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KUMASI

COLLEGE OF SCIENCE

DEPARTMENT OF CHEMISTRY



PREPARATION AND CHARACTERIZATION OF BANANA FIBER –HIGH
DENSITY POLYETHYLENE (HDPE) COMPOSITE.

A thesis submitted to the Department of Chemistry, College of Science, Kwame
Nkrumah University of Science and Technology in partial fulfilment of the
requirement for the award of MPhil in Polymer Science and Technology degree.

BY

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DECLARATION

I, hereby declare that apart from sources duly acknowledged in the reference section, this thesis is findings of my own research work presented towards an award of a Master of Philosophy Polymer Science and Technology and that, to the best of my knowledge, it contains no material previously published by another person nor submitted to any other University or institution for the award of any degree.

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DEDICATION

I dedicate this work to Mr. Stephen Aidoo, my father.

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ABSTRACT

The use of plant fiber as a reinforcing agent is a current development in polymer science to produce composite material that have higher strength and lower weight for several applications. In this research, banana fiber, which is a natural fiber has been employed as a reinforcing agent. Composites were fabricated using both treated banana, TBF and untreated banana fiber, UBF and HDPE with fiber content of 5, 7.5, 10 and 12.5% by injection moulding technique. Physico-mechanical properties such as tensile strength, impact strength, elongation at break point and young's moduli of the various types of composites were analysed. From the research, it was found out that, values have increased to a certain percentage and started decreasing gradually. The addition of 10 % TBF provided an enhancement in mechanical properties of composites in comparison with virgin HDPE. Young's moduli and water absorption of composites increased with increasing fiber addition. Also, weight of composites reduced with increasing fiber content. Mechanical properties of treated banana fiber TBF-HDPE composites were a little higher than untreated banana fiber UBF-HDPE composites. The FTIR analysis of the banana fiber for both TBF and UBF showed absorption peaks at 1633 cm^{-1} , 1244 cm^{-1} and 1016 cm^{-1} suggesting the presence of cellulose, hemicellulose and lignin present in the banana fiber whereas peaks at 1367 cm^{-1} and 1029 cm^{-1} in the prepared composite, suggested a physical interaction between the HDPE and the banana fiber. Micrographical analysis of composites showed that TBF-HDPE composites had a better adhesion within the HDPE matrix as compared to UBF. It was also seen that chemical treatment of banana fiber with NaOH, increased the interfacial bond between the banana fiber and HDPE matrix, thus improving mechanical properties of TBF-HDPE composites and decreasing the absorption of fiber.

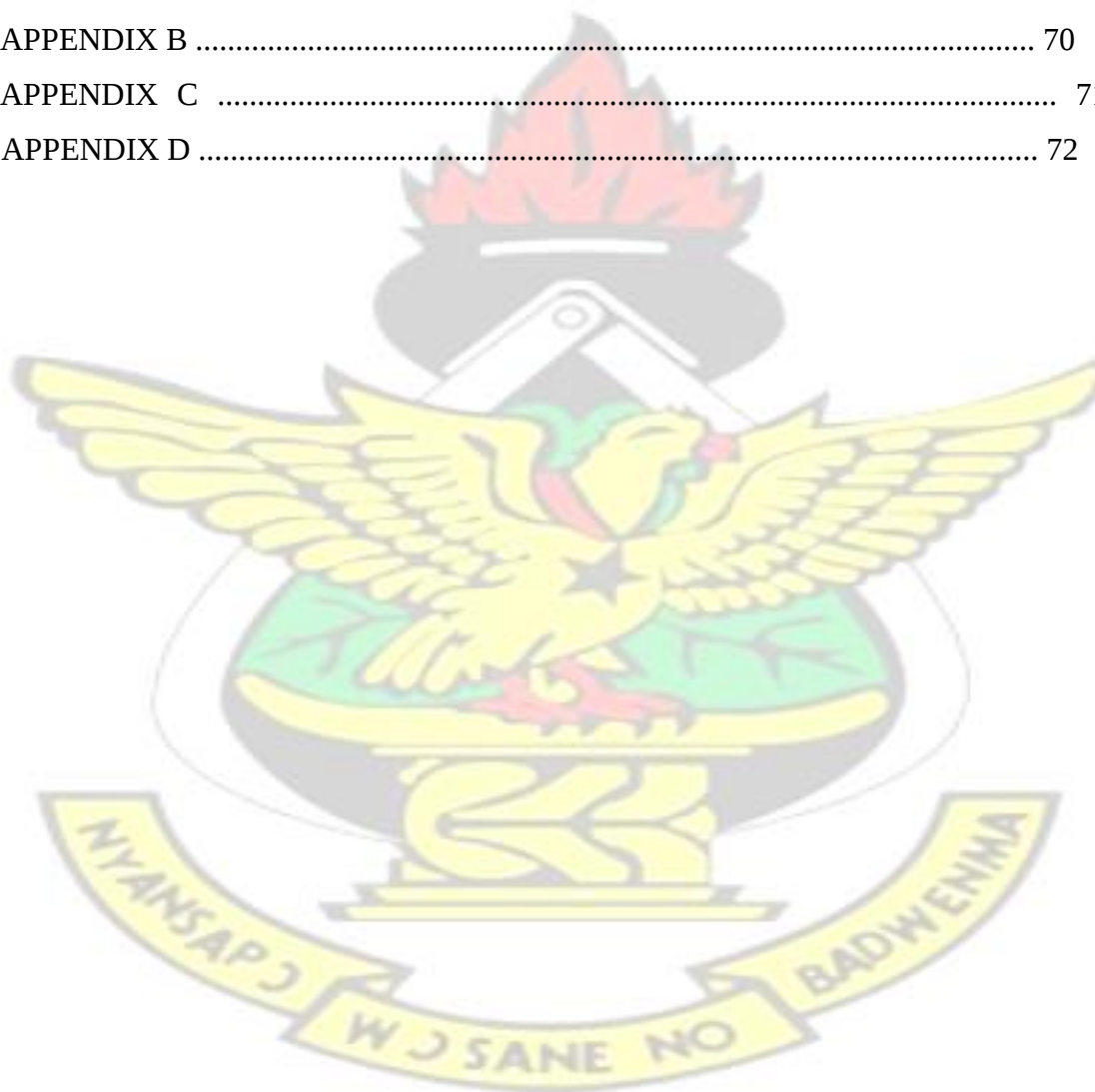
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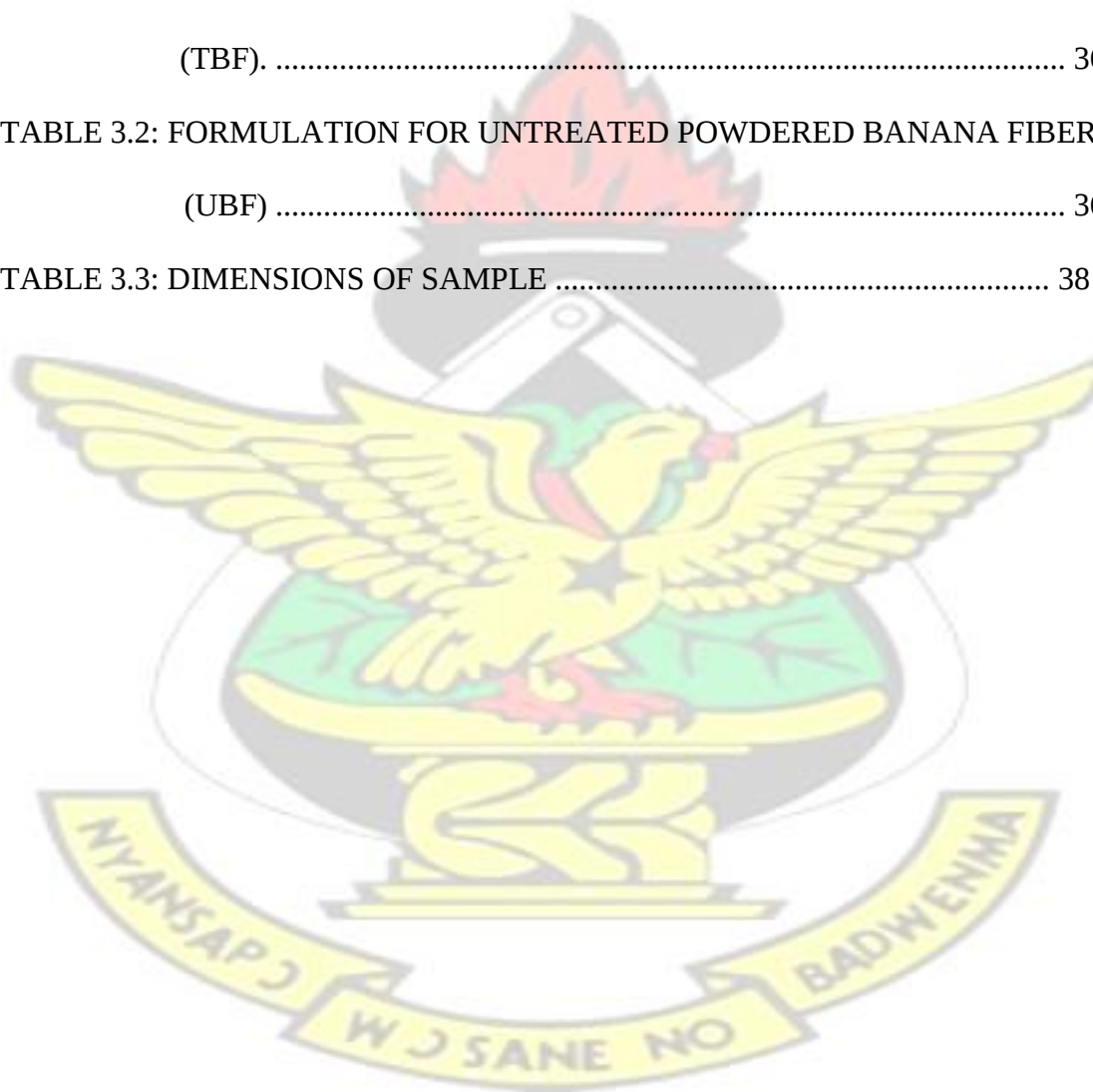
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LIST OF ABBREVIATIONS

ASTM	American Standard for Testing and Material
atm	atmospheres
CH ₃ COOH	Ethanonic acid (acetic acid)
CH ₃ CO	Methyloxidocarbon (acetyl)
CO ₂	Carbon Dioxide
FTIR	Fourier Transform Infrared Spectroscopy
g	Grams
GPa	Giga pascal
HDPE	High Density Polyethylene
KPa	kilo pascal
LDPE	Low Density polyethylene
LiOH	Lithium Hydroxide
J	Joule
KOH	Potassium Hydroxide
MA	Maleic anhydride
MPa	Mega pascal mm
Millimetres m ³	Meter
cube	
NaOH	Sodium Hydroxide
NMMO	N-methyl-morphine N-oxide
OH	Hydroxide
PE	Polyethylene
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PLLA	Poly (L-lactic acid)
PP	Polypropylene

PS	Polystyrene
PVC	Poly Vinyl Chloride
TBF	Treated Banana Fiber
Tg	Glass Transition Temperature
UBF	Untreated Banana Fiber
VS	Versus

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CHAPTER ONE

1. INTRODUCTION

Lately, composite materials have effectively replaced the commonly used materials in numerous less heavy and high strength applications. These composite materials are used in space science, leisure, construction works, sporting equipment, packaging and automotive industry (Malkapuram *et al.*, 2008). The explanations for composites designated for such uses are generally due to their strength to weight ratio which is high, ductile strength at higher temperatures and durability. Composites are materials made up of more than one constituents which are different chemically on a physical level possessing a different boundary and performance which is significantly not the same from those of any of the constituents (Hollaway, 2002). The main segment of composite material, which is unbroken in nature is known as matrix. This matrix is generally soft and mostly ductile. There is a secondary segment, which is the discontinuous part. This discontinuous segment is normally tougher segment which is known as reinforcement. This helps to reinforce this composites thus increasing the general mechanical performance of the matrix (Wambua *et al.*, 2003). Based on the kind of matrix used, composites may be grouped into three classes, which are metal matrix composites, polymer matrix composites and ceramic matrix composites. For individual category of composites there are appropriate use, which differs from each other. However, polymer is the most commonly used matrix in composite materials preparation (Hollaway, 2002).

The two main reasons for using polymeric matrix composite materials are:

1. Compared to ceramics and metal, polymeric matrix have less strength and stiffness and these limitations can be solved by reinforcing polymers with other materials.
2. Low processing temperature and pressure.

For these reasons, polymer matrix composites are developing quickly and before long becoming widespread for structural applications. The key classes of polymers employed as matrix materials are thermoplastics and thermosets. Thermoplastics (polypropylene, nylons etc.), may continually be made softer and refabricated using heat. On the other hand, thermosets like phenolic, epoxies etc., can undergo curing during preparation, subsequently becoming rigid and cannot be refabricated (Gowariker *et al.*, 2005).

Fiber reinforced polymer matrix composites are made up of reinforcing fibers inserted in a polymer matrix. The characteristics of matrix, fiber and its interface have abundant effect on the behaviour of composites. The use of cellulose fibers for reinforcement in composite is not novel (Baley, 2002). The use of straw and grass to reinforce mud bricks at the start of civilization shows that humans had used this knowledge for a long period. Concentration on the expansion and use of natural fiber reinforced composite materials in several manufacturing sectors in the last decade has received much attention (Mohanty *et al.*, 2000). The benefits of using natural fibers as possible substitutes in place for synthetic fibers in composite materials are simplicity of processing method and quick manufacturing time, and low cost of natural fiber thermoplastic composites. These make them better than over conventional materials, hence natural fibers become the best appropriate constituents used in vehicle industries as reinforcement (Frederick and Norman 2004). The foremost desirability of composite materials depends on the possibility of attaining very quick demoulding period. This improved composite substance behaviour is affected completely by interfacial bond strength between the fibers and the matrix (Bisanda *et al.*, 2000). Composite material is usually composed of two components, namely the matrix and filler also called reinforcement. The matrix integrates filler particles, shapes products appropriately and determines most of physical and chemical properties of material. The filler is responsible for additional enhancement of selected material properties (Work *et al.*, 2004).

Natural fibers are usually made up of cellulose, hemicellulose, lignin, pectin, waxes and water soluble substances. Natural fibers are grouped according to the source. These classifications include mineral fiber, animal fiber and plant fiber. Higher specific characteristics are the main advantages for using natural fiber composites. For this weight reduction is of primary concern. Report on plastics and cement reinforced with natural fibers such as jute, sisal, coir, pineapple leaf, bamboo, banana, sun hemp fiber has been studied (Collier *et al.*, 1996). Fiber obtained from banana is one of the essential natural fibers and is obtained from the bast of the plant *Musa Sapientum Linn*. The high cellulose amount and little microfibrillar angle show that fiber obtained from banana, can perform as an effective reinforcement in polymer matrix (Frederick and Norman, 2004).

