DEVELOPMENT AND CHARACTERIZATION OF RECYCLED HIGH DENSITY POLYETHYLENE (RHDPE)/NATURAL FIBRE COMPOSITES

BY

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DECLARATION

I declare that the work in this thesis titled "Development and Characterisation of Recycled High Density Polyethylene/Natural Fibre Composites" has been carried out by me in the department of Mechanical Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other institution.

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CERTIFICATION

This Thesis entitled DEVELOPMENT AND CHARACTERISATION OF RECYCLED HIGH DENSITY POLYETHYLENE/NATURAL FIBRE COMPOSITES by Linda Obiageli, NTIBUNKA meets the regulations governing the award of the degree of Masters of Science in Mechanical Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To the best mother in the world, Mrs. Concepta Ntibunka, whose love, financial and moral support led to the fulfillment of this dream.

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I wish to express my profound gratitude to the creator of the universe, the King of Kings and Lord of Lords. He alone was the source of my strength throughout this research experience.

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ABSTRACT

Fiber-reinforced polymer composites have played a dominant role for a long time in a variety of applications for their high specific strength and modulus. The fiber which serves as a reinforcement in reinforced plastics may be synthetic or natural. This research focuses on natural plant and animal fibres (palm kernel, locust bean husk, goat fur and sheep wool). It deals with the production and characterization of composites of these fibres reinforced with recycled high density polyethylene. The physical properties such as density, water absorption and thickness swelling were determined. The tensile strength, flexural strength, hardness, impact energy, and wear properties were investigated. Thermal, chemical and microstructural analyses were also carried-out on the developed samples. The study revealed the result of the variation of the engineering properties with %wt composition of fibre reinforcements. It also presented the effect of variation of fibre length on engineering properties showing 10 mm as the critical length of fibres. The thermal analysis showed the destruction temperature range of the composites to lie between 400 and 500 ^{0}C.

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NOMENCLATURE

PKF	-	Palm Kernel Fiber
LBHF	-	Locust Bean Husk Fiber
GFF	-	Goat Fur Fiber
SWF	-	Sheep Wool Fiber
RHDPE	-	Recycled High Density Polyethylene
XRF	-	X-Ray Fluorescence Analysis
SEM	-	Scanning Electron Microscope
EDS	-	Energy Dispersive Spectrometry
DTA	-	Differential Thermal Analysis
TGA	-	Thermo-gravimetric Analysis
PMCs	-	Polymer Matrix Composites
MMCs	-	Metal Matrix Composites
CMCs	-	Ceramic Matrix Composites
CCCs	-	Carbon/Carbon Composites
fl	-	Fiber Length
vf	-	Fiber Volume Fraction
TS	-	Thickness Swelling Rate
WA	-	Percentage Water Absorption
MOR	-	Modulus of Rupture
MOE	-	Modulus of Elasticity
σ	-	Tensile Strength *MPa*
µ	-	Coefficient of Friction

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Over the last thirty years, composite materials, plastics and ceramics have been the dominant emerging materials but it is noted that the volume of different compositions and the number of applications of composite materials have been growing steadily, penetrating and conquering world markets relentlessly. Modern composite materials constitute a significant proportion of newly fabricated products ranging from domestic products to sophisticated products (Prakash, 2009; Hull, 1996).

Efforts to produce economical and attractive composite components have resulted in several innovative manufacturing techniques currently used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, materials processing, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals. The use of composites has not been limited to aircraft industries but to other commercial applications in recent years. This is possible due to the introduction of new polymer resin matrix materials and high performance reinforcement fibers (Nayak, 2009; Prakash, 2009).

Natural fiber composites are emerging as realistic alternatives to glass-reinforced composites in many applications. Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP), and china reed fiber-PP are particularly attractive in automotive applications because of lower cost and lower density. Glass fibers used for composites have density of 2.6 g/cm^3 and cost between \$1.30 and \$2.00/kg. In comparison, flax fibers have a

density of 1.5 g/cm^3 and cost between $0.22 and $1.10/kg (Joshi *et al*, 2004). While, natural fibers traditionally have been used to fill and reinforce thermosets, natural fiber reinforced thermoplastics, especially polypropylene composites, have attracted greater attention due to their added advantage of recyclability (Joshi *et al*, 2004). Natural fiber composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components.

As industry attempts to lessen the dependence on petroleum based fuels and products there is an increasing need to investigate more environmentally friendly, sustainable materials to replace the existing glass fiber and carbon fiber reinforced materials (Zampaloni *et al*, 2007). Therefore, attention has recently shifted to the fabrication and properties of natural fiber reinforced materials. The automotive and aerospace industries have both demonstrated an interest in using more natural fiber reinforced composites, for example, in order to reduce vehicle weight, automotive companies have already shifted from steel to aluminum and now are shifting from aluminum to fiber reinforced composites for some applications.

This has led to predictions that in the near future plastics and polymer composites will comprise approximately 15% of total automobile weight (Mohanty *et al*, 2002; Zampaloni *et al*, 2007). In this work, some natural fibers were utilized as reinforcement with HDPE waste using physico-mechanical and thermal property as criteria.

1.2 Problem Statement

Natural fibre reinforced polymer composites have raised great interest among material scientists and engineers in recent years due to the need for developing environmentally friendly materials, and partly replacing currently used glass fibers for composite reinforcement. Glass fibres are widely used to reinforce plastics due to their low cost and

fairly good mechanical properties. However, these fibres have serious drawbacks with respect to health and safety during handling and processing of fibre products. They can cause acute irritation of the skin, eyes and the upper respiratory tract. Concerns have been raised for long-term development of lung scarring (i.e., pulmonary fibrosis) and cancer. When released, glass fiber does not degrade and results in environmental pollution and threatens animal life and nature significantly (Neeraj and Geeta, 2013; Wambua *et al.,* 2003).

1.3 The Present Work

It is against this backdrop (the stated problem) that the present research has developed and characterized recycled high density polyethylene (RHDPE)/Natural fiber composites: an alternative to conventional glass fiber reinforced composites.

1.4 Aim and Objectives

The aim of the present research is centered on the development and characterization of composites from recycled high density polyethylene (RHDPE) reinforced with plant fibre (locust bean husk and palm kernel) and animal fibre (sheep wool and goat fur). To achieve this aim, the following specific objectives are necessary:

i. To study the composition of the plant and animal fibres: palm kernel, locust bean husk, goat fur and sheep wool).
ii. To develop the composites using the polymer-fibre mix for each of the natural fibres.
iii. To study the mechanical and physical properties (tensile strength, flexural strength, hardness, impact energy, wear resistance, density, thickness swelling and water absorption) of the developed composites.
iv. To determine the effect of fibre length on the physical and mechanical properties of the developed composites

v. To study the microstructure of the composites using scanning electron microscope (SEM)

vi. To study the thermal properties of the developed composites.

1.5 Scope of the Study

The scope of this present research will be limited to the following areas:

i. Preparing the natural fibres and RHDPE prior to compounding.

ii. Formulation by varying the fibre amounts (5-25 wt %).

iii. Development of the composite by the compounding and heat pressing method.

iv. Testing the physical and mechanical properties of the developed composite.

v. Microstructural analysis of the developed composites.

vi. Thermal analysis of the developed composites.

vii. Comparative analysis of the natural fibers (plant and animal).

1.6 Significance of the Research

The new paradigm in the preparation of fiber reinforced composites is the use of natural fibers in place of petroleum-based synthetic fibers. Even though glass-fiber-reinforced composites have good mechanical properties, they exhibit shortcomings such as higher density, difficulty to machine, and poor recycling properties. Natural fibers have special advantages such as low cost, low energy consumption, low density, high specific mechanical properties, and non-abrasive and biodegradable properties when compared to synthetic fibers like glass. The use of natural fibers to make low cost and eco-friendly composite materials is a subject of green importance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter is a review of the papers that are pertinent to the studies carried out in this work. It also specifically considers some relevant concepts such as composition materials, natural fibre reinforced composite materials, mechanical and physical properties of natural fibre reinforced composite materials, classification and applications of natural fibre reinforced composites.

2.2 Composite Materials

When a material is reinforced it is most likely to form a composite. According to the dictionary of composite material technology, composite is a multiphase material formed from a combination of materials which differ in composition or form, remain bonded together and retain their identities and properties. Composites maintain an interface between components and act in concert to provide improved specific or synergistic characteristics not obtainable by any of the original components acting alone.

Modern composite materials constitute a significant proportion of the engineering materials market ranging from everyday products to sophisticated niche applications.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composite industries. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in designing, material processing,

tooling, quality assurance, manufacturing, and even programme management for composites to become competitive with metals (Mohanty, 2000).

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of the transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years (Gross, 2002).

Increasingly enabled by the introduction of newer polymer resin matrix materials and high performance reinforcement fibers of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume. The increased volume has resulted in an expected reduction in costs. High performance FRP can now be found in such diverse applications as composite armoring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc. (Chattopadhyay, 2004).

Furthermore, the need of composites for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decrease dead weight but also absorb the shock and vibration through tailored microstructures. Composites are now extensively used for rehabilitation/strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity (Chattopadhyay, 2004).

Unlike conventional materials such as steel, the properties of the composite material can be designed considering the structural aspects. The design of a structural component using

composites involves both material and structural design. Composite properties (e.g. stiffness, thermal expansion etc.) can be varied continuously over a broad range of values under the control of the designer. Careful selection of reinforcement type enables finished product characteristics to be tailored to almost any specific engineering requirement (Aziz, 2009).

Whilst the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience and skills of the designer in tapping the optimum potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials (Amar, 2005).

According to a presentation made at Genoa, Italy titled "Design and structural simulation of composites in transportation" on 28th June 2002, it was shown that CO_2 emission from automobiles through the use of composite material in their parts fabrication will be reduced to 167.5 g/km in 2003, then to 140 g/km in 2008 and it is expected to reduce further to 120 g/km by the year 2012 (Mangino and Indino, 2002).

2.3 Types of Composite Materials

Composites include:

i. Fibrous (composed of fibers, and usually in a matrix),
ii. Laminar (layers of materials),
iii. Particulate (composed of particles or flakes, usually in a matrix), and
iv. Hybrid (combinations of any of the above) (Brouwer, 2002).

2.4 Properties of Composite Materials

i. Physical properties include density, porosity, water leakage etc.

ii. Electrical properties include electric strength, flash over, volume and surface resistivity, power factor permittivity.

iii. Thermal properties are thermal conductivity, thermal expansion, and heat resistance

iv. Chemical properties of materials include resistance to reagents and oils.

v. Mechanical properties are tensile strength, compressive strength and impact strength etc.

For the purpose of this research, mechanical, thermal, chemical and physical properties like tensile strength, hardness, stiffness, toughness, impact values, wear resistance, TGA/DTA, XRF, density, thickness swelling and water absorption will be conducted. Some of such properties are defined below;

2.4.1 Strength

Sometime called tensile strength, strength is one of the most important mechanical properties since it determines the ability of a material to withstand stress without failure. It varies with the type of load applied and thus, it is possible to evaluate tensile strength and compressive strength**.**

2.4.2 Hardness

It is defined as the resistance of a material to local penetration.

2.4.3 Stiffness

It is a measure of the ability of a material to resist deformation under load. It is usually defined by the modulus of elasticity. Very often the engineer is concerned with the stiffness of the material rather than its strength.

2.4.4 Toughness

It is the ability of a material to absorb energy without rupturing. A tough material is able to absorb lots of energy before it fails under a load.

2.5 Classification of Composite Materials

Composites are usually classified by the material used for the matrix. The four primary categories of composites are;

i. Polymer matrix composites (PMCs)
ii. Metal matrix composite (MMCs)
iii. Ceramic matrix composite (CMCs) and
iv. Carbon/carbon composite (CCCs)

2.5.1 Polymer Matrix Composites (PMCs)

Most commonly used matrix materials are polymeric. In general, the mechanical properties of polymers are inadequate for many structural purposes, particularly; their strength and stiffness are low compared to those of metals and ceramics. These difficulties are overcome by reinforcing them with other materials. The reason for their common use is that the processing of polymer matrix composites does not involve high pressure and temperature. In addition, equipment required for manufacturing polymer matrix composites are simpler in

operation and structure. For these reasons polymer matrix composites were developed rapidly and became popular for structural applications.

2.5.1.1 Two Types of Polymer Reinforcement

These are;

i. Fiber reinforced polymers (FRP)

ii. Particle reinforced polymers (PRP)

i. Fiber reinforced polymers (FRP)

A fiber reinforced composite contains fibers and a polymer matrix. Fibers are the reinforcement and the main source of strength while the matrix glues all the fibres together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, fillers might be added to smooth the manufacturing process, impart special properties to the composites, and or reduce the product cost.

Common fiber reinforcing agents include asbestos, carbon/graphite fibres, beryllium carbide, beryllium oxide, molybdenum, aluminum oxide, glass fibers, polyamide, natural fibers etc. Similarly, common matrix materials include epoxy, phenolic, polyester, polyurethane, polyetherethyketone (PEEK), vinyl ester etc. Among these resin materials, PEEK is the most widely used epoxy, which has higher adhesion properties.

A fiber is characterized by its length being much greater compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages

the growth of incipient cracks normal to their enforcement that might otherwise lead to failure, particularly with brittle

matrices. Man-made filaments or fibers of non-polymeric materials exhibit much higher strength along their length since large flaws, which may be present in the bulk material, are minimized because of the small cross-sectional dimensions of the fibre. In the case of polymeric materials, orientation of the molecular structure is responsible for high strength and stiffness.

Fibers, because of their small cross- sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage due to handling. In discontinuous fibre reinforced composites, the load transfer function of the matrix is more critical than in continuous fibre composites.

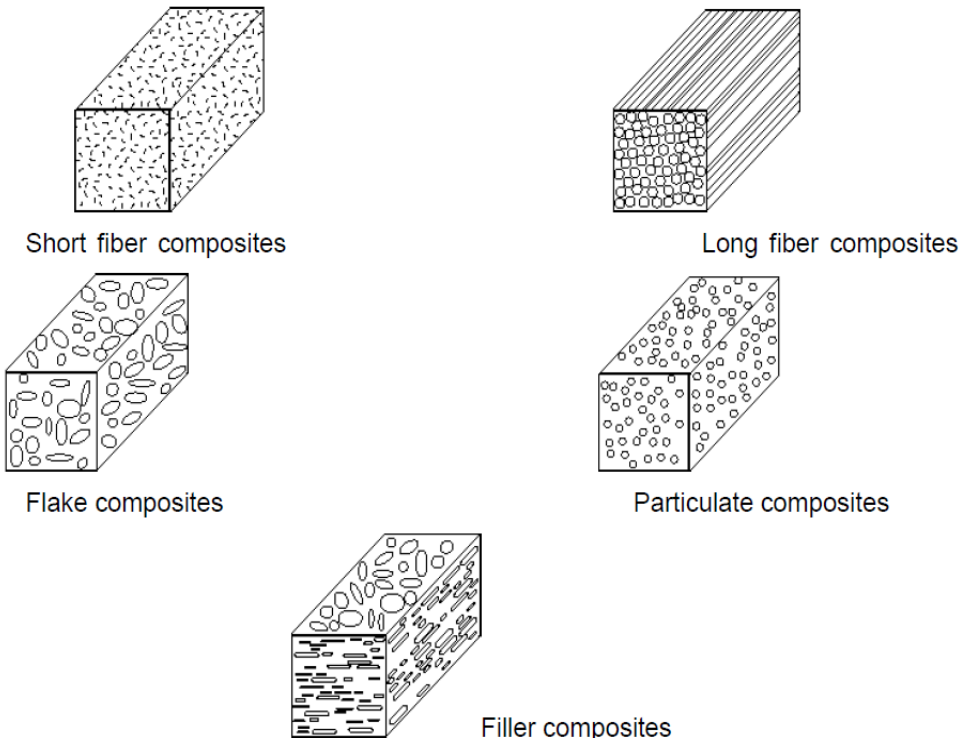


Figure 2.1 Different types of fibrous composite materials:

ii. Particle reinforced polymers

Particles used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials, including polymers and carbon black. Particles are used to increase the modules of the matrix and to decrease the ductility of the matrix. Particles are also used to reduce the cost of the composites. Reinforcements and matrices can be common inexpensive materials easily processed. Some of the useful properties of ceramics and glasses include; high melting temperature, low density, high strength, stiffness, wear resistance and corrosion resistance. Many ceramics are good electrical and thermal insulators. Some ceramics have special properties; some ceramics are magnetic materials; some are piezoelectric materials; and a few special ceramics are even superconductors at very low temperatures. Ceramics and glasses have one major drawback; they are brittle. An example of particle reinforced composites is the automobile tire, which has carbon black particles in a matrix of polyisobutylene elastomeric polymer (Smith, 1990).

2.5.2 Polymer Matrix Composite Materials (PMCs)

The word polymer means many parts- when a single molecule reacts with other molecules. Two major classes of polymers used as matrix material are thermosets and thermoplastics.

Thermosets are materials that undergo a curing process during part fabrication, after which they are rigid and cannot be reformed. They cannot be re-melted and reformed into other shapes but degrade or decompose when heated to high temperatures (Smith, 1990).

Thermoplastics can be repeatedly softened and reformed by application of heat. Thermoplastics require heat to make them formable and after cooling, retain the shape they were formed into. These materials can be re- heated and reformed into new shapes a number

of times without significant change in their properties. Most thermoplastics consist of very long chains of atoms covalently bonded together (Stephen, 1981).

2.5.2.1 Properties of Polymer Matrix Materials

They are relatively weak, low in stiffness, viscoelastic, and corrosion, solvent and fire resistant materials. Their strength and stiffness come primarily from the fiber phase, (Smith, 1990).

2.5.3 Metal Matrix Composites

Metal matrix composites have many advantages over pure metals like higher specific modulus, higher specific strength, better properties at elevated temperatures and lower coefficients of thermal expansion. Because of these attributes, metal matrix composites are now considered for a wide range of applications viz combustion chamber nozzles (in rocket and space shuttles), housings, tubings, cables, heat exchangers, structural members etc.

2.5.4 Ceramic Matrix Composites

One of the main objectives in producing ceramic matrix composites is for applications with high toughness requirements. Naturally, it is often found that there is an improvement in strength and stiffness of ceramic matrix composites.

2.6 Natural Reinforcement Materials

The use of plant fibres as reinforcement in composite materials is finding increasing interest in the automotive and building industries. The properties of plant fibre composites have been addressed in numerous research studies. New composite materials based on plant fibres and polymers are being increasingly used in the building industry and in the automotive industry.

Plant fibres, such as sisal, jute, hemp, flax, palm etc can be used as reinforcement for epoxy, polyester, PVC, PE or PP-type polymers in place of synthetic fibres (glass, Kevlar, carbon, etc.) (Brouwer, 2002).This substitution offers many benefits:

• **Economic:** lower costs, on account of significant reduction in energy savings.

• **Technical:** mechanical properties identical to those of traditional reinforcements, reduced tool wear and tear, high geometric stability of the manufactured parts, good insulation characteristics;

• **Environmental:** renewable resource, easy to recycle, no material toxicity, reduced fossil fuels content, CO2-neutral materials.

Natural fiber composite materials are being used for manufacturing many components in the automotive sector (Taj *et al*., 2007; Karus & Gahle, 2006; Saxena *et al.,* 2008, 2011; Mohanty *et al.,* 2005 and Xin *et al.,* 2007). Like glass, the natural fibers combine readily with thermoplastic or thermosetting matrices to produce commodity goods (Brouwer, 2002).

Plant fibers are mainly used in making the interior parts of passenger cars and truck cabins. Such materials, mainly based on cotton fibers recycled from textiles, have relatively high fiber content of more than 80% by weight.

2.7 Classification of Natural Fibres

Natural fibres are classified into three categories. These are plant fibres, animal fibres and mineral fibres (see fig. 2.2 below).

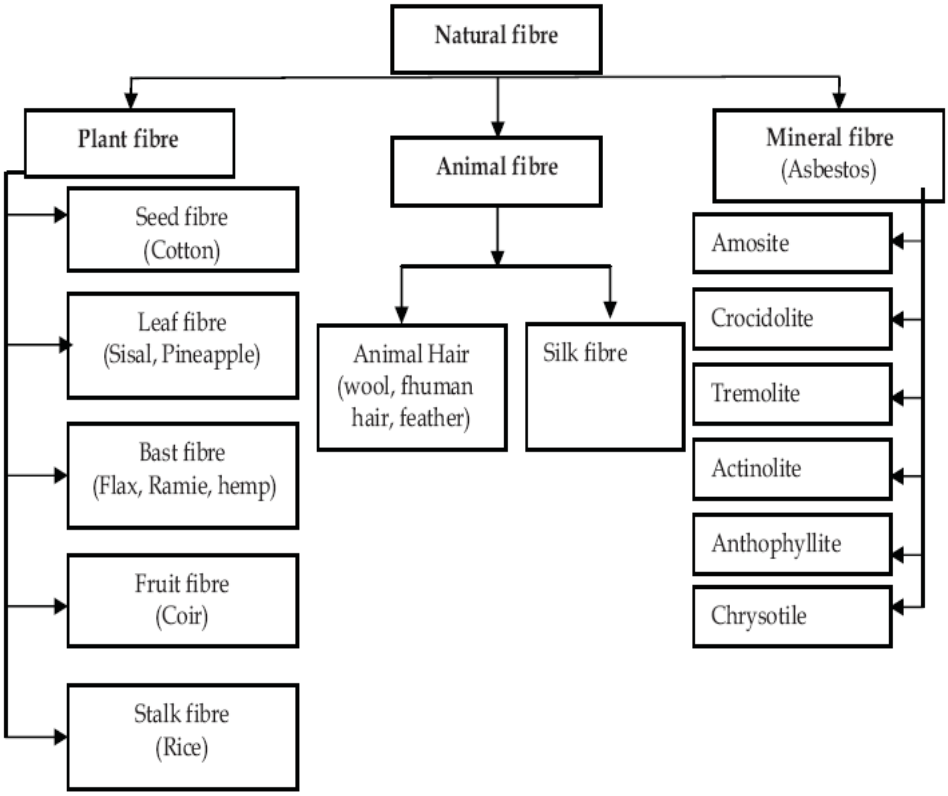


Figure 2.2: Classification of natural fibres reinforcement (Prum & Brush, 2002, 2003; Pettingill, 1970)

Natural fibers include those made from plant, animal and mineral sources. Natural fibers can be classified according to their origin.

- Animal fiber
- Mineral fiber
- Plant fiber

2.7.1 Animal Fibers

Animal fibers are generally made up of proteins; examples include hair, wool, silk, alpaca, and angora.

i. ***Animal hair*:** Fiber taken from animals or hairy mammals e.g. Sheep's wool, goat hair, alpaca hair, horse hair, etc. Wool is considered to be a protein called keratin. Its length usually ranges from 2 to 35cm depending on the breed of sheep/goat. Each

piece is made of three essential components; the cuticle, the cortex, and the medulla. The cuticle is the outer layer. The cortex is the inner structure made up of millions of cigar-shaped cortical cells. In wool processing, wool straight off a sheep/goat contains a high level of grease which contains valuable lanolin, as well as dirt, dead skins and vegetable matter. This semi grease wool can be worked into yarn and knitted into particularly water-resistant sweaters (Srinivas, 2011).

ii. ***Silk fiber:*** Fiber collected from dried saliva of bugs or insects during the preparation of cocoons. Examples include silk from silk worms.

iii. ***Avian fiber:*** Fibers from birds, e.g. feathers and feather fiber.

