 4.5 showed the effect of hybridization of bagasse and sisal, bagasse and coir on the flexuralstrengthof the composites.

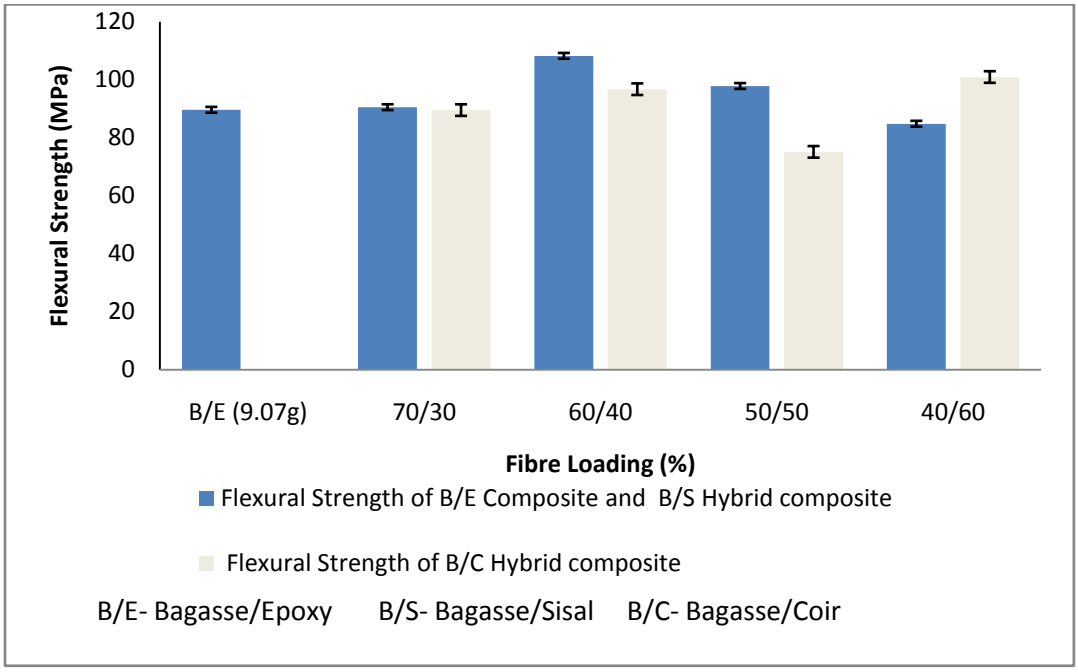



Figure 4.5: Effect of hybrid composition on the flexural strength of bagasse/epoxy composite.

It can be seen from Figure 4.5a that the composite having composition of 60% Bagasse/40%Sisal had the highest flexural strength value of 108.2 MPa with an improvement of about 20.75 % over the bagasse/epoxy composite, while 60%bagasse/40%coir had a value of 100.9MPa.

This increase in flexural strength could be as a result better fibre interaction between bagasse and sisal compared to bagasse and coir in the hybrid system. While the composite having composition of 50%bagasse/50% coir shows lowestflexural strength of 75.1 MPa which is lower than the bagasse/epoxy composite.

**4.1.6 Effect of hybrid composition on Flexural Strength of the composite samples.**Figure 4.6 showed theeffect of hybrid composition containing bagasse, sisal and coir on the flexural strength of the composites.

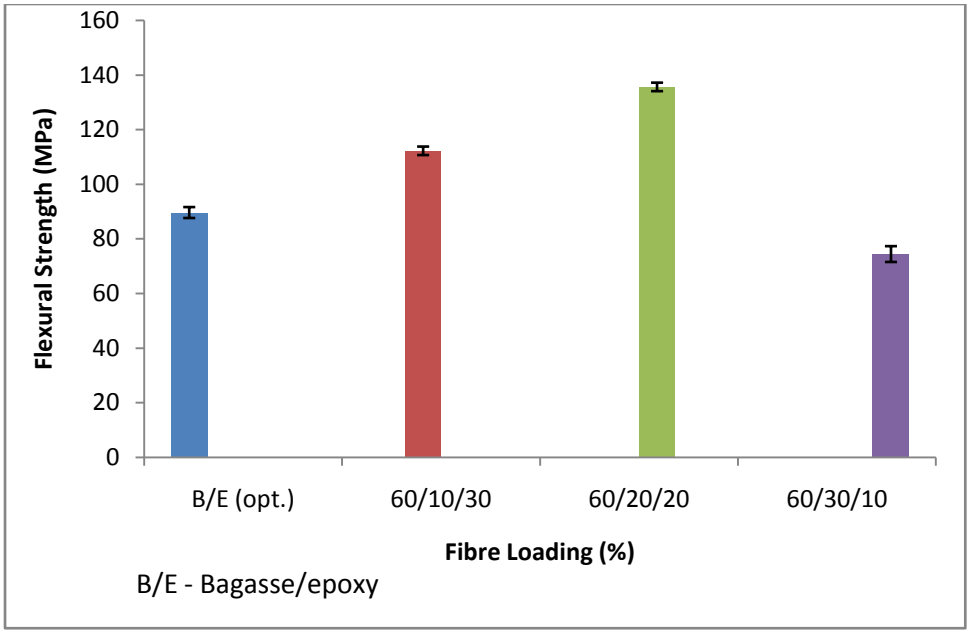



Figure 4.6: Effect ofHybrid composition on the Flexural Strength of Bagasse/Epoxy Composite.

In the case of the three-fibre hybrid composite system, the composite with composition of 60%B/20%S/20%C had the highest flexural strength value of 135.6MPa with better improvement of about 51.3% over the Bagasse/Epoxy composite. While that of 60%B/30%S/10%C showed the lowest flexural strength of 74.4 MPa.

The increase in the flexural strength is attributed to the fact that there is a synergistic interaction i.e better fibre-fibreinteraction in the hybrid situation.

### 4.1.7 Effect of fibre loading on flexural Modulus of the composite samples

The numeric values of the flexural modulus of bagasse/epoxy composite with the fibre loading of 0%, 5%, 10%, 15% and 20% as seen in Figure 4.7 are: 464.42 MPa, 1561.21 MPa, 1041.76 MPa and 1922.48 MPa respectively. The lowest modulus was observed at 0% fibre loading which is expected due to brittleness.

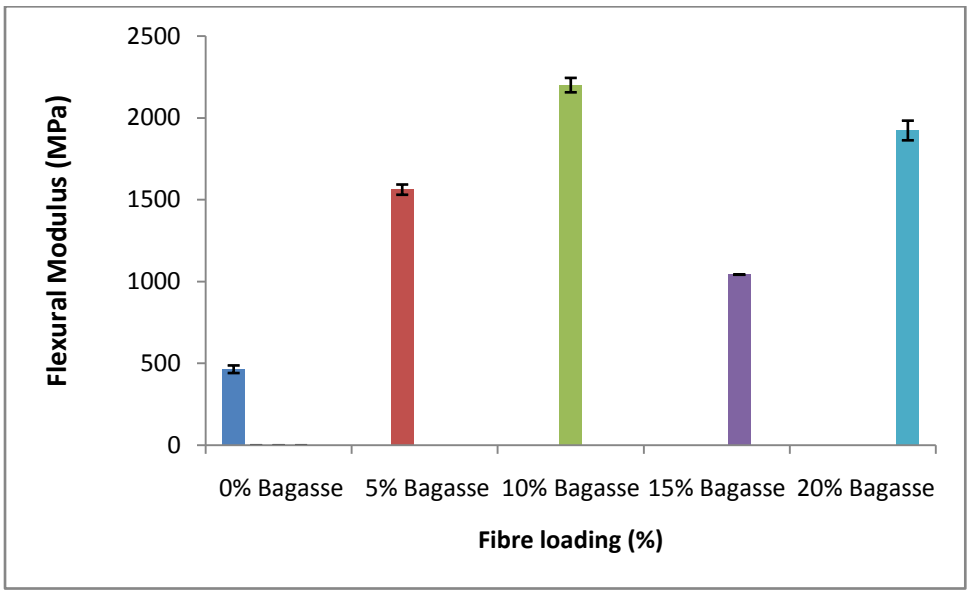



Figure 4.7:Effect of Fibre Loading on the Flexural modulus of Bagasse/Epoxy Composite.

As shown from the Figure 4.7, the flexural modulus of bagasse is lower before reinforcement but after hybridizing with sisal and coir fibres, the flexural strength was raised to the until it got to an optimum because the high modulus of elasticity of these fibres will help to carry a large amount of loads.

### 4.1.8Effect of hybrid composition on Flexural Modulus of the composite samples

Figure 4.8 showed the effect of hybridization of bagasse and sisal, bagasse and coir on the flexuralstrengthof the composites.

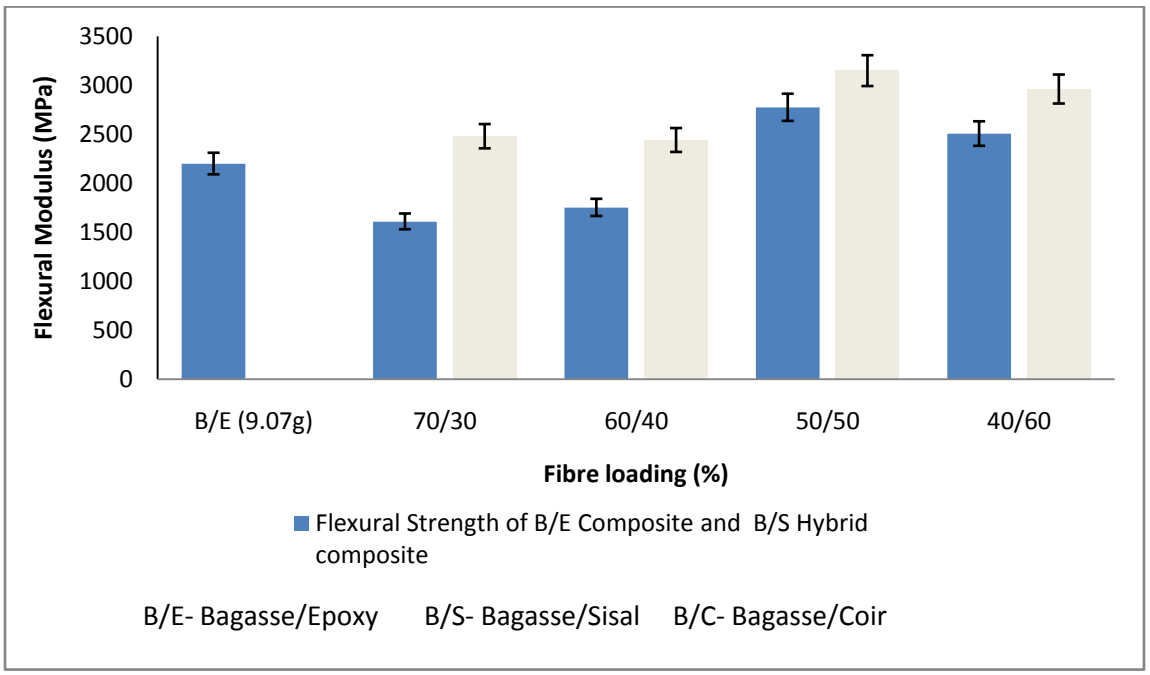



Figure 4.8: Effect ofHybrid composition on the Flexural modulus of Bagasse/Epoxy Composite.

