DEVELOPMENT AND CHARACTERIZATION OF WASTE NEWSPAPER PARTICULATE REINFORCED POLYESTER COMPOSITE

BY

ABUBAKAR ALIYU

DEPARTMENT OF MECHANICAL ENGINEERING,

AHMADU BELLO UNIVERSITY, ZARIA.

JULY, 2021

DEVELOPMENT AND CHARACTERIZATION OF WASTE NEWSPAPER PARTICULATE REINFORCED POLYESTER COMPOSITE

BY

Abubakar ALIYU B. Eng. (ABU) 2012
P15EGME8005

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD

OF A

MASTER OF SCIENCE DEGREE IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

JULY, 2021

Declaration

I declare that the work in this Thesis titled "**Development and Characterization of Waste Newspaper Particulate Reinforced Polyester Composite**" has been carried out by me in the **Department of Mechanical Engineering** under the supervision of Dr. M. Sumaila and Prof. D. M. Kulla. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma in this or any other institution.

Abubakar ALIYU …… ……....

Signature Date

Certification

This Thesis entitled "DEVELOPMENT AND CHARACTERIZATION OF WASTE NEWSPAPER PARTICULATE REINFORCED POLYESTER COMPOSITE" by Abubakar ALIYU meets the regulations governing the award of the degree of Master of Science in Mechanical Engineering of Ahmadu Bello University, and is approved for its' contribution to knowledge and literary presentation.

Dr. M. Sumaila	_____	_____
(Chairman, Supervisory Committee)	Signature	Date
Prof. D. M. Kulla	_____	_____
(Member, Supervisory Committee)	Signature	Date
Prof. D. M. Kulla	_____	_____
(Head of Department)	Signature	Date
Prof. Sani A. Abdullahi	_____	_____
(Dean, School of Postgraduate Studies)	Signature	Date

Acknowledgements

This dissertation would not have been possible without the support, guidance and encouragement from several individuals who, in one way or another contributed and extended valuable assistance in the preparation and completion of this study. First and foremost, I offer my sincere gratitude to my supervisors Dr M. Sumaila and Prof. D.M. Kulla for all the quality supervision, pieces of advices and guidance right from the very beginning of this research as well as giving me an extraordinary experience throughout this work. I am indeed much indebted to you for using your precious time to read through the dissertation and provide your critical comments. My special thanks go to the Head of Department Mechanical Engineering (Prof F.O Anafi) and all the staff of the department. I would like to acknowledge my Dad Alhaji Aliyu Muhammad, my Mum Hajiya Hafsat Salihu and all of my siblings for their support, prayers and encouragement.

Also my appreciation to my friends and colleagues: Yahya Gambo, Ibrahim Umar Musa, Buhari Zubairu, Ibrahim Attahir, Abdulmalik Bello Kofa and many others. Thank you all.

Abstract

Natural fibres reinforced polymer composite plays a vital role in the fuel efficiency and gas emission regulations of passengers' cars. One way to increase the fuel efficiency without compromising safety is to employ fibre reinforced composite materials in the body of the car so that weight reduction can be achieved. This study has developed and characterized a composite material using waste newspaper particulate (WNP) as reinforcement and unsaturated polyester as matrix. The mechanical, water absorption and tribological properties of the developed material were determined. The mechanical properties tested for were tensile, compressive, flexural, hardness and impact strength. Tensile properties of the material were observed to increase as the percentage of filler reinforcement increased with maximum tensile strength and modulus of 35.7MPa and 0.2298GPa respectively at 20wt% reinforcement. Determined compressive strength, hardness value and impact strength were 107.26MPa, 44.57HRF and 3.79kJ/m^2 respectively at 15wt% reinforcement. Flexural strength was observed to be decreased with increased percentage of filler reinforcement due to the increase in brittleness of the material as filler reinforcement was increased. Depth of penetration was determined to decrease as the fibre loading was increased, while there was an increase in the percentage of water absorbed by the material as the filler loading percentage and immersion time were increased. The maximum percentage of water absorbed was 0.8285 at 25wt% after 192hours of immersion in water. Thermal analysis conducted showed the materials' conductivity to increase when the percentage of the reinforcement was increased. The storage modulus (E´), loss modulus (E´´) and damping factor were determined using Dynamic Mechanical Analysis (DMA) and observed to be maximum at 20wt% reinforcement with maximum values of 4000MPa, 388MPa and 0.555 respectively at about a temperature of 130^{o}C. SEM results showed a good interfacial bonding between the matrix and reinforcement mostly at lower filler percentage explaining the reasons for better properties shown by the material at those percentages. XRF and FTIR analysis were conducted, and the result showed newspaper to contain –OH, C=C=C, N-O and C-O functional groups. The developed composite material had best results at 15 – 20wt% reinforcement which suggest the percentage of reinforcement for optimum service condition.

Table of Content

List of Figures

List of Plates

List of Tables

List of Appendices

Nomenclature

b = Width (mm)

t = Thickness (mm)

d = Depth of beam (mm)

L = Span of beam (mm)

D = Deflection (mm)

A = Cross sectional area (mm^2)

P = Load (kN)

F_n = Applied abrasive force (N)

σ_t = Tensile strength (MPa)

σ_c = Compressive strength (MPa)

σ_f = Flexural strength (MPa)

MOE = Modulus of Elasticity (GPa)

ρ = Experimental density of composite material (g/cm^3)

K = Thermal conductivity (W/m^oK)

$\frac{dT}{dx}$ = Temperature gradient ($^oK/m$)

Q_x = Rate of heat flow (w)

$w_{\%}$ = Percentage of water absorption

w_t = Weight at a time (g)

w_o = Initial weight of sample (g)

Δw = Weight loss (g)

W_1 = Weight of sample before abrasion test (g)

W_2 = Weight of sample after abrasion test (g)

W_s = Specific wear rate

S_s = Sliding dstance (mm)

ΔV = Volume loss of specimen (cm^3)

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Urbanization and industrialization and other domestic activities are increasing in both developed and underdeveloped countries in the world today which led to the increase in the amount of solid waste (SW) generated which are mostly decomposable in nature. On the other hand, the common problems are lack of collection coverage and open dumped landfill as the final disposal method (Shafiur Rahman, *et al.,* 2015). SWs are basically those thrown away materials, such as waste paper prints, plastics, leathers, food packaging materials etc. The method used in disposing most of these SW creates environmental pollution, such as the pollution of air, land and water (Yeny & Yulinah, 2012).

SW materials are increasing every after day, which mandates the need for proper management method so as to save our environment. Managing waste is one of the greatest challenges for human societies, as various Human daily activities results into the production of more waste with great challenge on how to manage it. 'Waste' is simply any unwanted materials from the production of a certain product or the product itself after its intended usage. Waste mostly has nothing to give into the environment aside pollution (Oriyomi & Oluwatobi, 2014). New or an entirely different product can be produced by recycling direct or indirect recycling of the SW. This not only reduces the amount of waste material, but can also greatly reduce the cost of producing new materials. Solid waste is of most interest is, as it is the most frequently occurring of all waste types as it occurs from individual or domestic, industrial and agricultural activities. Domestic waste in particular appears to pile up and its management is an important task for advanced cultures. Recycling is a good way to reduce waste, but it has been recorded that 40% of the waste to be recycled is in the waste stream during recycling. (Sangrutsamee, *et al.,* 2012). In an effort to address this issue, waste is used as raw materials for the manufacture of other materials. Paper tends to be the most popular as it is used in many fields, including stationery, packing cartons, disseminating news to people, and many more. Publication is a good example of recyclable

materials. Disposable paper available in abundance worldwide consists primarily of small, organic, cellulose fibers and is already being used in many local raw materials. Waste paper comes from a variety of sources, including newspapers, office and printing, etc. Each has a different type of fiber content, so combining all these different quality papers will reduce the purity of the fiber of the highest quality. An investigation into the potential of the various types of recycled waste paper as building materials is therefore necessary to gain an insight into their behavior and properties (Sangrutsamee, *et al.*, 2012).