Even though natural fibers have several benefits, they have some shortcomings. The limitations of natural fiber reinforced composites are elevated water absorption, high wettability and weak fiber-matrix bonding. Consequently, alteration of the surface of natural fibers through alkalization is considered. In the light of this, this research is done to study the preparation and characterization of banana fiber reinforced High Density Polyethylene composites. Effort will also be made to explore the effects of chemical treatment of the surface of natural fiber on the performance of the composites.

1.1 PROBLEM STATEMENT

Civil engineers have been looking for alternatives to steel and other alloys for reduction of cost of maintenance and mending of structures dented by corrosion and repeated use for many years now. Fiber Reinforced Polymers (FRP) are relatively a novel group of composite materials fabricated from fibers and matrix (resins) and have proved to be effective for the development and renovation of novel and weakening constructions works in structural (civil) engineering respectively. The synthetic fibers are usually fiber-glass, carbon or aramid.

Nevertheless, much apprehension concerning environmentally friendly materials, began to rise up in recent times, and their use today are far from fitting this approach. Properties of some natural fibers have been studied. The results reported indicated likely utilization of some natural fibers as substitutes to synthetic fibers like glass fiber in numerous uses. Banana fiber when used as a reinforcement agent in polymer composites possess some excellent mechanical properties coupled with a lower specific mass and is less costly. The nature of fiber incorporates lower toughness and lower strength compared to fiber of the glass. Conversely, recent advancement in chemical treatment of fibers has improved these properties.

1.2 JUSTIFICATION

Presently, banana fiber is a waste product of banana farming. These banana fibers are either not utilized fully or used partially. Properties of banana fibers give significant indication concerning their use as reinforcement agents in thermoplastic composites. Research has to be carried out to discover the suitability of banana fibers (natural fibers) as reinforcement agents in thermoplastic composites. This will be done by studying some mechanical properties and morphology of the prepared banana fiber polymer composite.

1.3 MAIN OBJECTIVE OF RESEARCH

The main objective of this study is to investigate the suitability of banana fiber as a reinforcement agent in polymer composites.

1.4 SPECIFIC OBJECTIVES

The specific objectives of this study are:

1. Preparing and investigating, suitability of banana fiber as reinforcement agent in polymer (high density polyethylene) by determining mechanical properties: tensile strength, impact strength, young's modulus and elongation at break point.

2. Determining the contribution of banana fiber to the composite strength.

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CHAPTER TWO

2. LITERATURE REVIEW

2.1 COMPOSITES

Composites are materials which consist of reinforcement, that have capacity to carry load, set in soft material called matrix (Hull and Clyne, 1996). The reinforcing agent is responsible for strength and stiffness by assisting in carrying structural capacity. The matrix which could either be organic or inorganic, keeps the reinforcement in fixed position and direction. Considerably, parts of the composites maintain their discrete, physical and chemical characteristics; however when combined to form a composite, they yield a blend, with abilities that separate components cannot produce alone (Hull and Clyne, 1996). Wood is an example of a natural composite. Wood is basically made up of cellulose, hemicellulose and lignin and it is a three-dimensional polymeric composite. In the biological world, some examples of composites exist. Teeth and bones are basically made up of inorganic crystals are hard in a tough collagen matrix (Bledzki *et al.*, 1998). Several important examples of composites historically exist in literature. An important one is the use of reinforcing agents like bamboo shoots, glued laminated wood in mud houses by people in Egypt, also in building of swords with laminated metals (1800 AD). Glass reinforced resins, generally called glass fiber emerged in the 1930s and were used to construct boats and aircrafts. From the 70s, the use of composites have extensively improved owing to discovery of novel fibers like carbon, boron and aramids. Also innovative metal and ceramic composite systems have emerged (Chawla, 1979). Looking back into the 19th century, a number of manufacturing factories for composite materials have emerged. This represents the 20th century just as noticeably as steel branded the 19th century. Since the last hundred years, the production of synthetic polymers have been increasing quickly that nowadays, it is likely to produce different kinds of polymers planned for precise purposes (Hollaway, 2002). Usage and interest in polymers and composites grew faster in the course of the World War Two. Composite supplies were utilized in various applications. Composites materials can be

utilized in the manufacture of satellites, automobiles, ships, submarines, aircrafts, sporting equipment, chemical processing machines etc. The Possibility of using these composite materials in medical science and microelectronic devices is also there (Hollaway, 2002).

Polymer fiber reinforced composite material is a mixture that comprises of a polymer matrix reinforced with fibers. The combination of the characteristics of the polymer and properties of fiber bring about a superior performance. With higher mechanical strength and physical behavior of the fiber combined along with the physical behavior of the polymer, the resulting composite material produce superior behavior capability. Through the blend, weaknesses of the separate constituents of the composite materials gives way to a product which have excellent structural and physical properties. The reinforcement in composites, enables composite materials to endure high load and have good bending abilities (Natural Fiber Composites, 2012).

From vehicle, plastic lumber, cosmetics industries, the use of natural fiber reinforced thermoplastic composites is becoming attractive. Plant fibers, as reinforcing agents give economic benefits like lower cost and lower processing temperature over traditional inorganic reinforcing agent and fillers like glass and mineral fibers. Natural fibers obtained from renewable resources also provide environmental benefits that include reduction in petroleum based products (Schemenauer *et al.*, 2000).

2.2 DEFINITION OF COMPOSITE

Composite materials are defined as materials composed of at least two phases, where due to the occurring synergistic effect the material is of different properties than properties of the components in which it is formed from (Work *et al.*, 2004). Composites are material which comprise of more than one chemically and physically different parts divided by a discrete boundary. These separate segments are joined carefully in order to attain a material with added beneficial mechanical, not achievable through any of the components only. As contrasting to

metal alloys, for each material preserves its discrete chemical, physical and mechanical properties (Shaw *et al.*, 2010).

2.3 POLYMER MATRIX COMPOSITES

Polymer matrix composites are the most advanced and readily available composites. The composite comprises of a thermosetting or thermoplastic polymer reinforced with a natural or inorganic fiber. These composites may be moulded into a diversity of dimensions and forms. These polymer composites offer good strength and stiffness in addition to being corrosion resistant. Polymer matrix is mostly used due to their lower cost, higher tensile strength and easy production procedure.

2.4 COMPONENTS OF FIBER REINFORCED COMPOSITES

When a composite is under stress the fibers that are reinforced in the matrix play a major part in the transfer of load by utilizing plastic flow of the matrix, causing a higher tensile strength of the composite. Distinct segments are within a composite material, these different segments (phases) together provides the composites with higher tensile strength and higher modulus.

The separate segments which create the entire composite are as:

1. Matrices
2. Reinforcing fibers
3. Interface (Hollaway, 2002).

2.4.1 COMPOSITE MATRICES

In a fiber reinforced composite material, the matrix main function is to ensure transfer of stress among the fibers, to offer block against hostile environs and keep the surface of the fiber from mechanical scratch. Tensile weight transport capability of a composite material is also dependent on matrix. Thus matrix (the binding agent) in a composite is of major significance and polymer is one of the most important matrices that has been reported (Chawla, 1987).

2.5 POLYMERS

Polymers are macromolecules that are made up of monomers. These monomers are mostly combined by covalent bonds. (Molecules between 4-10 atoms can combine to form monomer. These molecules comprise of at least hydrogen atom (H) and a carbon atom (C) generally bonded together by covalent bond). Polymerization is a main process by which polymers are produced. Fundamentally, there are two main kinds of polymers. These are natural polymers and synthetic polymer. Wood, fingernails and hair are examples of natural polymers whilst polyethylene, polypropylene and polystyrene are examples of the synthetic polymers (Gowariker *et al.*, 2005).

Polymer matrices reinforced with fiber are the main components of composite materials. In an attempt to improve flexibility and strength of a composite, polymers are commonly blended with reinforcing fibers. The matrix (polymer) acts as a binder by binding the fibers together, shields their surfaces against destruction throughout fabrication, management and the service life of the composite. The matrix also (polymer) transfers stresses to the fiber during load application. Polymer matrix should be thermally and chemically compatible for a long period of time (Hollaway, 2002).

2.6 DIFFERENT FORMS OF POLYMERS

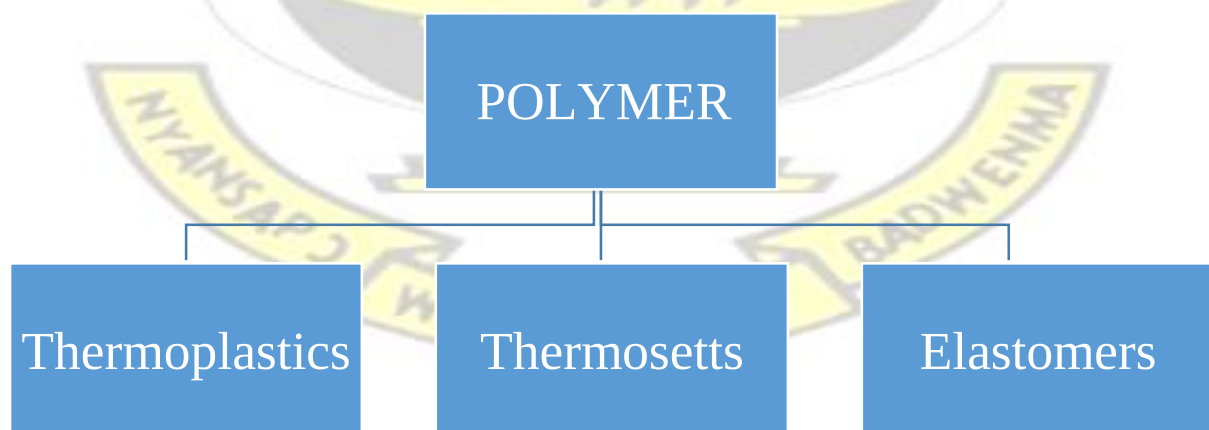


Figure 2.1: Different types of polymers

2.6.1 THERMOSETTING POLYMER

Unlike elastomers and thermoplastics, thermosets are stiff and do not stretch. They are hard and cross linked and not re-mouldable once moulded. Many kinds of thermoset polymers have been applied as matrix for plant fiber composites (Sinha, 2000). Epoxy is the most commonly used thermoset matrix and other matrices include vinyl ester, phenolic epoxy, and unsaturated polyester (Chawla *et al.*, 1997).

Unsaturated polyester is a common thermoset that is used in composites as matrix. Unsaturated polyester has a room temperature cure ability, transparency and good mechanical properties. Because of the advantages over other thermosets, they are produced extensively for industrial purposes (Sharifah *et al.*, 2005).

2.6.2 ELASTOMER POLYMER

Elastomers are long molecules, coiled and twisted in a haphazard way. They have ability to undergo huge deformation. Elastomers are a class of polymers that cannot be bonded or be melted but can swell. Elastomers are known as rubbers. Elastomers are cross linked structures bond together by weak attractive forces. Their glass transition temperature is below room temperature, this makes it soft and rubbery. Elastomers possess lower modulus and higher tensile strength relative to other polymers. Some items (parts) manufactured with elastomers are automobile tires, billows etc. (Crawford, 2006).

2.6.3 THERMOPLASTICS

A thermoplastic is a class of polymer which can be joined constantly. They are able to dissolve in several solvents. Thermoplastic are long and linear polymer that is less resistant to heat. Thermoplastics are very suitable for extrusion moulding and injection moulding because they can melt at high temperature and become solids again when allowed to cool. Since heating the thermoplastics causes the intermolecular forces to be broken thus becoming soft and flexible. Some examples of thermoplastics employed as matrices for plant fiber composites are as

follows: polypropylene, polystyrene, poly vinyl chloride, high density polyethylene, low density polyethylene, chlorinated polyethylene. The thermoplastic that have processing temperature less than 230°C are applicable for natural fiber reinforced composites. These are mostly polyethylene and polypropylene (Crawford, 2006). Polyamides, polyesters and polycarbonates are examples of thermoplastics that need manufacturing temperatures greater than 250°C thus not suitable in composite manufacturing devoid of fiber degradation (Sinha, 2000).

2.6.3.1 POLYETHYLENE (PE)

Polyethylene was first introduced into the market in United Kingdom in 1933 by the Imperial Chemical Industries Ltd. Polyethylene remains the most used thermoplastic in the world. It consist of common hydrocarbon and it is formed by the process called polymerization. The monomer used to form polyethylene is ethylene. It is manufactured by dehydration of ethanol. It can also be produced from hydrogenation of acetylene. By the process called cracking, polyethylene can be made, starting from crude oil. Low-density polyethylene and high-density polyethylene are dual foremost kinds of polyethylene that are frequently used in manufacturing (Gupta, 2010).

2.6.3.1.1 LOW DENSITY POLYETHYLENE (LDPE)

Low density polyethylene is manufactured under higher pressure polymerization, with pressure of 141855 KPa and a temperature of 180-250°C. The initiator for this process is oxygen. Low density polyethylene is semi crystalline solid with melting temperature of 110-125°C. The density range for polyethylene is between 918-935 kg / m³. At a temperature above 100°C, LDPE dissolves in several solvents but remain almost insoluble at room temperature. Low density polyethylene exhibit properties like hardness, crystallization and resistant to chemicals. These properties increase as density increases thus reduction in extent of short chain branching with LDPE. Other properties like tensile strength, softening temperature, coefficient of friction

and toughness decreases when the molecular weight of low density polyethylene increases. Nevertheless the toughness of LDPE ranges over a wide temperature (Gupta, 2010).

2.6.3.1.2 HIGH-DENSITY POLYETHYLENE (HDPE)

As the name suggests, high density polyethylene (HDPE) possess higher density compared with low density polyethylene. Its density is in the range of 935-965 kg/m³. In terms of crystallinity, high density polyethylene is more crystalline than low density polyethylene. HDPE is also slightly durable, harder, and costly compared with LDPE. The molecular forces with HDPE is stronger thus HDPE possess high tensile strength compared with LDPE. HDPE is also more opaque and can stand higher temperature, thus it can be used to make a lot of items such as containers, bottle caps, plastic bags, water tubes etc. (Crawford, 2006).

2.7 REINFORCING FIBERS

Strength of fiber reinforced composite is influenced essentially by the properties and structure of fiber. This is because when the matrix is under stress it transmit the load to the fibers. Thus, it is essential for the fibers to have higher young's modulus, higher tensile strength, variation between the individual fibers should be low and fibers should be able to retain their strength during fabrication and handling for effective use of reinforcement (Hollaway, 2012).

2.7.1 NATURAL FIBERS

Natural fibers are fibers acquired directly from natural sources like animals, plants and minerals. Among the natural sources of fiber, plant fibers are the frequently used in the composite industry. Plant fibers are also called vegetable fiber and usually composed of cellulose. Natural fibers have several important benefits above synthetic fibers. Because of these advantages of natural fibers, it has gained a lot attention from both academic and manufacturing sector. Presently, flax, jute, hemp, straw, rice husk, banana etc. are being researched into for use as reinforcing agents in plastics (Bledzki and Gassan, 1999). Wood filler

as reinforcing agent in plastics is increasing because of their several benefits like lightweight, reasonable strength and stiffness (Bledzki and Gassan, 1998). Hemp fiber which mainly consists of lignin and cellulose is derived from the plant *Cannabis sativa* and has been applied in biodegradable composites as reinforcing agent (Mwaikambo and Ansell, 2005).