From Figure 4.8, the composite having composition of 50% Bagasse/50%Sisal had the highest flexural modulus value of2773.42 MPa with an improvement of 43.7% over the Bagasse/Epoxy composite, While the composite having composition of 50%Bagasse/50% Coir shows aflexural modulus of 3147.78 MPa with a better synergistic improvement of 50% over bagasse/epoxy composite revealing that coir is a stiffer fibre compare to sisal.

### 4.1.9Effect of hybrid composition on Flexural Modulus of the composite samples.

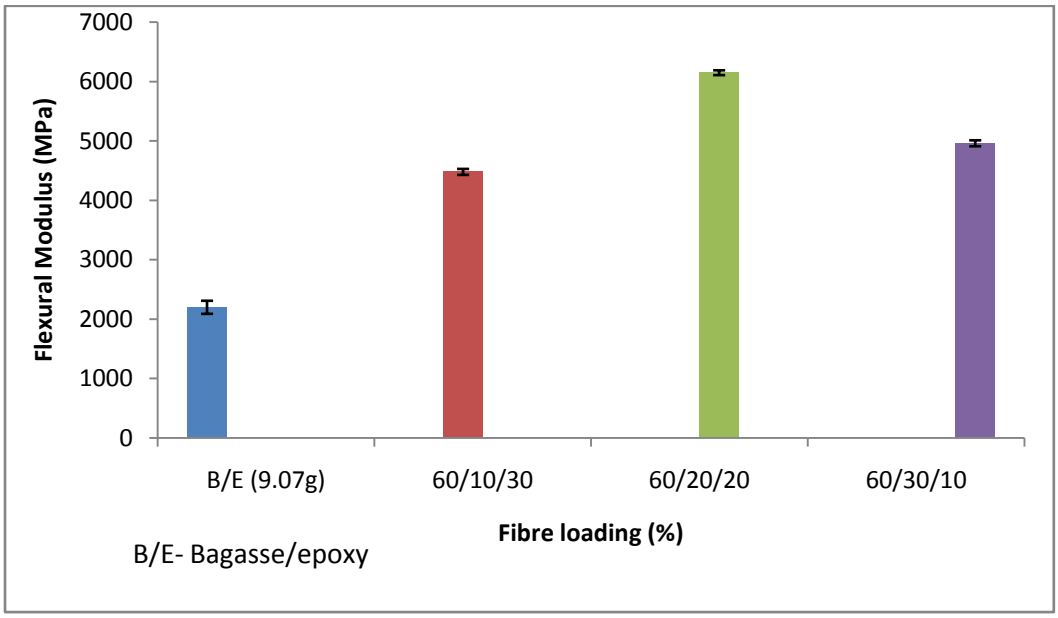



Figure 4.9: Effect ofHybrid composition on the Flexural modulus of Bagasse/Epoxy Composite.

The increase in the flexural modulus is attributed to the fact that there is a synergistic interaction between the stiffer and highly resilient fibres in the hybrid situation.

The increase in the flexural modulus was also reported by Cao *et al.*, (2006) in his research as discussed in the literature review.

### 4.1.10 Effect of fibre loading on Elongation at break of the composite samples

Elongation at break or strain is expressed as the ratio of total deformation to the initial dimension of the material body in which forces are being applied (Shuhadah and Supri, 2009).

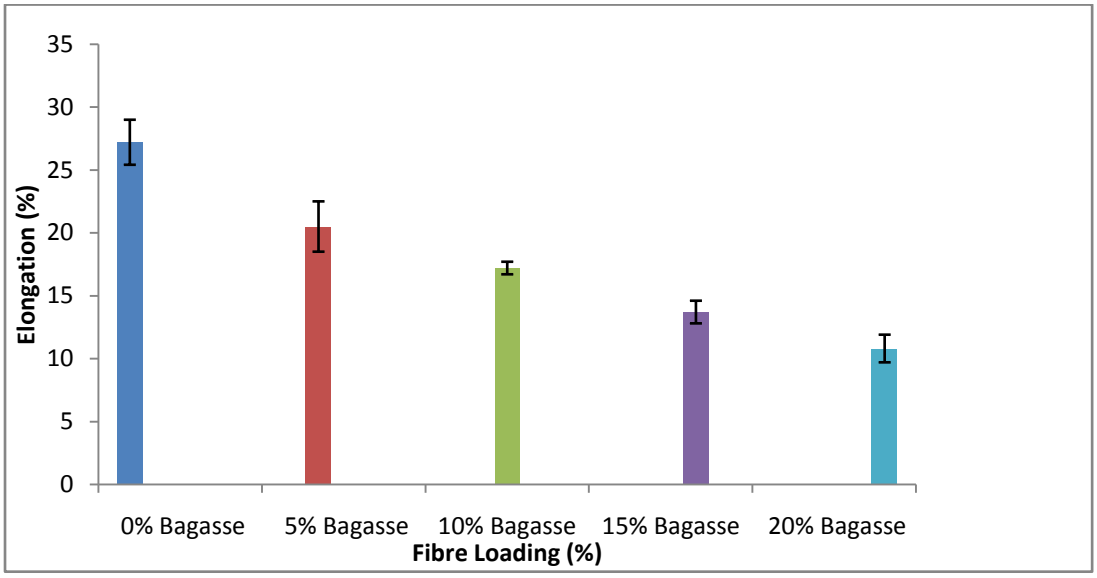



Figure 4.10: Effect of fibre loading on the Elongation of Bagasse/Epoxy Composite

Figure 4.10 revealed that as the fibre loading increases from 5% to 20%, the percentage elongation decreases from 20.5% to 10.8%. The decrease in the elongation is as a result of the fact that, as the percentage fibre loading increases, the compactness also increases thereby enhancing the stiffness. Thus, the stiffer the composite materials, the lower the percentage elongation due to the difficulty of the fibres to be extended (Netravali et and Luo, 1999).

### 4.1.11 Effect of hybrid composition on Elongation at break of the composite samples

Figure 4.11showed the elongation at break of the hybrid composites with varying fibre composition. When the bagasse was hybridized with sisal and coir fibres, the ductility of the composite was increased as a result gave a higher value than the 10% pure bagasse/epoxy composite at 60B/40S and 40B/60S.

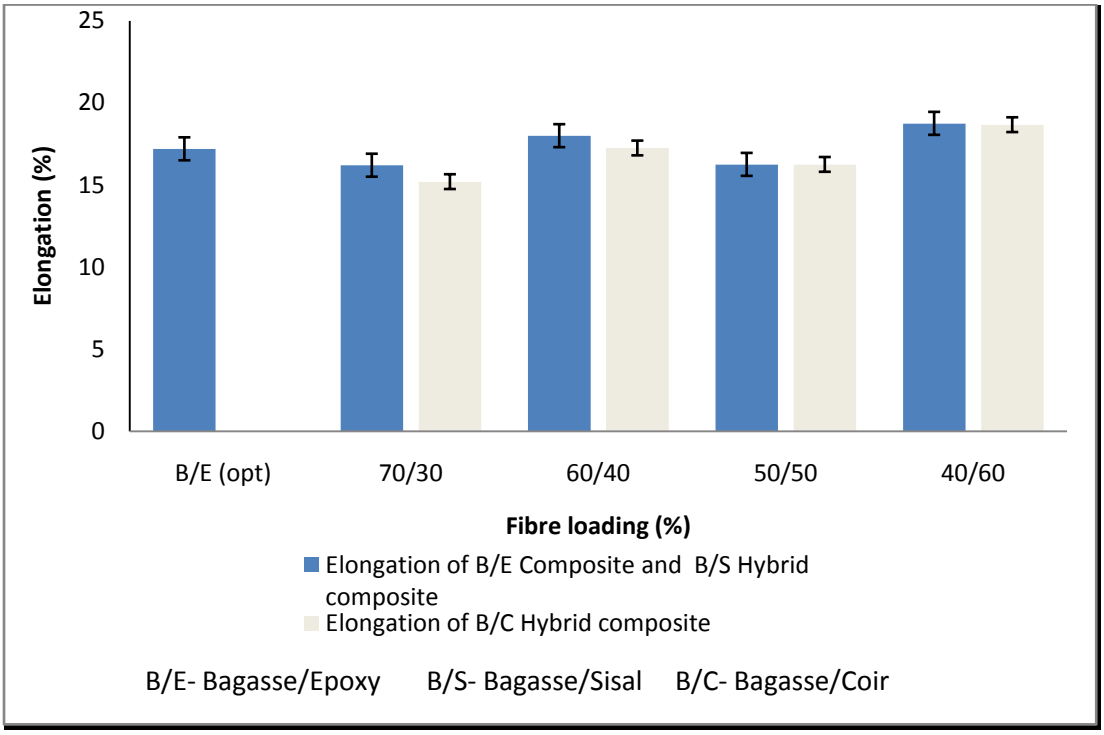



Figure 4.11: Effect ofHybrid composition on the Elongationof Bagasse/Epoxy Composite

The percentage elongation for 60 %B/40 %S/Epoxy composite gave 18.0% which is slightly higher than 17.25% for corresponding 60%B/40%C/Epoxy composite. While for 40% B/50%S/Epoxy composite the elongation registered was 18.75 % which is also lower than 18.67% obtained for the fibre loading of 40% B/60 % C composite. The decrease in the elongation could be as a result of the introduction of a stiffer coir fibre into the pure bagasse/epoxy composite.

### 4.1.12 Effect of hybrid composition on Elongation at break of the composite samples.

In Figure 4.12 below, the hybrid composite having composition of 60%B/10%S/30%C had the highest elongation of 19.75% followed by 60%/20%/20% having 16 % and then 60%/30%/10% having 15.25% elongation.