2.7.2 Mineral fibers

Mineral fibers are naturally occurring fibers or slightly modified fibers procured from minerals. These can be categorized into the following categories:

i. ***Asbestos****:* The only naturally occurring mineral fiber. Variations are serpentine, amphiboles and anthophyllite.

ii. ***Ceramic fibers***: Glass fibers, aluminum oxide, silicon carbide, and boron carbide.

iii. ***Metal fibers***: Aluminum fibers etc.

2.7.3 Plant fibers

Plant fibers generally comprise mainly cellulose: examples include oil palm, cotton, jute, flax, ramie, sisal and hemp. Cellulose fibers are used in the manufacture of paper and cloth. These fibres can be further categorized into the following classes;

i. ***Seed fibers***: Fibers collected from the seed and seed cases e.g. cotton, kapok, locust bean husk fibre etc. Locust bean husk fiber is obtained usually after extracting the gum from the husk which could be achieved by either boiling or soaking the husk for a couple of hours followed by scrubbing, or by drying the husk followed by grinding.

Most of the works carried out on these materials are only interested in the gum and as such, there is limited information about the fibrous material.

ii. ***Leaf fibers***: Fibers collected from the leaves e.g. sisal and agave.

iii. ***Skin fibers***: Fibers are collected from the skin or bast surrounding the stem of their respective plant. These fibers have higher tensile strength than other fibers. Therefore, they are used for durable yarn, fabric, packaging, and paper. Some examples are flax, jute, banana, hemp, and soya bean.

iv. ***Fruit fibers***: These fibers are collected from the fruit of the plant, e.g. palm kernel coconut (coir) fibers. Palm kernel fibre is a waste product of palm oil processing industries obtained after removing/extracting the oil by cooking and pounding the cooked palm kernel, followed by scrubbing and squeezing of the fibrous materials. Fibres from palm kernel are relatively stronger and flexible in both wet and dry states.

v. ***Stalk fibers***: Fibers of the stalks of plants e.g straws of wheat, rice, barley, and other crops including bamboo and grass. Tree wood is also such a fiber.

The natural fibers can be used to reinforce both thermosetting and thermoplastic matrices. Thermosetting resins, such as epoxy, polyester, polyurethane, phenolic etc, are commonly used today in natural fiber composites, where higher performance matrix is required. They provide sufficient mechanical properties particularly stiffness and strength, at acceptably low cost.

2.8 Applications of Natural Filler Composites

Natural fiber composites can be very cost effective materials for the following applications:

- **Building and construction industry**: Panels for partition and false ceilings, partition boards, walls, floor, window and door frames, roof tiles, mobile or pre-fabricated

buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc.

- **Storage devices**: post-boxes, grain storage silos, bio-gas containers, etc.
- **Furniture**: chairs, tables, showers, bath units, etc.
- **Electric devices**: electrical appliances, conductors, etc.
- **Everyday applications**: lampshades, suitcases, helmets, etc.
- **Transportation**: automobile and railway coach interiors, boats, etc.
- Toys

2.9 Advantages of Natural Filler composites

The main advantages of natural filler composites include (Joshi *et al.*, 2004):

- Low specific weight, resulting in a higher specific strength and stiffness than glass fibres.
- They are renewable resources and production requires little energy and CO_2 is used while Oxygen, O_2 is given back to the environment.
- Produced with low investment and cost which makes the material an interesting product for low wage countries.
- Reduced wear of tooling, healthier working conditions, with no skin irritation.
- Good thermal and acoustic insulating properties.

2.10 Review of Past Works

There are researches carried out on synthesizing and characterization of polyester resin from natural fibers, which are tested and put into various engineering applications. Some past researchers are enumerated below:

Reddy (2013) investigated the mechanical performance of high density polyethylene (HDPE) composites reinforced with green coconut fibers, produced by hand injection moulding technique. The work shows that successful fabrication of a green coconut fiber reinforced HDPE composites with different fiber lengths and fiber volume fractions are possible by simple hand injection technique. Mechanical properties viz., Tensile strength (TS) of the green coconut fiber reinforced HDPE composite material were found to be greatly influenced by fiber length as well as fiber volume fraction. Tensile strength of the composite material was found to decrease with increase in the fiber length (fl), but increased with increase in fiber volume fraction (vf) up to 40%, and then decreased slightly beyond this volume.

George *et al,* (2001) attempted to solve the problem of fiber–matrix adhesion when manufacturing biocomposites by applying an alkaline solution to the fibers. Natural fibers are mainly composed of cellulose, whose elementary unit, anhydro d-glucose, contains three hydroxyl (–OH) groups. These hydroxyl groups form intramolecular and intermolecular bonds, causing all vegetable fibers to be hydrophilic. The alkaline solution regenerated the lost cellulose and dissolved unwanted microscopic pits or cracks on the fibers resulting in better fiber matrix adhesion. Another method of improving fiber matrix adhesion discussed in this work was through the use of coupling agents. The coupling agents had two functions: to react with –OH groups of the cellulose and to react with the functional groups of the matrix with the goal of facilitating stress transfer between the fibers and the matrix.

Mohanty *et al,* (2000) compiled an overview on the different biofibers, biopolymers, and biocomposites comparing advantages and disadvantages of these materials. Different fiber–polymer composites were fabricated and tested in this work. The specific properties of natural fibers such as hemp, kenaf, jute, flax, and sisal were compared with traditional composite reinforcements showing that the density of these natural fibers were much lower than the traditional materials thereby leading to strength/weight ratios comparable with those of such widely used materials as E-glass and Aramid. Testing of the biocomposites demonstrated an optimal fiber content of approximately 30%.

Joshi *et al*. (2004) confirmed that natural fiber composites are environmentally superior to the glass fiber reinforced composites. They also found that these composites improved fuel efficiency in automobile applications.

Cheung *et al.* (2009) suggested the use of natural fiber mixed with biodegradable and bioresorbable polymers in the biomedical and bioengineered field. The coir fiber was investigated as reinforcement in polyester resin to design liquid storage tanks by Yousif and Ku (2011). The main application would be in designing storage tanks for different types of liquids. The samples were soaked in different solutions like water, salt water, gasoline, diesel, brake oil, engine oil and power steering oil for 6 months and it was confirmed that the liquid tanks can be manufactured for storing water, salt water, and diesel and engine oil

Wambua *et al,* (2003) evaluated several different natural fiber–polypropylene composites to determine if they had the ability to replace glass fiber–reinforced materials. Polypropylene with a very high melt flow index was used to aid in fiber matrix adhesion and to ensure proper wetting of the fibers. Samples were made with 40% fiber content of kenaf, coir, sisal, hemp, and jute. After the samples were fabricated, tensile and impact tests were run to compare the properties of these composites to those made with glass fiber. The tensile strengths all compared well with glass, except for the coir, but the only sample with the same

flexural strength was hemp. It was shown with kenaf fibers that increasing fiber weight fraction increased ultimate strength, tensile modulus, and impact strength. However, the composites tested showed low impact strengths compared to glass mat composites. This study demonstrated that natural fiber composites have a potential to replace glass in many applications that do not require very high load bearing capabilities.

A lot of research has been carried out in the area of composite development. A host of new applications is being investigated by the automotive industry. Material developers are constantly faced with the challenges of creating materials with good mechanical properties and of low density, thus the need for continuous research in composite material development. The transportation industries are utilizing increasing amounts of glass fiber- reinforced plastics in an effort to decrease vehicle weight and boost fuel efficiencies

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter describes the details of processing the composites and the experimental procedure followed for their characterization and property evaluation.

3.2 Materials

The following materials were used in this work:

a. Recycled high density polyethylene (RHDPE) as the matrix.
b. The reinforcement fillers include:
    i. Palm kernel fibres (PKF).
    ii. Locust bean husk fibres (LBHF).
    iii. Goat fur fibres (GFF).
    iv. Sheep wool fibres (SWF).

3.3 Equipment

The equipment used in this research includes:

i. Electrical hydraulic press,
ii. 2-roll mill compounding machine,
iii. Charpy impact testing machine,
iv. Hounsfield tensometer,
v. Laboratory balance,
vi. Metal mould,

vii. Scanning electron microscope (SEM),

viii. Thermogravimetric analyser (TGA/DTA),

ix. X-Ray fluorescent analyser (XRF).

x. Durometer.

xi. Pin-on-disc wear testing machine.

3.4 Methods

3.4.1 Preparation of Recycled High Density Polyethylene

Waste cans of yoghurt milk were collected from grocery stores/shops of Ahmadu Bello University main campus, Samaru, Zaria. They were washed, dried and reduced to approximately 5mm by 5mm pieces using manual cutting tools. This constituted the composite matrix.

3.4.2 Preparation of Palm Kernel Fibre

The palm kernel fibres were obtained from palm kernel seeds which were bought from Gboko central market Benue State, Nigeria. These seeds were then cooked properly to enhance the removal of the oil. They were further pounded, thereby separating the fibres from the shells. The fibres were then washed with warm water (about 70^{o}C), and then dried under the sun before being cut to 5 mm, 10 mm and 15 mm lengths (see Plate 3.1a).

3.4.3 Preparation of the Locust Bean Husk Fibre

The locust bean husk was bought from Baban Dodo market, Zaria city of Kaduna state. It was bought dry and pounded using mortar and pestle to separate the pulp from the fibres. The

pulp was disposed-of in powder form. The fibres collected were then peeled into smaller strands, and then cut to various lengths using manual cutting tools (see Plate 3.1b)



(a) Palm kernel



(b) Locust bean

Plate 3.1: Photograph of a ground (a) Palm Kernel and (b) Locust Bean Husk Fibres

3.4.4 Preparation of Sheep Wool/Goat Fur

The sheep/goat fur fibres were obtained from the Abattoir located along Kano road in Sabon Gari, Zaria LGA of Kaduna state. It involved the removal of the hair/wool from the skin. The wool/hair was then washed thoroughly with warm water and detergent. The fibres were finally sun-dried and reduced to lengths of 5, 10 and 15mm (see Plate 3.2).



(a) Goat fur



(b) Sheep wool

Plate 3.2: Photograph of (a) Goat Fur and (b) Sheep Wool Fibres

3.4.5 Sample Preparation

Metal molds were used in the production of the composite samples. The molds were designed to have a cavity that accommodated the composite sample slabs. The dimensions and shapes of cavities were made according to the size and shape of the samples as per ASTM Standard D 638-90 for tensile testing and ASTM Standard D 790-97 for flexural testing (ASTM, 2000). The particles and the binder were mixed by compounding into a homogenous mixture using a 2-roll mill compounding machine (see Plate 3.3). The compounded mixture was compressed at 180 ^{o}C and a pressure of 10 MPa in accordance with the work of Chike, (2014) in an electrically heated hydraulic press to form the composite slabs.

3.5 Determination of Density

The basic method of determining the density of board composite samples by measuring the mass and volume of the sample was used. A clean sample was weighed accurately in air using a laboratory balance (see Plate 3.5) and then suspended in water. The weight of the sample when suspended in water was determined, the volume of the sample was determined from the volume of water displaced by it (Archimedean principle).

The density of the sample was estimated from equation below (BSI, 1993b):

$$Density = \frac{Mass}{Volume} \tag{3.1}$$

3.6 Thickness swelling (TS) and Water absorption (WA) test

Specimen with dimension 50mm x 50mm were prepared for evaluation of the thickness swelling. The thickness at the middle of each test specimen was measured with a micrometer and then soaked in water for 24 hours before further measurement of the thickness. The thickness swelling rate (TS) was determined from the following formula (BSI, 2003).

$$TS_{24} = \frac{t_{24} - t_0}{t_0} x100\% \quad (3.2)$$

where TS is the thickness swelling rate (%), t_0 and t_{24} are the thickness at the middle of the test specimen

The values of the WA as percentages were calculated using the expression (BSI, 2003).

$$WA_{24} = \frac{w_{24} - w_0}{w_0} x100\% \text{ ,} \quad (3.3)$$

where WA_{24} is the water absorption (%) at time t = 24 hrs and W_0 is the initial weight.

3.7 Tensile Test

Tensile strength indicates the ability of a composite material to withstand forces that pull it apart as well as the capability of the material to stretch prior to failure. Tensile tests were carried out using a Hounsfield tensometer (see plate C1), with maximum load of 250 kN. The standard specimen was mounted at its ends into the holding grips of the testing machine. The machine is designed to elongate the specimen at a constant rate, and to measure the instantaneous applied load and the resulting elongations simultaneously using an extensometer. The ASTM standard test method for tensile properties of polymer composites with the designation D 3039-76 was used (ASTM, 2000). The Tensile strength is calculated from the formula below:

$$\sigma = \frac{P}{bh} \text{ ,} \quad (3.4)$$

where σ = the Tensile Strength, P is the axial load, b is the guage width and h is the guage thickness

3.8 Static Bending Test

Bending specimen 50 mm × 275 mm long were cut from each moulded composite slab. A concentrated bending load was applied at the centre with a length 15 times the thickness of

the specimen. The bending modulus of rupture (MOR) was calculated according to the following formula (BSI, 2003):

$$MOR = \frac{3P_bL}{2bh^2}, \quad (3.5)$$

where P_b is the maximum load (N), b is the width of the specimen (mm), h is the thickness of the specimen (mm), and L is the span (mm). The bending test was conducted using the universal materials testing machine.

3.9 Impact Energy Test

The reliability of a material can be determined by measuring its resistance to fracture, either ductile or brittle and fracture toughness (Ives, 2001). The impact test on the developed composite samples was carried out using a fully instrumented Charpy impact testing machine. A Charpy impact test was conducted on notched samples using standard square impact test samples measuring 80 x 10 x 10 mm with notch depth of 2 mm and a notch tip radius of 0. 02 mm at angle of 45^o (ASTM, 2000), and the results was recorded in Joules (J).

3.10 Hardness Test

The hardness test of composites is based on the relative resistance of its surface to indentation by an indenter of specified dimensions under a specified load. Samples of 30mm x 30mm x 4mm were tested for shore hardness values with a durometer (see Plate 3.9) at the Materials laboratory, Nigerian Institute of Leather and Science Technology (NILEST), Zaria-Nigeria.

3.11 Wear Test

The wear rate of the samples was measured using the pin on disc machine by the pin sliding over a cast iron surface. Two sets of tests were conducted by varying the load and speed as follows: (a) A load of 120kg, speed of 2.5 m/s and sliding distance of 1000 m, and (b) a load

of 40 kg, speed of 0.5 m/s and sliding distance of 1000 m. The test was carried out at the University of Witwatersrand**,** Johannesburg, South Africa. The initial weight of each sample was measured using a single pan electronic weighing machine. During the test, the pin was pressed against its counterpart rotating against a cast iron disc (hardness 65 HRC) of counter surface roughness of 0.3 μm. A friction detecting arm with a strain gauge attached and was loaded vertically against a horizontal rotating hardened cast iron disc. After running through a fixed sliding distance, the samples were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The differences in the weights measured before and after tests give the wear of the samples. The formula used to convert the weight loss into wear rate is:

$$\text{Wear rate} = \frac{\Delta W}{S} \tag{3.6}$$

where ΔW is the weight difference of the sample before and after the test in (g), S is total sliding distance in m.

The coefficient of friction was then calculated by:

$$\mu = \frac{F_f}{N}, \tag{3.7}$$

where μ is the coefficient of friction, F_f is the frictional force read directly from the friction detecting arm strain gauge and N is the normal reaction.

3.12 Thermal Properties

Thermal decomposition was observed in terms of global mass loss by using a thermal analysis instrument TGA Q50 thermogravimetric analyzer. This apparatus detects the mass loss with a resolution of 0.1 as a function of temperature. The samples were evenly and loosely distributed in an open sample pan of 6.4mm diameter and 3.2 mm deep with an initial

sample amount of 10mg. due to different bulk density, the depth of the sample layer filled in the pan was about 1-2 mm. The temperature change was controlled from room temperature (25 ± 3^0C) to 900^0C at a heating rate of 20 ^{0}C/min. The sampling segment was set as 0.5 second per point.

High purity nitrogen gas was continuously passed into the furnace at a flow rate of 60 ml/min at room temperature and atmospheric pressure. Before starting each run, the nitrogen gas was used to purge the furnace for 30 min to establish an inert environment in order to prevent any unwanted oxidative decomposition. The TG and DTA curves that were obtained from TGA runs were carefully smoothed at a smoothing region width of 0.2 ^{0}C by the least squares smoothing method, and analyzed using a universal analysis 2000 software from TA instruments.

3.13 X-Ray Fluorescent Spectrometry (XRF)

The elemental composition of the fibres (PKF, LBHF, GFF, and SWF) was determined using X-ray fluorescence (XRF) analysis in the Department of Chemistry, Ahmadu Bello University Zaria.

3.14 Micro-structural Analysis

The scanning electron microscope (SEM) JEOL JSM-6480LV was used to identify the surface morphology of the composite samples. The samples were first washed, cleaned thoroughly, air-dried and coated with 100Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Samples were sputter-coated with 5 % gold to increase surface conductivity.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

Figures 4.1 to 4.54, Tables B1 to B74 and Plates 4.1 to 4.13 showed the results of the various tests carried out on the developed composite samples.

4.1.1 Density

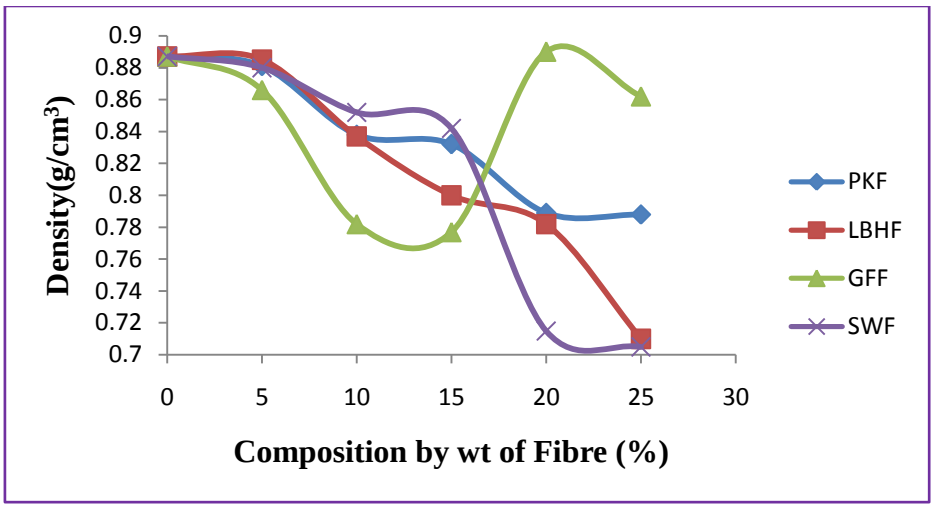


Fig. 4.1: Variation of density of 5mm fibre length composites versus % wt composition of the fibre.

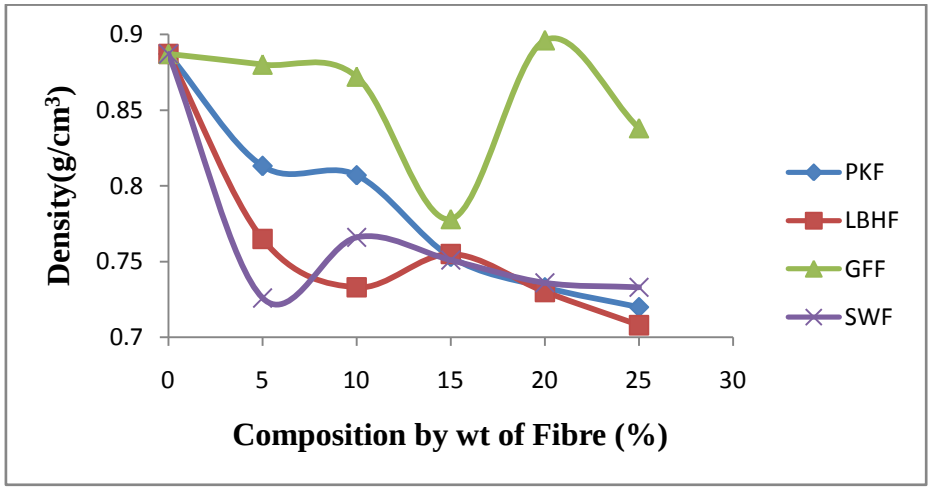


Fig. 4.2: Variation of density of 10mm fibre length composites versus % wt composition of the fibre.

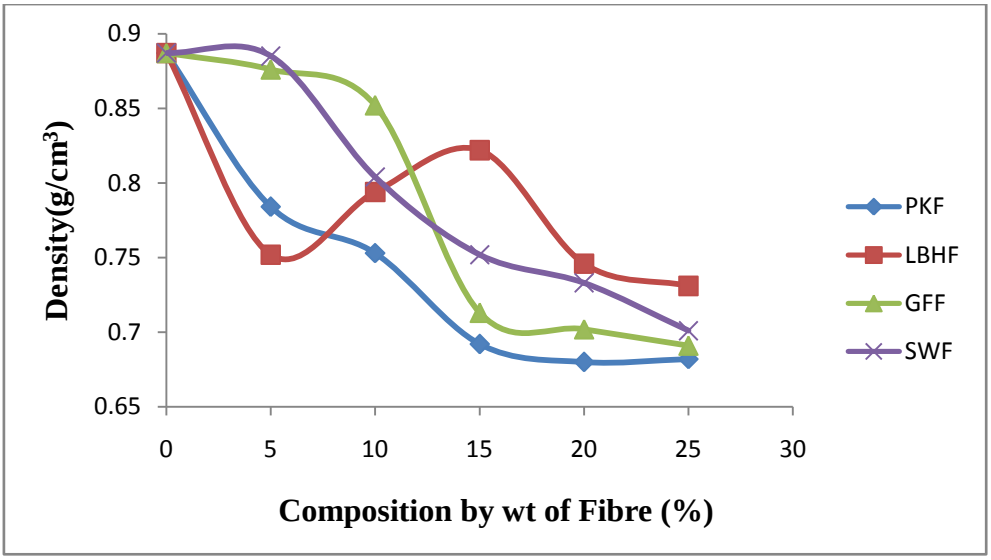


Fig. 4.3: Variation of density of 15mm fibre length composites versus % wt composition of the fibre.