Conventionally, hemp is employed to create cords however; nowadays this fiber has been employed to create articles like dresses, dolls and shoes (Rowell *et al.*, 2002). Biodegradable composite created from polyamide and cotton or flax possess good mechanical properties and biodegradability (Jiang and Hinrichsen, 1999). These composites may have a great possibility in reducing the use of petroleum centered polymer. Because of non-abrasiveness nature of flax fiber, lower cost and green revolution, the building, automobile and machine engineering are growing in the usage of flax fiber as reinforcing agent in polymer matrix, (Rowell *et al.*, 2002). Yang *et al.*, studied the influence of compatibilizers on the mechanical behavior and morphological behavior of plastic reinforced with rice husk powder. It was found out that, as fiber loading increases, the composites, prepared without compatibilizing agent caused a reduced in tensile strength and extra brittle, but considerable enhanced mechanical behavior with the fusion of compatibilizing agent. This means that, composite without a compatibilizing agent showed weak interfacial adhesion within the fiber and the matrix causing, composite to exhibit weak tensile strength nevertheless there was rise in tensile strength with addition of the compatilizers. (Hornsby *et al.*, 1997). Panthapulakkal *et al.*, (2006) prepared and studied wheat straw fibers, to estimate their possibility as reinforcing agent in plastic composites. Bamboo, a plentiful plant in Asia, has been used to create bamboo reinforced polymer (Rajulu *et al.*, 1998). Okubo *et al.*, (2004) prepared bamboo fiber composites for environmental reasons with straight hot press process. The fixed strength and inner nature after their creation was studied. It was established that higher mass content of bamboo fiber allowed the bamboo composites to rise their strength in the best efficient way.

2.7.1.1 NATURAL FIBER AND THEIR COUNTRIES OF ORIGIN

Natural fibers mostly consist of lignin and cellulose-comprising of spiral coiled cellulose microfibrils in a matrix of lignin and hemicellulose (Amar *et al.*, 2010).

Table 2.1. Fibers and countries of origin (Bilba *et al.*, 2007).

Fiber	Origin
Flax	Borneo
Hemp	Yugoslavia, China
Sun hemp	Nigeria, Guyana, Sierra Leone, India
Ramie	Honduras, Mauritius
Jute	India, Egypt, Guyana, Jamaica, Ghana, Malawi, Sudan, Tanzania
Kenaf	Iraq, Tanzania, Jamaica, South Africa, Cuba, Togo
Roselle	Borneo, Guyana, Malaysia, Sri Lanka, Togo, Indonesia, Tanzania
Sisal	East Africa, Bahamas, Antigua, Kenya, Tanzania, India
Abaca	Malaysia, Uganda, Philippines, Bolivia
Coir	India, Sri Lanka, Philippines, Malaysia

2.7.1.2 STRUCTURE OF NATURAL FIBERS

Fibers obtained from plants can be seen as composites with cavity cellulose fibrils bonded with lignin and hemicellulose matrices (Jayaraman, 2003). The lignin retains the water in a fiber, which act as a defense against natural outbreak. Lignin also gives the stem of a plant its guard counter to gravitational force and wind. Hemicellulose is the part of plant fiber that acts as a compatibilizer between the cellulose and lignin. In figure 2.2, it can be seen that, each fiber has a multifaceted, coated structure comprising of a thin major wall that is the primary coating placed through cell development surrounding a minor wall. The minor wall consist of three layers and the dense central layer decides the mechanical behavior of the fiber. The central layer comprises of a succession of spiral coiled cellular micro-fibrils shaped from lengthy series of cellulose molecules. The amorphous matrix segment in a cell wall is very multifaceted and comprises of hemicellulose, lignin, and in rare cases instants pectin. The hemicellulose molecules are hydrogen bonded to cellulose and act as reinforcing matrix between the cellulose

microfibrils, thus making the cellulose-hemicellulose network that is assumed to be the central structural constituent of the fiber cell (Rong *et al.*, 2001).

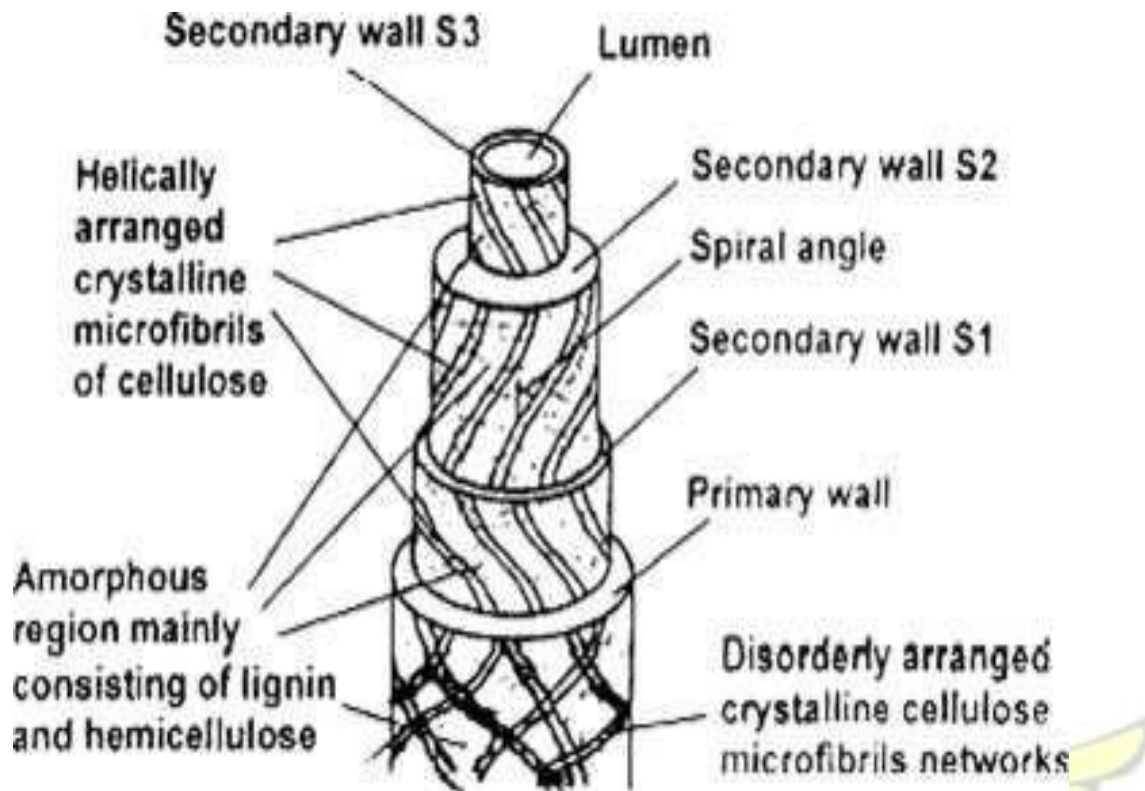


Figure 2.2: Structure of natural fiber (Rong *et al.*, 2001).

2.7.1.3 CHEMICAL STRUCTURE OF NATURAL FIBER

The component of some natural fiber differ by source, region of extraction and plant maturity. The main constituents of a completely matured plant fiber cell are cellulose, hemicellulose, lignin and pectin. They are hydroxyl polymers dispersed all over the fiber wall (Haigler, 1985).

2.7.1.3.1 CELLULOSE

Cellulose is crystalline segment that alternate with part of non-crystalline or amorphous part. Within the plant structure, it is the long and crystalline micro fibrils in the minor cell wall. The cellulose is responsible for the mechanical properties of the plant fiber (Thygesen *et al.*, 2006). Monomers in the cellulose are glucose and are held together by hydrogen bond within to form fibrils and micro fibrils without. Crystalline arrangement with higher stiffness and strength are formed with the hydrogen bonds. The amorphous cellulose part, possesses a low frequency of intermolecular hydrogen bonding, hence indicating volatile intermolecular (OH)

groups to be bonded with water molecules. The affinity of the amorphous part to bond with water makes it hydrophilic nature. However, small available intermolecular (OH) are accessible in crystalline cellulose. Crystalline cellulose become more hydrophilic compared to amorphous cellulose. Strong acid and alkali are needed to break the crystalline micro fibrils which is tightly packed cellulose chain with available -OH group present on the surface (Rowell *et al.*, 1997).

2.7.1.3.2 HEMICELLULOSE

Hemicelluloses vary from cellulose. First, not like cellulose, hemicellulose comprise of many glucose units which are not the same. Hemicelluloses show a substantial extent of chain branching, whereas cellulose is a linear polymer. The extent of polymerization of natural cellulose is far higher than that of hemicelluloses. Contrasting cellulose, the constituents of hemicelluloses vary from plant to plant (Bjerre and Schmidt, 1997).

2.7.1.3.3 LIGNIN

Lignin is plentiful and important polymeric organic constituent in the plant, apart from cellulose. Compression strength of natural fiber increases by bonding the fibers together to create a firm arrangement, ensuring the possibility for plants with hundred metres to stay straight. It is fundamentally entangled, polyaromatic, and crosslinked polymer emerging from the free radical polymerizations of two and three monomers structurally associated to propane (Sakakibara, 1991). Dissolution of lignin using chemicals helps in fiber separation. Lignin appears to perform as matrix within natural fibers. This behavior makes stress transfer on a micro-fibril level and single fiber level possible (Rowell, 1997).

Table 2.2: Some chemical composition of some natural fibers (Bilba *et al.*, 2007).

Fiber	Cellulose (Wt %)	Hemicellulose (Wt %)	Lignin (Wt %)
Flax	71	18.6-20.6	2.2
Hemp	70-74	17.9-22.4	3.7-5.7
Jute	61.1-71.5	13.6-20.4	12-13
Kenaf	45-57	21.5	8-13
Ramie	68.6-76.2	13.1-16.7	0.6-0.7
Nettle	86		
Sisal	66-78	10-14	10-14
Henequen	77.6	4.8	13.1
Banana	63-64	10	5
Cotton	85-90	5.7	
Coir	32-43	0.15-0.25	40-45

2.8 MECHANICAL PROPERTIES OF NATURAL FIBER

The enhancement of the mechanical behavior of plant fibers reinforced thermoset resin composites studied, showed a reduction in natural fibers through alkali treatment. This shows alkalization (mercerization) had major influence on the plant fiber structure and its mechanical properties (Bledzki and Gassan, 1999). For both treated and untreated composites, the Young's modulus was linearly dependent on fiber loading. When properties like fiber structure, chemical composition, and cellulose content were analyzed, it was observed that natural fiber can compete with synthetic fiber when used as a reinforcing agent. The mechanical behavior of composites is dependent mostly on the bond within matrix and the fibers because of alkali treatment (Bledzki and Gassan, 1999).

Composite of polypropylene reinforced with flax fiber was investigated. It was seen that the tensile strength and flexural strength of the composite were dependent on the weak bond existing and the tensile strength of the flax fiber. Physical structure of the fiber and the bond within the matrix and the fiber also influenced the flexural modulus of the composite (Van Den Oever *et al.*, 2000).

Polymer (polypropylene) reinforced with jute fiber was investigated by (Bledzki and Gassan 1999) and the behavior of the composite under fatigue and impact showed that there is a strong interfacial adhesion between the fiber and polymer. The impact of alkali treatment on the wettability and coherence epoxy reinforced with sisal composite showed that there was elimination of lignin and some waxes by alkalization. This increased the possibility of mechanical interconnection and chemical bonding (Bisanda 2000). Investigation of alkali treatment composites with jute fiber in relation to tensile and flexural strength was carried out. Jute fibers were treated with 5% alkali (NaOH) solution for 0, 2, 4, and 6 hours at 30 °C. Enhancement in the crystallinity in the fibers improved the modulus of the composite by 12 % and 68 % for 4 and 6, hours respectively. Strain at breaking point was decreased by 23 % for 8 hours of alkalization. Composites reinforced with alkali treated fibers showed enhanced mechanical behavior. The mechanical strength of the composites were improved for 4 hours fibers treatment at 35 % fiber content (Dipa *et al.*, 2001). Studies on the tensile and compressive strength of decorticated, hand isolated flax bast fibers indicates that, tensile strength of technical fiber bundles was found to depend strongly on the clamping length. Nevertheless, the compressive strength can be lowered severely by the decortications process. The standard decortications process induces kink bands in the fibers. These kink bands are found to contain cracks bridged by microfibrils. Single basic flax fibers have significantly higher strengths than conventional fibers. (Bos *et al.*, 2002).

Tensile behavior and stiffness of sisal fiber were established to differ with changing concentration of alkali chemical that also had a changing influence on the cell wall morphological properties, like the primary wall and secondary wall. Optimal tensile and Young's modulus properties were obtained at 0.16 % NaOH by weight (Jacob *et al.*, 2004). Alkalization altercate the internal properties of sisal fibers that showed definite stiffness that was almost similar as that of steel. These outcomes indicate, the properties of sisal fiber may

be chemically changed in order to achieve properties that will make sisal fiber suitable for substitute in man-made fibers. Alkali treatment was established, to have altered the surface structure of fiber bundles and the diameter reduced with higher concentration of the alkali (Maulik, 2001). Cellulose quantity improves a little at low sodium hydroxide concentration and decline at high sodium hydroxide concentrations. It was discovered that the tensile properties and toughness rises with increasing concentration of sodium hydroxide up to an optimum level of concentration (Mohanty *et al.*, 2000). Again tensile properties and Young's modulus increases as cellulose content reduces, whereas crystalline cellulose declines to some extent but with better crystalline filling order causing an improvement in mechanical properties. The enhancement with mechanical strength of alkalized hemp fiber bundles approves their usage as reinforcing agent (Mwaikambo and Ansell, 2005). Investigation into various chemical treatments of the Alfa fiber has been reported by Bessadok *et al.*, (2007). The various treatments involve acetylation, with the assistance of chemicals like acrylic acid and maleic anhydride. The influence of chemical treatment on the fibers was studied with infrared spectroscopy and surface energy. It was observed that chemical treatments decreased the general water absorption of Alfa fibers.

Table 2.3: Tensile properties of various natural fibers (Murali and Mohana, 2007).

Name of fiber	% Tensile strain	Average tensile strength(MPa)	Average tensile modulus(GPa)	Specific tensile strength (MPa)	Specific tensile modulus (MPa)	Density (kg/m ³)	% of moisture content
Vakka	3.46	549	15.85	0.6778	19.56	810	12.09
Date	2.73	309	11.32	0.3121	11.44	990	10.67
Bamboo	1.40	503	35.91	0.5527	39.47	910	09.16
Palm	13.71	377	2.75	0.3660	2.67	1030	12.08

Coconut	20.00	500	2.50	0.4348	2.17	1150	11.36
Banana	3.36	600	17.85	0.4444	13.22	1350	10.71
sisal	5.45	567	10.40	0.3910	7.17	1450	09.76

The chemical treatment of jute fibers by means of fatty acids derivate, impact hydrophilicity to natural fibers. This reaction was used in swelling and non-swelling solvents such as pyridine and dichloromethane. The development of ester groups, ensuing from the reaction of acid derivate with hydroxyl group of cellulose were investigated by elemental analysis and Fourier transform infrared spectroscopy. The characterization procedure used has shown that there is chemical interaction between the cellulose and the coupling agent. In this swelling solvent the availability of hydroxyl groups was enhanced (Corrales *et al.*, 2007).