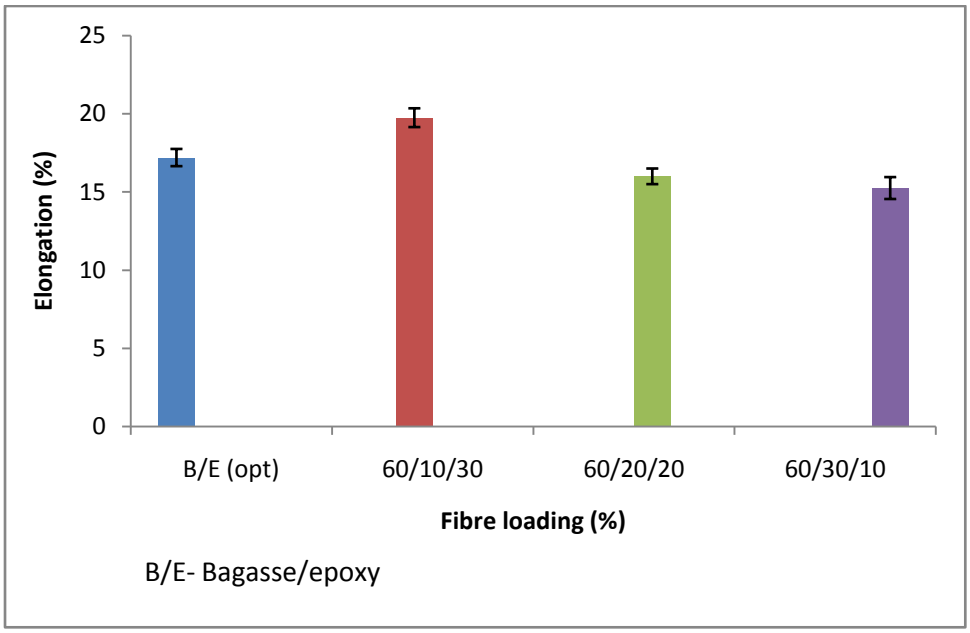



Figure 4.12:Effect ofHybrid composition on the Elongationof Bagasse/Epoxy Composite.

The decrease in the trend could be as a result of the increase in the compactness or crowdedness of the fibres within the composite system which in turn led to the decreased elongation.

### 4.1.13 Effect of fibre loading on Impact Strength of the composite samples

Figure 4.13 below indicates that the impact strength of pure bagasse/epoxy composite having percentage fibre loading 0%, 5%, 10%, 15% and 20% are 53 J/m$^2$, 35 J/m$^2$, 27J/m$^2$, 45J/m$^2$and 30 J/m$^2$ respectively with the highest value at 15% due to higher fibre content which can withstand mechanical shock. However, beyond that point there was a decrease due to low wettability of the fibre.

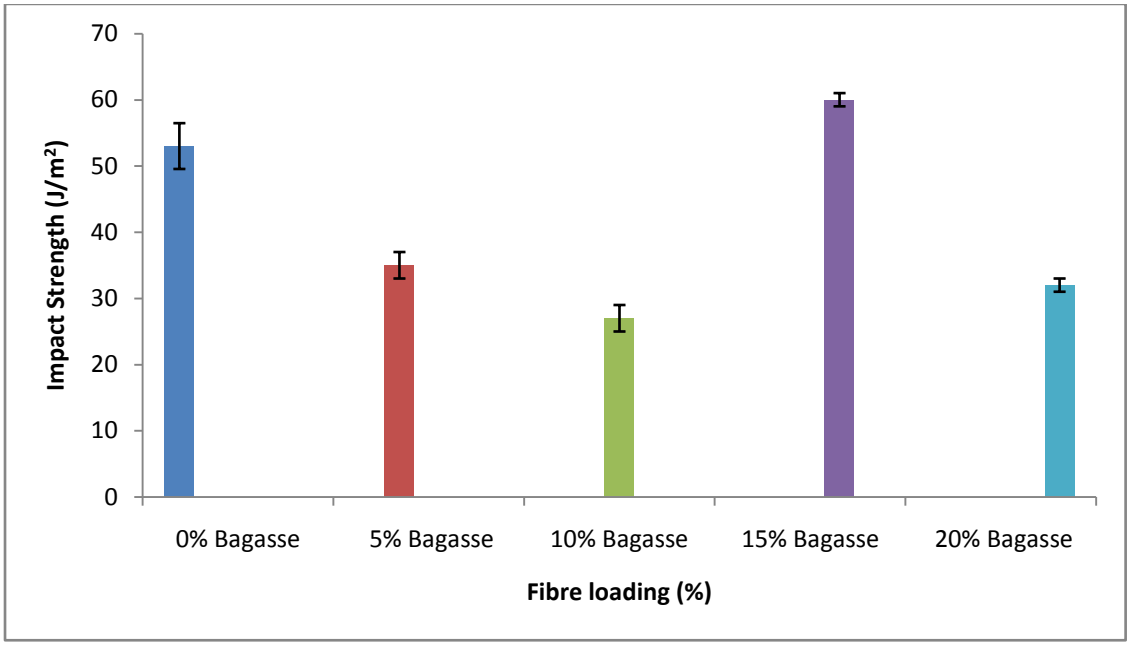



Figure 4.13: Effect of Fibre loading on the Impact Strength of Bagasse/Epoxy Composite.

### 4.1.14 Effect of Hybridization on the Impact Strength of Hybrid Composite

The impact strength of hybrid composites is in this trend: 50%B/50%S < 60%B/40%S 60%B/40%S < 40%B/60%S having 60.0 J/m$^2$, 53.0J/m$^2$ and 65.0J/m$^2$ respectively. Similarly, 50%B/50%C < 60%B/40%C having 73J/m$^2$ and 63J/m$^2$ respectively.

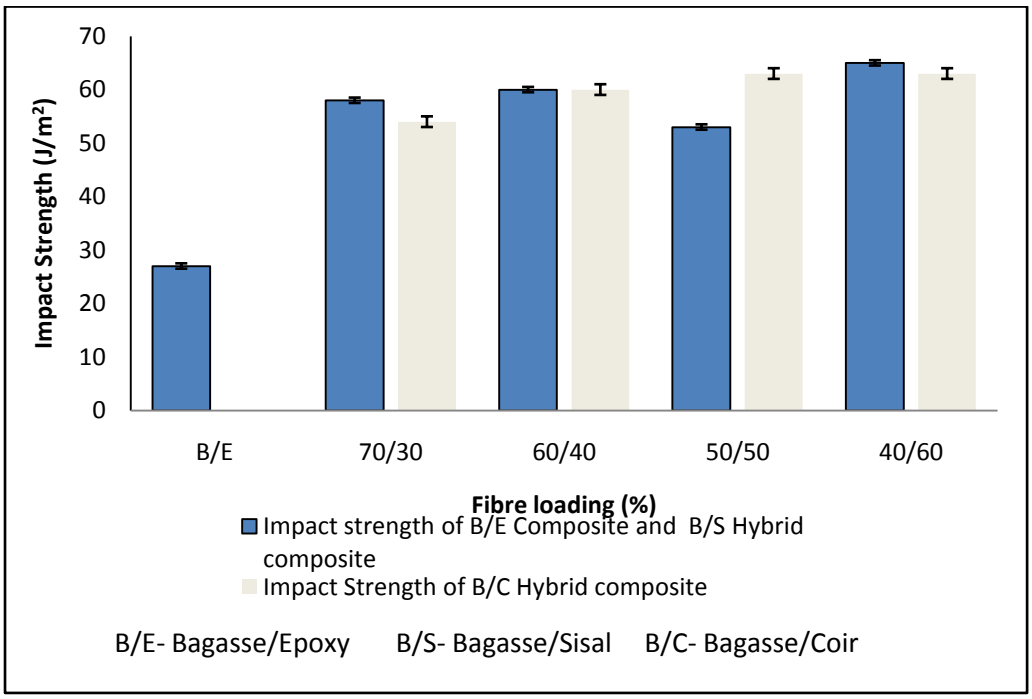



Figure 4.14:Effect of hybrid composition on the impact strength of bagasse/epoxy composite

The impact strength of hybrid composites is in this trend: 50%B/50%S < 60%B/40%S 60%B/40%S < 40%B/60%S having 60.0 J/m$^2$, 53.0J/m$^2$ and 65.0J/m$^2$ respectively. Similarly, 50%B/50%C < 60%B/40%C having 73J/m$^2$ and 63J/m$^2$ respectively. From the result above it clearly reveals that there was an improvement in the impact strength for all the hybrid compositions compared to the unhybridized bagasse/epoxy composite. This is due to the reinforcing effect of the sisal and coir fibres on the epoxy resin matrix. Therefore the fibres synergized and acted as a shock absorber against the impact stress encountered.

### 4.1.15 Effect of Hybridization on the Impact Strength of Hybrid Composite

In the case of the three-fibre hybrid composite system, the composite with composition of 60%B/20%S/20%C had the highest flexural strength value of 135.6MPa with increment of about 51.3% over the Bagasse/Epoxy composite. While that of 60%B/30%S/10%C showed the lowest flexural strength of 74.4 MPa.

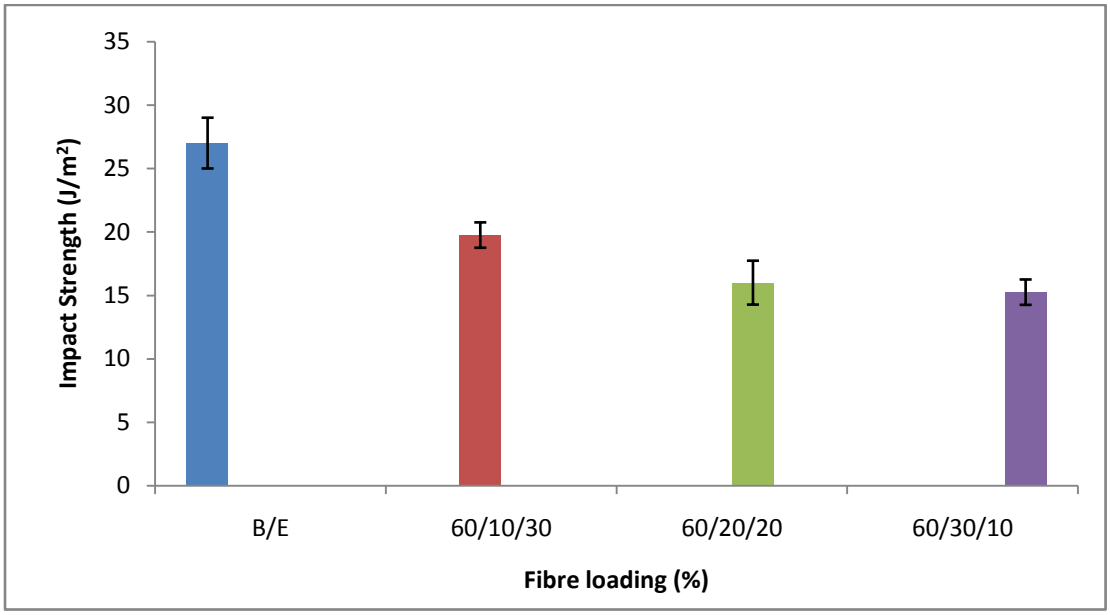



Figure 4.15: Effect ofHybrid composition on the Impact Strength of Bagasse/Epoxy Composite.