Old newspapers are an important source of potentially high-value resources that can be used to produce new products. Unfortunately, paper is not a material that can be recycled more than three times consecutively because cellulose fibres become shorter every time a recycling process is done, which results in reduced paper strength (Vachira, *et al.*, 2012). When recycled paper reaches this point, it is practically useless for further application in the same field, so a different approach is needed in order to take care of the paper which is at the end of its lifecycle. We can use the recycling process, for example, because this is one of the best waste management processes. Recycling is a process of transforming materials (waste) into new products to avoid waste of potentially useful materials, to reduce the use of fresh raw materials, reduce energy use, reduce air pollution (from incineration) and water pollution (from landfilling) by increasing the need for "conventional" waste disposal, and reduce greenhouse gas emissions relative to plastics. Paper is usually made from wood or cotton waste cellulose fibers. In daily life, the demand for and consumption of paper is still very high and grows every year, leading to waste problems. Waste paper (WP) means waste paper, excess paper, paper that is rejected. Waste paper comes from works of printing; paper processing plants, department stores, self-service stores, houses, etc (Vachira, *et al.* 2012).

For example, recent research work has shown the use of paper for producing cellulose reinforced polymer composites. By varying paper content as reinforcement, paper is used to produce composite material (Irena, *et.al,* 2015). The continuous demand for newer, stronger, stiffer, recyclable, fire resistant, less expensive and yet lesser weight materials in many engineering fields such as packaging industries, aero plane, automotive and construction has influence the need for these materials. Conventional composite materials (such as carbon, glass and synthetic fibres) need to be replaced due to some reasons associated with them like energy consumption, health concerns and their manufacturing method. Therefore, natural fibres and bio-degradable polymers can be considered as replacement of composites on this field (Liu *et al.,* 2005).

1.2 Statement of the problem

The emergence and survival of any technology depends on the availability of basic raw materials. In Nigeria and the world at large, unused newspaper is at a high capacity.

Paper amounting to over a total of 450 million is globally produced yearly and it is projected that by the year 2020, the demand for paper will reach 500million every year (Ali *et al.,* 2013).

Waste newspaper finds application in food packaging which results into people consuming such food unknowingly taking toxic chemicals along with the food (Kanungo, Rohit, & Thakar, 2017). The newspaper ink contains hazardous chemicals (2-napthylamine, 4-aminobiphenyl) which can trigger serious health problems when the food (hot or oily) comes in contact with the paper prints since the ink contains number of bioactive materials with known negative effects.

Most waste paper and newspaper will end up in landfill sites, while some will be incinerated. Thus, air (by incineration), water and land are polluted. Waste paper and paper recycling could not match the production of waste paper. (Akinwumi *et al.,* 2014) A unique opportunity for reuse is the use of waste paper as building material and as reinforcement in the manufacture of composite materials.

In Nigeria, solid waste generation is on the increasing side with waste paper (more of newspapers) amounting approximately to 32.17% of the total solid waste generated in Nigeria's popular cities (Lagos, Port Harcourt, Kaduna and Kano) (Bako, 2014). Researches have been carried out on waste papers and newspapers but mostly focused on determining the suitability of waste paper as a building/civil engineering material. Some other researches focused on producing a composite material from unused newspaper using different polymer matrix, to determine the mechanical properties of the waste newspaper composite (Bako, 2014).

The goal of this research was therefore to study the properties of a composite material made from waste newspaper using polyester resin as a matrix. The developed material's properties were studied to assess the potential for its use in mechanical applications. The research work will addressed alternative method for recycling waste paper which is environmentally friendly, less expensive and lower in terms of energy consumption/requirement.

1.3 Aim and Objectives

The aim of this research was to produce particulate filler reinforced polyester composite material from waste newspaper for automobile door hard pad application.

The objectives of the research include;

i. To produce, modify and characterize cellulose particulate filler from waste newspaper as reinforcement in producing polymer composite material.
ii. To carry out spectroscopic analysis of the functional groups of the particulate filler material.
iii. To produce composite material from modified waste newspaper cellulose fibre using unsaturated polyester resin (with 5%, 10%, 15%, 20% and 25% reinforcement by weight).
iv. To investigate the physico-mechanical properties (tensile strength, hardness, flexural and compressive strength), water absorption capacity and density of the produced composite material.

v. To determine the tribological properties of the developed composite material.

vi. To investigate the thermal conductivity and thermal properties of the composite material using Dynamic Mechanical Analysis (DMA).

vii. To study the microstructure (SEM) and physical properties (density and water absorption capacity) of the material.

1.4 Justification

Numerous researches (Guptaa & Singha, 2018; Choudhury, et al., 2017; Das, 2017 & Islam, et al., 2017) have been carried out on the utilization of wastepaper (which is fibrous/cellulose in nature) and other fibrous material for usage in building construction. Other researchers (Appusamy, et al, 2018 and Eskezia, et al., 2017) focused their attention on the production of fibre composites using other forms/ sources of natural fibre using epoxy resin or polypropylene polymer and other polymers which are quite expensive, which in turn makes their product significantly expensive.

On the other hand, unsaturated polyesters are cheaper than other polymer matrices, as such their products are less expensive, but good in low performance application and limited temperature performance.

The focus of this research work was on using waste newspaper particulate filler in the production of a composite material that is less expensive with improved properties. This made this research an important one.

Also, the research will go a long way in offering a standing solution to one of the problems faced in disposing millions of ton of solid waste generated annually.

1.5 Significance of the study

This research was aimed at solving the problem of environmental pollution and waste management/disposal by recycling waste newspaper (which is approximately 25 – 40% of municipal solid waste generated worldwide) (McKinney, 1995) by developing a composite material that is cost

effective, lighter and biodegradable. The term "waste" makes it easy to recall any unwanted items that have highlighted its utility and need to be disposed of immediately, regardless of the environmental effects of such disposal practices. Some of this waste products can be however recycled into new or different products that are environmentally friendly and can as well add value to the economic development of any society (Ataguba & Clement, 2016).

Lots of papers are discarded every year in the United States for example which is enough to build a 48 feet wall around the country. The amount of recycled waste paper every year is about 45% of the discarded paper, yet 55% of the paper is thrown away into the land. With about fifteen trees making a ton of paper, it means 720 million trees are used only once and thrown or buried into the land (Rahyan, *et al.*, 2008).

In Nigeria, waste generation increases with urbanization, and the four most industrialized cities are Lagos (home to about 60% of Nigerian industries), Rivers, Kaduna and Kano. The wastepaper generated in these states amounting to 32.17% of the total solid waste generated [9.80% (Lagos), 6.50% (Port Harcourt), 5.67% (Kaduna), and 10.20% (Kano)] (Bako, 2014)

Considering the incidences above, research into possible solutions to develop a better way of managing waste and converting used newspaper into a useful material is inevitable.

1.6 Scope and Limitation

The scope of this research work was limited to using washing and flotation method of de-inking used newspaper for the extraction of the cellulose filler contained in the paper. The filler were used as reinforcement for composite material to be produced, considering only polyester resin. The research work also examined the mechanical and physical properties along with the micro structure of the produced material.

The nature of bonding between the filler and matrix, weathering characteristics of the composite was not looked into.

CHAPTER TWO
LITERATURE REVIEW

2.1 History of Composite Material

Composite materials are manufactured by chemically combining two dissimilar materials (strong load carrying material known as reinforcement and a weaker material known as matrix) into a new material which may be better suited for a particular application than either of the original materials alone and has better properties than the individual properties of the parent components when used alone (Luna, et al., 2015). Unlike in alloys of metal, every material retains its separate properties such as the chemical, mechanical and physical properties (Campbell, 2010). Among living things such as seaweed, bamboo, wood and human bone, composite materials are available. About B.C. 3000. From sources among Egypt and Mesopotamia it was clear that river-boats were built from bundles of papyrus reeds embedded in a bitumen matrix. Another example of the composite making that flourished in the olden ages around 2500BC was the Egyptian mummification where naturally produced resin and rigid cocoon were used to wrap treated bodies. India and China have been known for several thousand years of using the pool. In India, resin was used to fill sword shafts and to make whetstones by combining shellac with fine sand in which it is considered the predecessor to modern composite manufacturing. The Greeks by 500BC were building ships with three banks of oars called triremes. Commonly used structural materials such as polymers, ceramics and metals are of fluctuating relative importance according to different societies throughout history. Ashby (Ashby, 1987) provides a historical variation of each group's relative importance from 10,000 B.C and extrapolates their significance to 2020. Because of their value, composites have been growing steadily since around 1960 and are expected to continue to increase over the next several decades. In 2002, sales opportunities for fiber-reinforced polymer composite were projected to exceed approximately 1.04 million metric tons (2.3 billion lbs) and volume growth of 15 percent was expected. An average annual growth rate of 3.0 percent is expected over the next few years to inject around 1.2 million tons of polymer fibres (Ashby, 1987).