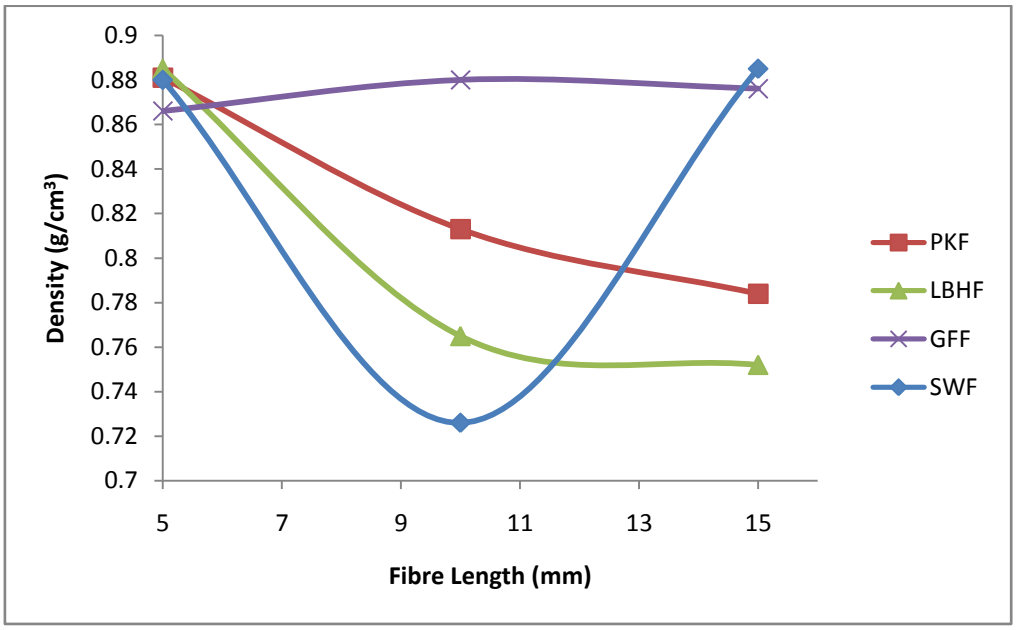


Fig. 4.4: Variation of density of composites versus fibre length

4.1.2 Water Absorption

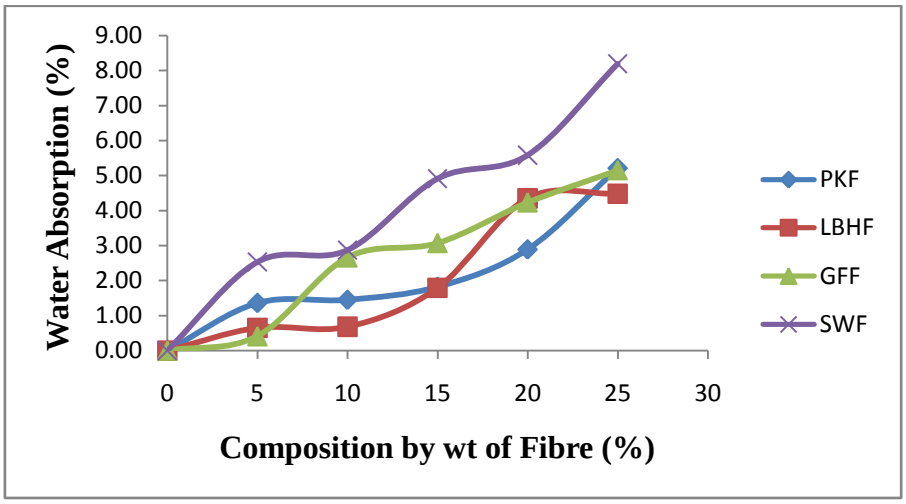


Fig. 4.5: Variation of water absorption of 5mm fibre length composites versus % wt composition of the fibre.

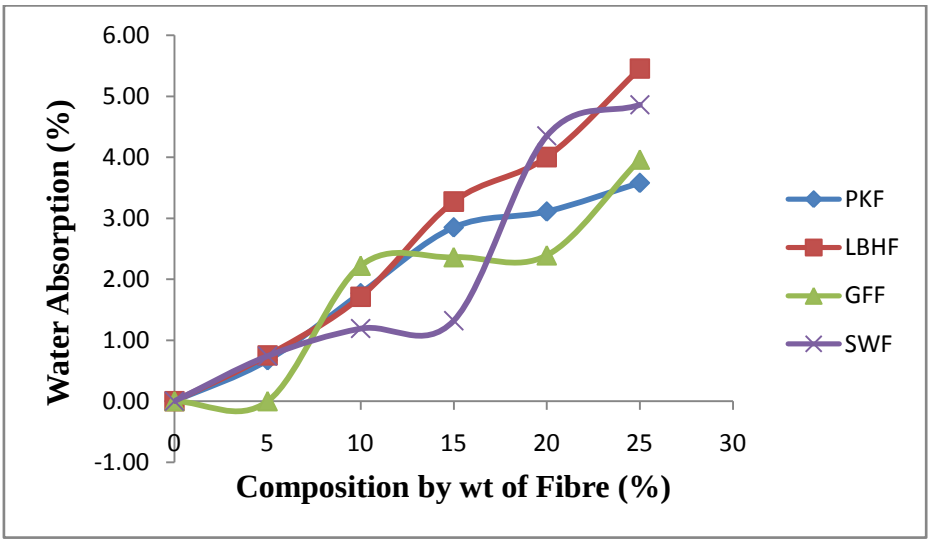


Fig. 4.6: Variation of water absorption of 10mm fibre length composites versus % wt composition of the fibre.

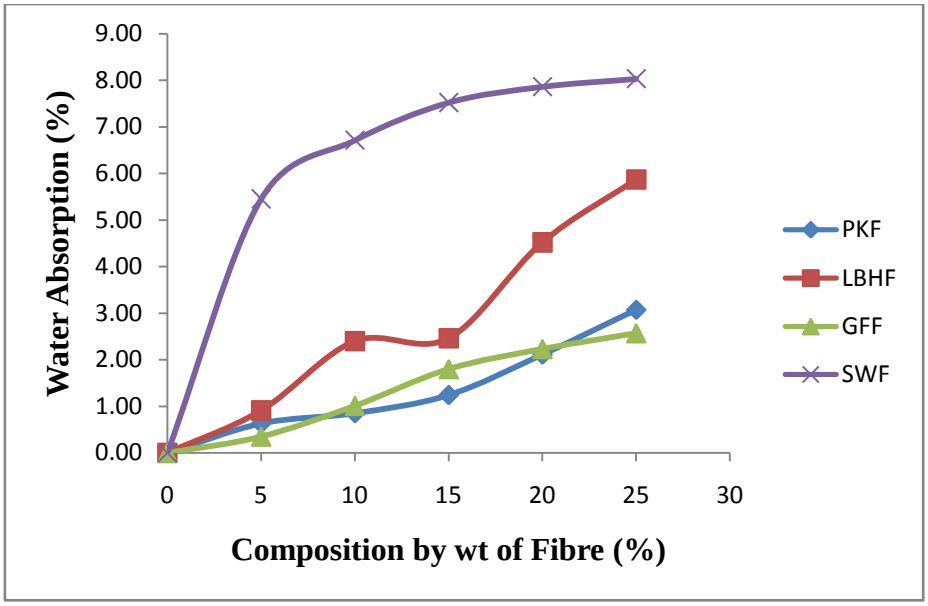


Fig. 4.7: Variation of water absorption of 15mm fibre length composites versus % wt composition of the fibre.

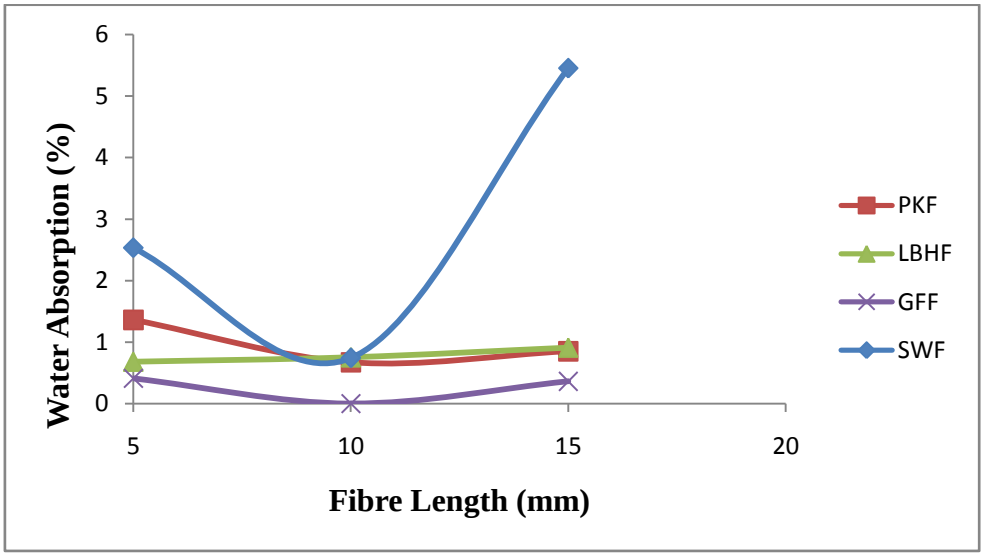


Fig. 4.8: Variation of water absorption of composites versus fibre length

4.1.3 Thickness Swelling

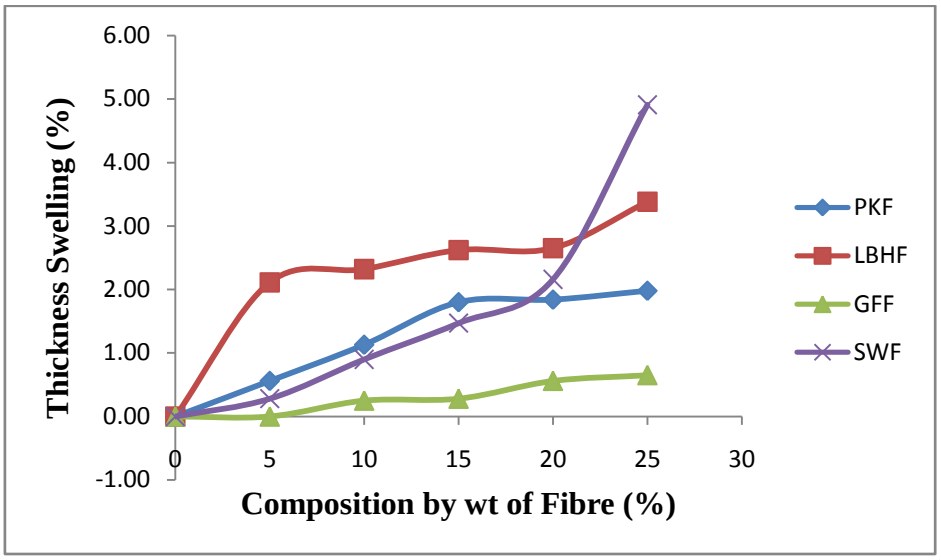


Fig. 4.9: Variation of thickness swelling of 5mm fibre length composites versus % wt composition of the fibre.

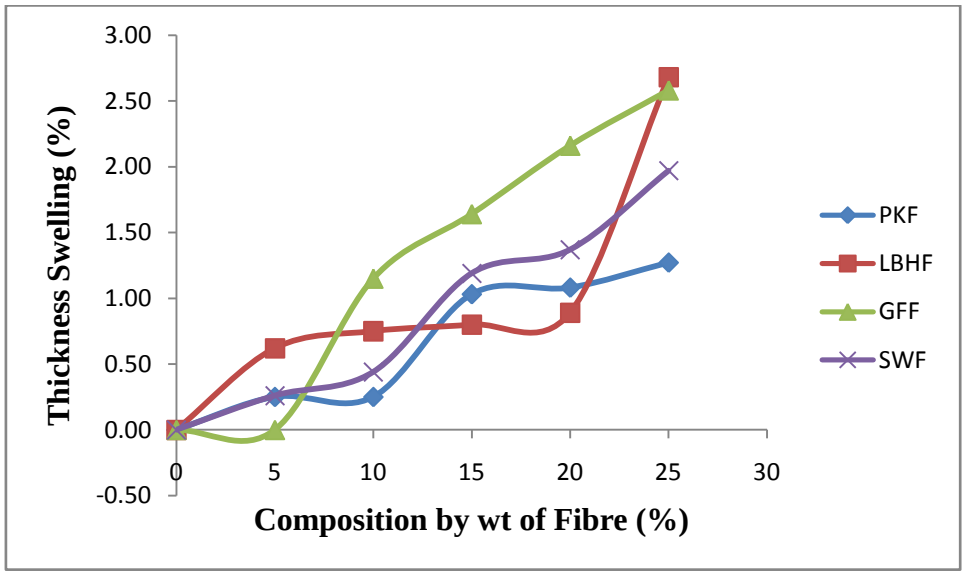


Fig. 4.10: Variation of thickness swelling of 10mm fibre length composites versus % wt composition of the fibre.

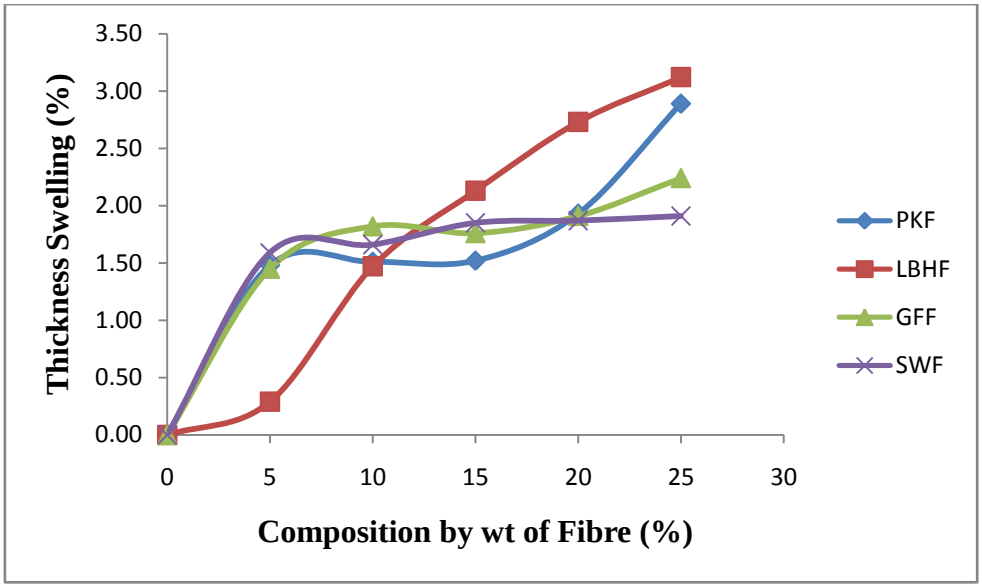


Fig. 4.11: Variation of thickness swelling of 15mm fibre length composites versus % wt composition of the fibre.

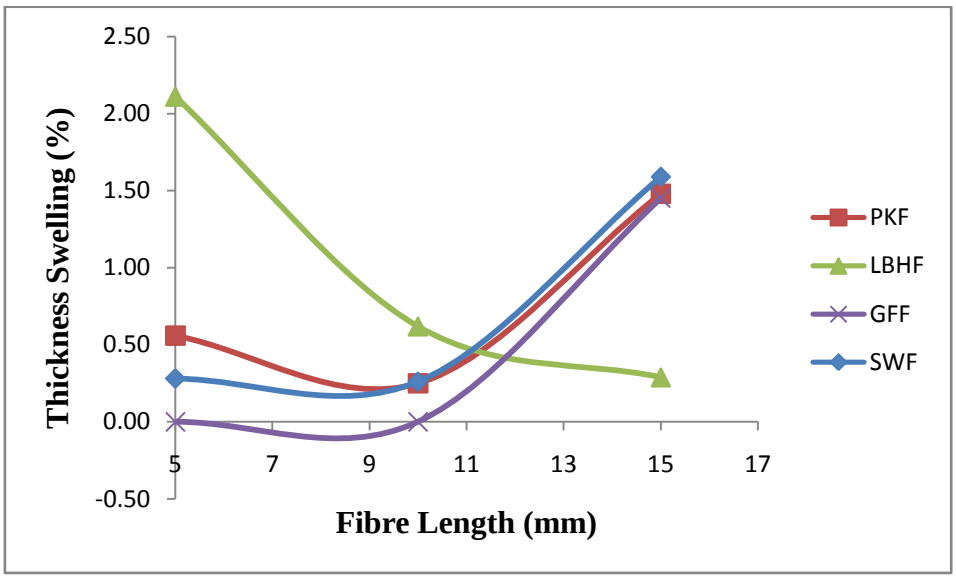


Fig. 4.12: Variation of thickness swelling of composites versus fibre length

4.1.4 Tensile Strength

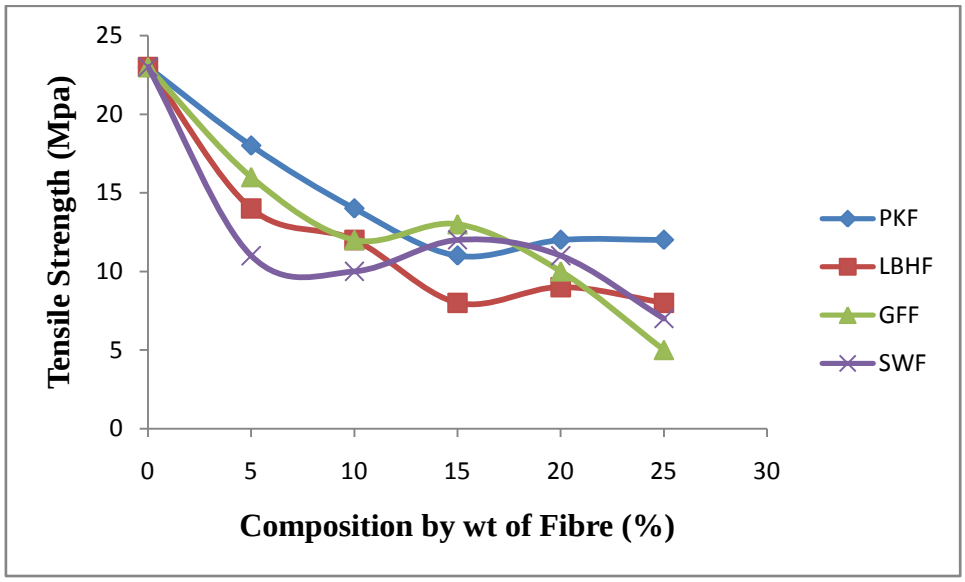


Fig. 4.13: Variation of tensile strength of 5mm fibre length composites versus % wt composition of the fibre.

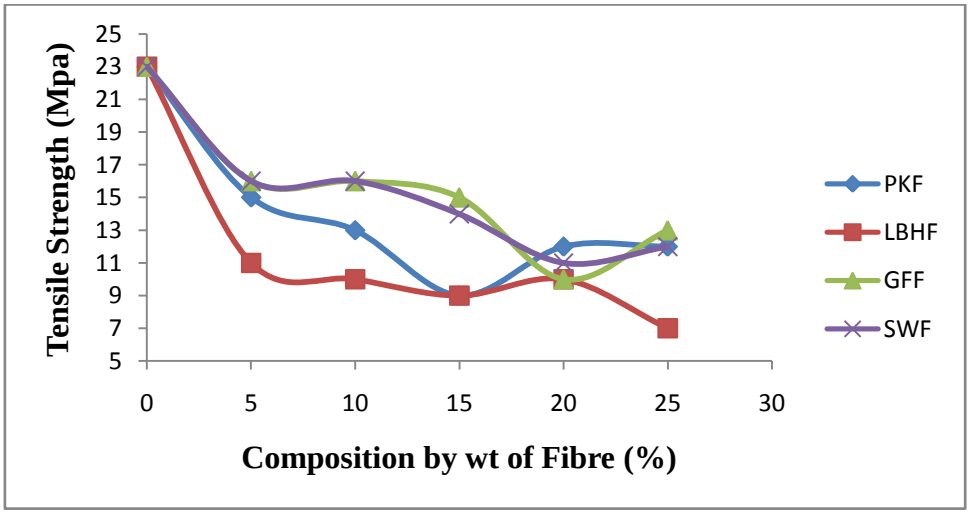


Fig. 4.14: Variation of tensile strength of 10mm fibre length composites versus % wt composition of the fibre

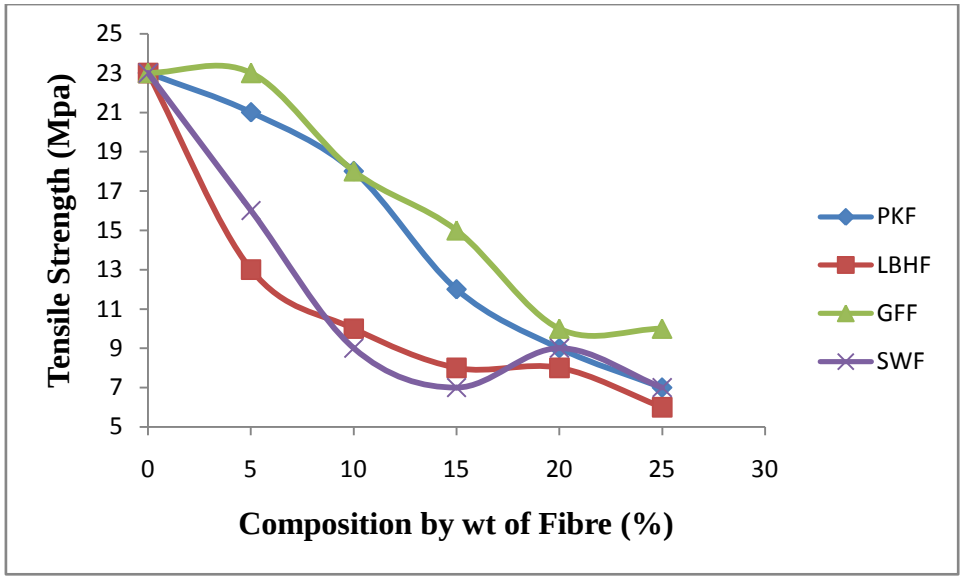


Fig. 4.15: Variation of tensile strength of 15mm fibre length composites versus % wt composition of the fibre.