In the case of the bagasse, sisal and coir reinforced epoxy composites, the trend of the impact strength are as follows: 60%B/30%S/10%C< 60%B/10%S/30 %C < 60%B/20%S/20 %C having 42J/m$^2$, 52J/m$^2$ and 65J/m$^2$ respectively.

The impact resistance isconsidered low for the resinshaving a value of 53 J/m$^2$due to the brittleness of the matrix, but after reinforcing it by fibres the impact resistance increased to about 65J/m$^2$ because the fibres will carry the maximum part of the impact energy when the composite material is exposed. All this will raise and improve the impact resistance (Baley *et al.*, 2006).

**4.1.16Effect of effect of fibre loading on the hardness of the hybrid composites**

Figure-4.16 represents hardness values with numerical values of 8.5RHF, 8.4RHF, 8.0RHF and 7.8RHF for 5%, 10%, 15% and 20% fibre loading respectively.

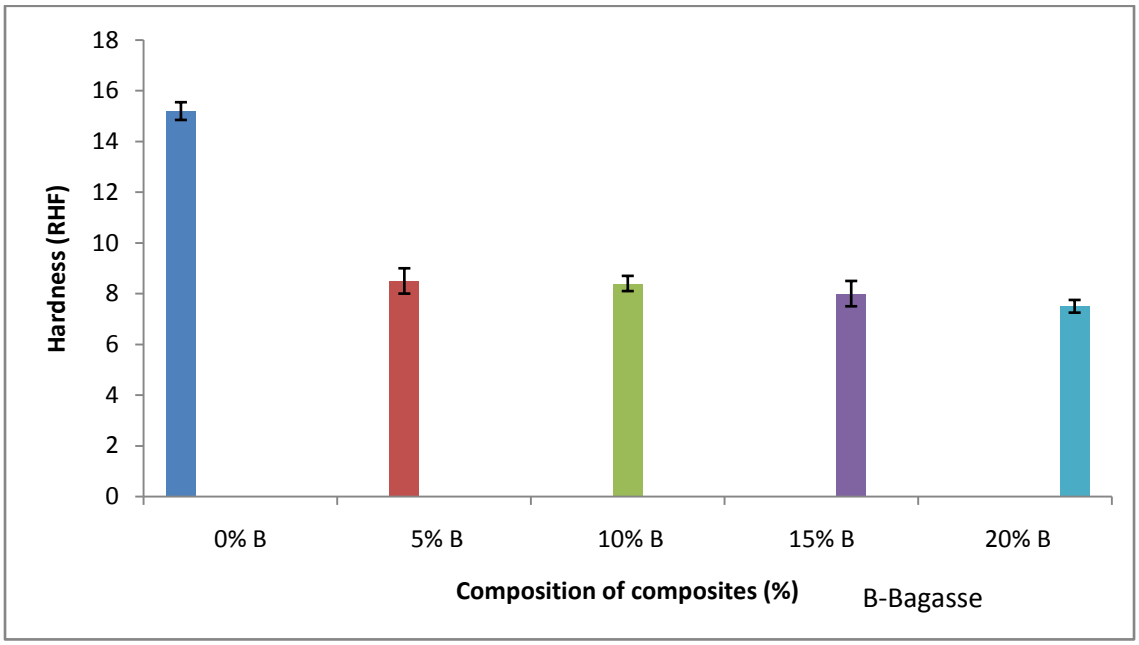



Figure 4.16: Effect of fibre loading on the hardness strength of Bagasse/Epoxy Composite.

**4.1.17 Effect of hybridization on the hardness of the hybrid composites**

The hardness was relatively increased when compared with the bagasse/epoxy composite when the coir fibre component was introduced into the composite.

The increased in the Rockwell hardness value was observed in the following order: 50%B/50%C > 60%B/40%C > 40%B/60 %C having values of 8.87 RHF > 8.63RHF > 8.23RHF respectively. This increase could be as a result of the presence of resilient coir fibre in the composite.

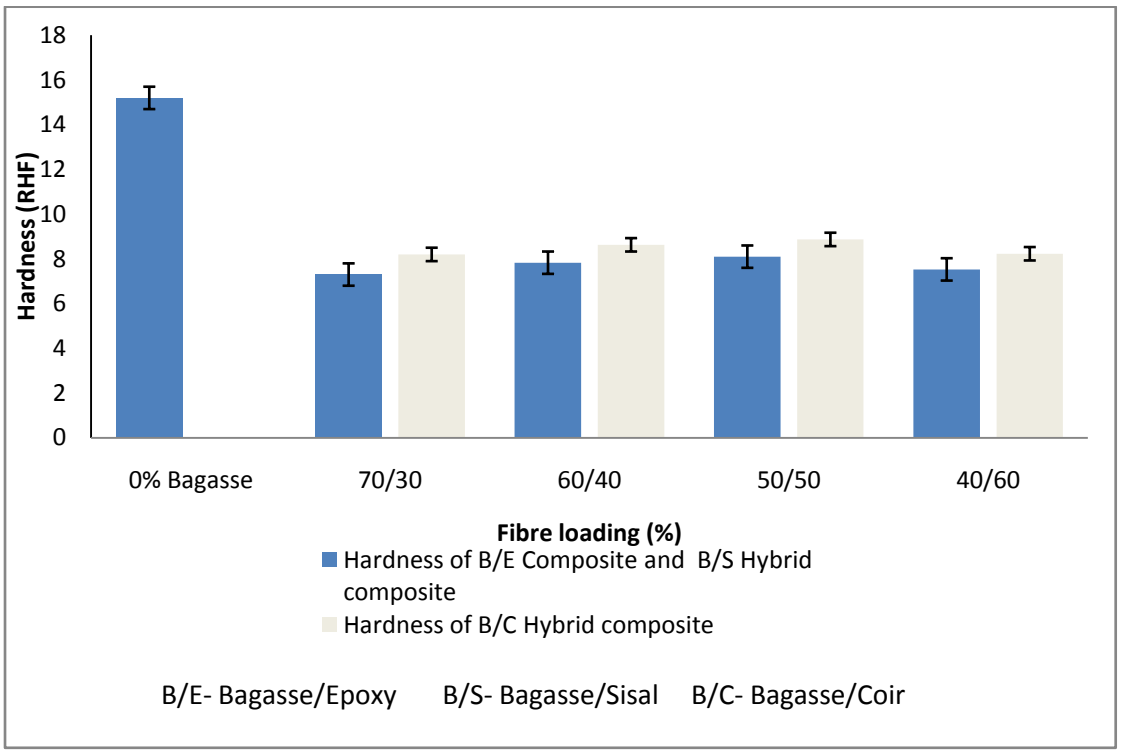



Figure 4.17:Effect ofHybrid composition on the Hardness of Bagasse/Epoxy Composite.

However, in Figure 4.17, the hardness strength for the hybrid composites showed that as the sisal component increased from 40% to 60%, the composition with 50%B/50%C showed the highest numerical strength of 8.87RHF followed by 60%B/40%C having 8.63RHF.

### 4.1.18Effect of hybridization on the hardness of the hybrid composites

In Figure 4.18, the hardness of the three-fibre hybrid composite system are as follows: 60%B/10%S/30%C > 60%B/20%S/20%C > 60%B/30%S/10%C having numerical values of 6.6RHF, 6.5RHF and 5.8RHF respectively.

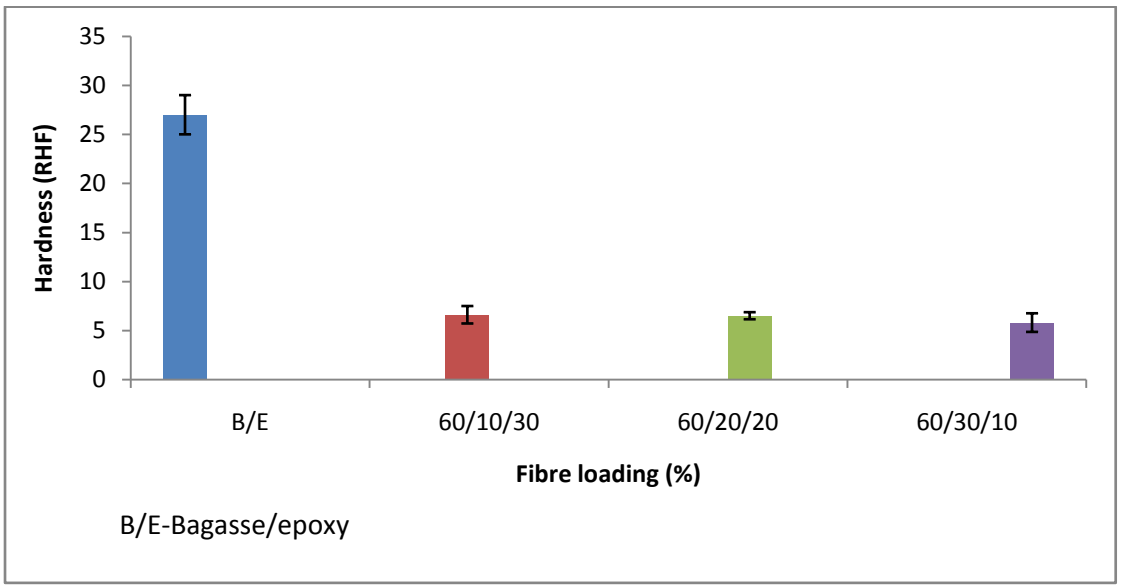



Figure 4.18:Effect ofHybrid composition on the Hardness of Bagasse/Epoxy Composite.

The hardness value decreasedwhen the resin is reinforced byfibres, as the fibre loading increased from 5% to 20%.Due to distribution the test load on fibres which decrease the penetration of test ball to the surface of composite material and by consequence raise the hardness of this material(Abbasi, 2003)**.** The hardnessslightly increased with the percentage of fibre reinforcement for the two-fibre hybrid composites with the highest value of 8.87RHF for 50%S/50%C. However hardness reduced when reinforcingfibres increased from 10% to 30% coir component because the samples sever from dynamic loads.

## 4.2 Physical Test

Physical parameters such as density, water absorption and SEM were determinedand results were discussed in this section.

### 4.2.19 Effect of Fibre loading on the Density of the bagasse Composites

Figure 4.19 revealed that increase in wt% of reinforced bagasse fibre from 5 % to 15 % resulted to increase in the density from 0.8525 to 1.3 g/cm$^3$.