A succession of fiber bundle tensile tests were done for the estimation of the influence of chemical treatments on the fiber tensile properties. It was observed that, alkali treatment have enhanced the mechanical strength of the kenaf fiber considerably relative to the untreated kenaf fiber (Edeerozey *et al.*, 2007).

Two thousand fibers randomly taken from a coir fiber stack were characterized. It was observed that length of the coir fibers was in the region of 8 to 337 mm. The fiber content with the dimension of 15-145 mm was 81.95 % of the measured fibers. Mass of the coir fiber with the dimension ranging between 35 to 225 mm accounted for 88.34 % of all measurements of fiber content. Composite of coir and rubber with fiber content of 60 % was prepared by heat press method. When fiber content become less or more than of 60 %, it may reduce the tensile behavior of the composite. Symington *et al.*, (2009) examined the tensile behavior of some plant fibers (kenaf, flax, jute, hemp, sisal). The samples were exposed to: room temperature, 65 % content of moisture, 90 % content of moisture and soaking fiber. Chemical treatment of

fiber have influence on the strength of plant fiber, and there can be an optimal practice situation, if capacity of the natural fiber in composite system is to be exploited (Wang and Huang, 2008).

Water absorption ability of unsaturated polyester reinforced composite was investigated. The tests were done by immersing the composite samples in sea water, distilled water and acidic solution for 21 days at room temperature respectively. It was observed that compression and behavior of the composites reduced as percentage of water absorbed increased (Akil *et al.*, 2009). The mechanical behavior of Borassus fruit fiber was examined. Two kinds of the borassus fibers which were located within the fruits part were coarse and fine fibers. These two fibers were treated with 5 % sodium hydroxide solution. Using the thermography, the first and last degradation temperatures, and the inflection temperature were measured. The thermal stability of the fibers was observed to rise a little with alkalization. The tensile behavior of both fibers were found to rise upon alkalization (Obi *et al.*, 2012).

Composites of some hemp fibers were investigated. The composite was prepared by mechanical mixing method, then hot pressed with water-ethanol recovery. The fiber was alkalized and ground and sieved. The size of the sieved fiber was between 45mm to 500mm. It was observed that mechanical behavior of composites was influenced by surface area, size, structural swelling, and crystallinity of fibers (Sirisart Ouajai and Shanks, 2009).

2.9 CHEMICAL MODIFICATIONS OF NATURAL FIBER

Preparation of polymer composites with plant fibers as reinforcing agents has increased radically in modern times (Singleton *et al.*, 2003). A good appreciation of the chemical structure and surface bonding of plant fiber is necessary for fabricating composite reinforced with natural fiber. The interfacial bonding within the reinforcing fibers and the matrix is essential in enhancing the mechanical behavior of the composites (Mukherjee *et al.*, 1984). The polar and hydrophilic nature of lingocellulosic fibers and the nonpolar properties of a lot of

polymers affect in blending challenges, resulting in non-homogeneous distribution of fibers within polymer resin that weakens the properties of the prepared composite. This presents a key hindrance to polymer reinforced composite. An additional severe weakness is the higher water uptake of plant fibers resulting in enlargement and existence of cavities within the interface in effect mechanical strength and decreases dimensional constancy of composites. Additional restraint to the effective utilization of plant fibers for long-lasting composite is lower microbial defense and exposure to decay. Therefore chemical alteration (mercerization) is used to improve the interphase of plant fibers. Chemicals might initiate hydroxyl groups or present new moieties which might efficiently knit with the matrix (Xue *et al.*, 2007).

The chemical treatment of natural fiber is planned to increase the adhesion within the fiber surface and the polymer matrix by altering the fiber surface and the fiber strength. Again chemical treatment reduces water uptake ability of the fiber and enhances the mechanical behavior.

2.9.1 ALKALI MODIFICATION (MERCERIZATION)

Mercerization is one of the best employed chemical treatments for plant fibers applied in reinforced polymers. The essential alteration through alkalization is the interruption of hydrogen bonds within the complex arrangement, by increasing surface roughness. Mercerization gets rid of some quantity of lignin and waxes within the external surface of the fiber cell wall (Mohanty *et al.*, 2000). As a result, mercerization straightly effects the fibril of the cellulose, extent of polymerization and the removal of lignin and hemicellulose compounds (Jahn, 2002).

From reports, it said that mercerization causes two influences on natural fiber:

1. It increases surface roughness causing improved mechanical interlocking.
2. It increases the quantity of cellulose showing on the fiber surface, hence increasing the number of probable reaction sites (Valadez-Gonzales, 1999).

Different alkali, such as sodium hydroxide, potassium hydroxide and lithium oxide, and its concentration can affect the extent of swelling, thus extend the lattice conversion into cellulose (Fengdel and Wegener, 1983). Alkaline treatment also affects hemicellulose, lignin and pectin which are non cellulose constituent in the plant fiber apart from the cellulose constituent (Weyenberg *et al.*, 2006). The effect of sodium hydroxide with 0.5, 1, 2, 4 and 10 % concentrations on treated sisal fiber reinforced composite was examined. It was established that, optimum tensile strength emerged with 4 % sodium hydroxide treatment at 25 °C (Jacob *et al.*, 2004). When 5 % sodium hydroxide treatment of plant fiber reinforced polyester composite studied, showed that, it had an improved tensile strength compared with 10 % sodium hydroxide treatment (Mishra *et al.*, 2003). With high concentrations delignification of natural fiber occurs and causes destruction to the fiber surface. Thus tensile strength of composite increase significantly with definite optimal sodium hydroxide concentration (Rakesh Kumar *et al.*, 2011).

2.10 ADVANTAGES OF NATURAL FIBER

Natural fibers are ecologically friendly, fully biodegradable, in abundance, renewable, of lower cost and lower density. Natural fibers are lighter compared to conventional fiber such as glass, are cheap and can perform highly to fulfil the profitable interest of manufacturers (Wambua *et al.*, 2003). Plastics reinforced with natural fiber has biodegradable polymer as matrix and is the best ecologically friendly item that may be used at the end of its life cycle.

Plant fiber composite is employed as a substitute for glass, generally for non-structural uses. Many automotive parts earlier prepared using glass fiber are now made using natural fiber (Larbig *et al.*, 1998).

2.11 SOME COMMON NATURAL FIBERS

2.11.1 JUTE FIBER

Jute fiber is an elongated, soft and glittery fiber. It is a fiber which is made of partly plant cellulose and wood lignin. These fibers are located in grey white region of the plant fiber. Weather conditions and soil nature determine the length of jute fiber which ranges between 14 meters. Jute is one of the toughest plant fibers with higher tensile strength and lower extensibility. Jute fibers are taken from bast of the jute plant. It can be used to create carpets, rugs, curtains, etc. and also fabricated into pulp and paper, and most importantly can be used as reinforcing fiber for composites (Maulik, 2001).

2.11.2 COCONUT FIBER (COIR)

Coconut fiber (coir) is a plant fiber taken out from the husk of coconut fruit and is located between the inner hard shell and the external coat of a coconut. Coir is dense and tough, and consist of lignin and cellulose. Coir has two main varieties, namely the brown and white coir. The brown coir is taken from fully ripened coconut. It is strong, non-abrasive and thick. White coir is gotten from not fully ripened coconut plant and it is smoother, finer and generally weaker than brown coir. Coconut fibers are mostly used in bonding with rubber latex to create material padding for the vehicle industry and can also be used for insulation and packaging (Swicofil, 2012).

2.11.3 BANANA FIBER

Banana belong to the *Musa* family. Banana plant is a vast perennial herb which form leaves that are up 2.7 meters long and 0.61 meter wide and fruits of about 10.2-30.5 centimeters. Its fruit, flower and pseudo stem are used as inexpensive source of vegetable and the leaf cover produces the fiber of profitable significance (Singh and Uma, 1996). Banana fiber currently is a waste by product of banana farming. Thus, devoid of any price effort, banana fiber may be acquired for manufacturing purposes. Banana fiber, a lignocellulose fiber, obtained from the

bast of pseudo-stem of banana plant, exhibit relatively decent mechanical behavior. “pseudostem” is a bundled, cylinder-shaped collection of leaf stalk bases (Idicula *et al.*, 2005).

2.11.3.1 BANANA FIBER COMPOSITION

Bast fiber, like banana are multifaceted in structure. Banana fiber is usually lignocellulose comprising of spiral cellulose in amorphous matrix of lignin and hemicellulose. For mechanical strength, the determining factor is the quantity of cellulose present. A great cellulose content gives appropriate mechanical properties for fibers. Lignin consist of nine carbon units resulting from exchanged cinnamyl alkanols. They are connected to the hemicelluloses and perform a significant part in the biological deterioration defense of the lignin cellulose material. Bilba *et al.*, (2007), investigated the chemical structure of banana pseudo stem by elemental analysis and the outcomes are as indicated in table 2.4. The manufacture procedures, structure, behavior and appropriateness of biological fibers for various industrial uses have been studied by Reddy *et al.*, (2005). They also studied the properties of banana, coir, barley straw and rice husks and results showed that banana fibers had a high cellulose content with 70-82 %.

Table 2.4: The composition of banana pseudo stem (Bilba *et al.*, 2003).

CONSTITUENTS	PERCENTAGE %
Cellulose	34.88 - 27.66
Hemicellulose	17.01 - 12.95
Lignin	15.73 - 14.41
Extractives	4.57 - 4.35
Moisture	11.16 - 8.32
Ashes	8.75 - 8.55

2.11.3.2 BANANA FIBER BASED COMPOSITES

Mechanical behavior of plant fibers, like flax, hemp, jute, and banana are very good and can contend with glass fiber in specific strength and modulus (Frederick and Norman, 2004). Corbiere-Nicollier *et al.*, (2001), have reported an optimal fiber loading of 40 % and Joseph *et*

al., (2002) have also reported that 40 % of untreated banana fibers loading offers a 20 % increase in the tensile strength with 34 % increase in impact strength.

Relative investigation of the mechanical behavior of banana fiber and phenol formaldehyde composites was carried out. In this study, the composites were prepared using banana fiber with variable fiber length and fiber loading. The investigation of tensile, flexural and impact properties of the composites showed that the optimal length of fiber necessary for banana fiber is diverse in phenol formaldehyde resin. The fiber displayed a consistent tendency of rise in properties with fiber loading, interfacial shear force gotten from single fiber pull out test (Joseph *et al.*, 2002). Polymer composite reinforced with banana fiber with fiber length of 30 mm and a fiber loading of 40 % revealed the optimal tensile strength for the composite (Haydaruzzaman *et al.*, 2007). Sapuan *et al.*, (2006), examined the tensile and flexural behavior of composite reinforced with banana fiber. The Statistical analysis done, exhibited rise in mechanical strength. From the analysis of the mechanical behavior of banana fiber reinforced composite revealed that banana fiber may be employed as effective reinforcement in polymer composites.

2.12 INTERFACE

Interface is an anisotropic switch area within the fiber and the matrix. Interface is known to be a significant part since it gives chemically and physically steady adhesion among the fibers and the matrix. If the prepared composite possesses feeble interface then the entire composite shall have lower mechanical strength and toughness. Likewise, a composite material with resilient interface can possess a higher strength and toughness and also brittleness. The properties of the interface part of the composite material are:

1. Elastic behavior of matrix and fiber
2. The presence of a perfect adhesion within the matrix and fiber

3. Particles nearer to the fiber exhibit the same properties as the particle in the main part of the composite.
4. The systematic arrangement of the fibers (Hollaway, 2002).

2.13 NATURAL FIBER COMPOSITES

Plant fiber composite materials are a set of composite systems that possesses reinforcing fibers obtained from renewable sources, plant or wood. Long before the term composite material was invented, natural fibers were used as reinforcing agent in material. For instance, in olden times, grass and animal hairs were frequently used to reinforce clay bricks. Study and development in plant fiber reinforced composites started in the middle of 1960's and since then the use of natural fiber reinforced composites has been massive. Composite reinforced with natural fiber is a developing region in polymer science (Birgitha, 2012).

In preparation of natural fiber composites, fiber-matrix adhesion plays a key part. Because the matrix within natural fiber composites transmit the load to the rigid fibers through shear stresses at the interface, it needs better adhesion within the thermoplastic material and the natural fibers. Weak bonding between the polymer and the fiber may weaken the mechanical strength of the composite and can make it susceptible to ecological outbreaks that can decrease its life period. Different natural fiber composites have different mechanical behavior since the behavior natural fiber depends on climate conditions for growth (Birgitha, 2012).

2.13.1 MECHANICAL PROPERTIES OF NATURAL FIBER COMPOSITES

Several research made on plant fiber composite materials reveal that their mechanical strength are intensely affected by several aspects like fiber-matrix adhesion, stress transfer at the interface etc. (Kahraman *et al.*, 2005). On evaluation of the mechanical properties composites prepared from polyester reinforced with jute fiber, it was observed that they possess better strengths than those of wood reinforced composite (Gowda *et al.*, 1999). Several reports on investigations carried out on numerous phases of polymer composites reinforced with banana

fibers are available (Pothan *et al.*, 2003). The efficiency of cellulose fiber in enhancing the toughness and decreasing the curbing in natural fiber polypropylene composite has been stated (Amash and Zugenmaier, 2000). Composites prepared with jute and kenaf fiber in polypropylene matrix were developed. The jute fiber showed an improved mechanical behavior as compared with kenaf fiber (Schneider and Karmaker, 1996). Srivastav *et al.*, (2007) investigated the influence of various loading volume on mechanical behavior of composites prepared from epoxy reinforced with jute/glass hybrid. Several investigators have also reported on mechanical behavior of natural fiber composites prepared by various manufacturing techniques. Compositated materials prepared from unsaturated epoxy and untreated jute fiber have been investigated and their tensile strengths, impact strength and young's moduli determined. (Chawla and Bastos, 1979). Prepared composite with unidirectional hemp fiber and epoxy by hand combing with fiber volume fraction of 0.2 had a tensile strength of 90 MPa and young's modulus of 8 GPa (Hepworth *et al.*, 2000). Several research dedicated to impact behavior of natural fiber reinforced composite, shows that the post-impact behavior of plain-woven jute/polyester composites exposed to low velocity exhibited poor impact behavior (Santulli, 2001). The fracture energies for the following natural fibers, sisal, banana and coir reinforced polyester composites by impact tests were determined. It was found that, apart from the coconut fiber, increase in fiber toughness was complemented by increase in fracture energy of the composite (Pavithran *et al.*, 1991). The influence of fiber content and fiber length in banana fiber reinforced epoxy composites was examined. It was noticed that the impact strength improved with higher fiber content and shorter fiber length (Tobias, 1993).