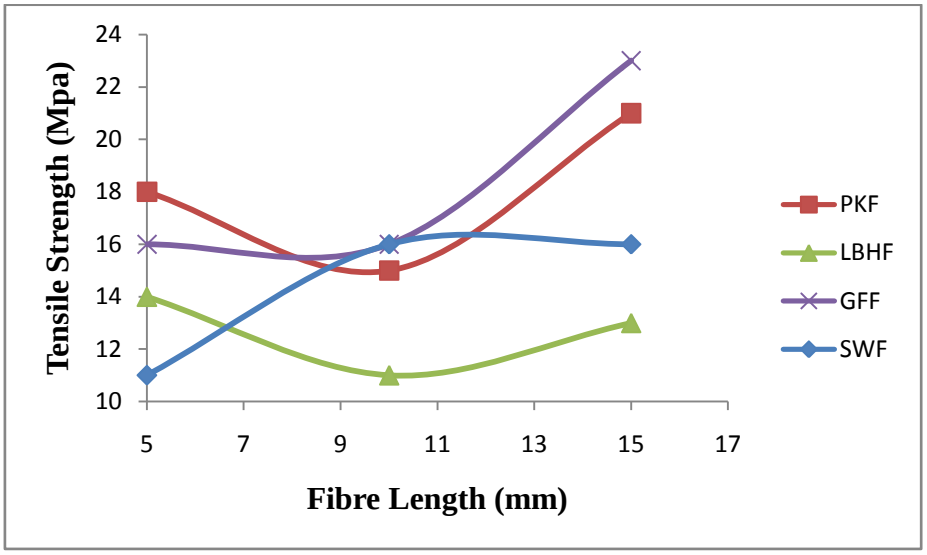


Fig. 4.16: Variation of tensile strength of composites versus fibre length

4.1.5 Flexural Strength

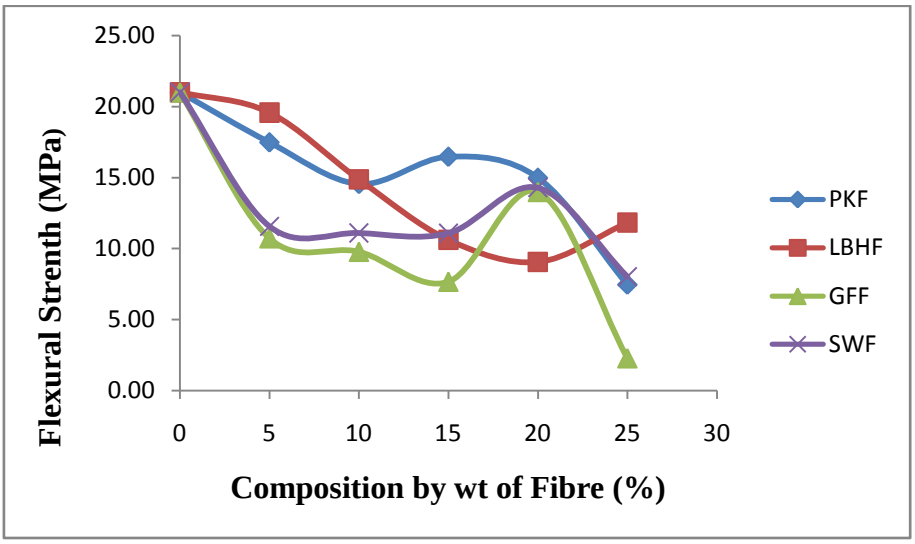


Fig. 4.17: Variation of flexural strength of 5mm fibre length composites versus % wt composition of the fibre.

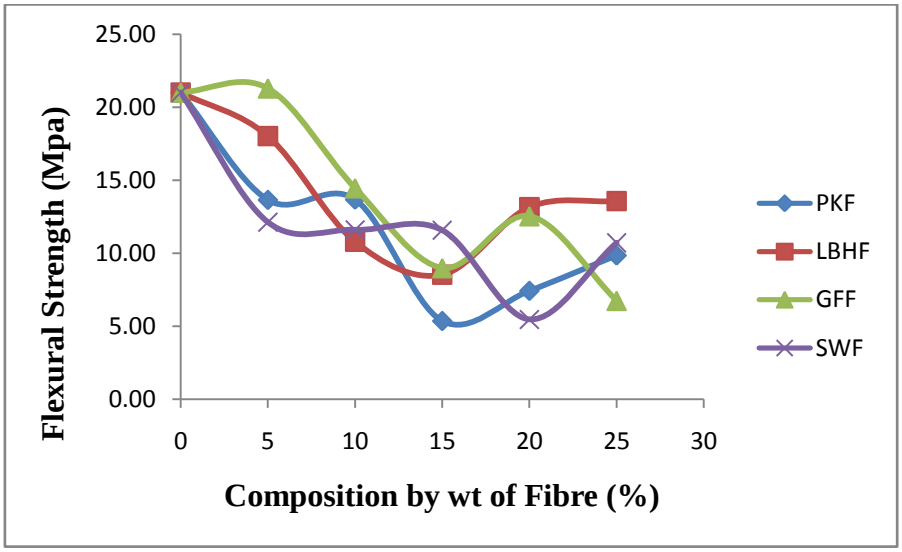


Fig. 4.18: Variation of flexural strength of 10mm fibre length composites versus % wt composition of the fibre.

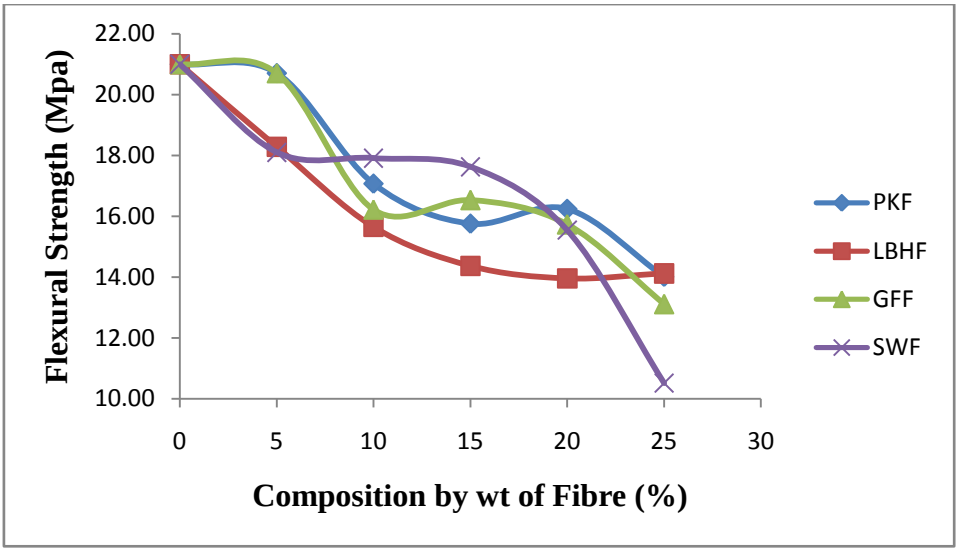


Fig. 4.19: Variation of flexural strength of 15mm fibre length composites versus % wt composition of the fibre.

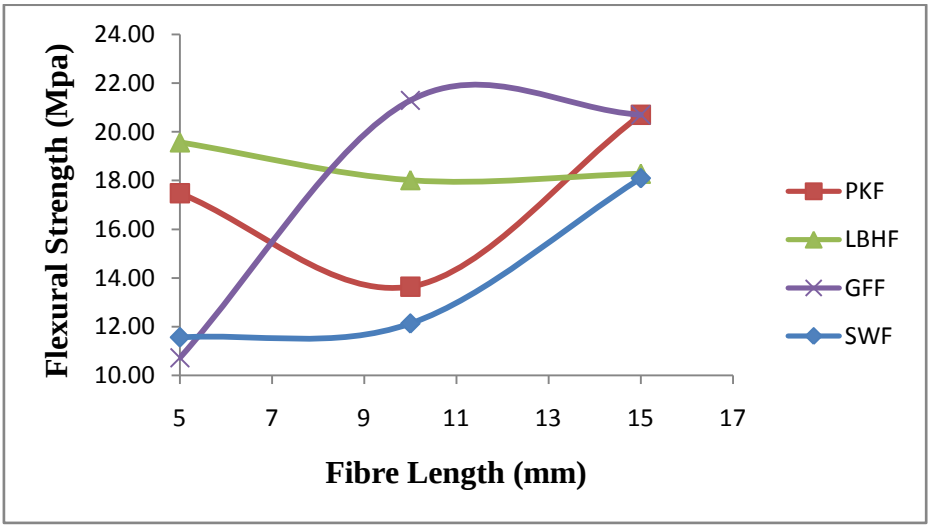


Fig. 4.20: Variation of flexural strength of composites versus fibre length

4.1.6 Impact Strength

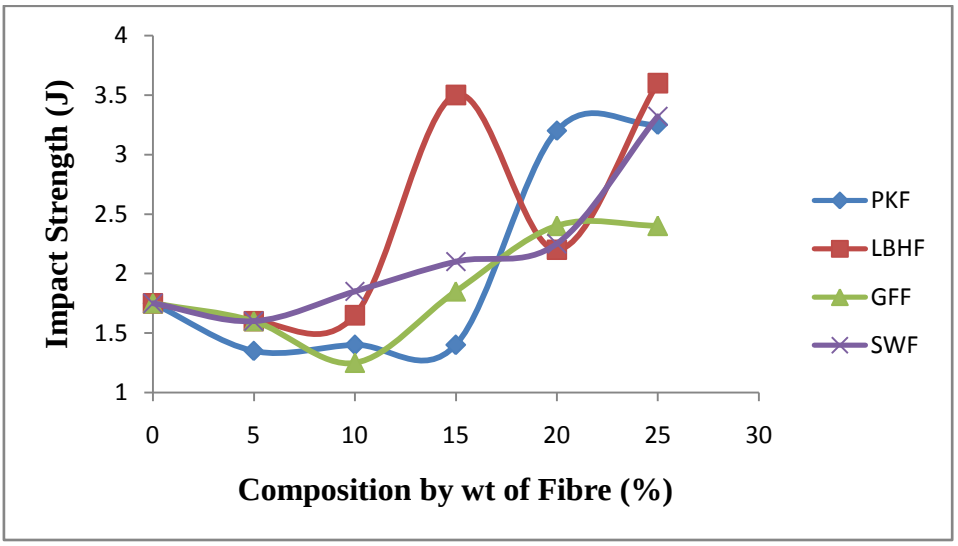


Fig. 4.21: Variation of impact strength of 5mm fibre length composites versus % wt composition of the fibre.

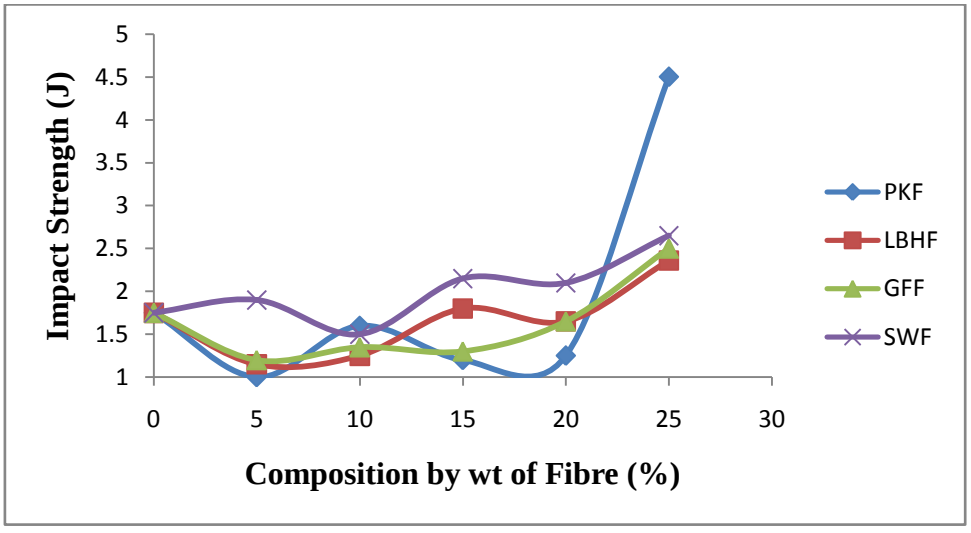


Fig. 4.22: Variation of impact strength of 10mm fibre length composites versus % wt composition of the fibre.

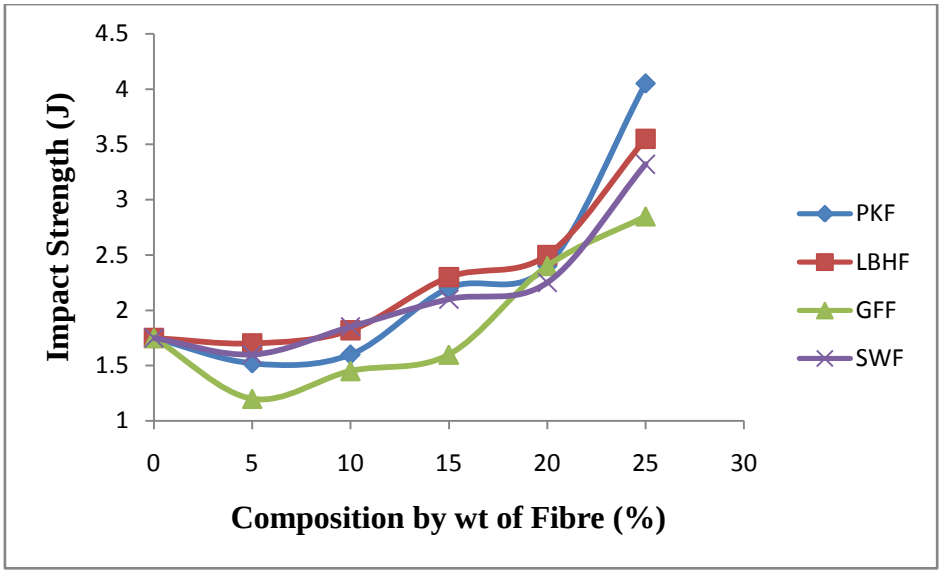


Fig. 4.23: Variation of impact strength of 15mm fibre length composites versus % wt composition of the fibre.

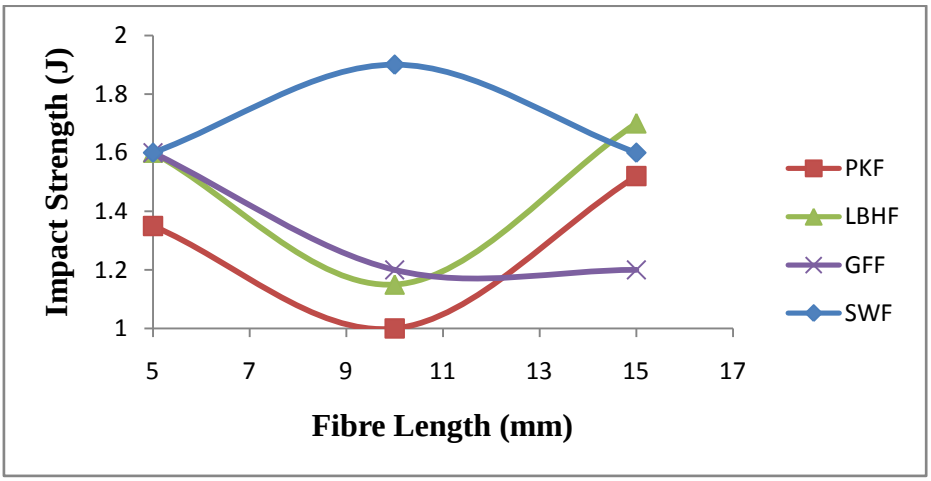


Fig. 4.24: Variation of impact strength of composites versus fibre length

4.1.7 Hardness

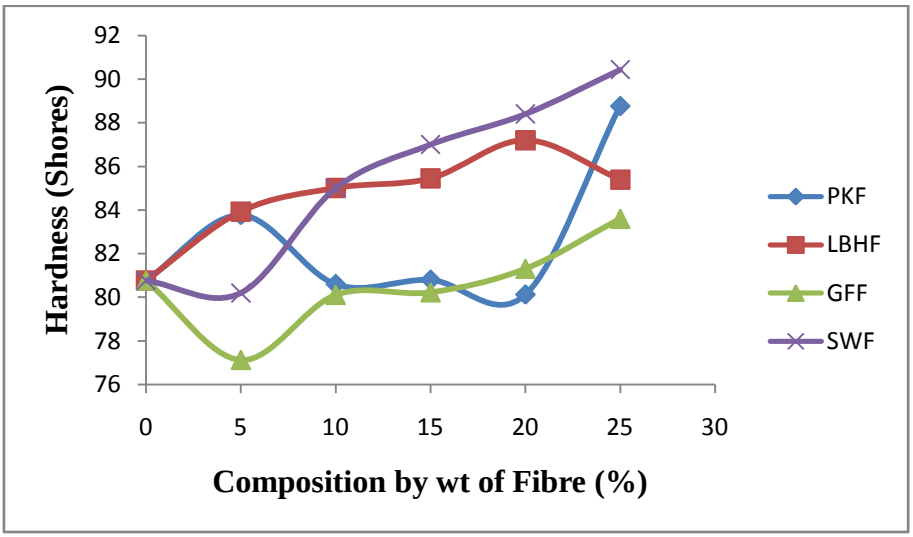


Fig. 4.25: Variation of hardness of 5mm fibre length composites versus % wt composition of the fibre.

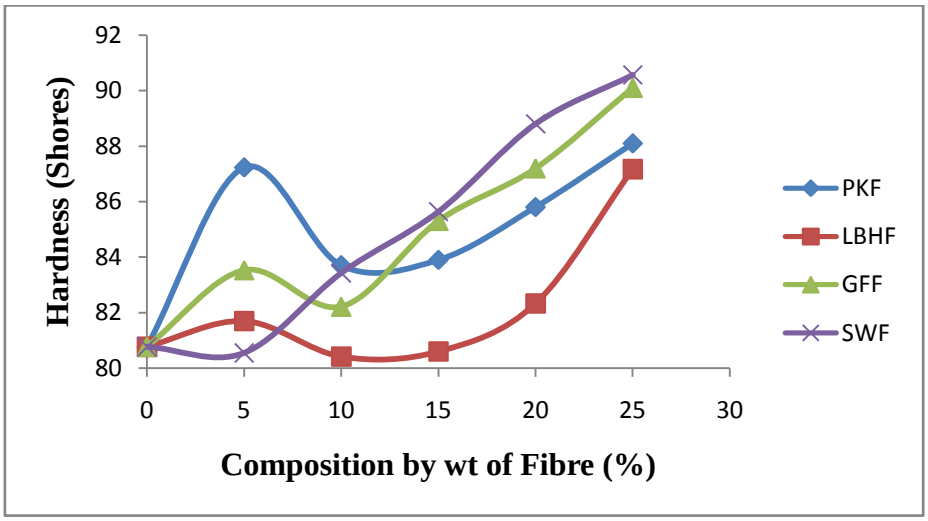


Fig. 4.26: Variation of hardness of 10mm fibre length composites versus % wt composition of the fibre.

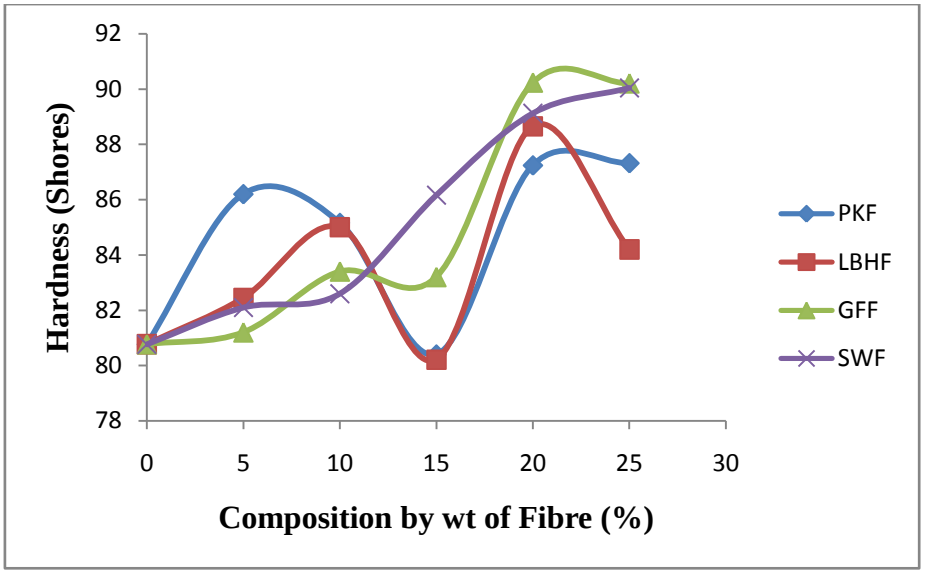


Fig. 4.27: Variation of hardness of 15mm fibre length composites versus % wt composition of the fibre.

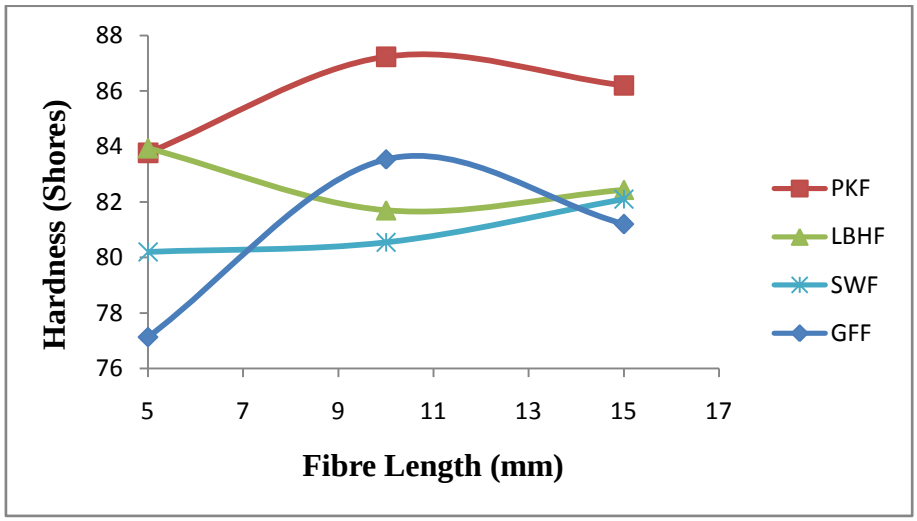


Fig. 4.28: Variation of hardness of composites versus fibre length

4.1.8 Wear Rate

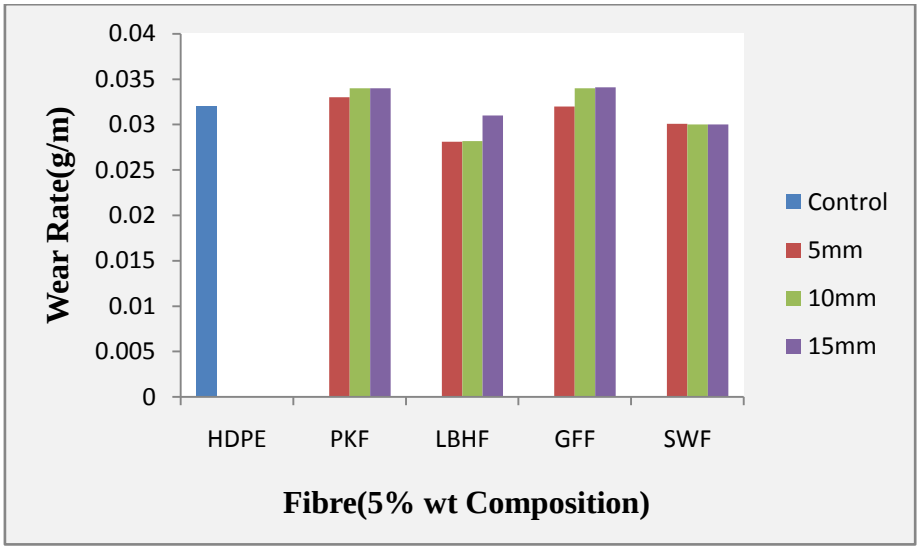


Fig. 4.29: Variation of wear rate versus %wt composition of fibre (40kg, 0.5m/s)