2.2 Classification of composite Materials

Generally, composite materials are classified into two (2) major groups, which are;

2.2.1 Classification Based on Matrix

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

a) Metal Matrix Composites (MMC): MMCs have several advantages over monolithic metals such as higher functional modules and strength, better properties at high temperatures, and minimal coefficient of expansion and good properties at high temperatures. MMCs are used for a wide range of applications because of these properties, such as combustion chamber nozzles (for room use), housings, tubing, structural components, heat exchangers and cables, etc.

b) Ceramic Matrix Composites (CMC): In the development of CMC, a major goal is to increase durability. Obviously, it is expected and often found that the strength and rigidity of ceramic composite are strengthened at the same time.

c) Polymer Matrix Composites (PMC): Polymers are the widely used matrix in composite production. The explanation for this is double. Polymers have structurally inadequate properties, particularly in terms of their rigidity and strength compared to ceramics. Polymers are combined with other materials to solve these difficulties by requiring low pressure and temperature in their manufacturing. Simpler materials are also required in the production of polymer composite, which means that the polymer matrix is rapidly formed in many applications (Chandramohan & Marimuthu, 2011).

Two types of polymer composites are:

i. Fiber Reinforced Polymer

The main components of fibre-reinforced polymer composites are fibres and matrix. The key reinforcement is fibres, while the matrix provides stability and ties the fibers together in form and controls the distribution of tension between the fibres. Often fillers are used to boost the production process and add special properties to the composites and/or reduce the cost of production. Among the common fillers used are molybdenum, asbestos, carbon / graphite fibres, carbide and beryllium oxide, aluminum oxide, glass fibres, and natural fibres. Epoxy, polyester, polyurethane and vinyl ester are among the commonly used matrix (Chandramohan & Marimuthu, 2011).

ii. Particle Reinforced Polymer

Particulate reinforced composite are those composite having particulates with roughly equal dimensions both in length and diameter as their reinforcement. They are used to improve wear resistance, friction reduction, high thermal performance, and to reduce shrinkage (Richardson, 1987). In this category of composite, the applied load is shared by the fibre and matrix. Types of particulate reinforcement materials used are ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials. A lot of ceramics have good electrical and thermal insulating properties. Some are magnetic while some have special properties. Ceramics and glasses are associated with one major setback which is brittleness. An automobile tire made from poly-isobutylene and carbon black particles is a good example of particulate reinforced composite (Chandramohan & Marimuthu, 2011).

2.2.2 Classification Based on Reinforcement

Composites can be classified as being of primary importance based on the characteristics of the reinforcing material. The classification can be as follows: (NDT Resource Center, 2016)

i. **Fiber Reinforced Composites**

The best-known fiber-reinforced composite is fiberglass-reinforced composite, but this class also includes carbon-epoxy and other advanced composites. The fibers can be discontinuous or long fibers, weaved sheets or whiskers. The ductile matrix is mixed with fibers when hardness is required, while the fibers are mixed with ductile matrix if the desired property is toughness. The length-to-diameter ratio of the fiber, the strength of the fiber-to-matrix bond and the volume of fiber are variables that affect the mechanical properties of the fiber composite (NDT Resource Center, 2016). Fiber materials predominantly used include:

a. **Glass** – Glass is the most common and cheapest fiber. Normally it is used to reinforce polymer matrices. Glass has a high strength of tensile and a fairly low density (2.5 g / cc).

b. **Carbon-graphite** - Carbon fibers are the material of choice in advance. Carbon is a very light element with a density of approximately 2.3 g / cc and a significantly higher stiffness than glass. Carbon fibers can be up to 3 times steel's rigidity and up to 15 times steel's strength. The graphic structure is preferred to the diamond-like crystalline structures to make carbon fiber because the graphic structure consists of densely packed hexagonal layers stacked in a lamellar fashion. **Polymer** – By aligning high molecular weight chains along the fiber axis, strong covalent polymer bonds can lead to impressive properties. Kevlar is an aramid (aromatic polyamide) made up of aromatic dominated strings, making them rigid polymers like rods. The stiffness can be as high as 125GPa and it has very low compression properties, although it is very good in stress. Kevlar fibers are mostly used in otherwise fragile matrices to improve strength.

c. **Ceramic** – Fibers made from materials such as aluminum and silicon carbide (silicon carbide) are suitable for very high temperature applications, as well as for the climate. Ceramics have

low stress and shear properties, so the majority of applications are in the particulate form as reinforcement.

ii. **Particle Reinforced Composites**

Larger particles (of few microns diameter) are used in this type of composite when compared with dispersion strengthened composite. The particles serves as the major load carriers, used to decrease the ductility and increase the modulus of the matrix. The automobile tire is a good example of a particulate material that has black carbon particles in a poly-isobutylene elastomeric polymer matrix. These are less costly and easier to make than plastic reinforced by fibre. Throughout polymer storage, particles can be easily added to the polymer matrix in an extruder or injection molder. The matrix, also does the load distribution and binding the particles together (NDT Resource Center, 2016).

2.3 Fiber Reinforced Composite Materials

Reinforcement have lengths greater than the cross-sectional dimensions in fibre-reinforced composites. Fibrous reinforcement is more of a mechanical means of improvement than a chemical means of changing a product to fulfill multiple applications of engineering (Fibre Science, 1995). These can be widely categorized as

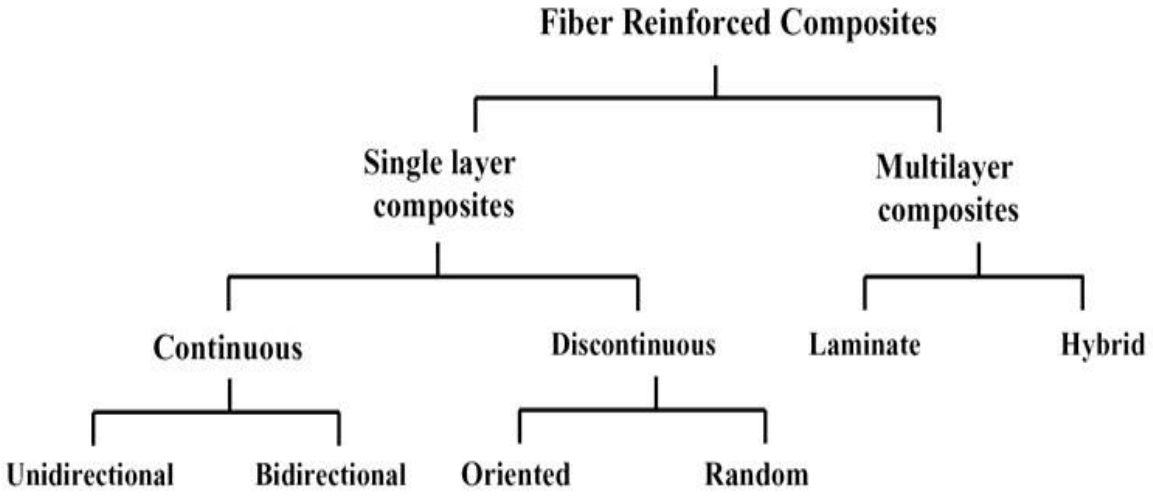


Figure 2. 1 Classification of fibre reinforced composite **(Fibre Science, 1995)**.

Based on overall dimensions, reinforcing fibre maybe short or long. Continuous fibres are those with long fibres reinforcement while the discontinuous are those with short or staple fibres embedded in a matrix. The fibre orientation in continuous fibres is unidirectional in order to produce enhanced strength properties. The length of short fibre is medium in short fibre composite. There is a wide difference between short and long composite fibre behavior.

2.3.1 Natural Fibre Polymer Reinforced Composite

Attention in the area of fibre reinforced composite is rapidly increasing from both the angle of researchers and industrialist. Natural fibres are cheap, renewable and recyclable. Examples of natural fibres used as reinforcement are pineapple ramie, cotton, sisal, kenaf, hemp and jute among others.