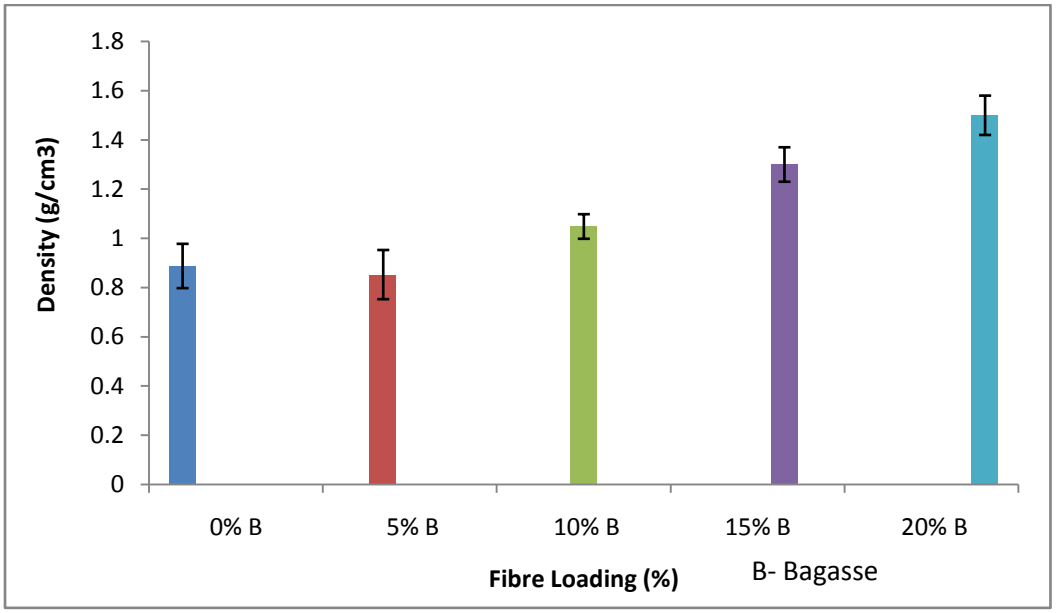



Figure 4.19: Effect of fibre loading on the Density of Bagasse/Epoxy Composite.

### 4.2.20 Effect of Hybridization on the Density of the bagasse Composites

Figure 4.20 showed a decrease in density, with increasing reinforcement from 40wt% to 60 wt% of sisal fibre.

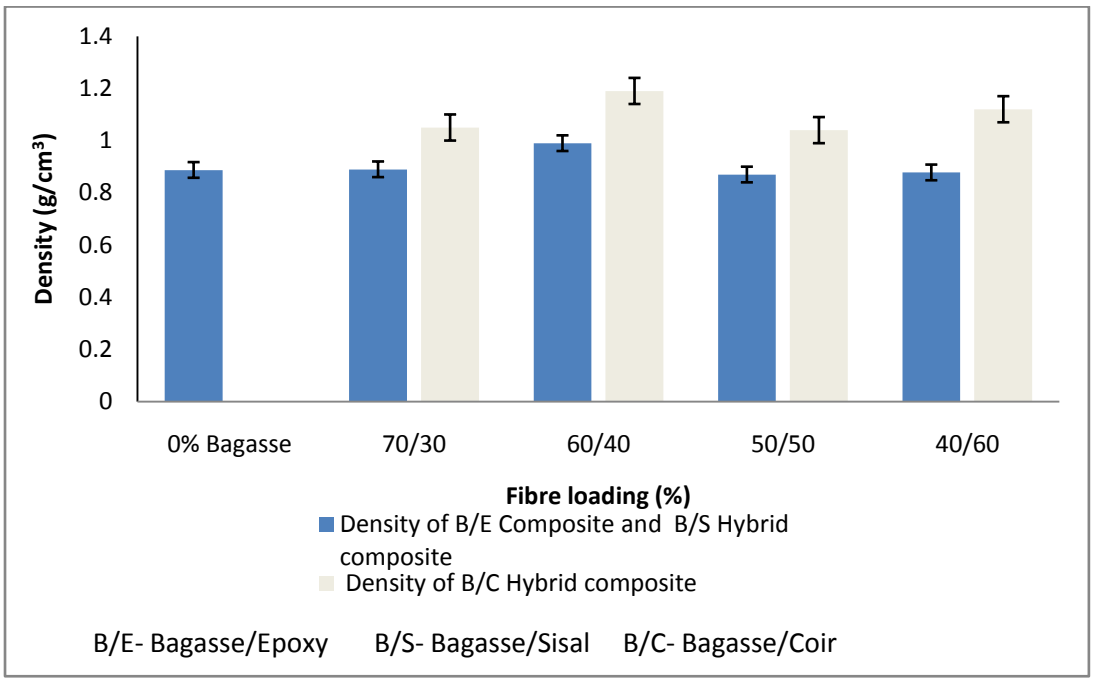



Figure 4.20: Effect ofHybrid composition on the Densityof Bagasse/Epoxy Composite.

It means that density decreases with increasein the % of sisal fibre within range of 40 % to 50 % which then have a little rise at 60% fibre loading as seen also in Figure 4.20.

### 4.2.21 Effect of Hybridization on the Density of the bagasse Composites

For the three-fibre hybrid composite system containing bagasse, sisal and coir fibres, the density was found to decrease as the % sisal fibre increases from 10% to 30% as shown in Figure 4.21. Thus, the decrease in the density is as a result of the decrease in the loading of the matrix as the fibre loading increase.

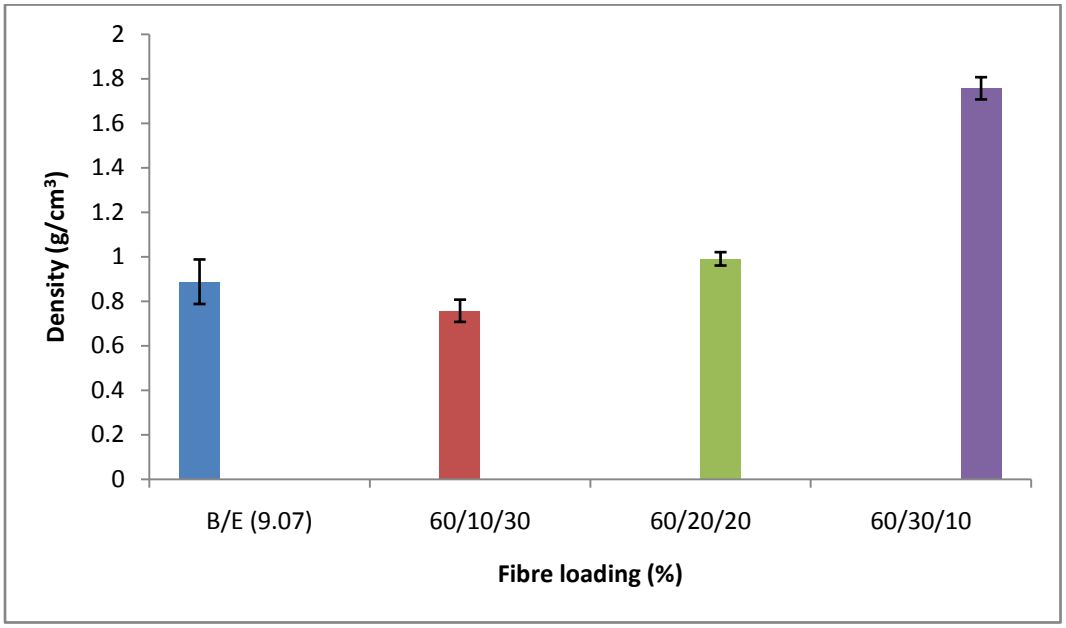



Figure 4.21: Effect ofHybrid composition on the Densityof Bagasse/Epoxy Composite.

Hence, it can be concluded that proper combination of bagasse, sisal and coir fibre reinforced epoxy composite material may have a variety of industrial applications when weight and strength would be the critical parameter in the design.

### 4.2.2Percentage Water Absorption

Water absorption is one of the major concerns inusing natural fibre composites in many applications. The water absorption characteristics of fibre reinforced epoxy composites werestudied by immersion in distilled water at room temperature.In thisstudy, 24 hrs water absorption was measured by theweight change method for the composites for 30 days.

#### 4.2.2.1 Percentage Water Absorption of a single fibre composite.

Below are the results of the water absorption test carried out on the bagasse/epoxy composites.

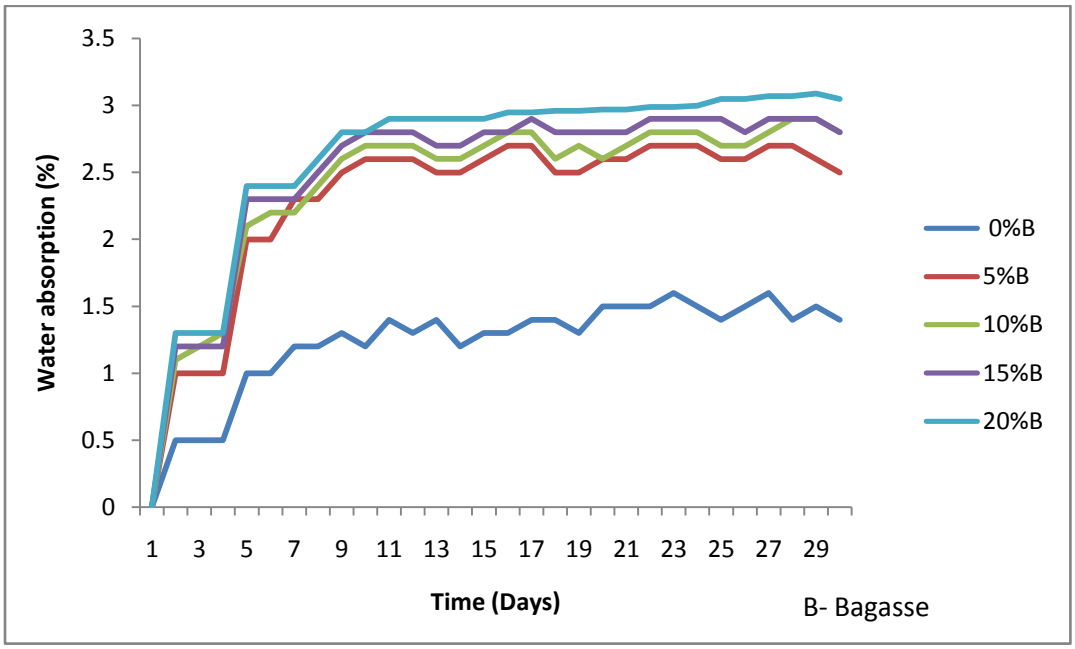



Fig 4.22: Percentage Water Absorption of a single fibre composite (Bagasse/Epoxy Composite).