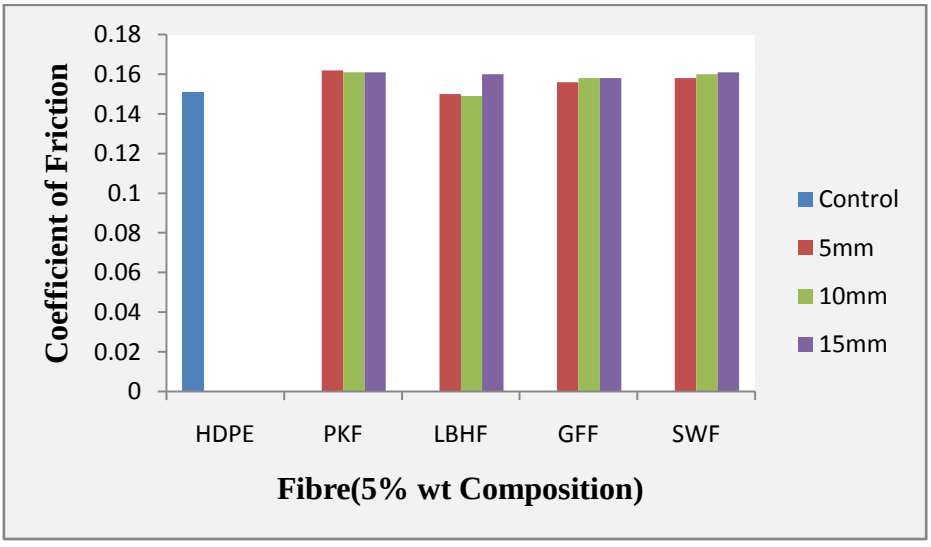


Fig. 4.30: Variation of coefficient of friction versus %wt composition of fibre (40kg, 0.5m/s)

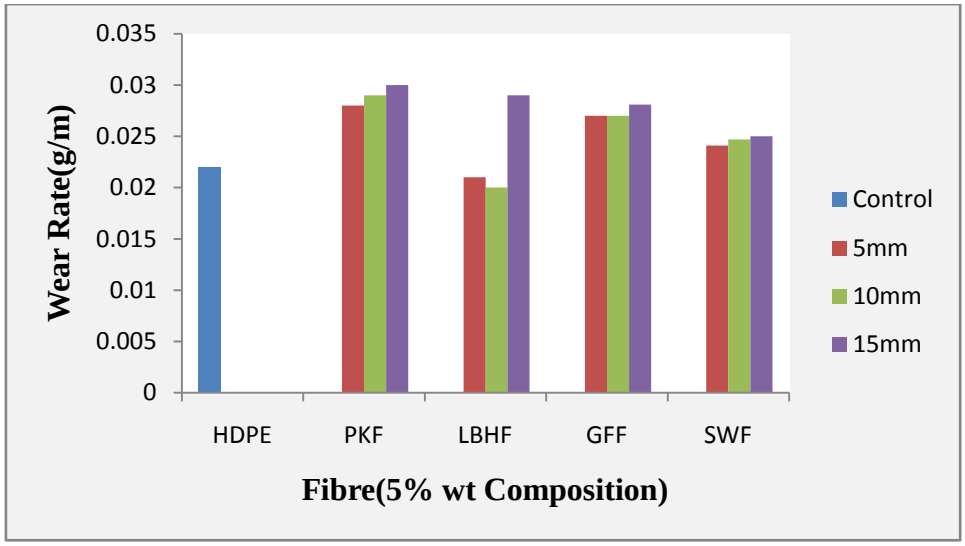


Fig. 4.31: Variation of wear rate versus %wt composition of fibre (120kg, 2.5m/s)

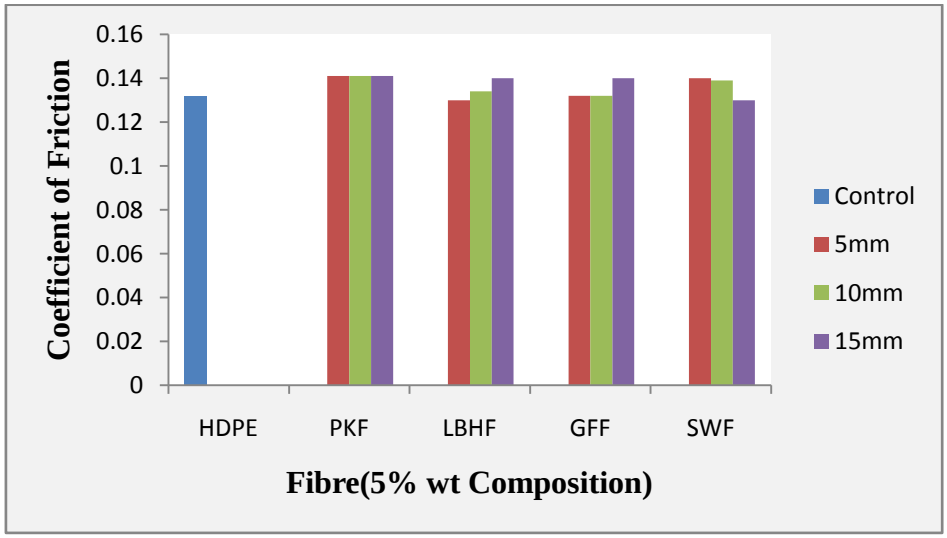


Fig. 4.32: Variation of coefficient of friction versus %wt composition of fibre (120kg, 2.5m/s)

4.1.9 Thermal Properties (DTA/TGA)

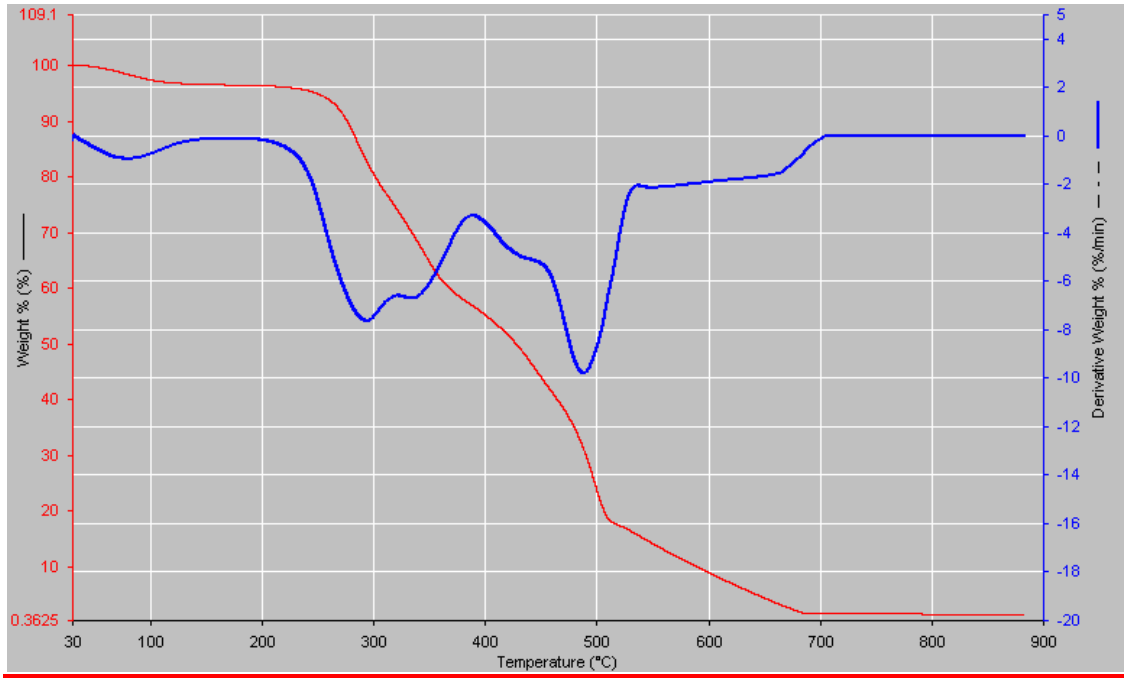


Fig. 4.33: DTA/TGA pattern of HDPE at 20°C/mins to 900°C

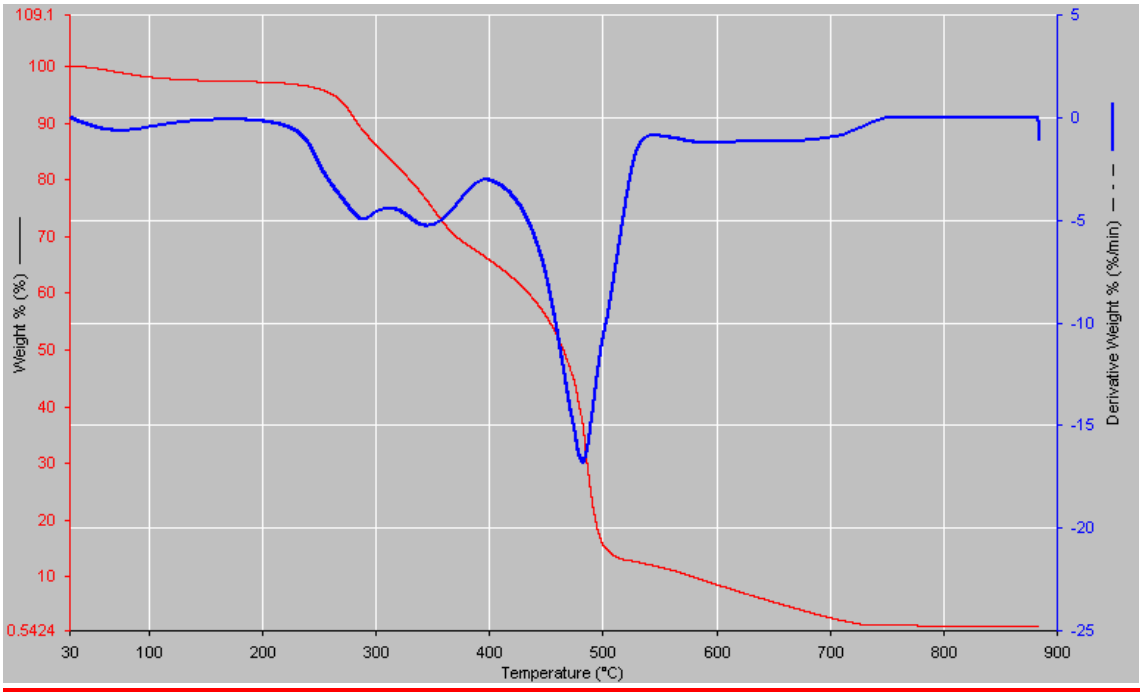


Fig. 4.34: DTA/TGA pattern of HDPE-PKF composite at 20°C/mins to 900°C

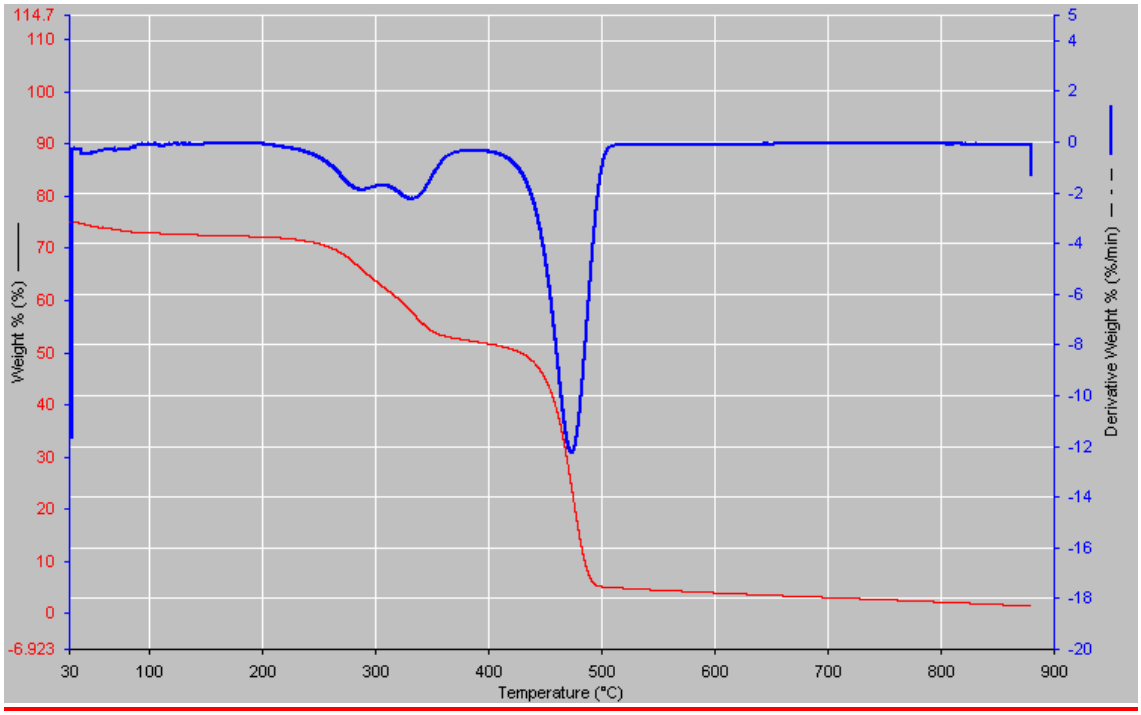


Fig. 4.35: DTA/TGA pattern of HDPE-LBHF composite at 20°C/mins to 900°C

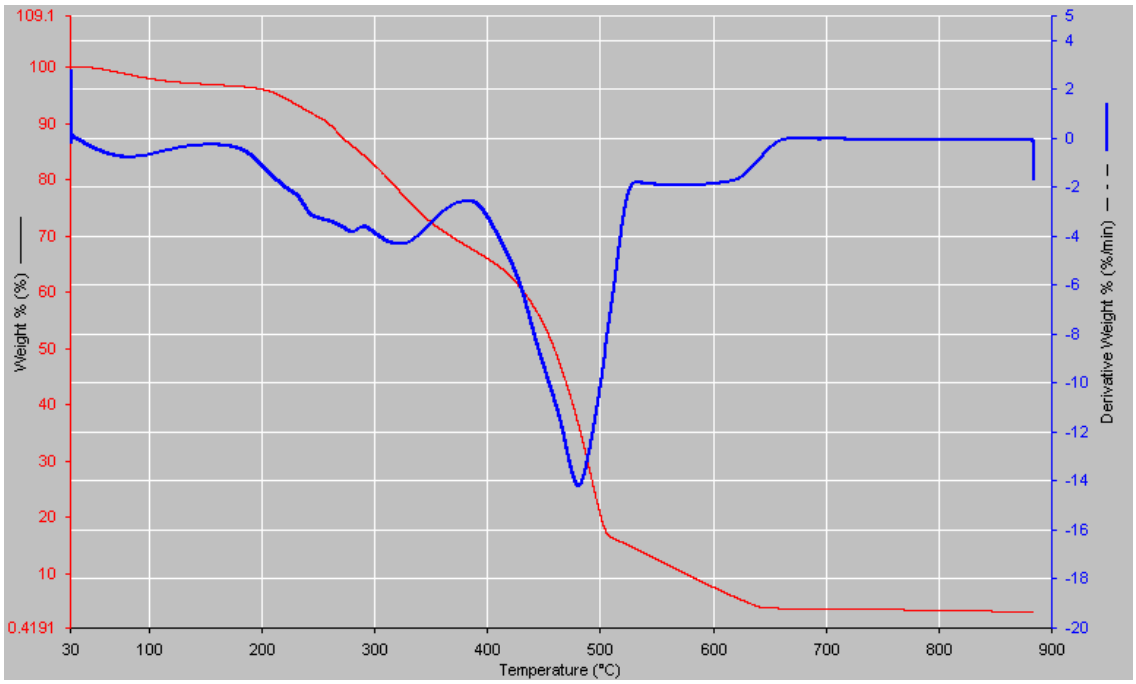


Fig. 4.36: DTA/TGA pattern of HDPE-GFF composite at 20°C/mins to 900°C

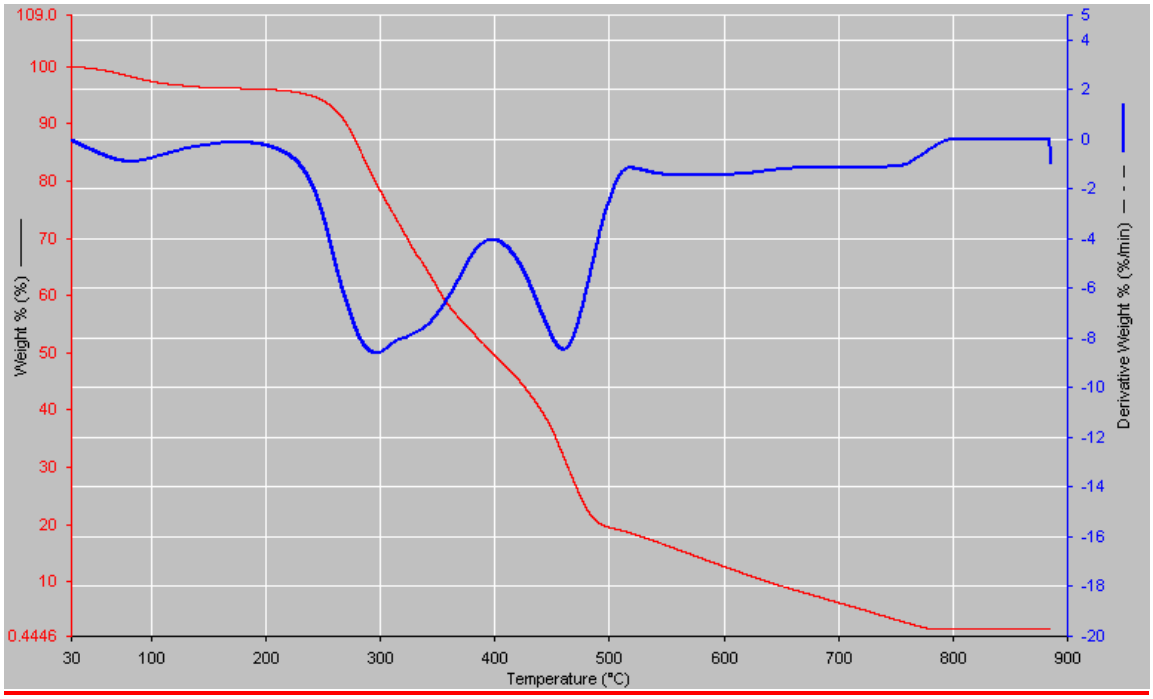


Fig. 4.37: DTA/TGA pattern of HDPE-SWF composite at 20°C/mins to 900°C

4.1.10 Scanning Electron Microstructures (SEM)

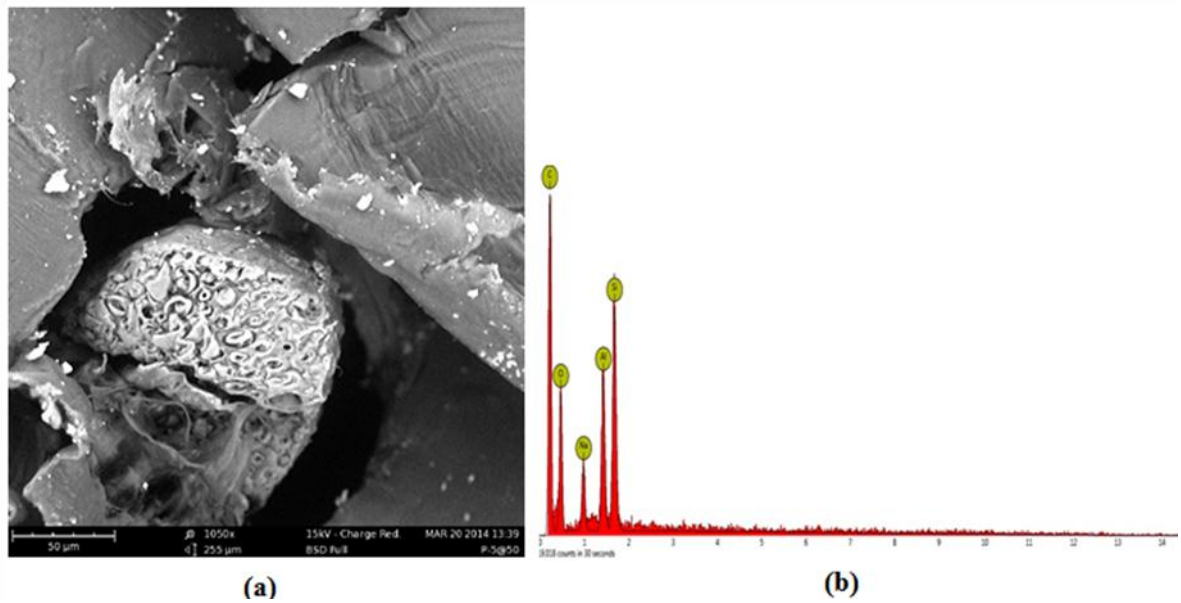
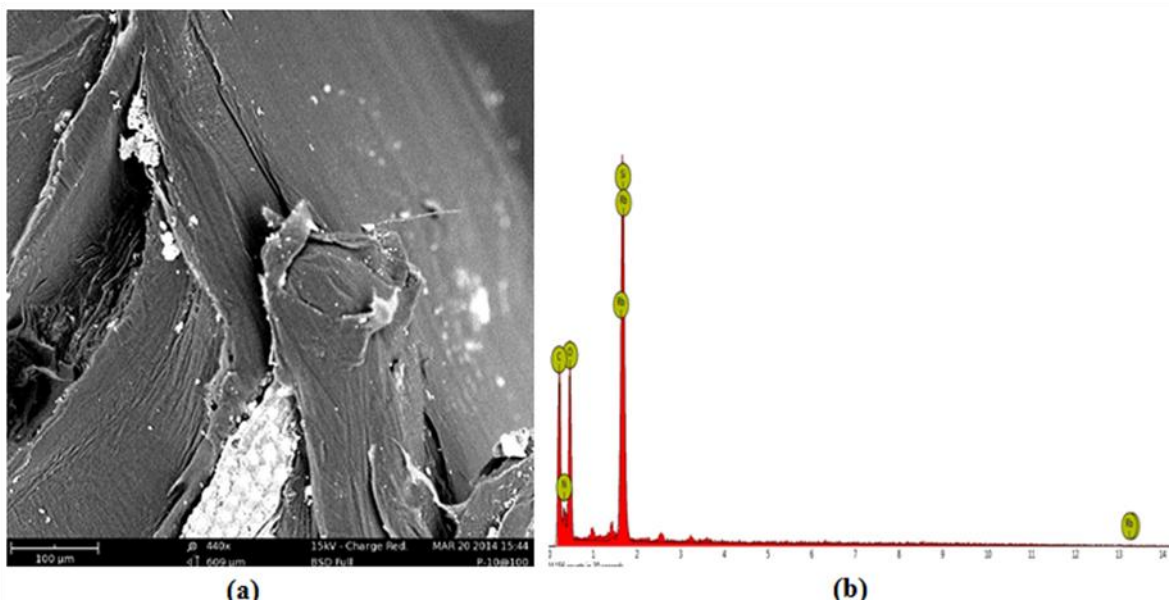
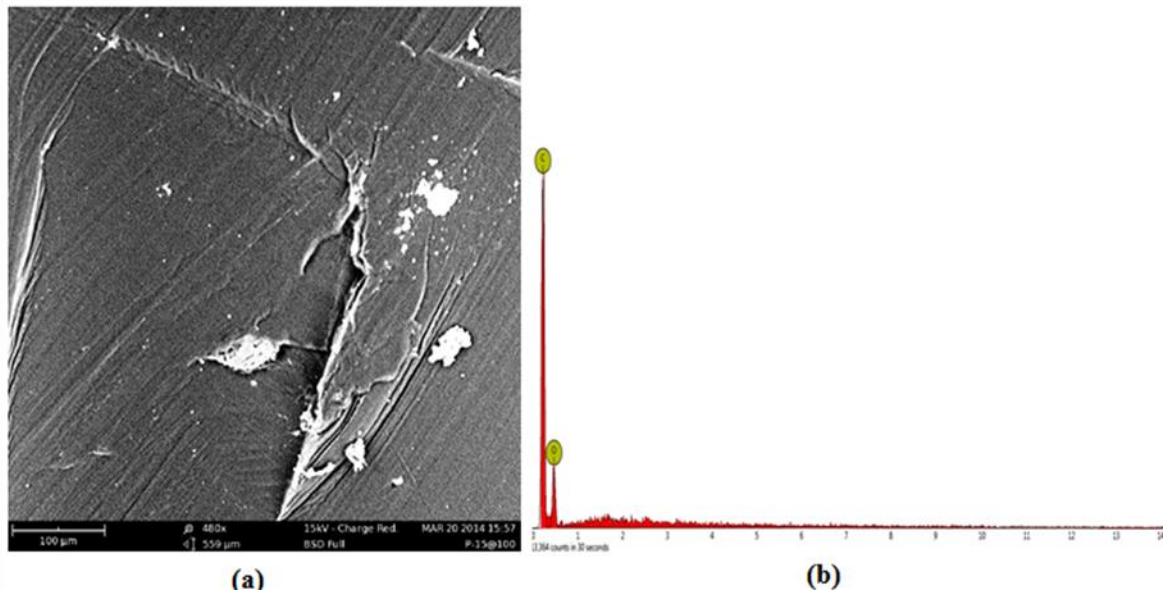