Because of their quality, renewability, low density and friendly mechanical properties, they are a good alternative to glass and carbon fibres. Natural fibre composite are environmentally friendly and finds application in building and construction, military and transportation industries (Chandramohan & Marimuthu, 2011).

2.3.2 Characteristics of Natural Fibre Reinforced Composite

A composite material consists of a continuous and discontinuous phase in which the discontinuous phase is harder and stronger, while the continuous phase is called the matrix. The matrix can be a metal, ceramic or polymer and forms the bulk of the material. The second phase embedded in the matrix is discontinuous and is usually stronger and harder than the matrix. The discontinuous phase strengthened and provides the composite overall mechanical properties. The geometry (length, shape and volume distribution) and reinforcement density also influences the properties of the material. The discontinuous phase can be triangular, prism, spherical or even circular, and the volume fraction can determine the interfacial region which plays as important role in deciding the degree of the matrix-reinforcement interaction.

2.3.3 Properties of Natural Fibre Reinforced Composite

The properties of composites (physical and mechanical) depends on the chemical composition of individual fibre (such as cellulose, lignin, hemicellulose, pectin, waxes, water content and other minors) under grooving and extraction/ processing methods conditions. The most recognized significant parameter for the variance of the mechanical properties of the fibres is grooving conditions (soil features, climate, aging conditions). The chemical composition of several natural fibers is summarized in Table 2.1

Table 2. 1 Chemical composition of natural fibers (Verma *et al*., 2003)

Fiber	Cellulose %	Lignin %	Diameter (µm)	Hemicellulose %	Elongation %
Coir	37	42	100 - 450	0.15	47
Banana	64	5	50 - 250	6 - 19	3.7
Sisal	70	12	50 - 200	10 - 14	5.1
Pineapple	85	12	20 - 80	16 - 19	2.8
Jute	71	13	15.9 - 20.7	13 - 20	3.0

Several factors, such as the length and diameter of the individual fibres affects the mechanical properties of natural fibres. The density and tensile properties are tabulated in Table 2.2.

Table 2. 2Properties of natural fiber materials (Abilash & Sivapragash, 2013)

Material	Densiy (g/cm^2)	Tensile strength (MPa)	Young modulus (GPa)	Failure strain (%)
Flax	1.45	500 - 900	50 – 70	1.5 - 4.0
Hemp	1.48	350 - 800	30 – 60	1.6 - 4.0
Jute	1.3	300 - 700	20 – 50	1.2 - 3.0
Bamboo	1.4	500 - 740	30 – 50	2
Sisal	1.5	300 - 500	10 – 30	2 - 5
Coir	1.2	150 - 180	4 – 6	20 - 40

2.4 Fibres

Fibres are hair-like material that are continuous and are identical to thread bits in isolated elongated pieces. You can spun them into filaments, strings or ropes. They can also be matted into sheets to produce products like papers or felt and used in composite materials (Bongarde & Shinde, 2014).

2.4.1 Classification of Fibres

Fibres for composite reinforcement can be classified in the figure below

- Natural fibers, and
- Artificial (Man-made) fibers

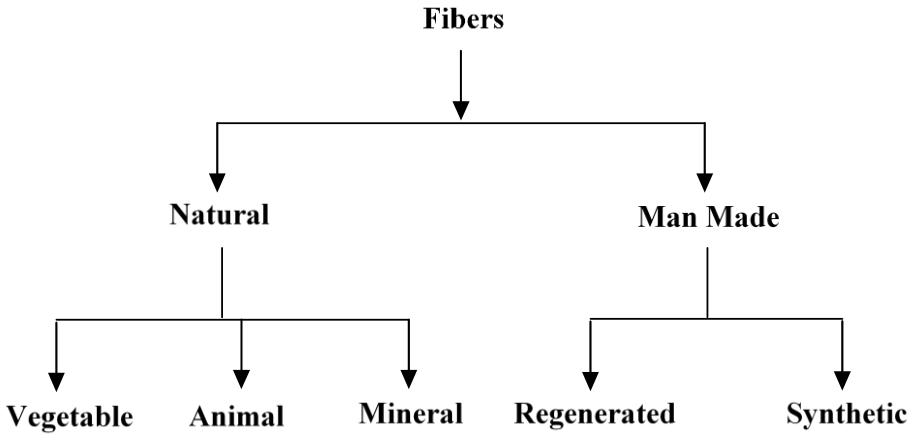


Figure 2. 2 Classification of Fibres

2.4.1.1 Natural Fibres

Depending on their source, natural fibres are mostly grouped into three:

i. Bast fibres: such as flax

ii. Seed hair: such as cotton

iii. Leaf fibres: such as sisal and abaca

Table 2. 3 The characteristics of these fibers - Mechanical Properties of Natural Fibres.

Fibre	Specific Gravity	Tensile Strength (MPa)	Modulus (GPa)	Specific Modulus
Jute	1.3	393	55	38
Sisal	1.3	510	28	22
Flax	1.5	344	27	50
Sunhemp	1.07	389	35	32
Pineapple	1.56	170	62	40
Glass fibre-E	2.5	3400	72	28

As observed from the Table 2.3, natural fibres are of less tensile strength than glass fibres though they have almost similar modulus. However, considering the specific modulus of the fibres, natural fibres had an advantage over glass fibres. Natural fibres are preferable in areas where weight reduction is desired.

Again, natural fibres can be sourced from animal, plant, mineral or even be man-made.

1) **Animal Fibers:** For general, animal fibers such as silk, wool, angora, mohair and alpaca contain proteins.

i. Animal hair (wool or hairs): Fiber or fur taken from poultries or hairy mammals. E.g. sheep's wool, goat hair (cashmere, mohair), alpaca hair, horse hair, etc.
ii. Silk fiber: Silk fibre obtained during cocoon preparation from fried saliva of bugs or insects. Examples of this include silk from silk worms.
iii. Avian fiber: They are fibers sourced from birds, e.g. feathers and feather fiber (Bongarde & Shinde, 2014).

2) Mineral fiber: Mineral fibres are slenderly modified or naturally occurring minerals. Examples are ceramic, asbestos and metal fibres (Chandramohan & Marimuthu, 2011).

3) Plant fiber: Plant fibers are those mainly comprising of cellulose. This fiber can be further categorized into following.

a) Seed fiber: They are sourced from seed and seed case. Examples are cotton and kapok.

b) Leaf fiber: They are fibers sourced from the leaves e.g. sisal and agave.

c) Skin fiber: Fibres are collected around the stem of their respective plant from the skin or bast. The strength of these fibres varies among plant source of the fibre. Therefore, for durable yarn, cloth, packaging and paper, these fibres are used. Flax, jute, banana hemp and soybean are some examples.

d) Fruit fiber: These are fibres whose source are hairy fruit plants, e.g. coconut (coir) fiber.

e) Stalk fiber: In addition, fibres are plants stalks such as wheat, straws, rice, barley, and other crops like bamboo and grass. Tree wood is another good example of this kind of fiber (Bongarde & Shinde, 2014)

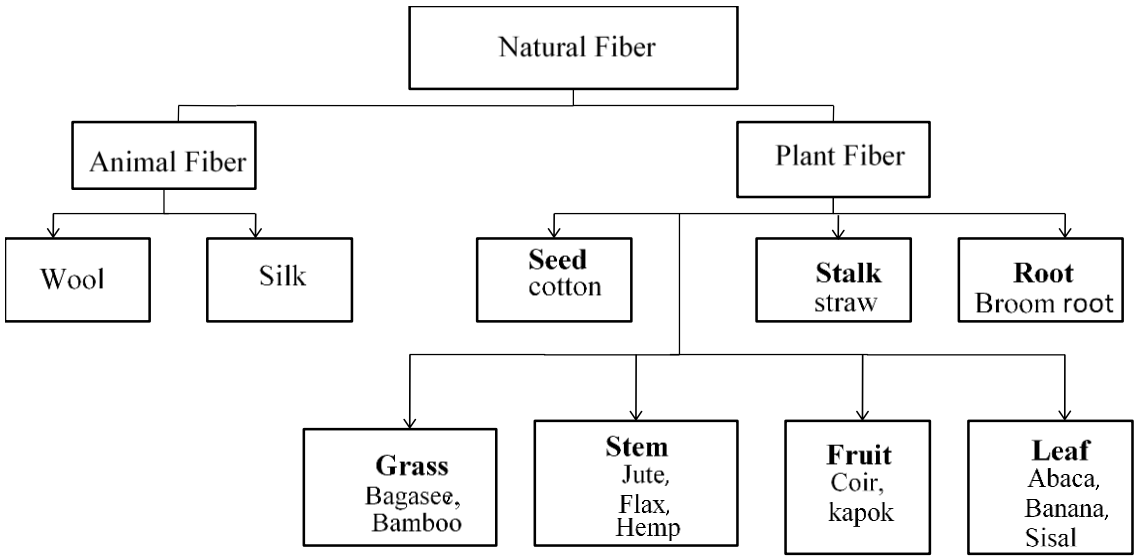


Figure 2. 3 Classification of Natural Fibres (Bongarde & Shinde, 2014)