2.13.2 APPLICATIONS OF NATURAL FIBER COMPOSITE

In recent times, there have been several research developments in the area of natural fiber composite materials. Mostly these investigates are based on the study of the mechanical behavior of composite with long or short natural fibers reinforcing agent. They are frequently

used to manufacture non-structural parts in the automotive industry like seat covers, doors panels and roofs. Studies on structure, behavior, fabrication, physical and mechanical strength of polymer based fiber composites were undertaken. The results of these composites have been estimated after introduction to indoor and outdoor weather conditions by destructive and nondestructive analysis procedures. The fabrication of several customer objects like voltage stabilizer cover, mirror casing and a projector cover (Satyanarayana *et al.*, 1990).

Investigation on the creation ideas, elaborate plan and preparation of woven banana fiber reinforced epoxy composites including household furniture has been reported. Banana fiber was as a viable reinforcement to create reinforced composite as another and novel material for domestic furniture applications at low cost (Sapuna and Maleque, 2005). Dweib *et al.*, (2006), studied the structure beams designed, manufactured and tried it. And it produced good results. From the results, huge scales composite structural panels were created. The behavior of polymer composites prepared from sisal, jute fibers and unsaturated polyester/epoxy matrix under different humidity, hydrothermal and weathering condition has been investigated. Before, different composite products like laminates/panels, doors, shuttering and door moulding materials were manufactured (Mathur, 2006). These materials are important to emerging nations in sight of their lower cost, saving in energy and applications as replacement materials. Challenges associated with natural fibers are discrepancy in the products behavior. Composite made from hybrid fiber of kenaf/glass reinforced epoxy for vehicle bumper was investigated. Results showed that mechanical properties like tensile strength, Young's modulus, flexural strength and flexural modulus are like glass mat thermoplastic, nonetheless impact strength was low, and showed the possibility for exploitation of hybrid fiber in some vehicle structural parts like bumper. Moreover, the impact strength can be enhanced by improving the structural scheme factors like thickness, curvature and strengthening ribs or by material enhancement like epoxy strengthening to change the ductility property to increase energy absorption (Davoodi *et al.*, 2010).

The last decade has seen an increase in the applications of natural fiber composites because of their notable properties like biodegradability and high specific strength. Presently, an upheaval in the use of natural fibers, as reinforcing agent in technical application, is going on mostly in the car and packaging manufacturing sector (Saira Taj *et al.*, 2007). Golf clubs can be manufactured with jute fibers, and tennis racket can be reinforced with coir. Bicycle structures can develop their strength from any of the thousand appropriate plants fiber (Saira Taj *et al.*, 2007).

The varied kind of products currently being manufactured, using natural fibers and bio-based matrix resulting from soybeans, results in novel group of biological based composites for several applications. These include vehicles as well as hurricane-resistant housing and structures (Rowell *et al.*, 1997). The building industry and the vacation business are the other sectors where composite are gaining grounds (Hanselka *et al.*, 1995).

2.14 FABRICATION OF NATURAL FIBER POLYMER COMPOSITES

Natural fiber composites are fabricated mostly with the basis of present procedures for handling polymer. Several approaches are available to produce natural fiber composites. These methods include press moulding, extrusion, injection moulding, compression moulding and matrix transfer moulding. Extrusion is extensively used in processing technique. Most of the present biological composite materials based on thermoplastic are processed by this method (Paul *et al.*, 2006).

2.14.1 EXTRUSION OF THERMOPLASTIC POLYMERS AND NATURAL FIBERS

In extrusion, the thermoplastic material is heated to a suitable temperature to prevent it from undergoing thermal destruction. The thermoplastic is heated by external heat source or mechanical shearing of the extruder that causes the thermoplastic to melt. Natural fibers in a form of powder are usually added to the polymer in a molten state. After the components have

been mixed well, it may be extruded straightway in the end produce or pelletized for injection moulding processes (Paul *et al.*, 2006).

CHAPTER THREE

3. METHODOLOGY

3.1 EXPERIMENTAL OVERVIEW

The experimental work was divided into three stages. The initial stage involved the preparation of banana fiber. The next stage involved the preparation of the composites for testing and the last stage was tensile strength testing, impact strength testing, elongation at break point, young's modulus, water absorption and surface morphology.

3.2 MATERIALS

High Density Polyethylene (HDPE), banana fiber and sodium hydroxide were the main materials used.

3.2.1 HIGH DENSITY POLYETHYLENE

High density polyethylene (HDPE) were obtained from Daniel Boateng Service (DBS) industry, Kumasi.

3.2.2 BANANA FIBER

Banana fiber currently is a surplus product of banana farming. Thus, devoid of any cost obligations, banana fiber may be obtained for industrial reasons. Banana fiber, a lignin cellulose fiber, extracted from the pseudo stem of banana plant.

3.2.3 CHEMICALS AND REAGENTS

Sodium Hydroxide pellets and sulphuric acid manufactured by Nice Chemical Pvt. Ltd.

Cochin-682024, India, with percentage purity of 98 % was used.

3.3 EQUIPMENT USED

3.3.1 EXTRUDER

An extruder designed and manufactured by J.B Engineering (Chippenham) Ltd Unit 20. Bumpers Enterprise Center, Chippenham, and Wiltshire SN14 60A, England was used. And it was located at the Mechanical Engineering Department, KNUST (Figure D1).

3.3.2 INJECTION MOULDER

A table top injection moulder designed and manufactured by J.B Engineering (Chippenham) Ltd Unit 20. Bumpers Enterprise Center, Chippenham, and Wiltshire SN14 60A, England was used. It was located at the Mechanical Engineering Department of KNUST (Figure D2).

3.3.3 MANUAL TENSILE TESTING MACHINE

A manual tensile testing machine (Capacity: 2000LB, model: T16) located at the Mechanical Engineering Department of KNUST was used. The machine was designed and manufactured by Saml. Dension and Son Ltd, Leeds 10, England. (Figure D3).

3.3.4 PENDULUM IMPACT TESTER MACHINE

A pendulum impact tester, located at the material testing laboratory at Physics Department of KNUST was used. This impact tester was manufactured by Tinus Olsen, Willow Grove PA, U.S.A. (Capacity: 406 J, Model: IT 406, impact velocity: 5.47m/s) (Figure D4).

3.3.5 HEATER

The heating was done using Tarsons Spinot burner (model MC 02), located at the polymer laboratory, Chemistry Department of KNUST (Figure D5).

3.3.6 BALANCE

Weighing of sample were done using Ohaus measuring balance manufactured by Corporation Florham park, NJ, USA (model: TS4KW), located at polymer laboratory, Chemistry Department, KNUST (Figure D6).

3.3.7 FOURIER TRANSFORM INFRA-RED SPECTROSCOPY ANALYSIS

A Bruker Alpha FTIR spectrometer manufactured by Bruker Optics and located at the Chemistry Department, KNUST (Figure D7), was used for the IR analysis.

3.3.8 MICROGRAPHICAL ANALYSIS

Leica DM2500 optical microscope at the material laboratory of the Physics Department, KNUST was used (Figure D8).

3.4 PROCESSING

3.4.1 BANANA FIBER

Banana trunks were collected from a local source in Atonsu, Kumasi. The banana trunks were cut into manageable size. After separation, the layers of banana trunks were rolled to loosen them for fiber separation. Impurities in the rolled layers of banana trunks such as broken fiber and coating of cellulose were removed manually.

The banana fibers were then immersed in water (retting) for seven days. This retting procedure makes the fibers easier to be separated. The fibers were sun dried until there was no moisture.

3.4.1.1 FIBER SURFACE MODIFICATION (CHEMICAL TREATMENT)

Some of the banana fibers were immersed in 5% sodium hydroxide solution for one hour. These banana fibers were then washed meticulously with diluted sulphuric acid to eliminate the non-reacted sodium hydroxide. Then the washed banana fibers were sun dried. Both the chemically treated and untreated fibers were ground and sieved to obtain their powdered form. The untreated banana fiber was dark brown in colour while the treated banana was light brown in colour (Figures 3.1 and 3.2).



Figure 3.1: Untreated banana fiber (UBF)



Figure 3.2: treated Banana fiber (TBF)

3.4.1.2 FTIR ANALYSIS

A small sample of the powdered High Density Polyethylene, treated banana fiber-high density polyethylene composite (TBF-HDPE), untreated banana fiber-high density polyethylene composite (UBF-HDPE), treated banana fiber (TBF) and untreated banana fiber (UBF) was

placed in the sample holder of the Bruker Alpha FTIR spectrometer and the spectrum recorded and used for the analysis. The wave number range of the scan was 4000cm^{-1} to 400cm^{-1} .

3.4.2 SAMPLE PREPARATION

3.4.2.1 COMPOSITE FORMULATIONS

The raw materials used for the sample preparation were High density polyethylene (HDPE) and powdered banana fiber (treated and untreated). Different formulation of composites were prepared using HDPE and powdered banana fiber for both treated and untreated, as shown in Tables 3.1 and 3.2. The HDPE and powdered banana fiber (treated and untreated) were mixed together to obtain a dry blended material for extrusion.

Table 3.1: Formulation for treated powdered banana fiber (TBF).

Formulation of HDPE (g) : TBF (g)	% TBF
190: 10	5
185 : 15	7.5
180 : 20	10
170 : 25	12.5

Table 3.2: Formulation for untreated powdered banana fiber (UBF)

Formulation of HDPE (g) : UBF (g)	% UBF
190: 10	5
185 : 15	7.5
180 : 20	10
170 : 25	12.5

3.4.2.2 EXTRUSION

Extrusions of the dry blends of the various formulations were done using a single screw extruder. The screw speed of the extruder was 120 rpm with feed rate of 50 g/hr. The die of the extruder was one hole strand die. Feed Zone: The dry blended material were introduced from the hopper mounted at top into the extruder barrel. It then entered the feed throat, came in contact with the screw. The rotating screw forced the material into the barrel which was heated

to 75°C. Compression Zone: Extra heat provided by screw pressure and abrasion taking place inside the barrel at temperature of 130°C melted most of material.

Metering Zone: At a temperature of 180°C, last particle melts and mixes to form a uniform composition. The melt was then pumped through the one hole strand die. The extrudates were air dried and then pelletized (cutting the strands of extrudates into smaller sizes) for injection moulding.



Figure 3.3: Strands of extrudates (10% TBF-HDPE)

3.4.2.3 INJECTION MOULDING

The samples were prepared according to ASTM D618 99. In injection moulding, pelletized samples of the different formulations (see tables 3.1 and 3.2) for the treated and untreated banana fibers were exposed to heat and pressure in a single stroke. The heating was done electrically, at temperature of 200°C at a retention time of 5 minutes. Enough force of 50 KN was applied to set the preferred figure and probable uniformity. Finally, the composition was

cooled for testing. The test samples were moulded into dumb bell shape with a uniform thickness



Figure 3.4: Prepared sample for testing (10% UBF-HDPE).

Table 3.3: Dimensions of sample

Total length	61 mm
Gauge length	36.5 mm
Diameter of sample	5 mm
Radius	2.5 mm
Cross sectional area	19.63 mm ²

3.4 MECHANICAL PROPERTIES

Majority of the research on natural fiber composites include study of mechanical properties as a function of fiber content and influence of different chemical treatments of fibers (Garcia *et al.*, 1995). In this work, composite with fiber contents of 5%, 7.5%, 10% and 12.5% and effect of chemical treatment (alkaline treatment) of fiber were studied. Banana fiber (TBF and UBF)-HDPE composites with 5, 7.5, 10 and 12.5 wt. % fiber content of composites were prepared by injection moulding method.

3.4.3.1 TENSILE TESTING

Tensile tester (Figure D3) was employed to measure the force necessary to break the sample and the degree to which the sample elongates to breaking point. The static tensile tests of the compositions were done according to ASTM D 638-01 (2002). The manual tensile testing machine consist of two jaws, upper and lower jaws in which the test sample is held. The lower jaw is connected to a heel to strain specimen and load wheel to apply load. Each test was done till tensile failure occurred. The force applied and the elongation at break point were recorded. For each sample three measurements were made and the average value was recorded and used to calculate the stress and strain values. The stress and strain value were calculated from the force applied and elongation at break point.

3.4.3.1.1 TENSILE STRENGTH (STRESS)

The stress also known as tensile strength, is the force per unit area. It is expressed in Mega Pascal (MPa). Tensile strength is one of the significant and usually measured properties of material used in structural applications.

$$\text{Tensile strength was calculated as tensile} = \frac{F}{A} \dots\dots\dots 1$$

Where: F is the applied force, N. A is the Cross-sectional area, mm².

3.4.3.1.2 ELONGATION AT BREAK POINT (STRAIN)

The strain expresses the increase in length of specimen (%) after stress is applied per original length of specimen.

$$\text{Elongation at break point (strain)} = \frac{\text{Change in length}}{\text{Initial length}} \times 100 \dots\dots\dots 2$$

3.4.3.1.3 YOUNG'S MODULUS

The young's modulus is expressed as stress per strain of a material and has a unit of (MPa)

$$\text{stress}$$

Young's modulus = $\frac{\text{stress}}{\text{strain}}$ 3

3.4.3.2 IMPACT TEST

The determination of the impact strength of composite is a method of relating its durability with other plastics or composites. Impact test was used to measure the composites resistance to impact from a swinging pendulum. The impact test of the composites specimen were done according to ASTM E-23 (2002). A safety lock holds the pendulum in a raised position, it is then released to strike the sample placed horizontally on the support. Three samples of each composite formulation were tested and results recorded. Impact energy was measured in joules (J). Impact strength was calculated by dividing the impact energy in Joules (J) by the cross-sectional area of sample. Impact strength was calculated as follows:

$$\text{Impact strength} = \frac{E}{A} \dots\dots\dots 4$$

Where: E is energy, Joules and A is area of specimen, mm².

3.4.3.3 WATER ABSORPTION

Water absorption test of composites were done according to ASTM D570 99 (2002). Dried samples were weighed using Ohaus balance. The weighed samples were submerged in boiling water for 2 hours. The heating was done using Spinot burner. After which they were removed by tongs and droplets of water on their surfaces were mopped with cotton wool and their weights measured. The mass of the sample were measured and results recorded. The test was performed in triplicates. The percentage increase in weight after soaking in water was calculated as follows:

$$\% \text{ Increase in mass} = \frac{\text{change in mass}}{\text{dried mass}} \times 100 \dots\dots\dots 5$$

3.4.3.4 FIBER CONTENT EFFECT ON MASS OF COMPOSITES

This test was done to determine the effect of fiber content on the overall mass of the composite prepared. Dried mass of the samples were measured using Ohaus balance. The difference in mass among the various composition were recorded in triplicates.

3.5 MICROGRAPHICAL ANALYSIS

Micrographical analysis of TBF and UBF composites were conducted using Lieca DM2500 optical microscope (Figure D8). The samples were placed on microscope slide at a magnification of 100 microns and micrograph were taken.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Sample codes used for the various formulation are UBF and TBF. UBF-HDPE composites for untreated banana fiber-High density polyethylene and also TBF-HDPE composites for treated banana fiber-High density polyethylene. The fiber content for the various formulation were 5%, 7.5%, 10% and 12.5%.