As the percentage fibre loading increases, the rate of water absorption slightly increased in this order: 0% < 5% < 10% < 15% < 20% bagasse/epoxy composite having a numeric value of 2.5%, 2.7%, 3%, and 3.5% respectively.

The water absorption in 0% bagasse (100%epoxy) was negligible due to its hydrophobic nature i.e does not have affinity for water.

**4.2.2.2 Percentage Water Absorption of the hybrid fibre composite.**

The trend of the hybrid composite is as follows 60 wt%B40%S <40 %B60 %C <60 %B/10 %S/30 %C having absorption rate of 6.5 %, 7 % and 10.8 % respectively. The increase is as a result of the incorporation of more hydrophilic cellulosic fibres into the composite system as shown in Figure 4.23.

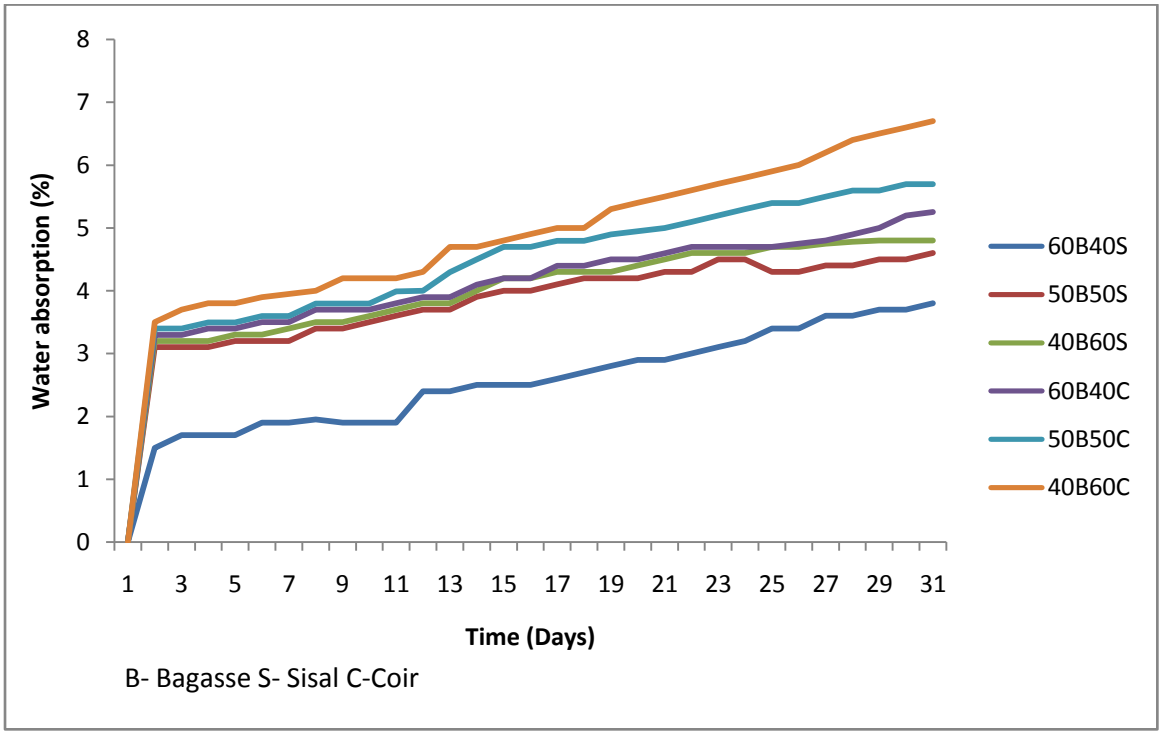



Figure 4.23: Percentage Water Absorption of two-fibre/matrix composite system of Bagasse/Sisal Epoxy Composite with time.

**4.2.2.3 Percentage Water Absorption of the hybrid fibre composite.**

Figure 4.22 and figure 4.24 showed that the maximum and minimum water uptake was observed by bagasse reinforced epoxy (BRE) and bagasse/sisal/coir reinforced epoxy (BSCRE) composites respectively.

The reason could be attributed to the fact that the incorporation of sisal and coir fibres increased the cellulosic site (i.e the OH group) which is hydrophilic in nature.

The rate of water absorption displayed by the fabricated composite material after 24 hrs is 0.7-1.7%, which is considerably low suggesting that the hybrid composite could gain out door applications.

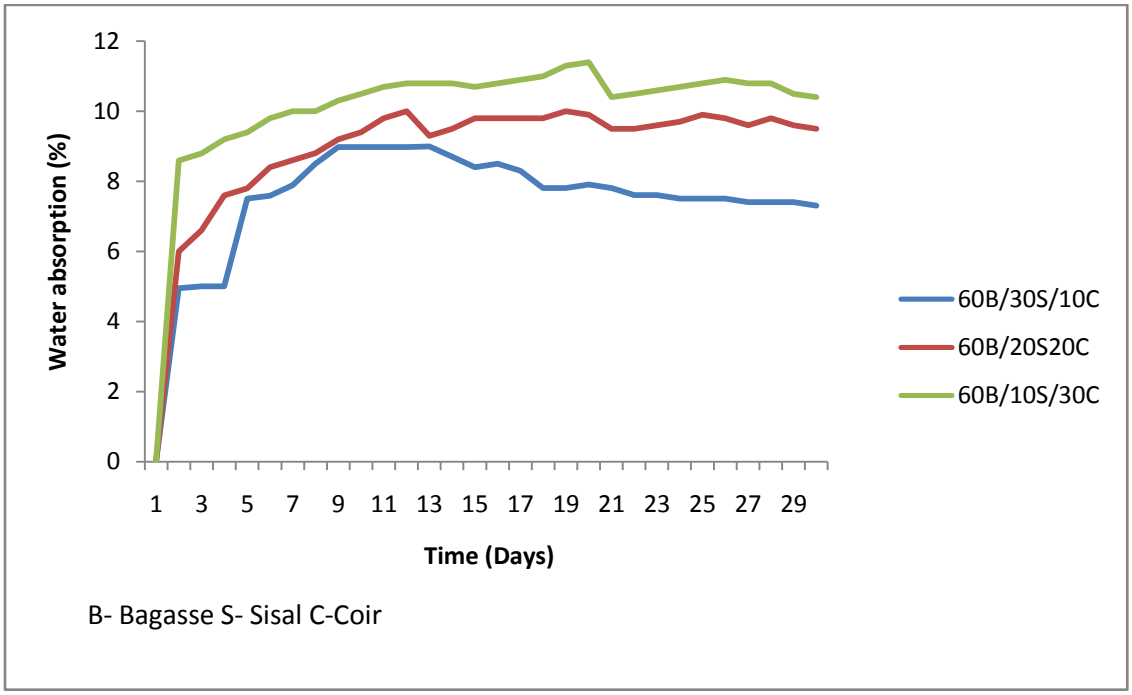



Figure 4.21: Percentage Water Absorption of three fibre composite (Bagasse/Sisal/Coir Reinforced Epoxy Composite).

### 4.2.3 Scanning Electron Microscopy

The Scanning Electron Microscopy testingpresents the fractured regions after tensile tests, revealing thefibres distribution in the matrix, fibres fractured in the matrix and fibrespull out holes as shown in the plates 4.1, 4.2, 4.3, 4.4 and 4.5.

#### 4.2.3.1**Micrograph** of **0% bagasse (100% Epoxy Resin)**

Plate 4.1showed the micrograph of the pure epoxy resin.

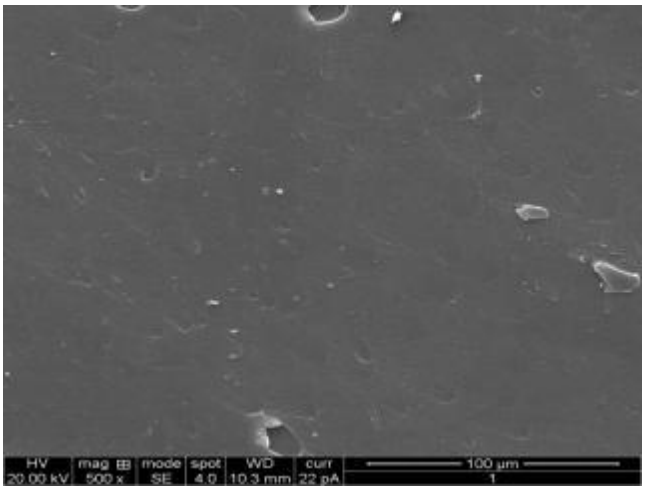



Plate 4.1: 0% bagasse (100% Epoxy Resin) at magnification 1000x.

The dispersion observed is uniform as expected as the control sample due to the homogeneity of the hydrophobic matrix. The micrograph is almost plain because there are no distortions in the morphology of the resin since fibres were not embedded in it.

### 4.2.3.2Micrograph of 10 % bagasse

Plate 4.2shows the SEM micrograph of bagasse/epoxy composite at10% fibre loading.




Plate 4.2: 10% Bagasse/Epoxy Composite at magnification 1000x.

The good fibre-matrix interaction and this could be as a result of the alkaline `treatment on the cellulosic fibre which enhanced the compatibility between the fibre and matrix.

### 4.2.3.3Micrographof60/40 bagasse/sisalepoxy hybrid composite

Plate 4.3 shows Bagasse/Sisal Reinforced epoxy hybrid composite at magnification of 1500x

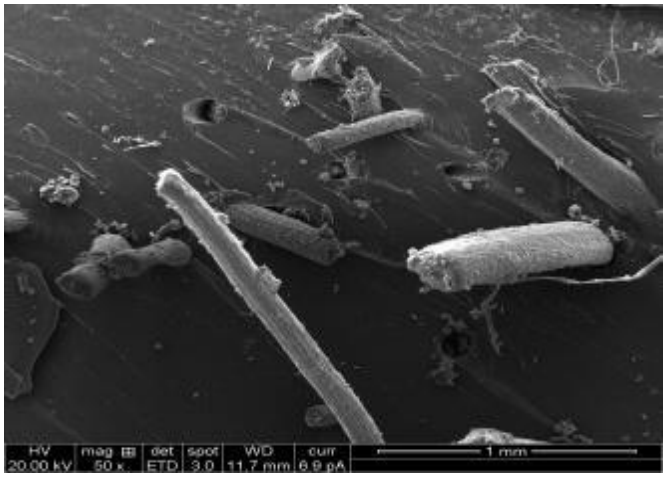



**Plate 4.3:Bagasse/Sisal Reinforced Epoxy Hybrid Composite at mag. of 1500x**

The SEM micrograph of the bagasse/Sisal fibres embedded in epoxy matrix in the aboveplate reveals good adhesive interaction between the fibres and the matrix indicatingenhanced mechanical properties of the hybrid composite.