2.4.1.2 Plant/Cellulose Fibre

Plant fibers are commonly known as either wood or non-wood fiber. Wood has properties that are major dependent on the type and location of a cell in the tree. Again, depending on the tree species, the mechanical properties of wood verity (Shinji, 2008 & Hughes, 2011). Wood is a mixture of cellulose

and lignin used in the manufacture paper as raw material. The rigidity of wood fibres is the product of the lignin that cements the fibres together. The elements of a natural are cellulose, hemicellulose, lignin, pectin, fat, wax and water soluble substances. Their compositions may differ according to species and growing conditions (Singleton, et al., 2003). Cellulose are the primary component of natural fibres. It is a linear polymer of condensation comprsing of units of D-anhydro-glucopyranose bonded together by β-1,4–glucosidic bonds.

2.5 Advantages of Composite Materials

Composites have advantages over their traditional counterparts, allowing them with a with strength-to-weight ratio to meet various design requirements. Some of the benefits of composite materials include:

i. Unit tensile strength is 4 to 6 times more than in steel or aluminum (depending on type reinforcements used).
ii. They have improved impact torsional rigidity properties.
iii. Energy embedded in composites is lower than other metallic structural materials such as steel, aluminum etc.
iv. Composites have better damping properties while in operation than metals.
v. Composites can meet complex design requirements and can be more versatile than metals.
vi. Long life with excellent fatigue, resistance to environmental factors and low maintenance.
vii. Composites have lower life cycle cost compared to metals.
viii. Composites have outstanding resistance to corrosion and fire.
ix. In composite joints and fastener are avoided (Chandramohan & Marimuthu, 2011).

2.6 Limitations of Composite Materials

Some of the demerits associated with advanced composites are as follows:

i. Raw materials and manufacturing costs are high.
ii. Composites can easily be damaged because they are more fragile when compared with metals.
iii. Matrices used in composite making are weak, therefore, low toughness.

iv. Disposal and reuse of composite may be difficult.

v. Difficulty when it comes to attachment.

vi. Composite repair brings about new problems, due to time consuming of curing, curing process requires special tools and technology, difficulty in analysis of the composite and matrix maybe subjected to environmental degradation.

2.7 Application of Composite Materials

Composite materials finds applications in the following areas;

i. **Aircraft/aerospace:** Although the composite materials used for aerospace application are minimal, they are mostly advanced materials produced using advanced technology.

ii. **Ship building:** Composite materials are used in ship building industry for producing different types of boats used for a variety of activities like transportation, submarines, lifeboats and motor boats.

iii. **Construction Industry:** Composite materials are widely used in constructing light and large houses, cooling towers, storage tanks, architectural features and many others.

iv. **Mechanical Manufacturing:** Composite materials finds application in lots of mechanical production ranging from fan blades, pumps, gears and other machinery parts.

v. **Electrical and Electronic Industry:** In electrical and electronics, composite materials are used as insulators, production of laminates, retaining ring and poles for street light.

vi. **Transportation Industry:** Cars, trains, and others transportation means are areas where composite materials are greatly used. In automotive industries for example, composite are used in the production of interior components such as dashboard, door panel, floor and other components. Composites are also used in railway transport in areas like the carriage door and passenger carriage. Composite materials have become the champion of the new materials in transportation (Ru-Min, Shui-Rong, & Ya-Ping, 2011).

vii. **Wind Power Generation:** Composite materials are used in wind generation mostly in the fan blades because of their light weight. The monetary value of power is substantially determined by the elements of the blade. Carbon and glass are duly utilized in the present day fabrication of blades (Piyoosh *et al.*, 2013).

2.8 Polyester Resin

Polyesters are macromolecules prepared through condensation polymerization of di-functional acids or anhydrides with di-functional epoxy resins or alcohol (Grayson & Eckroth, 1985). About 30 million pounds of polyester resin are produced worldwide (Goodman, 1988). They are used for commercial purposes such as manufacture of plastics, coatings and composite production (Morgan, 1965).

Polyesters are cheap, easily accessible and are used in quite a range of fields. They can be saturated or unsaturated (liquid form). Liquid polyesters can be stored for months and even years under ambient conditions. Catalysts are added to polyesters to facilitate its curing time. The curing time for polyesters as a function of the catalyst decomposition rate which can be improved by raising the temperature. The decomposition rate of catalyst can be enhanced by adding a small quantity of an accelerator such as cobalt nalphthanate (Mallick, 2007). When cured, polyesters are usually transparent and rigid or flexible. Depending on the service requirements and resin formulation, they can be used for up to about 75ºC or higher. Polyesters have other merits such as compatibility with few glass fibers.

2.9 Review of Past works

A number of studies were carried out on several types of natural fibers to study how these fibers when sue in the fabrication of composites affects their properties and to determine the suitability of their usage for automotive application;

Pandiatmi, *et al.*, (2019) researched to optimize the bending strength of polyester composite with coastal cottonwood tree bark fibrea and fly ash as filler. Mathematical model using the response surface

method with central composite design were used to analyse the obtained. Minitab 16 software was used by the reseaches in processing the results. A model equation was developed from the analysis of the results for maximum bending strength as $100296 + 5009X_1 - 2710X_2 - 10285X^1_2 - 3006X^2_2 - 1415X_1xX_2$. The best condition of the developed composite material was found to be at 52.79% fibre volume fraction and 9.73% filler volume fraction with a bending strength of 100.05 MPa.

Yuhazri, *et al*., (2018) carried out a research to compare the properties of wooven and non-woven kenaf/epoxy composite for automotive car door map application. Hand lay-up technique was used to manually produce a composite from which tensile and flexural strength were tested for. The obtained properties of the developed composite were compared with properites of an already existing material already in use for car door map application. The addition of both wooven and non-woven kenaf fibre into epoxy resin increases its stremgth. The maximum tensile force and flexural strength were observed to be 6.08 kN and 111.87 MPa. The findings showed that the possibility of using the developed material to replacing existing material used in Car door map pocket.

Appusamy, *et al*., (2018) experimented on the mechanical properties and charactriazation of parathemium short fibre reinforced polymer matrix composite. Parathemium plant fibres were extracted and used as reinforcement in epoxy resin to produce the composite. Impact, hardeness and flexural properties of the material were studied after been subjected into a solution of different concentration. The result findings revealed that the hardness and impact properties of the material increased with increase in chemical concentration used for surface treatment of the fibres. However, the flexural strength decreased with increased amount of chemical concentration. They suggested the material can be used for automotive application.

Guptaa & Singha, (2018) worked on flexural and Dynamic Mechanical Analysis (DMA) of Ploylactic Acid (PLA) coated sisal fibre reinforced polyester composite. The result showed a positive effect upon

incoorporation of PLA coated sisal fibres into polyester resin. PLA coated composites were observed to better flexural performance such as breaking force of 131.32 N, flexural strength of 65.2 MPa, flexural modulus of 1.854 GPa and percentage elongation of 13.25% than polyester and pure sisal composite with 98.66 N, 49.33 MPa, and 1.266 GPa and 15.8% as breaking force, flexural strength, flexural modulus and percntage elongation respectively. Higher storage modulus E´ was observed in PLA coated composite than the polyester and pure sisal composite which was attributed to good interfacial bonding between the fibre and matrix. Polyster samples were observed to have the highest damping factor due to molecular motion at higher temperature than composite samples of PLA coated sisal and pure sisal.