1.1 FTIR ANALYSIS

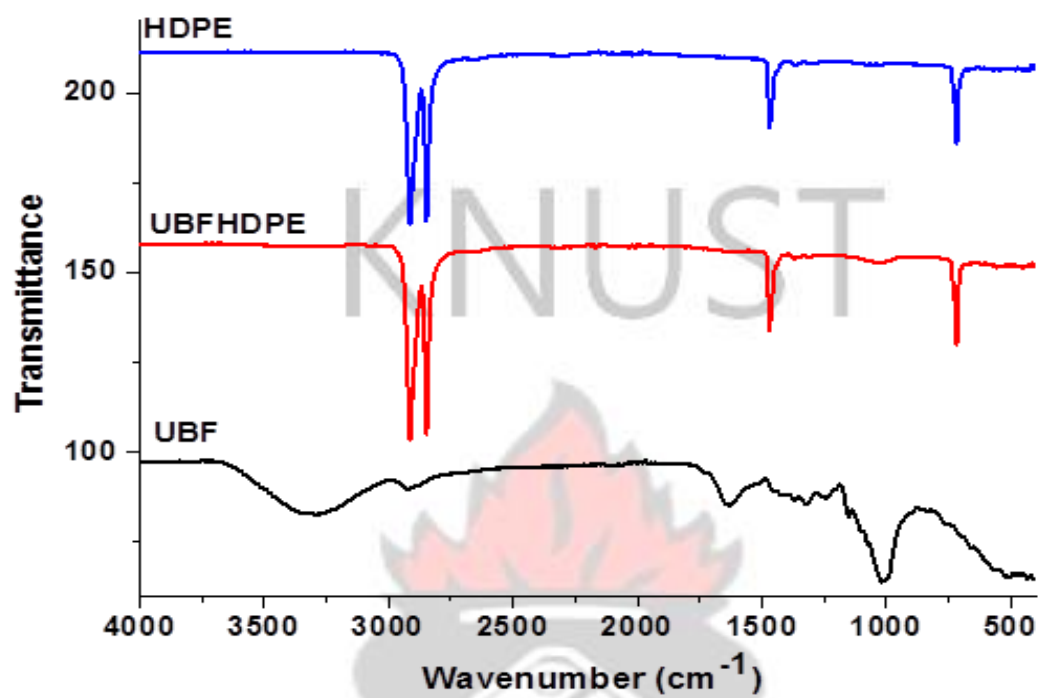


Figure 4.1: FTIR for UBF, UBF-HDPE (10%) and HDPE

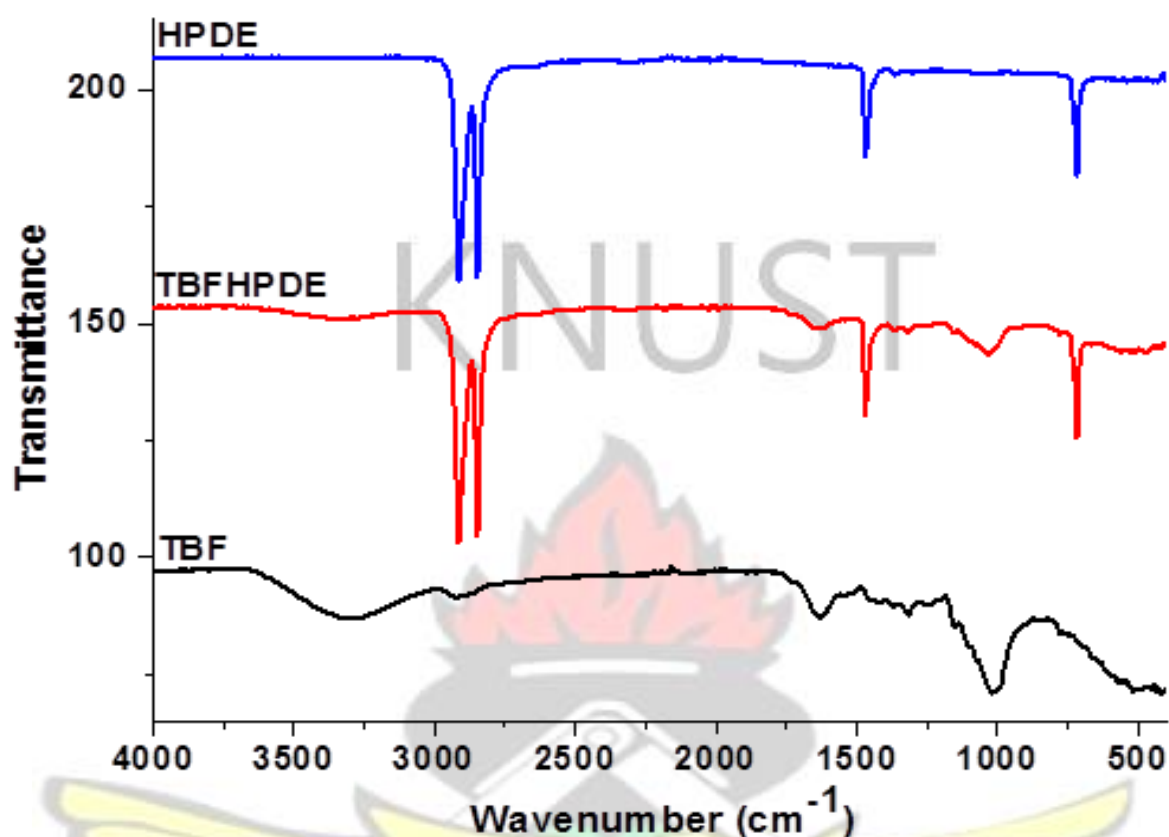


Figure 4.2: FTIR spectra for TBF, TBF-HDPE (10%) and HDPE

The FTIR spectra for UBF, UBF-HDPE and HDPE, TBF, TBF-HDPE and HDPE are shown in figure 4.1 and 4.2 respectively. The spectra of UBF and TBF do not show any significant difference. This can be attributed to the fact that alkalization did not introduce any new group (Chang *et al.*, 2001). The strong and broad peak at 3288 cm⁻¹ may be ascribed to hydroxyl (OH) extending vibration. The appearance of very strong intense and broad peak is a clear indication of many hydroxyl groups present in natural fibers. This also supports the fact that the hydroxyl group is polymeric in nature (Shamsuri *et al.*, 2013). A noticeable peak that was observed at 2923 cm⁻¹ may be due to methyl group (CH₂) asymmetric stretching.

The vibration at 1633 cm⁻¹ can be attributed to carbonyl (CO) of aldehydes. At 1244 cm⁻¹ CO-C stretching vibration of ester was observed whereas C-O stretching of hydroxyl (OH)

functionality was seen at 1016 cm^{-1} . These peaks are generally observed in cellulose, hemicellulose and lignin present in natural fiber (Bilba *et al.*, 2007).

In general TBF showed profound intensities as compared to UBF. This can be due to reduction in waxes and lignin content present in the fiber after alkaline treatment (Sgriccia *et al.*, 2008). For HDPE, the backbone molecule of polyethylene had peaks at 2913 cm^{-1} and 2847 cm^{-1} . These may be assigned to methyl group (CH_2) asymmetric and symmetric stretches respectively (Shamsuri *et al.*, 2013). Peaks at 1470 cm^{-1} can be assigned to C-H bending deformation whereas the peak at 717 cm^{-1} shows CH_2 rocking deformation (Gulmine *et al.*, 2002). For the composites UBF-HDPE and TBF-HDPE, apart from the backbone polyethylene peaks, new peaks at 1367 cm^{-1} and 1029 cm^{-1} were seen. These peaks are almost absent in UBF-HDPE but quite intense in TBF-HDPE. These peaks may be ascribed to conformational variations produced by the interaction within the fiber and the matrix (Islam *et al.*, 2011). These results suggest the presence of physical interaction within the banana fiber and the HDPE.

4.2 MECHANICAL PROPERTIES

The results obtained for tensile test and impact test are presented in tables A.3 and A.5 respectively.

4.2.1 TENSILE STRENGTH

Tensile strength is the load required to break a sample and the degree to which the sample elongates at the break point.

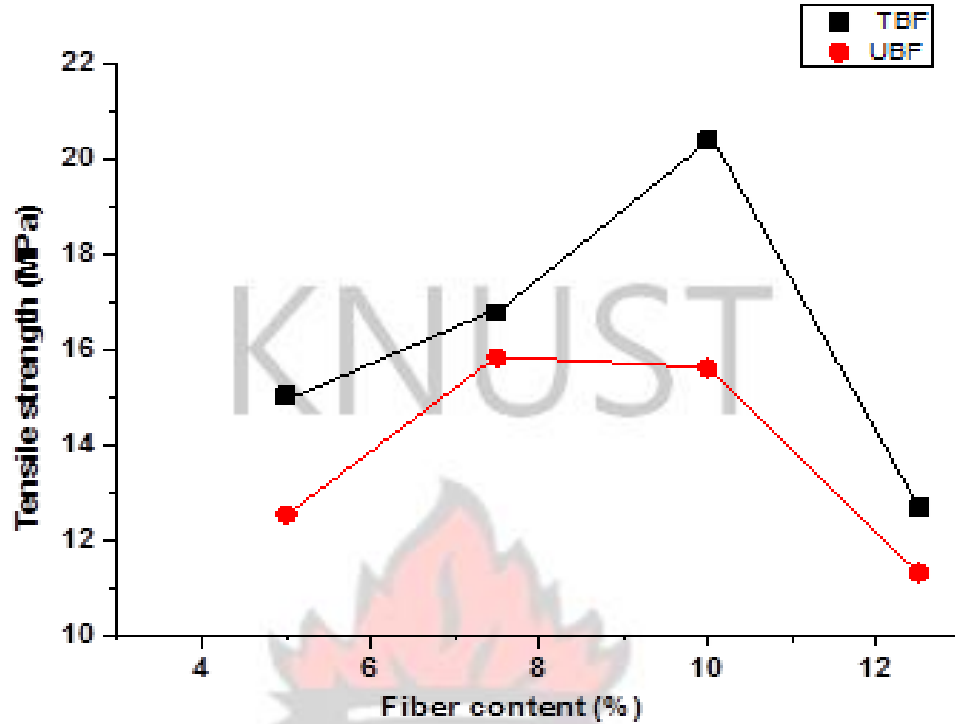


Figure 4.3: Tensile strength (MPa) vs Fiber content (wt. %) of both TBF and UBF HDPE composites.

It was observed that tensile strength of TBF- HDPE composites increased with increasing fiber content up to 10% fiber loading and began to decrease (figure 4.3). This decline may be ascribed to weak interfacial adhesion occurring within the TBF-HDPE above 10 % fiber content. It was also observed that, tensile strength of UBF- HDPE composites increased up to 7.5 % fiber content, then began to decrease. This may be ascribed to poor bonding within the UBF and the HDPE matrix above 7.5 % fiber content (Xue *et al.*, 2007). It was also observed from figure 4.3, that TBF- HDPE composites show higher tensile strength than UBF-HDPE composites. This may be due to better interfacial bonding in TBF-HDPE composites than UBF-HDPE composites (Mukherjee *et al.*, 1984). Overall, the TBF-HDPE composites had a better tensile strength than UBF-HDPE composites. The moulded virgin HDPE had a tensile strength

value of 19.108 MPa that was higher than most the composite except for TBF-HDPE at 10 % fiber loading which had a value of 20.393 MPa.

4.2.2 ELONGATION AT BREAK POINT

Elongation at break point, which is also called fracture strain is the ratio of change in length to initial length after break of the test sample. It states the ability of the composite to withstand changes of form devoid of crack development.

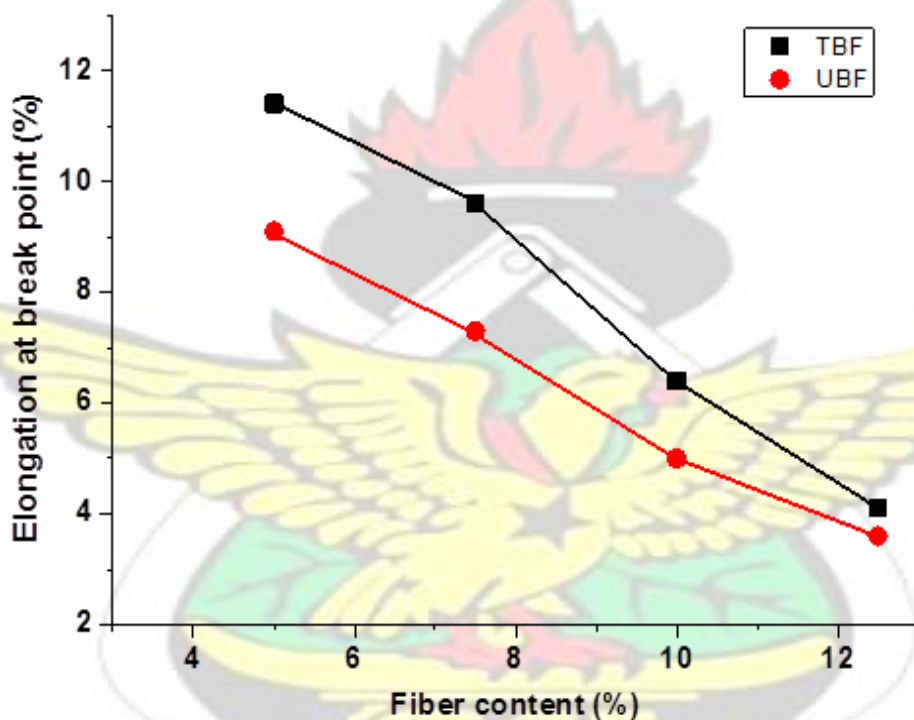


Figure 4.4: Elongation at break point (%) vs fiber content (wt. %) of TBF and UBF HDPE composites.

Elongation at break point of composites are shown in the figure 4.4. It is obvious that elongation decreases when fiber content increases. This indicates that, the presence of fiber prevented the slide of composite causing low ductility. Again from figure 4.4 it can be observed that TBF-

HDPE composites have high elongation at break point than UBF-HDPE composites, thus TBF-HDPE composites can be tougher than UBF-HDPE composites

(Sandeep *et al.*, 2007).

4.2.3 YOUNG'S MODULUS

The Young's modulus of a composite shows the association between stress and strain in a composite which is a measure of the stiffness of the composite (Bachtair *et al.*, 2008).