Plate 4.1: SEM microstructure of PKF-RHDPE for 5mm fiber length composite (a) Image (b) EDS



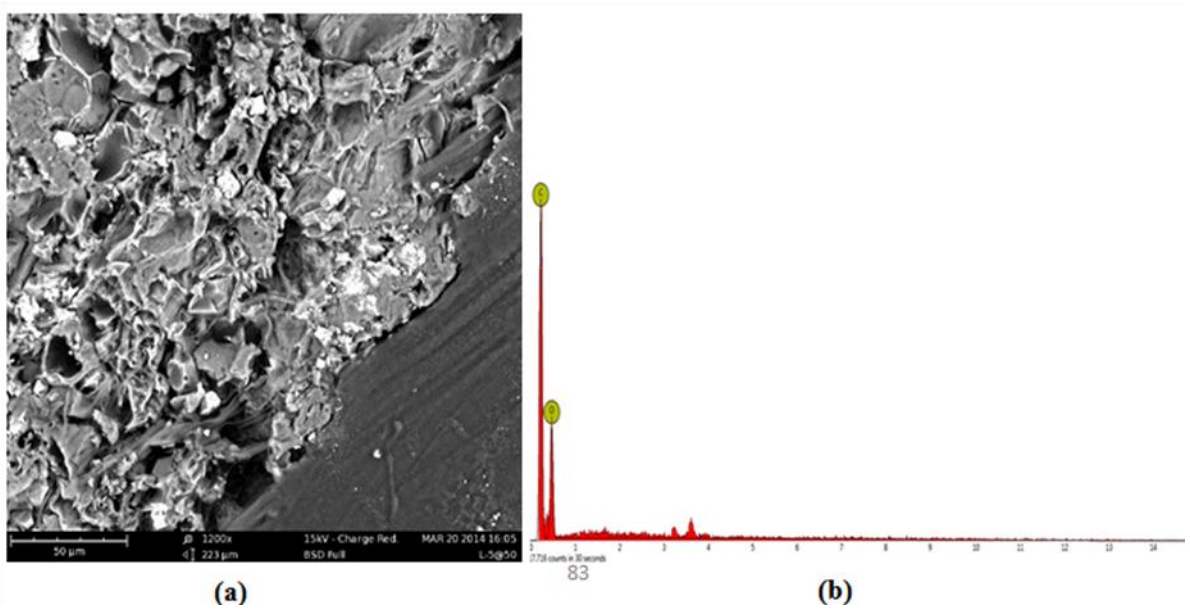
(a) (b)

Plate 4.2: SEM microstructure of PKF-RHDPE for 10mm fiber length composite (a) Image (b) EDS



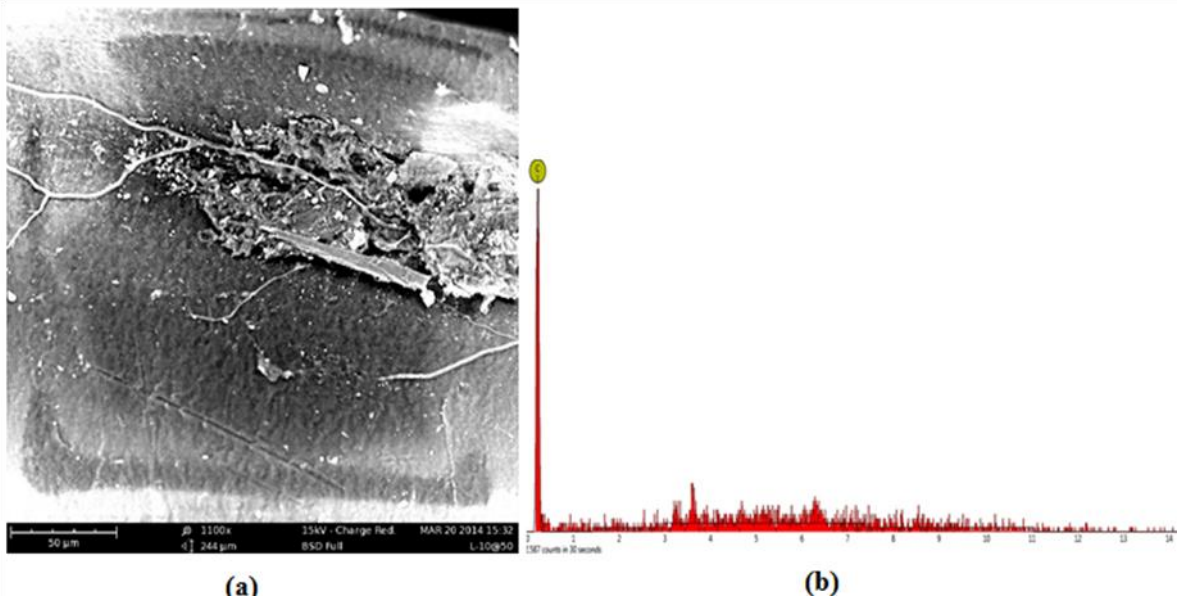
(a) (b)

Plate 4.3: SEM microstructure of PKF-RHDPE for 15mm fiber length composite (a) Image (b) EDS



(a) (b)

Plate 4.4: **SEM microstructure of LBHF-RHDPE for 5mm fiber length composite (a) Image (b) EDS**



(a) (b)

Plate 4.5: SEM microstructure of LBHF-RHDPE for 10mm fiber length composite (a) Image (b) EDS

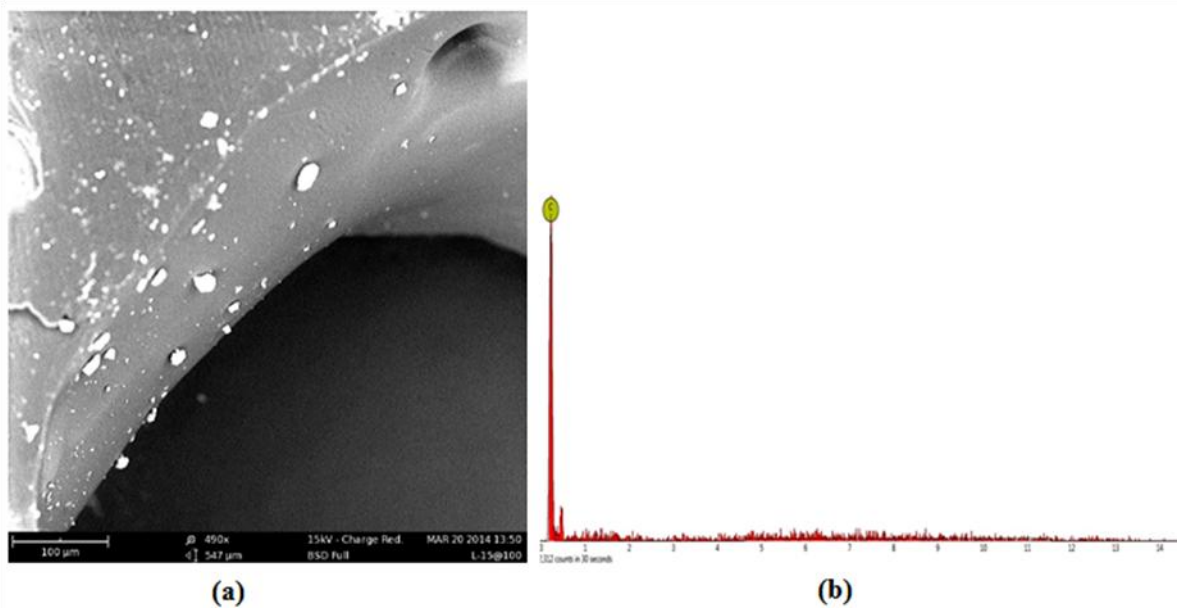


Plate 4.6: SEM microstructure of LBHF-RHDPE for 15mm fiber length composite (a) Image (b) EDS

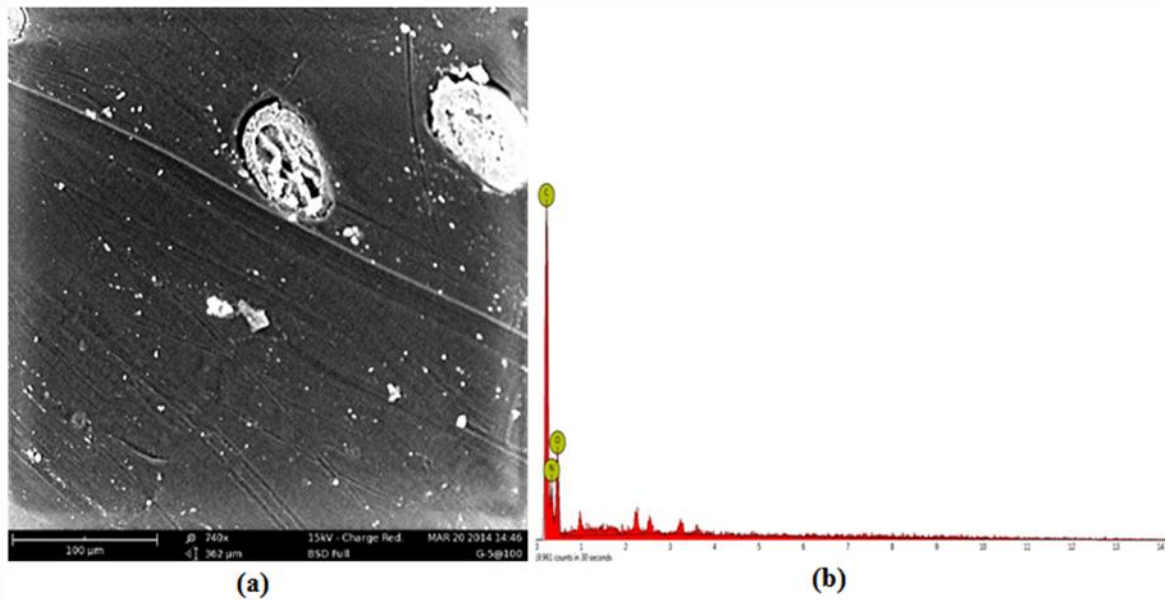
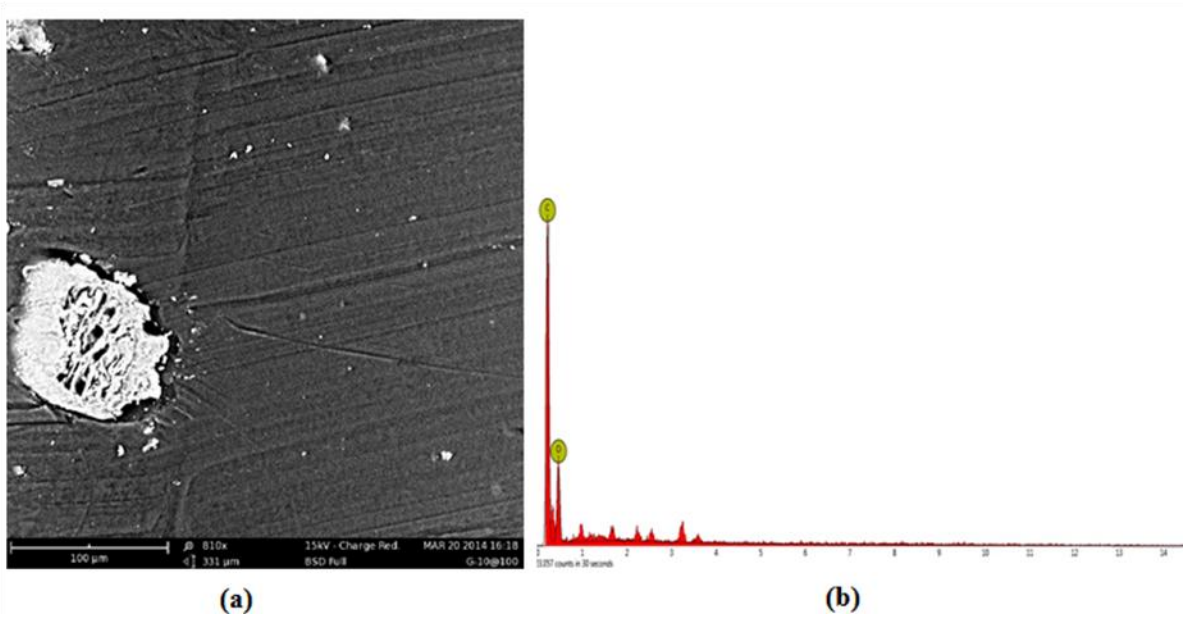
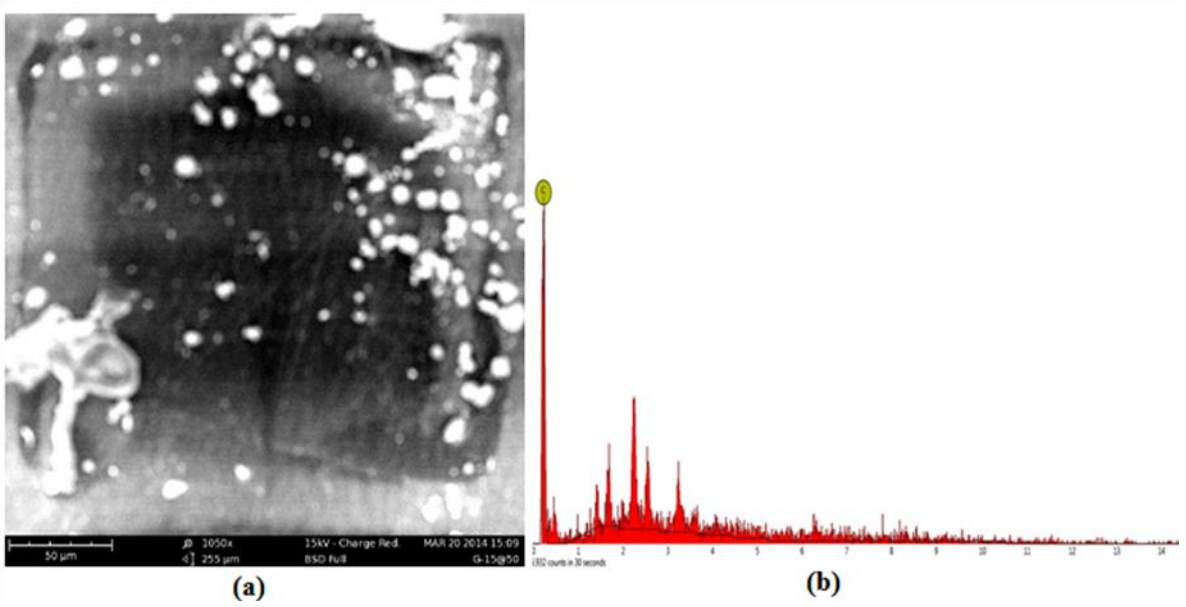


Plate 4.7: SEM microstructure of GFF-RHDPE for 5mm fiber length composites (a) Image (b) EDS



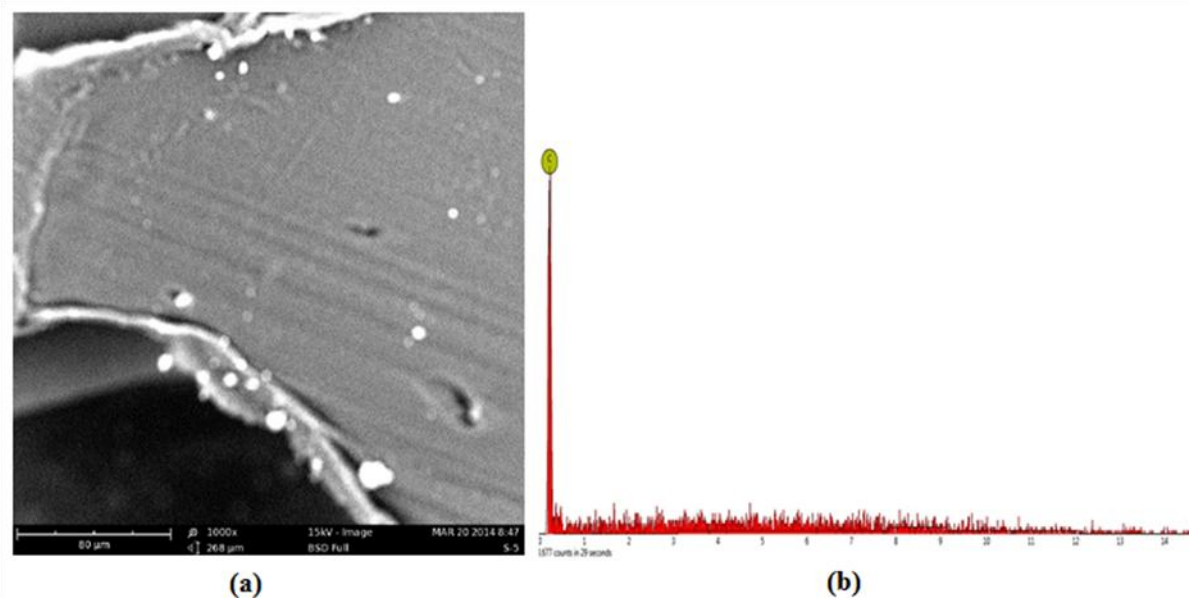
(a) (b)

Plate 4.8: SEM microstructure of GFF-RHDPE for 10mm fiber length composite (a) Image (b) EDS



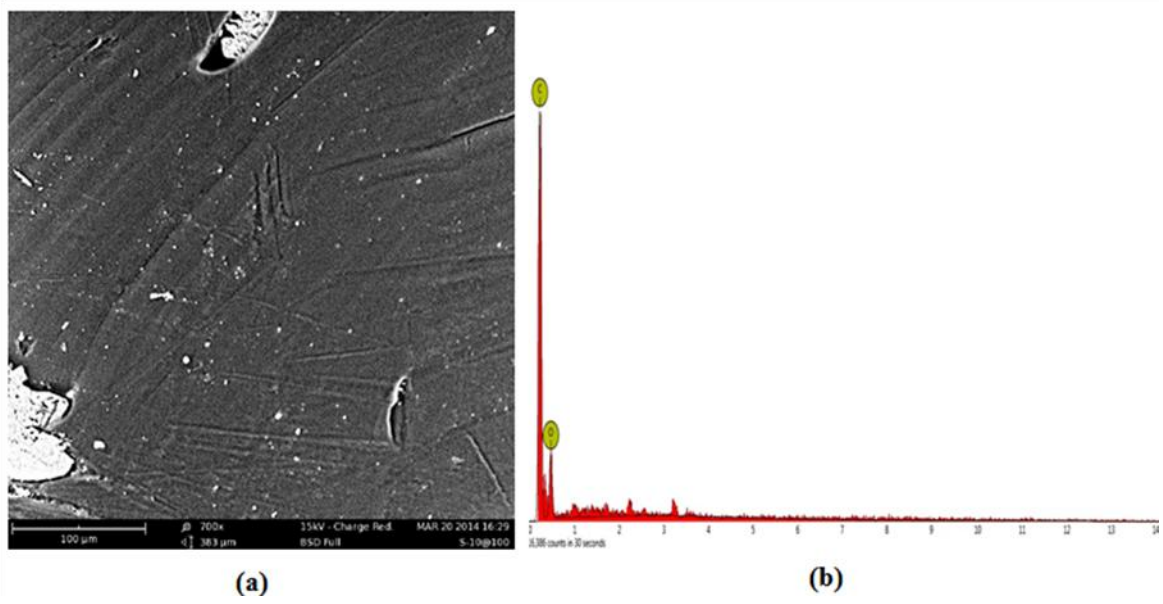
(a) (b)

Plate 4.9: SEM microstructure of GFF-RHDPE for 15mm fiber length composite (a) Image (b) EDS



(a) (b)

Pate 4.10: SEM microstructure of SWF-RHDPE for 5mm fiber length composite (a) Image (b) EDS



(a) (b)

Plate 4.11: SEM microstructure of SWF-RHDPE for 10mm fiber length composite (a) Image (b) EDS

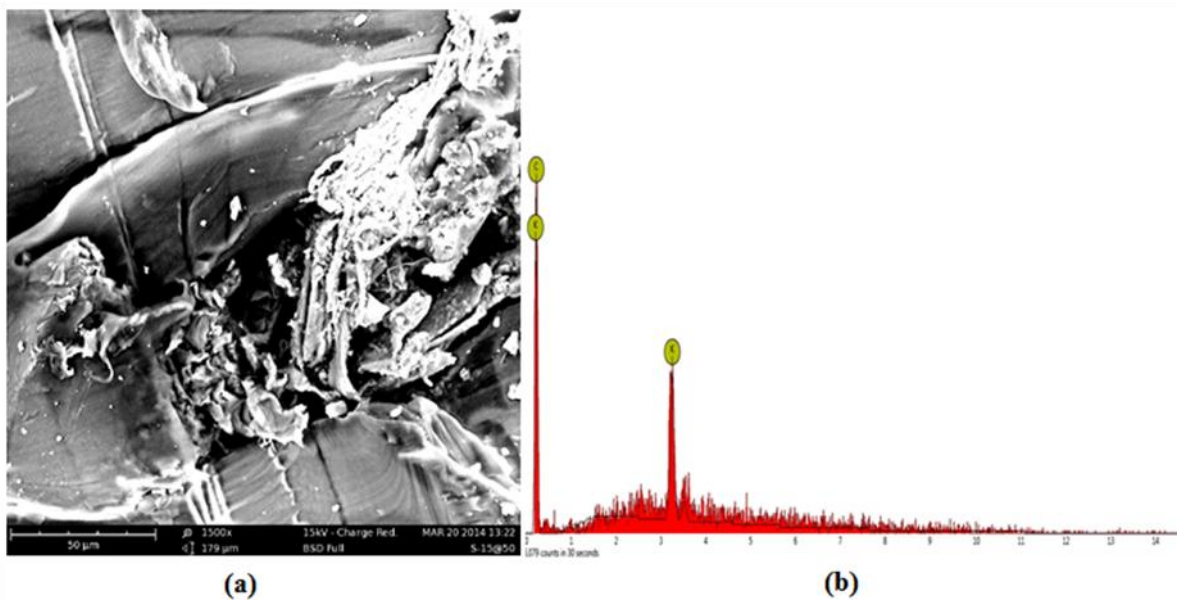


Plate 4.12: SEM microstructure of SWF-RHDPE for 15mm fiber length composite (a) Image (b) EDS