**4.2.3.4Micrographof60/40 bagasse/coir epoxy hybrid composite**

Plate 4.4shows bagasse/coir reinforced epoxy composite at magnification of 1500x.




**Plate 4.4: Bagasse/Coir Reinforced Epoxy Composite at magnification 1500x**.

Plate 4.4shows a poor fibre-matrix interaction in the composite. There are some observed voids. This defect may be as a result of inhomogeneous mixture.

The observed voids in the micrograph indicate a point of fibre pull out after deformation by the tensile testing. However, there is a point of loose bonding. This defect may be as a result of improper dispersion of the matrix during the casting process of the composite.

**4.2.3.3Micrographof bagasse/sisal/coir reinforced epoxy hybrid composite at magnification of 1500x**

From the image in plate 4.5, it indicates the micrograph of bagasse/Sisal/Coir hybridfibres in epoxy matrix.

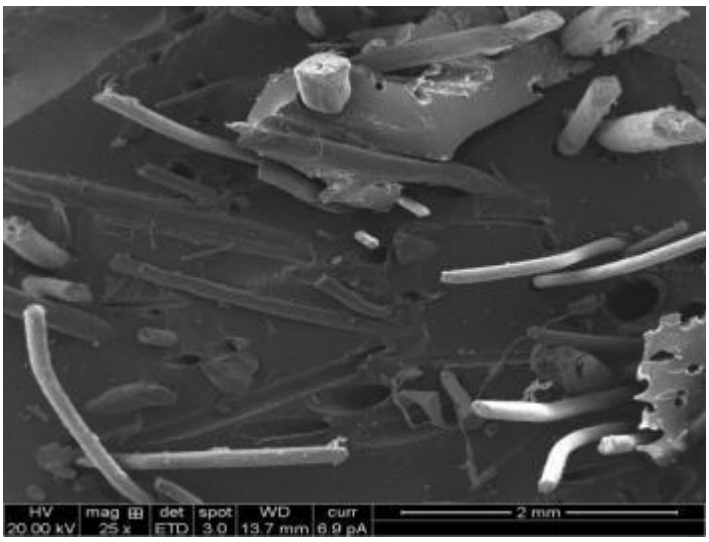



**Plate 4.5: Bagasse/Sisal/Coir (60B/20S/C20) Epoxy Composite at magnification 1500x**.

There is no voids and pull out of fibres of the specimen. Which shows that the bonding between the fibres and epoxy resin was highresulting in increased strength.

# CHAPTER FIVE

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

## 5.1 Summary

The main aim of this research work was to fabricate a hybrid composite based upon bagasse fibre using epoxy as the matrix. The bagasse fibre is very cheap and readily available; however it has moderate tensile and flexural strength compared to other natural and synthetic fibre composites.Hence the incorporation of sisal and coir fibre enhancedthe mechanical properties of bagasse/epoxy composites and a prototype crash helmet was developed based on the best hybrid formulation and mechanical performance.

The fibres (i.e bagasse, Sisal and Coir) were first harvested and extracted from their plants so that they could have high ratio of length to thickness. Thereafter, they were gently washed in warm water in order to remove some earthly impurities and then finally rinsed in cold water according to the various pretreatment conditions of the fibres.

The fibes were then cut into short staple forms (7.5mm fibre length) before casting into composite in a glass mould by varying the percentage fibre loading to obtain the optimum blend ratio.

After casting, the slabs of the composite samples were cut using hack saw into specifications based on the machine requirements and then tested for mechanical properties. The results obtained from the test were studied and compared.

From the results and discussion in the previous chapter, the following summary is then made:

a. The bagasse/epoxy composite gave the highest tensile strength at 10% weight fraction31.3MPa when compared to that of 3%, 5%, 15% and 20% fibre loadings.However, when blended with sisal, the tensile strength was raised to 43.6MPa with the composition of 60%B/40%S having an increase of 39.3% over the pure Bagasse/Epoxy composite while that of 60%B/40%C registered a strength of 40.6MPa(which is slightly lower than 60%B/40%S) having an increase of 29.7% over the pure Bagasse/Epoxy composite. From the results it was observed that the tensile strength was further enhanced in the three-fibre/matrix hybrid system of Bagasse/Sisal/Coir reinforced epoxy composites. A numerical strength value of 53.25MPa was obtained with an increase of 70.1% over the pure Bagasse/Epoxy composite. This improvement was obviously as a result of the incorporation of stronger fibres into the composite system.

b. It was also observed that similar trend was followed for the flexural strength. 10% bagasse/epoxy composite registers the highest strength having 89.6MPa when compared to other percentage fibre loading.

The hybrid composites gavebetter strength. 60%B/40%S gave values of 108.2MPa with an improvement of 20.75% while the composite with the composition of 60%B/40%C has a value of 100.9MPa.The highest valuewas recorded by 60%B/20%S/20%C which has a value of 135.6MPa with an improvement of 51.3%. The numerical strength values were improved after hybridization as follows in this order: 60%B/20%S/20%C > 60%B/40%S >60%B/40%C.

c. Decrease in the percentage elongation was observed as the fibre loading increases from 20.5 to 10.8% for pure bagasse/epoxy composite this is due to the compactness or crowdedness of the fibres as the fibre loading increases thereby making the composites more rigid and difficult to extend.

d. There is a good improvement in the impact strength of the hybrid composites compared to the bagasse/epoxy composite with the highest impact strength of 60J/$m^2$ at 15%. When sisal fibre was incorporated, the impact strength remained the same at 40% having a value of 60J/$m^2$. However, upon incorporation of coir fibre, the impact strength was raised remarkably to 73J/$m^2$ at 40% of coir.

e. The hardness decreases from 5% to 20% fibre loading having the following values: 8.5RHF, 8.4%RH, 8.0RHF, 7.8RHF and 7.8RHF respectively. There was no obvious improvement in the hardness with the incorporation of the sisal fibre. The hardness was improved when the coir fibre component was introduced into the composite.

f. The density of the composites showed a decrease from as the fibre loading increases for the pure bagasse/epoxy composite ranging from 0.8525 to 1.3g/$cm^3$. A decrease was also observed in a hybrid system from 40%-60% sisal fibre loading. Hence, it can be concluded that proper combination of bagasse, sisal and coir fibre reinforced epoxy composite material may have a varieties of industrial application when weight and strength would be the critical parameter in the design.

h. From the SEM analysis, it is cleared in some of the micrographs that there is better fibre-matrix interaction in the specimens.

## 5.2 Conclusion

This work shows the successful production of Bagasse/sisal/coir fibre reinforced-epoxy hybrid composites with simple hand lay-up technique which reveals the conversion of waste to wealth. This work resulted in the following deductions:

i. It has been noticed that the mechanical properties of the composites such as Tensile test;flexural strength, flexural modulus, impact strength and Rockwell Hardness were influenced by the hybridization of sisal and coir fibrescompared to the bagasse/epoxy composite.

ii. From the result it was observed that the tensile strength three-fibre/matrix hybrid system of Bagasse/Sisal/Coir reinforced epoxy composites registered the highest numerical strength value of 53.25MPa havingan increase of 70.1% over the pure bagasse/epoxy composite. This improvement was obviously as a result of the incorporation of stronger fibres into the composite system.

iii. In the case of the three-fibre hybrid composite system, the composite with composition of 60%B/20%S/20%C had the highest flexural strength value of 135.6MPa with increment of about 51.3% over the Bagasse/Epoxy composite. While that of 60%B/30%S/10%C showed the lowest flexural strength of 74.4 MPa.

iv. The density of the composites showed a decrease from as the fibre loading increases for the pure bagasse/epoxy composite ranging from 0.8525 to 1.3g/cm$^3$. A decrease was also observed in a hybrid system from 40%-60% sisal fibre loading.

Hence, it can be concluded that proper combination of bagasse, sisal and coir fibre reinforced epoxy composite material may have a varieties of industrial application when weight and strength would be the critical parameter in the design.

**Table5.2.1: Comparison of the Mechanical Properties results obtained with literature**

| Samples | Modulus GPa | Impact Strength ($J/m^2$) | Toughness (J) |
|---|---|---|---|
| Ogabi and Dauda (2016); Bagasse/sisal/coir hybrid epoxy composite | 6.000 | 65 | _ |
| Yuhazri and Dan (2007);10% coir with 90% epoxy resin. | 8.773 | 9.95 | _ |
| Murali et al (2014): 40% hybrid (jute, banana sisal fibres) with 60% epoxy. | _ | 53.06 | _ |
| AdemohandOlanipekun,(2015)20% oil palm composite helmet Shell. | 3.439 | 24.44 | 3.28 |

**Table 5.2.2: Comparison of the Physical Properties result obtained with literature**

| Samples | Colour | Mass (Kg) | Thickness (mm) |
|---|---|---|---|
| **Nigeria (Bagasse)** | Silver/Camour | 3.05 | 6.0 |

| | | | |
|---|---|---|---|
| **British** | Silver | 3.25 | 2.0 |
| **US** | Dark blue | 2.12 | 10 |
| **Chinese** | Silver | 3.56 | 3.0 |

Source: Academy Laboratory, NDA Kaduna

### 5.3 Recommendations

This research has contributed toknowledge by using hand lay-up technique to fabricatea hybrid composite which may serve as a protective helmet material when modifiedfor both civilianandmilitary applications. Some recommendations are seen below:

a. Examination of the use of natural polymer as matrix, fully biodegradable.

b. The alkaline treatment could be varied in order to obtain an optimumpoint for better compatibility and higher mechanical strength.

c. The use of silicone mould to replicate more samples at a shorter time without destruction.

d. Ansys software could be used for modelling and simulation of the helmet design.

e. Investigation of the ballistic properties of the crash helmet.

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## APPENDICES

### APPENDIX A: TENSILE STRENGTH OF COMPOSITES.

TABLE 4.1**:** Tensile Strength of Bagasse/Epoxy Composites.