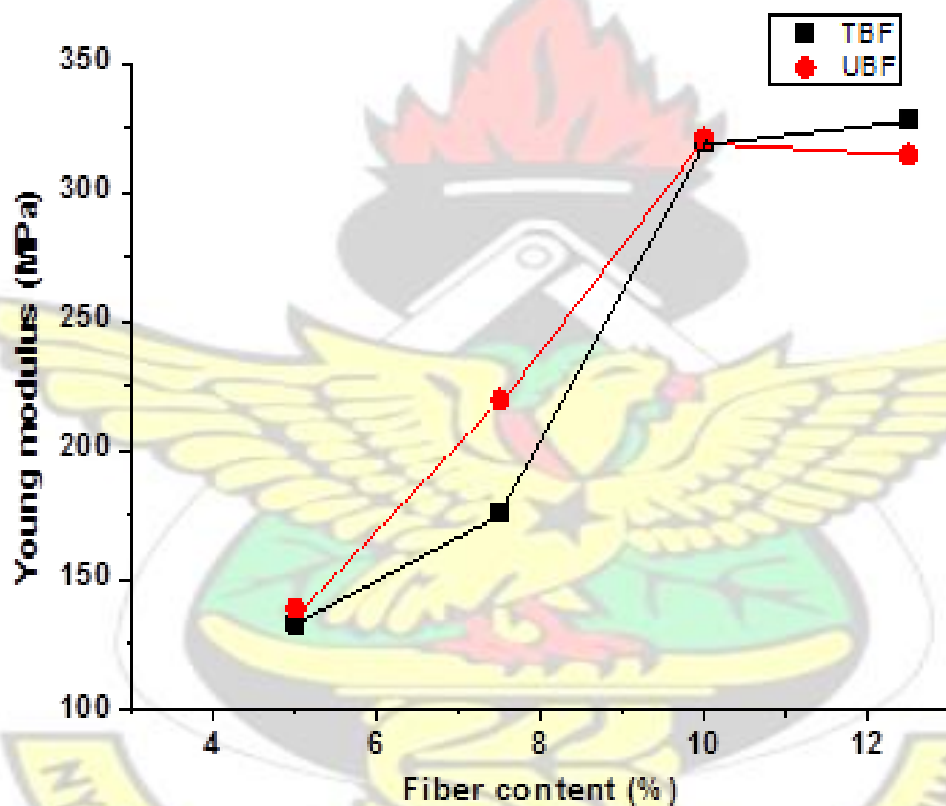


Figure 4.5: Young's modulus (MPa) vs fiber content (wt. %) of TBF and UBF HDPE composites.

Figure 4.5, shows young's modulus of TBF-HDPE and UBF-HDPE composites. It can be observed that young's modulus of UBF-HDPE composites increased when the fiber content was increased up to 12.5 %. It was also observed that young's modulus of UBF-HDPE

composites were slightly higher than TBF-HDPE composites, except above 12.5%. Since young's modulus is a degree of stiffness of a composite, it can be stated, that stiffness of composite increases with increasing in fiber content which is consistent with the observation made by Shibata *et al.*, (2005). From this it can be said that UBF-HDPE composites are stiffer than TBF-HDPE composites.

4.2.4 IMPACT STRENGTH

Impact resistance is a measure of a composite materials ability to dissipate energy before final failure occur. The impact strength of material (composite) is dependent on two parameters:

1. Ability of the fiber to absorb energy to stop crack spread
2. Weak interfacial adhesion which brings micro-spaces within the filler and the matrix and how resultant crack is spread (Sreenivasan *et al.*, 2011).

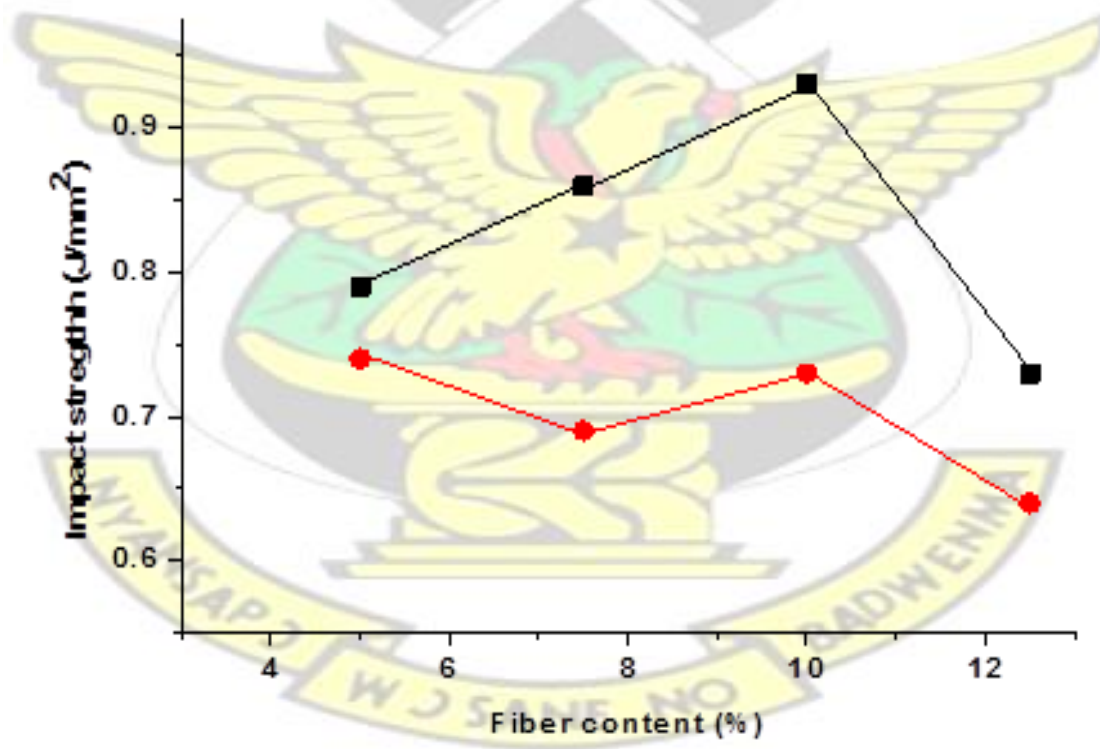


Figure 4.6: Impact strength (J/mm²) vs Fiber content (wt. %) of TBF and UBF HDPE composites.

Better impact strength depend on good bonding. The degree of bonding and fiber withdrawal are few of the parameters which affect the impact strength of fiber composite (Tobias, 1993). From figure 4.6, it was seen that there was gradual increase in impact strength from 5 %, 7.5 % to 10 % fiber content for TBF-HDPE composite. This gradual increase was due to fiber content increase and good bonding within the TBF and the HDPE matrix. The fiber was well embedded in the HDPE matrix, hence the ability to absorb more energy. Decrease in impact strength for 12.5% fiber content TBF-HDPE indicates poor adhesion of TBF with the HDPE even though fiber content was higher. For UBF-HDPE composites 5 % fiber loading had the highest impact strength (Figure 4.6). This can be attributed to good bonding between UBF 5% and HDPE as compared with 7.5 %, 10 % and 12.5 %. Low impact strength for 7.5 %, 10 % and 12.5 % UBF indicate that there was poor adhesion of fiber within the HDPE matrix. This shows that rise in fiber content did not improve the impact strength of UBF- HDPE composites. From figure 4.6, it was also found that TBF-HDPE composites show high impact strength than UBF HDPE composites. This shows that the surface modification (alkalization) of fibers improved adhesion in TBF-HDPE than UBF-HDPE in which the fibers were not chemically treated. Mysamy and Rajendran, (2011) observed that the impact strength of natural fiber composites could solely be enhanced by reducing the fiber content up to a certain percentage and by increasing the friction stress between the fiber and the matrix. From results obtained, it can be inferred that TBF-HDPE composites are tougher than UBF-HDPE composites since TBF-HDPE composites showed higher impact strength than UBFHDPE composites.

4.2.5 WATER ABSORPTION

Water absorption behavior of a fiber reinforced composite had significant consequences because of the rise in the use of the composites for structural material. Water absorption behavior of the composites is influenced by fiber content, temperature, area of the exposed surfaces, void content, hydrophilicity etc. of the separate constituents. This study examined the effect of fiber content on water adsorption.

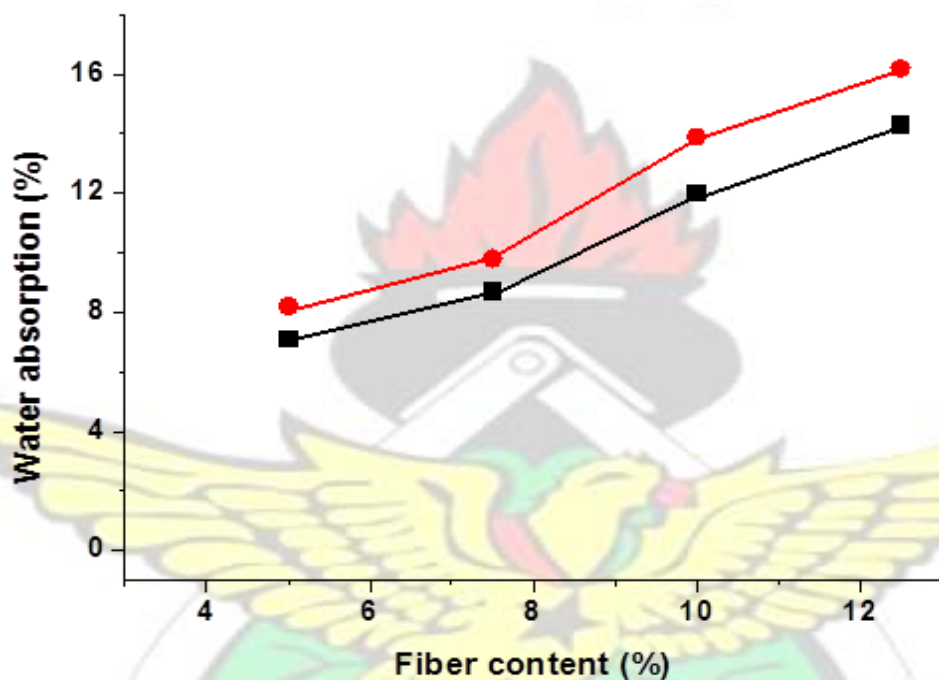


Figure 4.7: increase in mass (%) vs fiber content (wt. %) for TBF and UBF-HDPE composites.

The influence of fiber loading on water absorption (%) in boiling water HDPE-banana fiber for both TBF and UBF composites as shown in figure 4.7. It was observed that water absorption rose with increasing fiber content. From the results, water absorption for both UBF and TBF-HDPE composites were similar since water absorption for both TBF and UBF increased with increasing fiber content. The rise in water absorption can be due to the failure of the matrix to totally saturate the fiber at higher fiber content which facilitates moisture intake (Sarani and

Poh, 2002). It can then be inferred that water adsorption of banana fiber HDPE composite is dependent on fiber content. The high fiber content resulted in increase in percentage water absorption. In low fiber content, the fiber is firmly embedded in the HDPE matrix, thus, lowering fibers exposure to water resulting in low percentage of water absorption. Mylsamy and Rajendran (2011) observed that additional mass gain by natural fiber composites resulted from water molecules getting interlocked in the composites. Hence, possibilities are that the water molecules will affect the interface by subsequently debonding of the fiber and the matrix internally and causing composite structural failure. Again, from figure 4.7, it is also observed that UBF-HDPE composites had good absorption than TBFHDPE composites. This may be ascribed to weak bonding of UBF in HDPE matrix thus exposing the fiber to adsorb more water.

4.2.6 EFFECT OF FIBER CONTENT ON MASS OF COMPOSITES

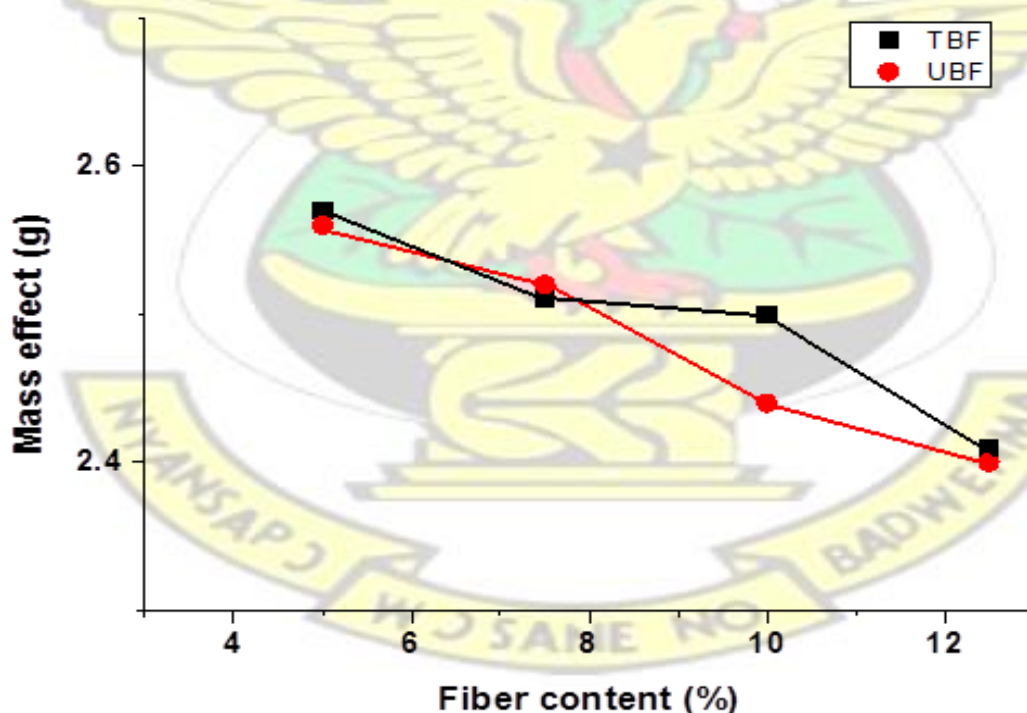


Figure 4.8: mass of sample (g) vs fiber content (wt. %) TBF and UBF-HDPE composites.

From figures 4.8, it can be observed that mass of both UBF-HDPE and TBF-HDPE composites decreased with rising fiber content. This can be attributed to weak adhesion within the banana fibers and the HDPE matrix with increasing fiber loading. This weak bonding results in fiber being more exposed, occupying more space with the HDPE matrix, thus, reducing the weight of the composites (Leonard and Ansell, 1999). It can be observed from figures 4.8, that the decrease in weight was gradual from 5 % to 7.5 % fiber loading for both TBF and UBF HDPE composites. Above 7.5%, UBF showed a sharp decrease in weight.

4.2.7 INFLUENCE OF CHEMICAL TREATMENT (ALKALIZATION)

Alkalization improved the mechanical behavior of banana fiber. From figures 4.3, 4.5 and 4.6, it can be observed that, the mechanical properties (tensile strength, young's modulus and impact strength) of TBF-HDPE composites has improved significantly as compared with UBF-HDPE composites.

4.3 MICROGRAPHICAL ANALYSIS

The surface of the composites was observed using an optical microscope with a magnification of 100 microns.