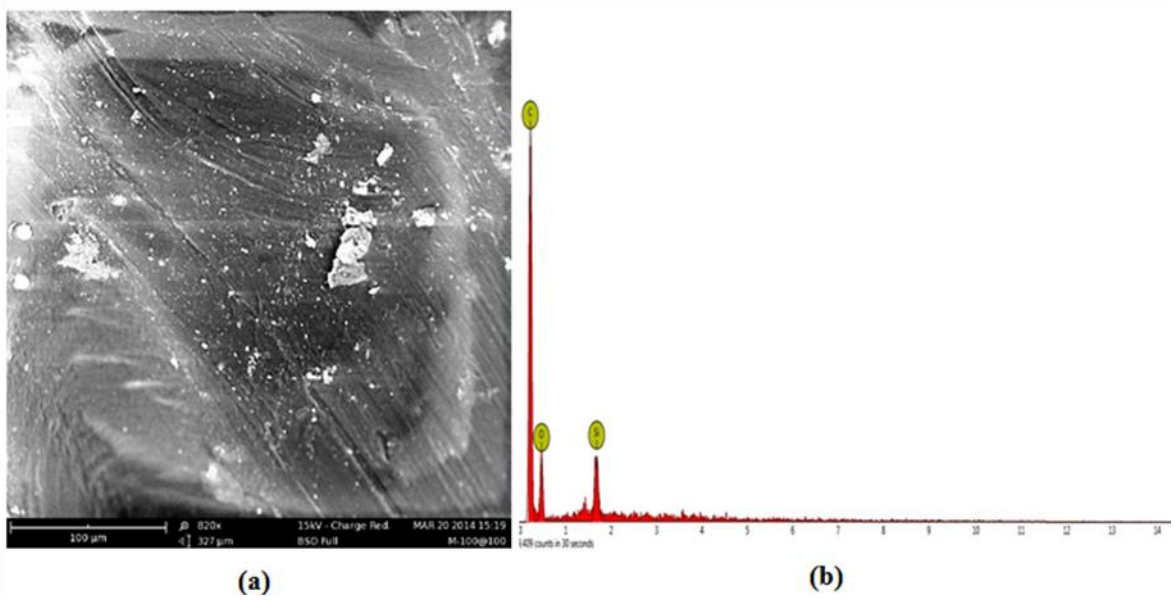


Plate 4.13: SEM microstructure of RHDPE (a) Image (b) EDS

4.2 Discussion of Results

4.2.1 Physical Properties

4.2.1.1 Density

It can be seen from Figs. 4.1 to 4.3 that the composite samples of all the fibres: PKF, LBHF, GFF and SWF increase in density with increase in reinforcement. GFF shows higher density relative to those of SWF and plant fibres. It reaches its highest value of approximately 0.9 g/cm^3 at 15 % composition in both 5 mm and 10 mm fibre lengths.

Fig. 4.4 shows the variation of the composite densities with length of fibres. The animal fibres depict higher densities than the plant fibres; which indicate a reduction in density as the length of fibres increases.

4.2.1.2 Water Absorption/Thickness Swelling

Figs. 4.5 to 4.7 and Figs. 4.9 to 4.11 show the behavior of the various compositions of the composite materials' water absorbing and thickness swelling capacity. These figures illustrate significant percentages of water absorption/thickness swelling of these composites as the absorption rate is due to the absence of water repellent agents in the composite mixes.

It is further observed in Fig. 4.8 and 4.12 that the increase in fibre length accompanies a corresponding increase in the water absorption. LBHF however shows a decrease in water absorption with increased length of fibres.

4.2.2 Mechanical Properties

4.2.2.1 Tensile Strength

The tensile strength behavior of the composite samples is observed to decrease as the percentage composition of the fibres increases. Figs. 4.13 to 4.15 show greatest strength

value at 0 % reinforcement and least strength at 25 % fibre reinforcement. In all figures stated above, GFF shows relatively higher strength values with its maximum value of 23 MPa at 5 % fibre composition and 15mm fibre length. Fig. 4.16 shows the tensile strength's variation with the fibre lengths. As the length of fibre increases the tensile strength of the composites also increases. It can be deuced that with lengths of fibres beyond 15 mm, significant strength values will be reached. The tensile strength values obtained in this study however show significantly higher maximum values than those of the composite developed by Chike (2014). The tensile strength of fibre reinforced composites depends on the relative magnitudes of the *mean fibre length* and the *critical fibre length*. This may be defined as the minimum length which will allow the development of sufficient stress to fail the fibre at its midpoint. Only composites containing fibres that vary much longer than the critical value will exhibit strengths of the corresponding continous fibre composites. Short fibres decrease the reinforcement efficiency. When the fibre lengths are shorter than critical length failure will no longer involve fracture of the fibres and will be governed by *fibre pull-out.*

4.2.2.2 Flexural Strength

Figs. 4.17 to 4.19 display the result of the flexural strength test conducted on the developed composite samples. It is observed from the above figures that the trend is consistent for all the natural fibres used and reveals a reduction in flexural strength as the composition of fibre increases. This is in agreement with the tensile strength behavior. It is observed that at 5 mm and 15 mm fibre lengths, PKF based composites show higher strength while GFF based composites show higher strength at 10mm fibre length. The variation of flexural strength with fibre length as seen in Fig 4.20 shows that longer fibre-composites show greater flexural strength properties. This result is in agreement with the reseach work of Sanjay (2010).

4.2.2.3 Impact strength

Figs. 4.21 to 4.23 show results obtained from impact strength tests. It can be seen that the developed composites increase in the capacity to withstand impact loading with % wt increase in fibre reinforcement. This is in line with works carried out (Zang, 2006 and Andrea 1993). SWF and LBHF composites demonstrate relatively higher impacts strengths than PRF and GFF composites. Fig. 4.24 shows the variation of fibre lengths with impact energy. The plant fibre composites increase in impact energy as the fibre length increases. The SWF composites show max impact energy (1.9 J) at 10 mm length of fibre while GFF composites display strength reduction with increase in fibre length from 5 mm to 15 mm.

4.2.2.4 Hardness

Figs. 4.25 to 4.27 show the variation of hardness with composition of the natural fibre reinforcements. The shore hardness values increase as the % wt composition increase with the maximum shore hardness of 90.57 shores exhibited by SWF at 25 % with 10 mm fibre length. The composite made from SWF displays higher hardness values as seen in all three (3) fibre lengths. GFF composite also show good hardness properties second to SWF as depicted in Fig.4.26 and 4.27. The hardness-fibre length variation as seen in Fig. 4.28 shows best hardness properties at 10 mm fibre length for GFF and PKF. LBHF and SWF however show their maximum hardness values at 5 mm and 15 mm respectively. The high hardness values of the developed composite materials are due to their good compaction ratios. This agrees with the research conducted (Suddin *et al* 2004).

4.2.2.5 Wear

Figs.4.29 and 4.31 show the wear rate of the produced samples at varying loads and velocities (40 kg, 0.5 m/s and 120 kg, 2.5 m/s respectively). The wear increases as the fibre lengths

increase from 5 mm to 15 mm. This may be attributed to the looser packing/bonding of the microstructure of the longer fibre samples with the resin. The shorter fibres were observed to have stronger bonds due to their close packing, thereby showing lower wear. Palm kernel fibre composites reportedly showed highest wear rates (in line with findings of Amaren *etal*, 2013) while locust bean husk fibre composites displayed least wear. For applications such as automobile bumpers and other interior accessories, the developed composites with minimal wear rates are desirable. Figs. 4.30 and 4.32 illustrate the variation of the coefficient of friction with length of fibres. At 40 kg load, LBHF, GFF and SWF composites increase in wear rates while PKF composite shows reduction in wear rate with increase in fibre length. At 120 kg, PKF composites maintain a constant friction coefficient of 0.141; SWF composite shows a decrease while LBHF and GFF composites both indicate increase in friction coefficient with fibre length. Also worthy of note is the least wear rate/coefficient of friction value shown by the pure HDPE sample. This is due to the strong intermolecular bonds in the matrix.

4.2.3 Thermal analysis (TGA/DTA)

The temperatures of destruction of the developed composites were determined from DTA/TGA curves as seen in Figs. 4.33 to 4.37. The TGA curves show the samples in three stages; the vaporization phase and two decomposition phases. The DTA on the other hand indicates the temperatures of maximum decomposition/destruction.

The initial weight loss is as a result of water vaporization from the samples and occurs between 100-200 ^{o}C. The degradation of the reinforced samples started between (300-400 ^{o}C) while LBHF started between 400 and 500 ^{o}C. Above these temperature ranges, the thermal stability of the developed composites gradually decreases and degradation of the samples occurs. The DTA curve illustrated the temperature ranges where maximum

decomposition/destruction of the samples occurred. The figures stated above show destruction temperatures between 400 and 500 ^{o}C. This result suggests the allowable temperature limit of application of these developed composites and highlights LBHF to have greater thermal resistance capacity. These materials display a behavior similar to that exhibited by composites developed by Chike (2014).

4.2.4 X-Ray Florescence (XRF) Analysis

The elemental composition using XRF analysis of PKF, LBHF, GFF and SWF and their spectra are shown in Tables 4.75 to 4.78 and Figs.4.38 to 4.41. The analysis shows predominance of SiO_2, K_2O, SO_3, CaO, Fe_2O_3, over other trace elements. SiO_2, CaO, and Fe_2O_3, are known for their hardness and strength. These are responsible for the samples' improved mechanical properties.

4.2.5 Micro-structural Analysis

A microstructure study was made on the developed samples before being subjected to loading. The SEM images and EDS of the composites are shown in Plates 4.1 to 4.13. The resin is seen as the dark regions in the photographs. The fibres are seen to be detached from the resin surface due to poor interfacial bonding. This can however be improved by chemical treatment of the fibres before compounding. The presence of uneven fibre distribution in the matrix is due to the random fibre orientation adopted during the compounding and pressing stage and is probably the cause of the reduced flexural and tensile strength with higher fibre compositions. In all samples micrographed, the EDS revealed high amounts of Carbon (C). Other constituents include; Na, K, Si, O and N.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results and discussions of the study, the following conclusions can be drawn:

i. The work shows the successful development of PKF, LBHF, GFF, and SWF with recycled high density polyethylene (RHDPE) resin composites by the simple compressive technique.

ii. The density of the composites dropped as the percentage of the fibres increased. The density was also observed to reduce with increasing length of fibres.

iii. The percentage water absorption and thickness swelling increased with increasing weight fraction of fibre reinforcement. They were both observed to increase with increase in fibre length.

iv. The tensile strength of the developed composites dropped as the fractional weight of the reinforcement increased. This was in line with the flexural strength behavior. Both properties increased with the fibre length of the reinforcement.

v. The Impact strength of the composite materials increased with increasing weight fraction of reinforcement. This was a similar observation made for their hardness properties.

vi. The wear rate of the composite samples increased with fibre length and showed highest wear rate for the palm fibre based composites. For PKF composite, wear rate at 40 kg, 0.5 m/s for 5 mm, 10 mm and 15 mm fiber lengths were 0.034 g/m, 0.035 g/m and 0.036 g/m respectively. At 120 kg, 2.5 m/s, wear rate for PKF composites of fiber lengths 5 mm, 10 mm and 15 mm were 0.027 g/m, 0.029 g/m and 0.032 g/m respectively.

vii. The DTA/TGA showed maximum degradation/destruction temperature of the composites to occur at 400 to $500\,^{0}C$ and showed that LBHF composite had the highest thermal tolerance.

viii. The microstructure study showed poor interfacial bonding between reinforcement and matrix leading to low mechanical properties.

ix. The critical length of fibres was found to be 10 mm. Fibre lengths beyond this gave unpredictable mechanical properties.

5.2 Recommendations

At the end of the work, the following recommendations are made:

i. The fibres should always be subjected to thorough cleaning (washing) with NaOH prior to compounding to enhance fibre-matrix bonding.

ii. Water repellents should be used in the manufacture of composite materials to reduce the water absorption (WA) and thickness swelling (TS) tendency.

iii. The evaluation of fibre orientation should be made for directional fibres to improve the mechanical properties of the composites and predict their behavior with more certainty.

5.3 Contributions to knowledge

The following are some of the contributions to knowledge of this work:

i. The critical length of natural fibers is found to be 10 mm, and composites produced from this length show better physical properties compared to ones produced from 5 mm and 15 mm lengths of fibers, while samples produced from 15 mm length of natural fibers show better mechanical properties.

ii. Thermal analysis shows the maximum destruction temperature range of the composites to lie between 400 ^{0}C and 500 ^{0}C.

iii. Industrial designers and researchers can design and develop components using natural fibers and plastics in the production of car parts. This will be of great benefit to Nigeria and the world at large.

iv. The work has recast the importation of some automotive components to Nigeria, especially the importation of car fenders and bumpers.

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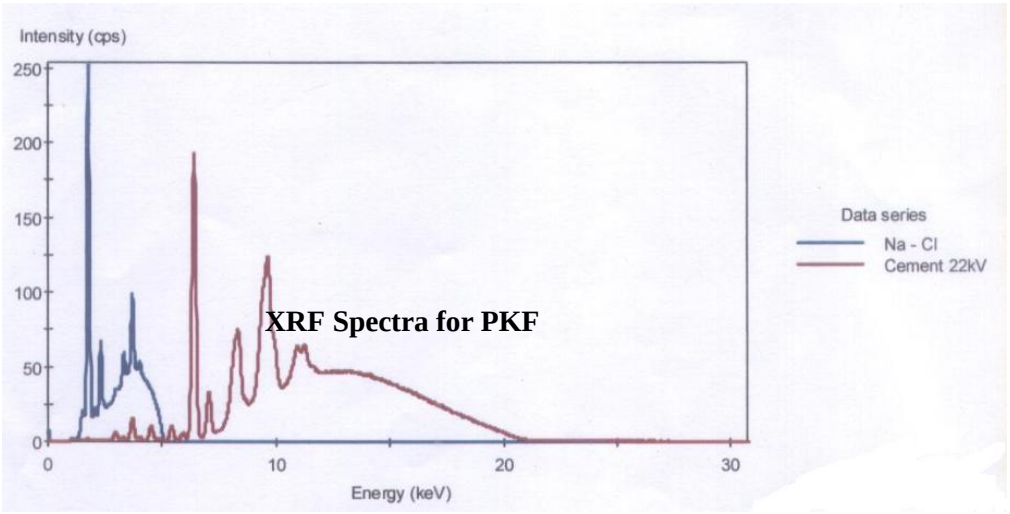
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APPENDIX A

X-RAY FLUORESCENCE ANALYSIS FOR THE NATURAL FIBERS

Table A1: Elemental composition of PKF using XRF analyser

Element	Concentration (wt%)
Na_2O	1.927
MgO	0.261
Al_2O_3	3.389
SiO_2	73.322
P_2O_5	0.950
SO_3	7.598
Cl	0.181
K_2O	0.555
CaO	4.348
TiO2	1.543
Cr_2O_3	0.569
Mn_2O_3	0.150
Fe_2O_3	5.153
ZnO	0.032
SrO	0.021



XRF Spectra for PKF

Table A2: Elemental composition of LBHF using XRF analyser

Element	Concentration (wt%)
Na_2O	0.000
MgO	1.911
Al_2O_3	5.395
SiO_2	32.458
P_2O_5	4.695
SO_3	5.664
Cl	6.527
K_2O	21.421
CaO	12.421
TiO2	0.947
Cr_2O_3	0.168
Mn_2O_3	0.266
Fe_2O_3	7.843
ZnO	0.012
SrO	0.052

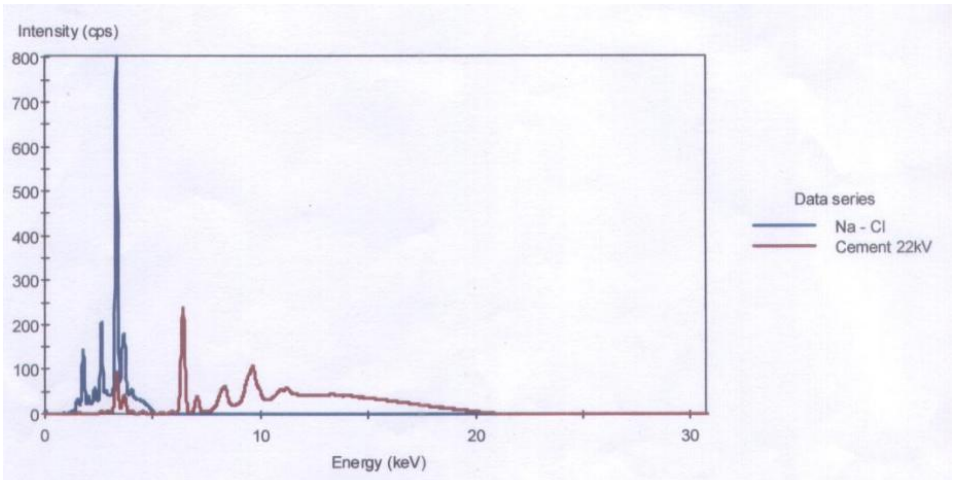
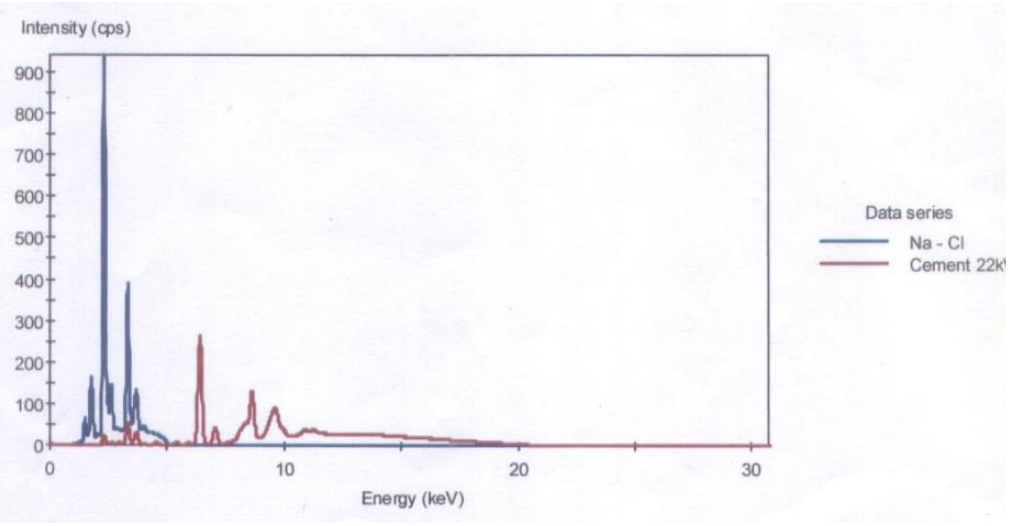


Table A3: Elemental composition of GFF using XRF analyser

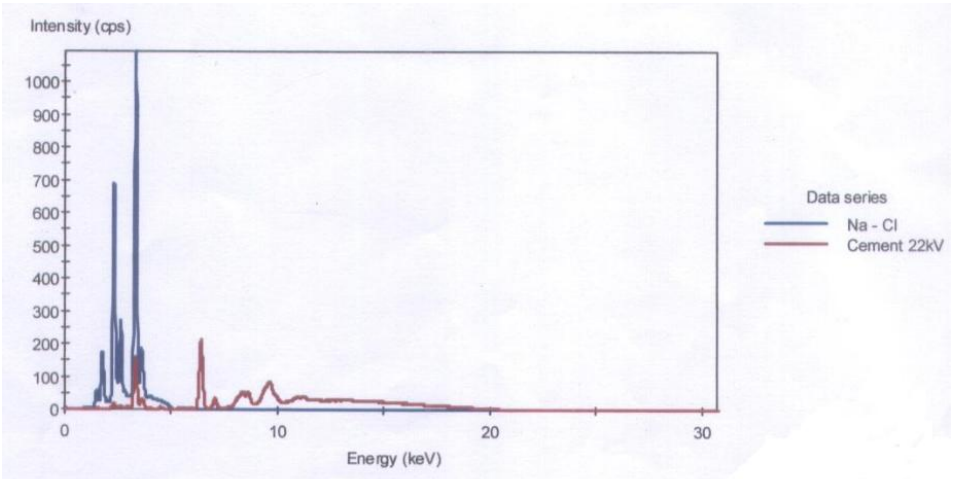
Element	Concentration (wt%)
Na_2O	1.179
MgO	0.847
Al_2O_3	6.154
SiO_2	20.401
P_2O_5	1.346
SO_3	49.592
Cl	3.143
K_2O	7.450
CaO	4.871
TiO2	0.474
Cr_2O_3	0.245
Mn_2O_3	0.076
Fe_2O_3	3.521
ZnO	0.697
SrO	0.007



XRF Spectra for GFF

Table A4: Elemental composition of SWF using XRF analyser

Element	Concentration (wt%)
Na_2O	2.159
MgO	0.481
Al_2O_3	5.220
SiO_2	20.744
P_2O_5	1.318
SO_3	35.074
Cl	5.327
K_2O	21.453
CaO	3.822
TiO2	0.616
Cr_2O_3	0.132
Mn_2O_3	0.063
Fe_2O_3	3.318
ZnO	0.267
SrO	0.006



XRF Spectra for SWF

APPENDIX B

TEST RESULTS FOR THE DEVELOPED HDPE/NATURAL FIBER COMPOSITES

Table B1: Density Test Values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.94	3.30	0.881
3	90-10	2.75	3.30	0.838
4	85-15	2.74	3.30	0.832
5	80-20	2.76	3.50	0.789
6	75-25	2.87	3.60	0.788

Table B2: Density Test Values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	3.00	3.70	0.813
3	90-10	2.81	3.50	0.807
4	85-15	2.80	3.70	0.753
5	80-20	2.56	3.50	0.733
6	75-25	2.78	3.90	0.720

Table B3: Density Test Values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.70	3.50	0.784
3	90-10	2.45	3.30	0.753
4	85-15	2.58	3.70	0.692
5	80-20	2.41	3.60	0.680
6	75-25	2.59	3.80	0.682

Table B4: Density Test Values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.92	3.30	0.885
3	90-10	3.07	3.70	0.837
4	85-15	2.80	3.50	0.800
5	80-20	2.75	3.50	0.782
6	75-25	2.88	4.10	0.710

Table B5: Density Test Values for 10mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.67	3.40	0.765
3	90-10	2.33	3.20	0.733
4	85-15	2.75	3.60	0.755
5	80-20	2.74	3.80	0.730
6	75-25	2.73	3.90	0.708