Islam, *et al*., (2017) studied the effect of coconut shell powder as filler on the mechanical propeerties of coir-polyester composite. The addition of coconut shell powder (CSP) as filler material into coir polyester composite improved the mechanical properties of the material. Maximum tensile, flexural and impact strength of the resulting composite were found to be 26 MPa, 57 MPa and 52 kJ/m^2 respectively which are obtained at 30wt% content of the reinforcing material. The research showed that the addition of coconut shell powder as filler into coir-polyseter composite improved the mechanical properties of tensile , flexural and impact strength by 44.44%, 128% and 62.5%respectively than the unfilled composite.. The research also revealed that the gamma radiation of the composite is improved by the addition fo the foller material.

Das, (2017) studied the mechanical and water swelling properties of waste paper reinforced unsaturated polyseter. Composites samples were compounded in three different compositions of 30, 40 and 50wt% of shredded waste paper. Tensile and flexural strength of dry and wet samples were studied while X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) was used in the characterization of the composite. Maximum tensile strength of dry and wet samples were found to be

70.2 ± 8.72 MPa and 50 ± 7.71 MPa respectively at 50wt% while flexural strength was 96.76 ± 13.83 MPa and flexural modulus of elasticity was 74.71 ± 14.27 MPa all for the dry samples and equally observed at 50wt% waste paper reinforcement. The result findings concluded that the moisture absorption by the composite have a decreasing effect on the tensile, flexuaral and Interlaminar Shear Strength (ILSS) of the composite. Fibre content and percentage of moisture uptake increases with increase in fibre volume fraction due to increase in cellulose content in the reinforcing material.

Choudhury, *et al.*, (2017) investigated the effect of particulate filler on mechanical properties of polyester based composite. The polymer composite materials were successfully developed using hand-lay-up echnique with glass/carbon fibre filled with different percentages of silicon carbide particles. Hardness, flexural and impaact strength if the developed composite were evaluated. The research findings showed a reduction in the flexural strength of carbon-polyester, glass-polyester and hybrid-polyester as the percentage of silicon carbide (SiC) increases. Impact strength of the three composite gradually decreases with SiC as filler at 2.5wt%, but increases with further addition of SiC at 5wt%. It was concluded that the incoorporation of SiC filler modifiied the flexural and impact strenght of the composite for glass, carbon and hybrid fibre reinforcement.

Eskezia, *et al.*, (2017) carried out an analysis on the finite element of internal door panel of a car considering Bamboo fibre reinforced epoxy composite. A suitable model of internal door panel of Toyota DX model was developed and transient dynamic sructural anlysis of the internal door panel was conducted using finite element method. The performance of the Bamboo Fibre Reinforced Epoxy Composite (BFREC) was compared with the performance of previously recommended material in use. Analysis of BFREC using CATIA V5 R20 modelling software shows the minimun mass equivalent, stress values of the front door to be 1.34 Kg and 36.58 MPa while for the rear door 1.2 Kg and

36.63MPa. The analysis after comparison with previous materials in used showed suitability and recommended the use of BFREC for internal structural automotive panel.

Hanamanagouda, *et al*., (2016) worked on the mechanical properties of raw jute polyester composite. Volume of the jute fibres in random orientation were varied from 0-25% with an increment of 5% to develop the polymer composite using hot compression moulding. They produced composite samples by varying the the thickness of the samples between 3-5mm. The research showed that the tensile strength of the composite increases as volume percentage of the reinforcing fibre increases upto 25% for both samples of 3mm and 5mm with a tensile strength of 43.6 MPa and 37.28 MPa respectively. Flexural strength also increased as the fibre content increases with 3mm samples showing better strength than samples of 5mm thickness with 246.46 MPa and 152.3 MPa recorded for 3mm and 5mm samples. Similar trend was seen for impact test with the 3mm sample at 25% filler content absorbing more impact energy of 147.5 N-m while 5mm specimen absorbed 10.91 N-m at 25% filler content.

Ataguba & Clement, (2016) Conducted a research to determine the properties of ceiling boards produced from composite of Waste Newspaper (WNP) and Rice Husk (RH) with industrial starch as a binder. Thermal conductivity, water absorption, modulus of elasticity and flexural strength of the material were tested. The results obtained from the study showed that thee material with a composition of 60%:40% WNP/RH mix can give optimum performance and compares favorably with conventional ceiling materials as light, weight/low density ceiling boards and can be used in low cost building work in Sub-urban and rural areas in developing countries.

Shafiur Rahman, *et al*., (2015) In their research work made comparison between recycled waste paper reinforced polymer composite and hardboard. Samples of Paper Board Reinforced Polymer Matrix Composite (PBRPMC) were fabricated using polyester resin. Mechanical properties, surface morphology and water absorption capacity of the composite were examined. The prepared PBRPMC's

mechanical properties such as tensile strength, flexural strength, cracking strength, and structural impact strength were much higher than hardboard, and PBRPMC's water absorption ability was much lower than hardboard. The Tensile Strength (TS) of PBRPMC was 26 MPa and Flexural Strength (FS) to be 49.25 MPa which showed better strength as compare to hardboard with TS value as 3.73Mpa and FS value of 5.35 MPa. Water absorption capacity of PBRPMC was better than that of hardboard with about 2%.

Oriyomi & Oluwatobi, (2014) In their research on "Assessment of the Suitability of Paper Waste as an Engineering Material" assessed the suitability of paper waste as a civil and architectural material. Shredded waste newspaper was watered, dewatered and mixed with CaCO3 and cement to produce samples of varying mixture proportion of 1:1, 1:1.5 and 1:2. Abrasion, flexural and compressive strength test as well as water absorption rate and modulus of elasticity test of the composite were determined. The test result showed a better property of the fabricated material for compressive, flexural and water absorption with 3.50 N/mm^2, 0.31 N/mm^2 and 17.00% respectively (which is at a mix ratio of 1:1). They determined the modulus of elasticity as 0.1 N/mm^2 which was within the required standard of 2 N/mm^2 by ASTM 208-72.

Vijaya *et al.*, (2014) studied the dielectric strength of particulate reinforced composite of industrial waste (with used papers inclusive) with the effect of silane coupling using unsaturated polyester and polypropylene. Samples were produced with 0%, 0.3% and 0.5% silane coupling each for unsaturated polyester and polypropelene. Their result showed that silane coupling enhances the dielectric strength of the samples with samples from polypropylene having stronger dielectric strength than unsaturated polyester.

Velev, Takev, & Samichkov, (2014) experimented on the physical and mechanical properties of aged and non-aged polymer composite using polypropylene matrix with 10% fiberized old newspaper oxo-

degradeble. The influence of filler treatment with polyvinyl acetate water dispersion with carboxymethyl cellulose on the properties of external flat foil made of composite was studied. The properties of the obtained composite upon the addition of lignocellulose filler material was observed to be significantlly improved. Weather resistance of the foil product increases as well as the physical and mechanical properties of the composite upon the use of polyvinyl acetate as filler material.

Reis, *et al.*, (2014) studeid the mechanical properties of Recycled Kraft paper residue polyester composites. Kraft Paper Residue(KPR) was utilised as reinforcement in unsaturated polyester matrix in shredded form of 30, 40 and 50wt% proportions of reinforcement. The produced composite was characterized based on tensile andn flexural properties. Tensile properties were observed to increase with increase in the percentage of KPR in polyester resin with laminate samples exhibiting higher strength of 65.95±1.23 MPa for UTS and 46.17±3.77 GPa for tensile modulus. Similarly, results of flexural strength was reported to be fluctuating for 30, 40 and 50wt% KPR reinforcement but with laminated samples showing maximum values of 104.47±8.4 MPa and 4.99±0.36 GPa for flexural strength and flexural modulus of elasticity.

Serrano, *et al.*, (2013) estimated the shear strength, orientation factor and mean equivalent instrinsic tensile strength in old newspaper fibre/polypropylene composite. They produced composite samples compounded with 40wt% ONF fibres, 0-80% of MAPP and 15% calcium carbonate as binder. The result showed ONPas potential reinforcement of PP composite when a 2-6wt% of MAPP was added. The equivalent mean intrinsic tensile strength of ONP fibres at failure was found to be 514.3±34.7 MPa. The mean orientation factor of the ONP/PP/MAPP composite was found to be 0.346±0.02 representing a mean oreintation angle of 39.9^0, and mean interfacial shear strength of ONP/PP/MAPP composite to be 14.57±0.63 MPa.