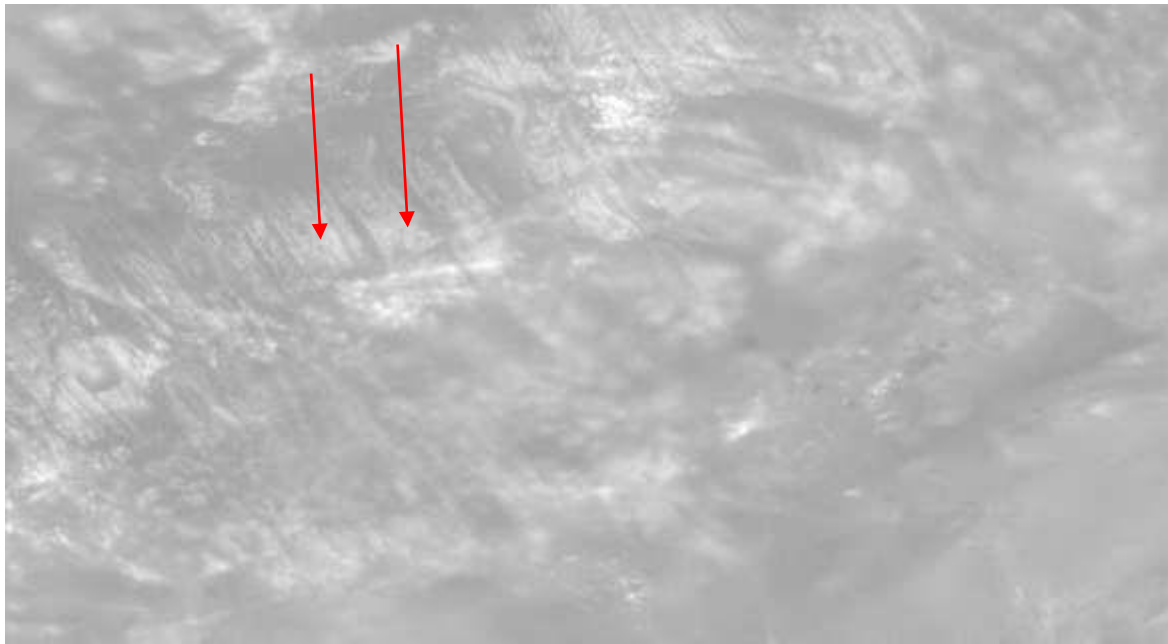


Figure 4.9: Optical micrograph (100 microns) of UBF-HDPE composites.

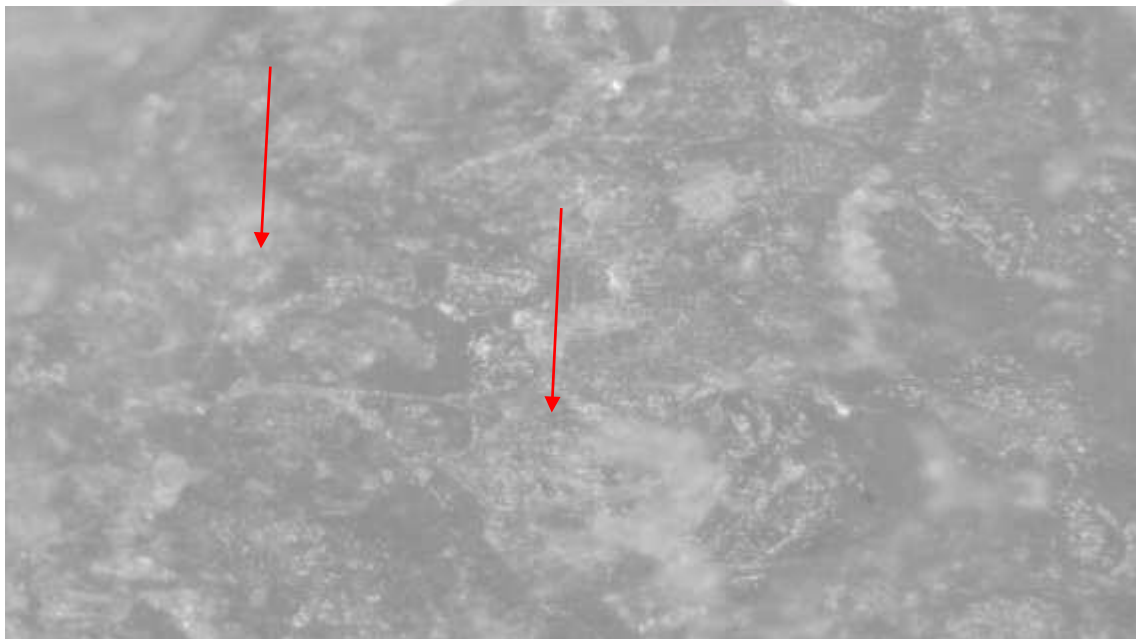


Figure 4.10: Optical micrograph (100 microns) of TBF-HDPE composites

The degree of load transferred to the fiber is dependent on critical fiber length, dispersion, fiber arrangement relation to each other and the compatibility within fiber-matrix interfaces (Leonard and Ansell, 1999). Figure 4.9 illustrates the micrographs of UBF-HDPE composites. The arrow points to fiber agglomeration. It shows bonding of the UBF to the matrix are

randomly arranged and poor. It can be observed that some of the fibers agglomerate together. Micrograph of TBF-HDPE composite is given in figure 4.10. It shows a better dispersion of TBF within the HDPE matrix. From figures 4.3, 4.5 and 4.6, it can be observed that the mechanical properties (tensile strength, young's modulus and impact strength) of TBF-HDPE composites were improved as compared with UBF-HDPE composites. For the randomly arranged fiber composites, mechanical property may be poor because of weak fiber dispersion among the fiber matrix interface. Improving factors such as the dispersion of fibers, significantly improves in composite properties (Fakirov, 2007).



CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The composites of both treated and untreated banana fiber-HDPE have been synthesized and characterized.

The tensile strength and impact strength of the prepared composites increased gradually to a certain level of fiber content and started to decrease. For TBF-HDPE composites, the tensile strength and impact strength increased with increasing fiber content up to 10 % and began to decrease. This makes 10 % fiber content the optimum fiber content for TBF-HDPE composite with the highest tensile and impact strength. A similar trend was observed in UBFHDPE composites, except that the optimum fiber content for tensile strength was realized at 7.5 % and impact strength at 10 %.

The Young's moduli, which transfer into stiffness and water absorption for the prepared composite increased linearly with increasing fiber content. TBF-HDPE at 12.5 % fiber content gave the highest Young's modulus value of 328.18 MPa. UBF-HDPE at 12.5 % fiber content absorbed much water with increase in weight of 16.2 %. However, elongation at break point and mass of composites prepared decreased with increasing fiber content. Chemical modification to decrease hydrophilicity of plant fiber is important, thus increasing their bonding with hydrophobic matrix. Significant improvements in mechanical properties was observed in TBF-HDPE which was treated with alkali. FTIR spectra of UBF and TBF were almost similar. Absorption peaks at 1633 cm^{-1} 1244 cm^{-1} and 1016 cm^{-1} suggested the presence of cellulose, hemicellulose and lignin present in the banana fiber whereas peaks at 1367 cm^{-1} and 1029 cm^{-1} in the prepared composite, suggested a physical interaction between the HDPE and the banana fiber. From the micrographical images obtained, it was observed that TBF-HDPE composites had a good adhesion than UBF-HDPE composites, since voids were noticed

more in UBF-HDPE composites. In general, fiber content and chemical treatment of fiber influenced the mechanical properties of composites and banana fiber can be used as reinforcing agent for HDPE polymers.

5.2 RECOMMENDATIONS

Based on this research study, the following recommendation can be made:

- Further studies with other pre-treatment methods should be done.
- Different polymer matrix with banana fiber should be studied.
- Other tests such as flexural, hardness should be done on banana fiber-HDPE composites.

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APPENDICES

APPENDIX A

Table A.1: Tensile properties of TBF-HDPE composites

SAMPLE TYPE	LOAD (N)	EXTENSION (mm)	STRESS (MPa)	ELONGATION AT BREAK POINT (%)	YOUNG'S MODULUS (MPa)
TBF 5%	302.464	4	15.408	10.9	141.358

TBF 5%	293.568	4.5	14.955	12.3	121.585
TBF 5%	289.120	4	14.728	10.9	135.119
TBF 7.5%	338.048	4	19.768	10.9	181.377
TBF7.5%	302.464	3.5	15.408	9.6	160.500
TBF 7.5%	298.016	3	15.182	9.6	185.146
TBF 10%	400.320	2.5	20.393	6.8	299.897
TBF 10%	320.256	2	16.315	5.5	296.636
TBF 10%	480.384	2.5	24.472	6.8	359.882
TBF 12.5%	222.400	1	11.330	2.7	419.630
TBF 12.5%	275.776	2	14.049	5.5	255.436
TBF 12.5%	249.088	1.5	12.689	4.1	309.487

Table A.2: Tensile properties of UBF-HDPE composites.

SAMPLE TYPE	LOAD (N)	EXTENSION (mm)	STRESS (MPa)	ELONGATION AT BREAK POINT (%)	YOUNG'S MODULUS (MPa)
UBF 5%	249.088	3.5	12.689	9.6	132.177
UBF 5%	222.400	3.5	11.329	9.6	118.329
UBF 5%	266.880	3	13.596	8.2	165.805
UBF 7.5%	320.256	2.5	16.315	6.8	239.926
UBF7.5%	296.964	2.5	15.103	6.8	222.103
UBF 7.5%	315.808	3	16.088	8.2	196.195
UBF 10%	351.632	1.5	17.913	4.1	436.902
UBF 10%	291.568	2	14.853	5.5	270.054

UBF 10%	276.224	2	14.072	5.5	255.855
UBF 12.5%	266.880	1.5	13.562	4.1	330.780
UBF12.5%	222.400	1.5	11.329	4.1	276.317
UBF 12.5%	177.920	1	9.064	2.7	335.704

Table A.3: Average tensile properties of TBF and UBF HDPE composites.

SAMPLE TYPE	TBF 5%	TBF 7.5%	TBF 10%	TBF 12.5%	UBF 5%	UBF 7.5%	UBF 10%	UBF 12.5%
TENSILE STRENGTH (MPa)	15.030	16.78	20.393	12.689	12.538	15.835	15.612	11.318
YOUNG'S MODULUS (MPa)	132.68	175.6	318.80	328.184	138.770	219.408	320.937	314.267
ELONGATION AT BREAK POINT (%)	11.4	9.6	6.4	4.1	9.1	7.3	5.0	3.6

TableA.4: Results obtained for impact energy (J) and impact strength (J/mm²) of both TBF and UBF HDPE composites.

SAMPLE TYPE	IMPACT ENERGY (J)	IMPACT STRENGTH (J/mm ²)	SAMPLE TYPE	IMPACT ENERGY (J)	IMPACT STRENGTH (J/mm ²)
TBF 5%	16	0.81	UBF 5%	15	0.76
TBF 5%	15	0.76	UBF 5%	15	0.76
TBF 5%	16	0.81	UBF 5%	14	0.71
TBF 7.5%	17	0.87	UBF 7.5%	13	0.62
TBF 7.5%	16	0.82	UBF 7.5%	14	0.71
TBF 7.5%	18	0.92	UBF 7.5%	14	0.71
TBF 10%	20	1.02	UBF 10%	14	0.71
TBF 10%	17	0.87	UBF 10%	16	0.82
TBF 10%	18	0.92	UBF 10%	13	0.66
TBF 12.5%	16	0.82	UBF 12.5%	13	0.66
TBF 12.5%	13	0.66	UBF 12.5%	13	0.66
TBF 12.5%	14	0.71	UBF 12.5%	12	0.61

Table A.5: Average impact energy (J) and impact strength (J/mm²) values.

SAMPLE	IMPACT ENERGY (J)	IMPACT STRENGTH (J/mm ²)	SAMPLE	IMPACT ENERGY (J)	IMPACT STRENGTH (J/mm ²)
TBF 5%	15.76	0.79	UBF 5%	14.67	0.74
TBF 7.5%	17.00	0.86	UBF 7.5%	13.67	0.69
TBF 10%	18.33	0.93	UBF 10%	14.33	0.73
TBF 12.5	14.34	0.73	UBF 12.5%	12.66	0.64

APPENDIX B

Table B.1: Water absorption properties for UBF-HDPE composites.

SAMPLE TYPE	DRIED MASS (g)	WET MASS (g)	CHANGE IN MASS (g)	%INCREASE IN MASS
UBF 5%	2.57	2.76	0.19	7.4
UBF 5%	2.59	2.80	0.21	8.1
UBF 5%	2.54	2.77	0.23	9.1
UBF 7.5%	2.52	2.74	0.25	9.96
UBF 7.5%	2.49	2.75	0.24	9.63
UBF 7.5%	2.53	2.78	0.25	9.88
UBF 10 %	2.47	2.75	0.28	11.33
UBF 10%	2.45	2.79	0.37	15.10
UBF 10 %	2.41	2.76	0.31	12.86
UBF 12.5%	2.39	2.79	0.40	16.73
UBF 12.5%	2.42	2.78	0.38	15.70
UBF 12.5%	2.40	2.81	0.39	16.25

Table B.2: Water absorption properties for TBF-HDPE composites.

SAMPLE TYPE	DRIED MASS (g)	WET WEIGHT (g)	CHANGE IN MASS (g)	% INCREASE IN MASS
TBF 5%	2.61	2.78	0.17	6.51
TBF 5%	2.59	2.79	0.20	7.72
TBF 5%	2.53	2.71	0.18	7.11
TBF 7.5%	2.50	2.74	0.24	9.60
TBF 7.5%	2.52	2.72	0.20	7.90
TBF 7.5%	2.50	2.71	0.22	8.80
TBF 10%	2.48	2.74	0.26	10.48
TBF 10%	2.50	2.79	0.29	11.60
TBF 10%	2.42	2.76	0.34	14.04
TBF 12.5%	2.38	2.75	0.34	14.14
TBF 12.5%	4.41	2.74	0.36	14.93
TBF 12.5%	2.43	2.77	0.34	13.99

Table B.3: Average water absorption properties of TBF, UBF HDPE composites and HDPE

SAMPLE TYPE	DRIED MASS (g)	WET MASS (g)	CHANGE IN MASS (g)	% INCREASE MASS
UBF 5%	2.56	2.77	0.21	8.2
UBF 7.5%	2.52	2.75	0.25	9.8
UBF10%	2.44	2.77	0.32	13.9
UBF 12.5%	2.40	2.79	0.39	16.2
TBF 5%	2.57	2.76	0.18	7.11
TBF 7.5%	2.51	2.72	0.22	8.76
TBF 10%	2.50	2.76	0.29	12.04
TBF 12.5%	2.41	2.75	0.35	14.35

APPENDIX C

Table C.1: Average mass of various composition of samples

SAMPLE TYPE	MASS OF SAMPLE (g)
UBF 5%	2.56
UBF 7.5%	2.52
UBF10%	2.44
UBF 12.5%	2.40
TBF 5%	2.57
TBF 7.5%	2.51
TBF 10%	2.50
TBF 12.5%	2.41

APPENDIX D



Figure D.1: J.B Engineering extruder



Figure D.2: Injection moulding machine



Figure D.3: Saml. Dension and Son manual tensile testing machine



Figure D.4: Pendulum impact tester



Figure D.5: Spinot heater



Figure D.6: Ohaus balance



Figure D.7: Bruker alpha FTIR spectrometer



Figure D.8: Leica DM2500 optical microscope



Figure D.9: The test sample



Figure D.10: Fractured sample in the tensile machine



Figure D.11: Fractured a sample after tensile test