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Tensile Strength (MPa) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 57.30 |
| 2 | 5 | 95 | 17.70 |
| 3 | 10 | 90 | 31.30 |
| 4 | 15 | 85 | 30.40 |
| 5 | 20 | 80 | 20.40 |

Table 4.2a: Tensile Strength of Bagasse/Sisal/Epoxy Hybrid Reinforced Composite

| S/N | wt% of BF | wt% of SF | Mass of fibre Blend (g) | Tensile Strength (MPa) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 28.50 |
| 2 | 60 | 40 | 9.07 | 43.60 |
| 3 | 50 | 50 | 9.07 | 36.60 |
| 4 | 40 | 60 | 9.07 | 35.60 |

Table 4.2b: Tensile Strength of Bagasse/Coir hybrid Reinforced Epoxy Composite.

| S/N | wt% of BF | wt% of CF | Mass of fibre Blend (g) | Tensile Strength (MPa) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 30.50 |
| 2 | 60 | 40 | 9.07 | 40.60 |
| 3 | 50 | 50 | 9.07 | 35.60 |
| 4 | 40 | 60 | 9.07 | 36.60 |

Table 4.3: Tensile Strength of Bagasse/Sisal/Coir-Epoxy Hybrid Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of fibre blend (g) | Tensile Strength (MPa) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 53.25 |
| 2 | 60 | 20 | 20 | 9.07 | 47.00 |
| 3 | 60 | 30 | 10 | 9.07 | 46.20 |

**APPENDIX B: FLEXURAL STRENGTH AND MODULUS OF COMPOSITES.**

Table 4.4: Flexural Strength of Bagasse/Epoxy Composites.

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Flexural Strength (MPa) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 198.50 |
| 2 | 3 | 97 | 48.2 |
| 3 | 5 | 95 | 55.6 |
| 4 | 10 | 90 | 89.6 |
| 5 | 15 | 85 | 73.10 |
| 6 | 20 | 80 | 48.88 |

Table 4.5a: Flexural Strength of Bagasse/Sisal Reinforced Epoxy Composite.

| S/N | wt% of BF | wt% of SF | Mass of fibre blend (g) | Flexural Strength (MPa) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 90.50 |
| 2 | 60 | 40 | 9.07 | 108.20 |
| 3 | 50 | 50 | 9.07 | 97.80 |
| 4 | 40 | 60 | 9.07 | 84.80 |

Table 4.5b: Flexural strength of Bagasse/Sisal/Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of CF | Mass of fibre blend (g) | Flexural Strength (MPa) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 89.50 |
| 2 | 60 | 40 | 9.07 | 96.70 |
| 3 | 50 | 50 | 9.07 | 75.10 |
| 4 | 40 | 60 | 9.07 | 100.90 |

Table 4.6: Flexural strength of Bagasse/Sisal/Coir Epoxy Reinforced Composite.

| S/N | wt% of BF | % of SF | wt% of CF | Mass of fibre blend (g) | Flexural Strength (MPa) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 112.20 |
| 2 | 60 | 20 | 20 | 9.07 | 135.60 |
| 3 | 60 | 30 | 10 | 9.07 | 74.40 |

Table 4.4: Flexural modulus of Bagasse/Epoxy Composites.

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Flexural Modulus(MPa) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 464.42 |
| 2 | 5 | 95 | 1561.21 |
| 3 | 10 | 90 | 2199.46 |
| 4 | 15 | 85 | 1041.76 |
| 5 | 20 | 80 | 1922.48 |

Table 4.5b: Flexural modulus of Bagasse/Sisal/Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | Mass of fibre blend (g) | Flexural modulus(MPa) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 1609.27 |
| 2 | 60 | 40 | 9.07 | 1751.74 |
| 3 | 50 | 50 | 9.07 | 2773.42 |
| 4 | 40 | 60 | 9.07 | 2505.52 |

Table 4.5b: Flexural modulus of Bagasse/Sisal/Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of CF | Mass of fibre blend (g) | Flexural Modulus (MPa) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 2478.5 |
| 2 | 60 | 40 | 9.07 | 2439.68 |
| 3 | 50 | 50 | 9.07 | 3147.78 |
| 4 | 40 | 60 | 9.07 | 2960.04 |

Table 4.6: Flexural modulus of Bagasse/Sisal/Coir Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of fibre blend (g) | Flexural Modulus (MPa) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 4478.5 |
| 2 | 60 | 20 | 20 | 9.07 | 6147.78 |
| 3 | 60 | 30 | 10 | 9.07 | 4960.04 |

**APPENDIX C: ELONGATION OF COMPOSITES.**

Table 4.7: Elongation at break of Bagasse/Epoxy Composite.

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Elongation (%) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 27.20 |
| 2 | 5 | 95 | 20.50 |
| 3 | 10 | 90 | 17.20 |
| 4 | 15 | 85 | 13.70 |
| 5 | 20 | 80 | 10.80 |

Table 4.8a: Elongation at break of Bagasse/Sisal/Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | Mass of fibre blend (g) | Elongation (%) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 16.20 |
| 2 | 60 | 40 | 9.07 | 18.00 |
| 3 | 50 | 50 | 9.07 | 16.25 |
| 4 | 40 | 60 | 9.07 | 18.75 |

Table 4.8b: Elongation at break of Bagasse/Coir Reinforced Epoxy Composite.

| S/N | wt% of BF | wt% of SF | Mass of fibre blend (g) | Elongation (%) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 15.20 |
| 2 | 60 | 40 | 9.07 | 17.25 |
| 3 | 50 | 50 | 9.07 | 16.25 |
| 4 | 40 | 60 | 9.07 | 18.67 |

Table 4.9: Elongation at break of Bagasse/Sisal/Coir Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of Fibre Blend (g) | Elongation (%) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 19.75 |
| 2 | 60 | 20 | 20 | 9.07 | 16.00 |
| 3 | 60 | 30 | 10 | 9.07 | 15.25 |

**APPENDIX D: IMPACT STRENGTH OF COMPOSITES.**

Table 4.10: Impact Strength of Bagasse/Epoxy Composite

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Impact strength ($J/m^2$) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 53 |
| 2 | 5 | 95 | 35 |
| 3 | 10 | 90 | 27 |
| 4 | 15 | 85 | 60 |
| 5 | 20 | 80 | 32 |

Table 4.11a: Impact strength of Bagasse/Sisal/Epoxy Composite.

| S/N | % of BF | % of SF | Mass of fibre blend (g) | Impact Strength ($J/m^2$) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 58 |
| 2 | 60 | 40 | 9.07 | 60 |
| 3 | 50 | 50 | 9.07 | 53 |
| 4 | 40 | 60 | 9.07 | 65 |

Table 4.11b: Impact Strength of Bagasse/Coir Reinforced Epoxy Composite

| S/N | wt% of BF | wt% of CF | Mass of fibre blend (g) | Impact Strength ($J/m^2$) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 54 |
| 2 | 60 | 40 | 9.07 | 60 |
| 3 | 50 | 50 | 9.07 | 63 |
| 4 | 40 | 60 | 9.07 | 63 |

Table 4.12: Impact Strength of Bagasse/Sisal/Coir/Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of Fibre Blend (g) | Impact Strength ($J/m^2$) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 52 |
| 2 | 60 | 20 | 20 | 9.07 | 65 |
| 3 | 60 | 30 | 10 | 9.07 | 42 |

**APPENDIX E: HARDNESS OF THE COMPOSITES.**

Table 4.13: Hardness of Bagasse/Epoxy Composite.

| S/N | wt% Mass of Bagasse | wt% Mass of Epoxy | Hardness (HRF) |
|---|---|---|---|
| 1 | 0 (Control) | 100 | 15.20 |
| 2 | 5 | 95 | 8.50 |
| 3 | 10 | 90 | 8.40 |
| 4 | 15 | 85 | 8.00 |
| 5 | 20 | 80 | 7.50 |

Table 4.14a: Hardness of Bagasse/Sisal Epoxy Composite.

| S/N | wt% of BF | wt% of SF | Mass of Fibre Blend (g) | Hardness (HRF) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 7.30 |
| 2 | 60 | 40 | 9.07 | 7.83 |
| 3 | 50 | 50 | 9.07 | 8.10 |
| 4 | 40 | 60 | 9.07 | 7.53 |

Figure 4.14b: Hardness of Bagasse/Coir Epoxy Composite.

| S/N | wt% of BF | wt% of CF | Mass of fibre blend (g) | Hardness (HRF) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 8.20 |

| | | | | |
|---|---|---|---|---|
| 2 | 60 | 40 | 9.07 | 8.63 |
| 3 | 50 | 50 | 9.07 | 8.87 |
| 4 | 40 | 60 | 9.07 | 8.23 |

Table 14.15: Hardness of Bagasse/Sisal/Coir Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of Fibre Blend (g) | Hardness (HRF) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 6.60 |
| 2 | 60 | 20 | 20 | 9.07 | 6.50 |
| 3 | 60 | 30 | 10 | 9.07 | 5.80 |

Table 14.15: Hardness of Bagasse/Sisal/Coir Epoxy Reinforced Composite.

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of Fibre Blend (g) | Hardness (HRF) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| | BF | | | | |
| 1 | 60 | 10 | 30 | 9.07 | 6.60 |
| 2 | 60 | 20 | 20 | 9.07 | 6.50 |
| 3 | 60 | 30 | 10 | 9.07 | 5.80 |

**APPENDIX F: DENSITY OF COMPOSITES.**

Table 4.16: Density of Bagasse/Epoxy Composite

| S/N | wt% Mass of Bagasse | wt% Mass of epoxy | Density ($g/cm^3$) |
|---|---|---|---|
| 1 | 0 | 100 | 0.8875 |
| 2 | 5 | 95 | 0.8525 |
| 3 | 10 | 90 | 1.048 |
| 4 | 15 | 85 | 1.300 |
| 5 | 20 | 80 | 1.500 |

Table 4.17a: Bagasse/Sisal Epoxy Composite

| S/N | wt% of BF | wt% of SF | Mass of fibre blend (g) | Density ($g/cm^3$) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 0.890 |
| 2 | 60 | 40 | 9.07 | 0.990 |
| 3 | 50 | 50 | 9.07 | 0.870 |
| 4 | 40 | 60 | 9.07 | 0.878 |

Table 4.17b: Bagasse/Coir Epoxy Composite

| S/N | wt% of BF | wt% of CF | Mass of Fibre Blend (g) | Density ($g/cm^3$) |
|---|---|---|---|---|
| 1 | 70 | 30 | 9.07 | 1.050 |
| 2 | 60 | 40 | 9.07 | 1.190 |
| 3 | 50 | 50 | 9.07 | 1.040 |
| 4 | 40 | 60 | 9.07 | 1.120 |

Table 4.18: Density of Bagasse/Sisal/Coir/Epoxy Reinforced Composite

| S/N | wt% of BF | wt% of SF | wt% of CF | Mass of Fibre Blend (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 1 | 60 | 10 | 30 | 9.07 | 0.757 |
| 2 | 60 | 20 | 20 | 9.07 | 0.9903 |
| 3 | 60 | 30 | 10 | 9.07 | 1.7565 |

**5.4Pictures of the prototype helmets**



**Safety helmets**



**Metal helmet (Model from NDA Kaduna)**



**Composite helmet (Sample 1)**



**Composite Helmet (Sample 2)**



**Inside view**