López, *et al.*, (2013) evaluated the mechanical, thermal and water sorption properties of Newspaper fibre reinforced thermoplastic starch biocomposite obtained by melt processing. Composite samples were produced with thermoplastic starch (TPS), glycerol as plasticizerin content of 20 and 30wt%and polybutylene adipate-co-terephthalate(PBAT) as biodegradeble polymer. Result of the research showed that the recovered fibres from newspaper effectively act as reinforcement by increasing the tensile properties of TPS by about 260% (10.56 MPa0). PBAT addition to the composite formulation caused a sharp decrease in the water uptake of the composite. Thermal analyses using DTMA evidently showed that the reinforcing fibres had little to no effect on the thermal decomposition of TPS.

Aramide, *et al.*, (2012) experimented on the mechanical Properties of a Polyester Fibre Glass Composite'. Fibre glass polyester composite samples with fibre glass were fabricated with different fibre glass volume fractions (5%, 10%, 15%, 20%, 25% and 30%). Tensile, flexural and impact properties of the materials were determined. The reseach showed improvement in the tensile and flexural properties with increase in fibre glass volume and then characterise fibre-glass composite with high toughness. 0.25 was concluded to be the optimun volume fraction of fibre glass.

Ayrilmis, *et al.*, (2011) carried out a researh "Coir fibre reinforced polypropylene composite panel for automotive applications". In the study, the physical, mechanical and flammability properties of coconut fibre reinforced polypropylene composite were investigated. The result a significant improvement in the tensile properties and water absortion capacity of the material by dimensional staability of the composite. The maximum tensile strength, flexural strength and modulus of elasticity and Janka hardness value as 17.8 MPa, 30.6 MPa, 3345 MPa and 4916 N respectively. Based on the findings, the optimal formulation of the composite was obtained from a mixture 60wt% coir fibre, 37wt% polypropylene and 3wt% MAPP. Morealos, the findings suggested the use of the produced composite for automotive non-structural application as a door pannel.

Rezaei, *et al.*, (2008) carried out a research on the development of short-carbon fibre-Reinforced Polypropylene (SCF/PP) composite for car bonnet application. Composite were produced five samples of carbon-fibre and polyproplene using melt blending and hot-pressing technique. Tensile, flexural, hardness and impact properties of the produced composite were determined. The results of their findings shows as increase in the tested proeprties of the material with increase in the length nad composition of the fibre. Maximum tensile strength and modulus, hardness and impact strength of the material were 40 MPa, 4610 MPa, 97HRF and 44 J/m respectively. The findings showed that SCF/PP composite with 10wt% reinforcement is a good option for replacing commercial steel bonnet.

Shan Ren & David, (1993) carried out a reseach on nrewspaper fibre reinforced (NPF) polypropylene(PP) composite. The reseach aimed at examining the effects of manufacturing conditions, additives and interfacial modification on the mechanical properties of the NPF composite. Maliac ahydride modified polypropylene (MAPP) was used as a coupling agent for interfacial enhancement. The research findings show that composite made by direct application of newspaper sheets into PP doubled the strength of the composite. The reseach also showed that it is possible to use other natural fibres such as chemical wood pulp, thermomechanical pulp, recycled corrugated board to enhance the properties of PP.

2.11 Reseach Gap

From the extant literature reviewed, most reseaches carried out are to determine the suitability of applying composite materials made from natural fibres for automotive non-structural application. Again, other reseaches carried on newspaper as reinforcemnet in composite materials making focused on finding the possilities of using waste newspaper as building materials or the characterization of its properties. To the best of my knowledge, no reseach was carried out to determine the possible usage of newspaper as reinforcement for automotive interior application. Hence, this reseach tends to bridge that gap and equally provide another alternative for managing waste newspaper.

2.10 Theoretical Background

2.10.1 Tensile Strength

Tensile test is an essential and general engineering test to obtain parameters related to a material like ultimate tensile strength, yield strength, percentage elongation and area reduction, and Young Modulus. Material selection for engineering application is made based on the parameters obtained from the tensile analysis of the material. Tensile strength of a material indicates how the material reacts when subjected to tensional force (Khurmi & Gupta, 2008). It also gives information about the capability of a material to stretch prior to its failure. The tensile strength will be evaluated using the relationship below;

Tensile Strength $\sigma_t = \frac{F}{A}$ (N/m^2) ---------- 2.1

Tensile Modulus = $\frac{Fl}{Ae}$ (MPa) ---------- 2.2

A is rectangular cross sectional area: b x t (mm^2)

e is the extension of the material

l is the gauge length of the sample (mm)

2.10.2 Compressive Strength

It measures the compressive load required to compress or crush a material. Other properties of a material that can be determined from compressive strength include modulus of elasticity, yield stress and deformation beyond yield point.

The compressive strength of the material can be determine using the formula below (Rajput, 2008)

$\sigma_C = \frac{P}{A}$ ---------- 2.3

Where A = $b \times t$

b is the width of the composite sample (mm)

t is the thickness of the composite sample (m

2.10.3 Flexural Strength

Flexural strength gives the extent to which a material will behave when subjected to simple beam loading condition. Flexural strength test is done on flexible materials such as polymers, wood and composites. Two test method are usually available; 3-point flex and 4-point flex. The test measures the required force/load to bend a beam under point loading. The results analyzed helps in selecting material that will support point loading (Bower, 2009).

The flexural strength was calculated thus;

$$\sigma_f = \frac{3PL}{2bd^2} \text{----------2.4}$$

$$\text{Modulus of Elasticity (MOE)} = \frac{PL^3}{4bd^2D} \text{ ---------- 2.5}$$

Where σ_f is the Flexural strength in (MPa)

P = maximum force at failure (KN)

d = height of the beam (mm)

L = length of the beam (mm)

D = Deflection of the beam (mm)

b = width of the beam (mm) (Rajput, 2008).

2.10.4 Hardness Test

Hardness of a material is the resistance of the material to scratch, cutting, indentation or abrasion. It is measured in several scales such as Rockwell hardness, Brinell hardness, and Vickers hardness (Elia, 2003). The result of hardness test of a material are usually expressed in numbers according to a particular accepted scale of the measurement. Hardness of a material is a characteristic of the material derived from its composition, thermal and mechanical history of the material which are essentially th

microstructure of the material. Higher hardness values obtained from a material implies low indentation while lower values implies deep indentation (Senthiil & Sirsshti, 2014).

2.10.5 Water Absorption Capacity

Water absorption of a composite material is the amount of moisture or water the material absorbs when immersed in water for a particular period of time. The amount of moisture absorbed by a material significantly affects the physical and mechanical properties of that material, as well as its dimensional stability and durability. Mechanical properties are deteriorated as water is absorbed by a composite material as water not only affects unfilled polymer matrix physically or chemically but also damage the fibre-matrix interface and the hydrophilic natural fibres (Panthapulakkal & Sain, 2007). Assuming one-dimension based Frick's law, the water absorption capacity of the composite is calculated using the formula below:

$$W\% = \frac{Wt - Wo}{Wo} \times 100\% \quad \text{---------- 2.6}$$

where W_o and $W_{(t)}$ denotes the oven-dried weight and weight after time t, respectively.

2.10.6 Thermal Properties

2.10.6.1 Thermal Conductivity

Thermal conduction is a process in which heat transfer takes place by kinetic motion or direct impact of molecules from an area of higher temperature to that of lower temperature. Higher molecular energies arise from higher temperatures and when higher energy molecules interact with lower energy molecules, energy transfer takes place. The simplest conduction heat transfer can be describes as "one dimensional heat flow". The heat conduction empirical law is named after Joseph Fourier who used it in his theory of heat analytics. This law states that the rate of heat flow by conduction in a given direction is given as

$$q_x = \frac{Qx}{A} = -k\frac{dT}{dx} \text{ ----------2.7}$$

Where q_x: heat flux in the positive x direction (W/m^2)

Q_x: rate of heat flow through area A in positive x direction (W)

A: Sectional Area (m^2)

k: thermal conductivity (W/m°K)

$\frac{dT}{dx}$: Temperature gradient in x direction (°K/m).