Table B6: Density Test Values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.51	3.30	0.752
3	90-10	2.91	3.70	0.794
4	85-15	2.83	3.40	0.822
5	80-20	2.43	3.30	0.746
6	75-25	2.61	3.60	0.731

Table B7: Density Test Values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.40	2.80	0.866
3	90-10	2.62	3.40	0.782
4	85-15	2.92	3.80	0.777
5	80-20	2.83	3.20	0.890
6	75-25	2.31	2.70	0.862

Table B8: Density Test Values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	3.24	3.70	0.880
3	90-10	2.11	2.40	0.872
4	85-15	2.24	2.90	0.778
5	80-20	2.51	2.80	0.896
6	75-25	3.01	3.60	0.838

Table B9: Density Test Values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.87	3.30	0.876
3	90-10	3.19	3.70	0.852
4	85-15	2.54	3.56	0.713
5	80-20	2.60	3.70	0.702
6	75-25	2.02	2.90	0.691

Table B10: Density Test Values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.37	2.70	0.880
3	90-10	2.67	3.10	0.852
4	85-15	2.50	3.00	0.842
5	80-20	2.31	3.20	0.715
6	75-25	2.63	3.70	0.705

Table B11: Density Test Values for 10mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	2.54	3.50	0.726
3	90-10	2.69	3.50	0.766
4	85-15	3.03	4.00	0.751
5	80-20	2.06	2.80	0.736
6	75-25	2.44	3.30	0.733

Table B12: Density Test Values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1	100-0	2.84	3.20	0.887
2	95-5	3.20	3.60	0.885
3	90-10	2.69	3.30	0.804
4	85-15	2.17	2.90	0.752
5	80-20	2.32	3.20	0.733
6	75-25	2.45	3.50	0.701

Table B13: Thickness Swelling and Water Absorption Values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.55	3.57	2.94	2.98	0.56	1.36
3	90-10	3.55	3.59	2.76	2.80	1.13	1.45
4	85-15	3.70	3.77	2.75	2.80	1.80	1.82
5	80-20	3.81	3.88	2.77	2.85	1.84	2.89
6	75-25	4.05	4.13	2.88	3.03	1.98	5.21

Table B14: Thickness Swelling and Water Absorption Values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.95	3.96	3.00	3.02	0.25	0.67
3	90-10	3.95	3.96	2.82	2.87	0.25	1.77
4	85-15	3.90	3.94	2.81	2.89	1.03	2.85
5	80-20	3.70	3.74	2.57	2.65	1.08	3.11
6	75-25	3.95	4.00	2.79	2.89	1.27	3.58

Table B15: Thickness Swelling and Water Absorption Values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.38	3.43	1.57	1.58	1.48	0.63
3	90-10	3.55	3.60	2.46	2.48	1.51	0.85
4	85-15	3.52	3.57	3.01	3.05	1.52	1.24
5	80-20	3.71	3.78	2.38	2.43	1.93	2.11
6	75-25	4.50	4.63	3.26	3.36	2.89	3.07

Table B16: Thickness Swelling and Water Absorption Values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.8	3.88	3.07	3.09	2.11	0.65
3	90-10	3.45	3.53	2.92	2.94	2.32	0.68
4	85-15	3.44	3.53	2.80	2.85	2.62	1.79
5	80-20	4.15	4.26	2.76	2.88	2.65	4.35
6	75-25	3.85	3.98	2.90	3.03	3.38	4.48

Table B17: Thickness Swelling and Water Absorption Values for 10mm LBHF-RHDPE

S/N	%Wt. Composition RHDPE-LBHF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.25	3.27	2.67	2.69	0.62	0.75
3	90-10	3.95	3.98	2.34	2.38	0.75	1.71
4	85-15	3.75	3.78	2.75	2.84	0.80	3.27
5	80-20	4.51	4.55	2.75	2.86	0.89	4.00
6	75-25	4.10	4.12	2.75	2.90	2.68	5.45

Table B18: Thickness Swelling and Water Absorption Values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.50	3.51	2.76	2.79	0.29	0.91
3	90-10	2.88	2.92	3.41	3.49	1.47	2.40
4	85-15	3.74	3.82	2.45	2.51	2.13	2.46
5	80-20	4.00	4.11	2.87	3.00	2.73	4.52
6	75-25	4.00	4.12	3.20	3.39	3.12	5.87

Table B19: Thickness Swelling and Water Absorption Values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	2.90	2.90	2.41	2.42	0.00	0.41
3	90-10	4.00	4.10	2.63	2.70	0.25	2.66
4	85-15	3.55	3.56	2.93	3.02	0.28	3.07
5	80-20	3.60	3.80	2.84	2.96	0.56	4.23
6	75-25	3.10	3.12	2.33	2.45	0.65	5.15

Table B20: Thickness Swelling and Water Absorption Values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	4.00	4.00	3.25	3.25	0.00	0.00
3	90-10	2.60	2.63	2.25	2.30	1.15	2.22
4	85-15	3.05	3.10	2.12	2.17	1.64	2.36
5	80-20	3.10	3.18	2.51	2.57	2.16	2.39
6	75-25	3.70	3.78	3.03	3.15	2.58	3.96

Table B21: Thickness Swelling and Water Absorption Values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.45	3.50	2.82	2.83	1.45	0.35
3	90-10	3.41	3.47	3.12	3.15	1.82	1.01
4	85-15	4.55	4.63	3.76	3.83	1.76	1.80
5	80-20	4.00	4.08	3.51	3.59	1.91	2.23
6	75-25	3.87	3.96	3.77	3.87	2.24	2.57

Table B22: Thickness Swelling and Water Absorption Values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.60	3.61	2.37	2.43	0.28	2.53
3	90-10	3.35	3.38	2.67	2.74	0.90	2.54
4	85-15	3.40	3.43	2.65	2.78	1.47	4.91
5	80-20	3.70	3.78	2.51	2.65	2.16	5.58
6	75-25	3.60	3.73	2.32	2.51	4.91	8.19

Table B23: Thickness Swelling and Water Absorption Values for 10mm SWF-HDPE Composite

S/N	%Wt. Composition RHDPE-SWF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.80	3.81	2.69	2.71	0.26	0.74
3	90-10	4.53	4.55	2.53	2.56	0.44	1.19
4	85-15	3.35	3.39	3.04	3.08	1.19	1.32
5	80-20	3.65	3.70	2.07	2.16	1.37	4.35
6	75-25	3.05	3.11	2.47	2.59	1.97	4.86

Table B24: Thickness Swelling and Water Absorption Values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	$t_0(hrs)$	$t_{24}(hrs)$	$m_0(g)$	$m_{24}(g)$	*TS (%)*	*WA (%)*
1	100-0	3.35	3.35	2.83	2.83	0.00	0.00
2	95-5	3.15	3.20	2.02	2.13	1.59	5.45
3	90-10	3.64	3.70	2.48	2.65	1.66	6.71
4	85-15	4.32	4.40	3.06	3.29	1.85	7.52
5	80-20	3.70	3.77	4.13	4.45	1.87	7.86
6	75-25	4.00	4.08	3.88	4.19	1.91	8.03

Table B25: Tensile Strength Test Values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	10.70	3.50	0.672	0.018
3	90-10	11.05	3.65	0.552	0.014
4	85-15	10.60	3.50	0.390	0.011
5	80-20	10.90	3.25	0.627	0.012
6	75-25	10.60	3.80	0.498	0.012

Table B26: Tensile Strength Test Values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	Tensile Force (KN)	UTS(GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.00	3.60	0.579	0.015
3	90-10	10.80	3.65	0.513	0.013
4	85-15	10.25	4.25	0.369	0.009
5	80-20	10.50	3.60	0.447	0.012
6	75-25	10.60	3.50	0.447	0.012

Table B27: Tensile Strength Test Values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	Tensile Force (KN)	UTS(GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.30	2.80	0.664	0.021
3	90-10	11.20	3.55	0.716	0.018
4	85-15	11.20	3.52	0.473	0.012
5	80-20	11.10	3.71	0.371	0.009
6	75-25	11.50	3.60	0.290	0.007

Table B28: Tensile Strength Test Values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.20	3.75	0.417	0.014
3	90-10	10.50	3.50	0.435	0.012
4	85-15	11.10	3.85	0.330	0.008
5	80-20	10.70	4.05	0.384	0.009
6	75-25	10.70	4.15	0.333	0.008

Table B29: Tensile Strength Test Values for 10mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	10.80	4.10	0.468	0.011
3	90-10	9.90	4.10	0.186	0.010
4	85-15	10.25	4.25	0.369	0.009
5	80-20	11.05	3.55	0.406	0.010
6	75-25	10.90	3.85	0.312	0.007

Table B30: Tensile Strength Test Values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.20	3.50	0.510	0.013
3	90-10	10.85	2.88	0.312	0.010
4	85-15	11.20	3.74	0.335	0.008
5	80-20	11.20	4.00	0.358	0.008
6	75-25	11.30	4.00	0.271	0.006

Table B31: Tensile Strength Test Values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.30	3.30	0.606	0.016
3	90-10	10.15	3.65	0.456	0.012
4	85-15	10.80	3.55	0.481	0.013
5	80-20	10.25	3.90	0.384	0.010
6	75-25	11.30	3.15	0.177	0.005

Table B32: Tensile Strength Test Values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.10	3.20	0.576	0.016
3	90-10	10.10	2.40	0.381	0.016
4	85-15	10.75	3.10	0.504	0.015
5	80-20	10.30	2.60	0.540	0.010
6	75-25	10.85	3.50	0.489	0.013

Table B33: Tensile Strength Test Values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	w (mm)	t (mm)	Tensile Force (KN)	UTS(GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.40	2.80	0.734	0.023
3	90-10	11.30	3.41	0.694	0.018
4	85-15	11.00	4.55	0.751	0.015
5	80-20	11.00	4.00	0.440	0.010
6	75-25	11.20	3.87	0.433	0.010

Table B34: Tensile Strength Test Values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	10.80	2.90	0.330	0.011
3	90-10	10.45	3.35	0.354	0.010
4	85-15	11.10	2.85	0.504	0.012
5	80-20	11.40	3.30	0.411	0.011
6	75-25	11.05	3.50	0.258	0.007

Table B35: Tensile Strength Test Values for 10mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.30	4.25	0.474	0.019
3	90-10	10.80	3.10	0.522	0.016
4	85-15	10.45	3.75	0.543	0.014
5	80-20	11.15	2.70	0.336	0.011
6	75-25	10.75	2.85	0.378	0.012

Table B36: Tensile Strength Test Values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w (mm)	t (mm)	Tensile Force (KN)	UTS (GPa)
1	100-0	11.30	3.25	0.852	0.023
2	95-5	11.30	2.70	0.366	0.012
3	90-10	11.30	3.64	0.946	0.023
4	85-15	11.20	3.60	0.282	0.007
5	80-20	11.10	3.70	0.370	0.009
6	75-25	11.25	4.00	0.315	0.007

Table B37: Flexural Strength Test Values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	P(N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	50.7	3.50	108	17.48
3	90-10	50.2	3.40	84	14.55
4	85-15	50.7	3.40	96	16.46
5	80-20	49.7	3.60	96	14.98
6	75-25	50.1	4.40	72	7.46

Table B38: Flexural Strength Test Values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	50.1	4.20	120	13.65
3	90-10	50.4	3.50	84	13.67
4	85-15	51.1	4.20	48	5.35
5	80-20	50.8	4.00	60	7.42
6	75-25	50.9	3.80	72	9.84

Table B39: Flexural Strength Test Values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w(mm)	t(mm)	P(N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	52.0	3.20	110	20.70
3	90-10	51.2	3.50	107	17.07
4	85-15	49.8	3.80	113	15.76
5	80-20	50.4	4.10	137	16.24
6	75-25	53.0	4.50	150	14.01

Table B40: Flexural Strength Test Values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	50.3	3.50	120	19.57
3	90-10	50.7	4.00	120	14.87
4	85-15	49.7	4.00	84	10.62
5	80-20	50.4	4.30	84	9.06
6	75-25	51.0	4.00	96	11.82

Table B41: Flexural Strength Test Values for 10mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	51.0	3.80	132	18.01
3	90-10	49.0	3.70	72	10.79
4	85-15	50.5	4.10	72	8.52
5	80-20	52.0	4.20	120	13.15
6	75-25	50.8	3.50	84	13.57

Table B42: Flexural Strength Test Values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	48.6	3.10	85	18.28
3	90-10	51.5	4.10	135	15.65
4	85-15	50.0	4.00	114	14.37
5	80-20	52.0	3.70	99	13.96
6	75-25	51.6	3.50	89	14.12

Table B43: Flexural Strength Test Values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	w(mm)	t(mm)	P(N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	53.5	2.90	48	10.72
3	90-10	51.4	4.90	120	9.77
4	85-15	51.4	3.50	48	7.66
5	80-20	53.9	4.00	120	13.98
6	75-25	51.8	3.20	12	2.27

Table B44: Flexural Strength Test Values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	53.8	3.70	156	21.29
3	90-10	53.4	2.50	48	14.45
4	85-15	47.9	2.90	36	8.98
5	80-20	53.0	3.30	72	12.54
6	75-25	53.2	4.10	60	6.74

Table B45: Flexural Strength Test Values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	51.6	3.10	102	20.70
3	90-10	49.8	3.50	98	16.22
4	85-15	50.5	4.40	161	16.53
5	80-20	51.4	3.70	110	15.73
6	75-25	51.4	2.80	53	13.11

Table B46: Flexural Strength Test Values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w (mm)	t (mm)	P (N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	51.1	3.50	72	11.56
3	90-10	51.4	4.60	120	11.09
4	85-15	50.4	3.60	72	11.08
5	80-20	52.8	4.00	120	14.28
6	75-25	52.1	3.80	60	8.02

Table B47: Flexural Strength Test Values for 10mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w(mm)	t(mm)	P(N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	51.6	3.50	72	12.13
3	90-10	50.9	3.40	72	11.60
4	85-15	50.7	4.30	108	11.58
5	80-20	51.0	3.60	36	5.47
6	75-25	50.0	3.00	48	10.72

Table B48: Flexural Strength Test Values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	w (mm)	t (mm)	P(N)	MOE (MPa)
1	100-0	50.0	4.01	168	21.00
2	95-5	51.2	2.80	72	18.10
3	90-10	50.5	3.40	104	17.91
4	85-15	52.6	3.50	113	17.63
5	80-20	48.4	4.10	126	15.55
6	75-25	51.6	3.60	70	10.52

Table B49: Impact Energy Test values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.35
3	90-10	1.40
4	85-15	1.40
5	80-20	3.20
6	75-25	3.25

Table B50: Impact Energy Test values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.00
3	90-10	1.60
4	85-15	1.20
5	80-20	1.25
6	75-25	4.50

Table B51: Impact Energy Test values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.52
3	90-10	1.60
4	85-15	2.20
5	80-20	2.40
6	75-25	4.05

Table B52: Impact Energy Test values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.60
3	90-10	1.65
4	85-15	3.50
5	80-20	2.20
6	75-25	3.60

Table B53: Impact Energy Test values for 10mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.15
3	90-10	1.25
4	85-15	1.80
5	80-20	1.65
6	75-25	2.36

Table B54: Impact Energy Test values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.70
3	90-10	1.82
4	85-15	2.30
5	80-20	2.50
6	75-25	3.55

Table B55: Impact Energy Test values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.60
3	90-10	1.25
4	85-15	1.85
5	80-20	2.40
6	75-25	2.40

Table B56: Impact Energy Test values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.20
3	90-10	1.35
4	85-15	1.30
5	80-20	1.65
6	75-25	2.50

Table B57: Impact Energy Test values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.20
3	90-10	1.45
4	85-15	1.60
5	80-20	2.40
6	75-25	2.85

Table B58: Impact Energy Test values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.60
3	90-10	1.25
4	85-15	1.65
5	80-20	1.80
6	75-25	2.75

Table B59: Impact Energy Test values for 10mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.90
3	90-10	1.50
4	85-15	2.15
5	80-20	2.10
6	75-25	2.65

Table B60: Impact Energy Test values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Impact Energy (J)
1	100-0	1.75
2	95-5	1.60
3	90-10	1.85
4	85-15	2.10
5	80-20	2.25
6	75-25	3.32

Table B61: Hardness Test values for 5mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Hardness (Shores)
1	100-0	80.77
2	95-5	83.77
3	90-10	80.60
4	85-15	80.80
5	80-20	80.12
6	75-25	88.77

Table B62: Hardness Test values for 10mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Hardness (Shores)
1	100-0	80.77
2	95-5	87.23
3	90-10	83.70
4	85-15	83.90
5	80-20	85.80
6	75-25	88.10

Table B63: Hardness Test values for 15mm PKF-RHDPE Composite

S/N	%Wt. Composition RHDPE-PKF	Hardness (Shores)
1	100-0	80.77
2	95-5	86.20
3	90-10	85.16
4	85-15	80.40
5	80-20	87.24
6	75-25	87.32

Table B64: Hardness Test values for 5mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Hardness (Shores)
1	100-0	80.77
2	95-5	83.93
3	90-10	85.01
4	85-15	85.45
5	80-20	87.20
6	75-25	85.40

Table B65: Hardness Test values for 10mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Hardness (Shores)
1	100-0	80.77
2	95-5	81.70
3	90-10	80.42
4	85-15	80.60
5	80-20	82.33
6	75-25	87.17

Table B66: Hardness Test values for 15mm LBHF-RHDPE Composite

S/N	%Wt. Composition RHDPE-LBHF	Hardness (Shores)
1	100-0	80.77
2	95-5	82.44
3	90-10	85.00
4	85-15	80.21
5	80-20	88.65
6	75-25	84.20

Table B67: Hardness Test values for 5mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Hardness (Shores)
1	100-0	80.77
2	95-5	77.13
3	90-10	80.11
4	85-15	80.23
5	80-20	81.31
6	75-25	83.60

Table B68: Hardness Test values for 10mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Hardness (Shores)
1	100-0	80.77
2	95-5	83.53
3	90-10	82.22
4	85-15	85.31
5	80-20	87.20
6	75-25	90.10

Table B69: Hardness Test values for 15mm GFF-RHDPE Composite

S/N	%Wt. Composition RHDPE-GFF	Hardness (Shores)
1	100-0	80.77
2	95-5	81.20
3	90-10	83.40
4	85-15	83.20
5	80-20	90.23
6	75-25	90.20

Table B70: Hardness Test values for 5mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Hardness (Shores)
1	100-0	80.77
2	95-5	80.20
3	90-10	85.00
4	85-15	87.00
5	80-20	88.40
6	75-25	90.43

Table B71: Hardness Test values for 10mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Hardness (Shores)
1	100-0	80.77
2	95-5	80.55
3	90-10	83.43
4	85-15	85.64
5	80-20	88.80
6	75-25	90.57

Table B72: Hardness Test values for 15mm SWF-RHDPE Composite

S/N	%Wt. Composition RHDPE-SWF	Hardness (Shores)
1	100-0	80.77
2	95-5	82.10
3	90-10	82.60
4	85-15	86.16
5	80-20	89.12
6	75-25	90.04

Table B73: Wear Test under 40kg Load at 0.5m/s and 1000m sliding speed

Fibre(5% Composition)	Fibre Length	Wear Rate (g/m)	Coefficient of Friction
PKF	5	0.0330	0.162
	10	0.0340	0.161
	15	0.0340	0.161
LBHF	5	0.0281	0.150
	10	0.0280	0.149
	15	0.0310	0.160
GFF	5	0.0320	0.156
	10	0.0340	0.158
	15	0.0341	0.158
SWF	5	0.0301	0.158
	10	0.0300	0.160
	15	0.0300	0.161
Control	———	0.0320	0.151

Table B74: Wear Test under 120kg Load at 2.5m/s and 1000m Sliding distance

Fibre(5% Composition)	Fibre Length	Wear Rate (g/m)	Coefficient of Friction
PKF	5	0.0280	0.141
	10	0.0290	0.141
	15	0.0300	0.141
LBHF	5	0.0210	0.130
	10	0.0200	0.134
	15	0.0290	0.140
GFF	5	0.0270	0.132
	10	0.0270	0.132
	15	0.0281	0.140
SWF	5	0.0241	0.140
	10	0.0247	0.139
	15	0.0250	0.130
Control	———	0.0220	0.132

APPENDIX C

PICTURES OF THE EQUIPMENT USED IN THE PRODUCTION AND TESTING OF THE HDPE/NATURAL FIBRE COMPOSITES

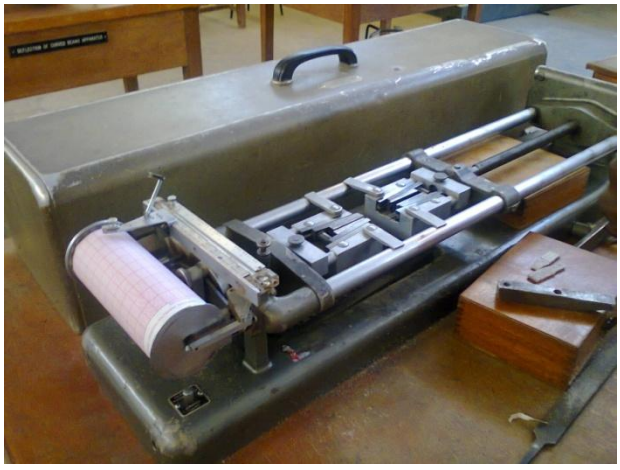


Plate C1: Tensile test measurement using a Hounsfield Tensometer in Mechanical Engineering Department, Ahmadu Bello University, Zaria.



Plate C2: Two Roll Mill Machine in the Nigerian Institute of Leather and Science Technology (NILEST, Zaria)



Plate C3: Electrical Hydraulic Press in the Nigerian Institute of Leather Science and Technology (NILEST, Zaria)



Plate C4: Density Measurement using Laboratory Balance in the Multi-User Science Research Laboratory, ABU Zaria



Plate C5: Impact Testing Machine in the Metallurgical Engineering Department, ABU Zaria

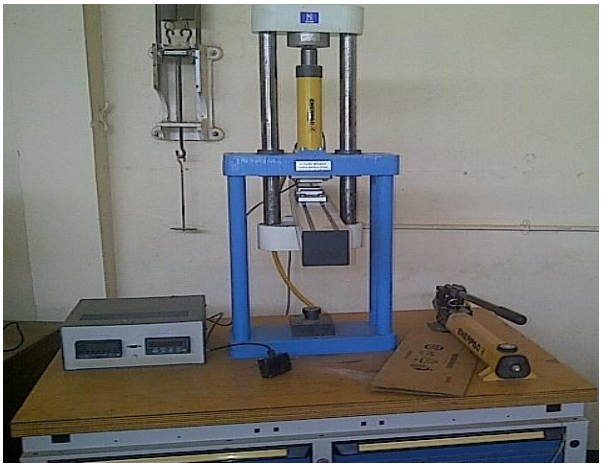


Plate C6: Enerpac Universal Materials Testing Machine in the Mechanical Engineering Department, ABU Zaria



Plate C7: Hardness test measurement using a Durometer in the Nigerian Institute of Leather and Science Technology (NILEST), Zaria