2.10.6.2 Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis (DMA) is the process by which a stress or strain is applied to a specimen and the reaction is analyzed to obtain phase angle and deformation information. The theory of DMA calculation is such that a sinusoidal stress is applied and the resulting strain in the material is measured so that the storage module, loss module and tangent loss or damping variable can be calculated. By studying the dependence of these parameters on temperature or frequency, it is possible to show the dynamic mechanical properties (such as thermodynamic transitions and other molecular relaxation) of the materials and their applications (Oboh, *et, al.,* 2018). DMA has been a reliable test in analyzing the thermal behavior of a material. DMA makes the calculations of storage modulus (E´), loss modulus (E´´) and the damping factor possible as a material is subjected to certain temperature change and deformation frequency. Results are typically provided as a graphical plot of E', E'', and Tan δ versus temperature. Transition regions (such as glass transition temperature) can be identified and used for quality control or product development (Reddy & Reddy, 2014).

2.10.7 Tribology

Tribology is the study of surfaces that are interacting in a relative motion. It includes wear lubrication, frictional field, solid to solid as well as solid to liquid interaction. Friction is the opposition to motion whenever solids interact. Wearing of a surface allows us to understand the extent of material's damage

or removal from one or both sides of interact solid surfaces. Wear happens mostly when surface irregularities interact. Wear and friction are not material properties, but a tribo system's reaction (Witold, *et al.*, 2010). Abrasion and erosion processes are most of the common wear mechanism in industrial application that shortens the life span of expensive machine parts. Abrasive wear, which accounts for 63% of the total cost of wear, occurs when hard asperities of one surface travel over another softer surface under pressure, penetrates and extracts material from the softer surface, leaving grooves and cracks (Neale & Gee, 2001). It is indispensable to have a knowledge of wearing processes under precise sliding conditions for components subjected to tribological loading. Breakage is not the only major reason behind failure of sliding parts but also surface deterioration or wear due to rubbing against hard surfaces (Avci, *et al.*, 2013).

The eqautions (2.8) to (2.11) used in calculating the specific wear rate of the produced composite material are:

Weight loss $\Delta w=(w_1-w_2)$ ---------- 2.8

Where Δw is the weight loss (g)

W_1 is the weight of the sample before abrasion test

W_2 is the weight loss of the sample after abrasion test

Volume loss (ΔV) of the specimen was estimated in the following manner:

$$\Delta V = \frac{w1-w2}{\rho} \times 1000 \quad \text{---------- 2.9}$$

ρ is the experimental density of the composite material (g/m^3)

The Specific wear rate W_s (m^3/Nm) of the composite shall be calculated in the following manner:

$$W_s = \frac{\Delta V}{F_n \times S_s} \quad \text{---------- 2.10}$$

Where F_n is the applied load (N)

S_s is the sliding distance (m) (Gaurav, *et al.*, 2013).

2.10.8 Surface Treatment of Fibres

2.10.8.1 Alkaline Treatment

Alkaline treatment is among the most common chemical treatment in natural filler when they are used as reinforcement in polymer composite. Researches showed that alkaline treatment to be more effective than acetylation (Srinivasa, *et al.*, 2017). Hence, alkaline treatment was adopted in this research work. The distribution of hydrogen network is the major modification done in alkaline treatment of natural filler thereby increasing the surfaces roughness of the filler (Li, *et al.*, 2007).

Addition of aqueous sodium hydroxide enhances the ionization of the hydroxyl group to the alkoxide. The reaction taking during the procedure is shown below (Rakesh et. al, 2011):

$$NaOH + Fiber\text{-}OH \rightarrow Fiber\text{-}O\text{-}Na^{+} + H_2O$$

Alkaline treated filler showed improved properties (60% increase tensile strength, 40% in flexural strength and 30% in impact strength) than those treated with lower and higher alkaline concentration. This is as a result of enhanced aspect ratio in the matrix and so the interaction area between the filler and matrix (Liu, *et al.*, 2007).

Because of the lignin and hydroxyl groups from cellulose, natural filler responds to surface modifications. The hydroxyl group is involved in the hydrogen bond formation in the cellulose molecules as such reducing the activity of the filler in polymer matrix. Chemical treatments mostly introduces new molecules or energized the hydroxyl groups and effectively brings about a better interlock with the matrix. Polarity and surface tension of filler can be changed by applying simple chemical treatments to the filler (Farsi, 2012).

2.8.10.2 Silane coupling

Silanes are used in the surface treatment of natural filler to enhance their bonding and stability with polymer matrix. They reduce the number of cellulose hydroxyl groups in the interface between the filler and matrix leading to the formation of silanols. Silanols react with the hydroxyl groups of the filler to form a covalent bond. By the application of silanes to natural filler, hydrocarbon chains are formed which restrain the swelling of the filler by creating a cross linked network from the covalent bonding of the filler and the matrix (Xie *et al.*, 2010).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Materials

The materials used in the research work were:

a) Waste newspaper

b) Polyester resin

c) Methyl ethyl ketone peroxide (MEKPO)

d) Cobalt (II) nephthanate

e) 3-(Trimethoxy silyl) propyl methacrylate

f) Lubricant

g) Litmus paper (Red)

h) Sodium hydroxide (aqueous solution)

i) Acetic Acid

3.2 Equipment/Machines

a) Mould

b) Bunsen burner

c) Beaker (S-Pyrex, 250 ml)

d) Sensitive Weighing Machine (Adventurer, Model: AX222/E, Serial No: B424708773, Readability 0.001 g)

e) Tensile testing machine (House field extensometer, Cross head speed-7.5mm/min, Capacity-20 KN)

f) ENPAC Universal Testing Machine (Cat.Nr.261) - 100KN load capacity

g) Impact testing machine (Charpy Universal Impact Testing Machine, Cat.Nr.412)

h) Hardness testing machine [VICKERS Hardness Testing Machine, MVI-PC, Model: 8187.5 LKV(B)]

i) Scanning Electron Microscope (SEM) machine (Phenom ProX by PhenomWorld)

j) Tribometer (Anton Paar 6.1.19 Tribotester)

k) Dynamic Mechanical Analyzer (DMA 242E, Artmis)

l) Fourier transform infrared spectroscopy (FTIR) Analyzer (CARY630, Agilent Technologies)

3.3 Methodology

3.3.1 Formation of WNP

Waste newspapers were collected from vendors around Samaru, Zaria. The papers were cut into smaller sizes of an average size of 30 – 40 mm. The cut newspapers were soaked in tap water for a period of 72 hours after which they were grinded into paste for ease of treatment of the surface. The grinded paper paste was water drained and later completely sun dried.

3.3.2 Alkaline Treatment

A 5% concentration aqueous solution of NaOH was formed and used to soak the sun dried grinded paper particulate. The paper was soaked for 42 hours in the aqueous sodium hydroxide solution after which it was washed distilled water in other to neutralize the alkalinity of the particulate. Litmus paper was used to test the basicity of the washed paper particulate. The washing process was done until there was no change on red litmus paper, and then later dried under the sun. Alkaline (sodium hydroxide) treatment enhances the ionization of the hydroxyl group to the alkoxide.

3.3.3 Saline Coupling

3-(Trimethoxy silyl) propyl methacrylate was chosen in this work because of its better bonding with polyester resin. The alkaline treated paper particulate were further treated in a 1% concentration of 3-(Trimethoxy silyl) propyl methacrylate solution. The particulates were soaked in the silane solution for 42 hours, sun dried and later sieved using a sieve of 710 μm. 3-(Trimethoxy silyl) propyl methacrylate was choose because of its better bonding with polyester resin. With the silanes treatment of the particulate, hydrocarbon chains are formed which restrain the swelling of the particulate by creating a cross linked network from the covalent bonding of the particulate filler and the matrix.

3-(Trimethoxy silyl) propyl methacrylate with 1% concentration was used for the silane treatment of the already alkaline paper fibres.

3.3.4 Casting of Composite

The surface treated WNP was weighed to 5, 10, 15, 20 and 25 weight percentage of the cast polyester (control) samples. The weighed particulates were thoroughly mixed with polyester resin already measured and poured into a beaker. 1% volume of Methyl ethyl ketone peroxide and cobalt (II) naphthanate were added into the mixture of the polyester and particulate filler and stirring was continued manually for about five minutes. The composite mixture was then poured into mold produced according to ASTM specification for various test samples. The composite mixture was allowed to set in the mold for 2 hours. Petroleum jelly was applied at the surface of the mold as lubricant for easy removal of the composites after setting. The produced composite samples were further dried under the sun for additional period of 72 hours before test were carried out.

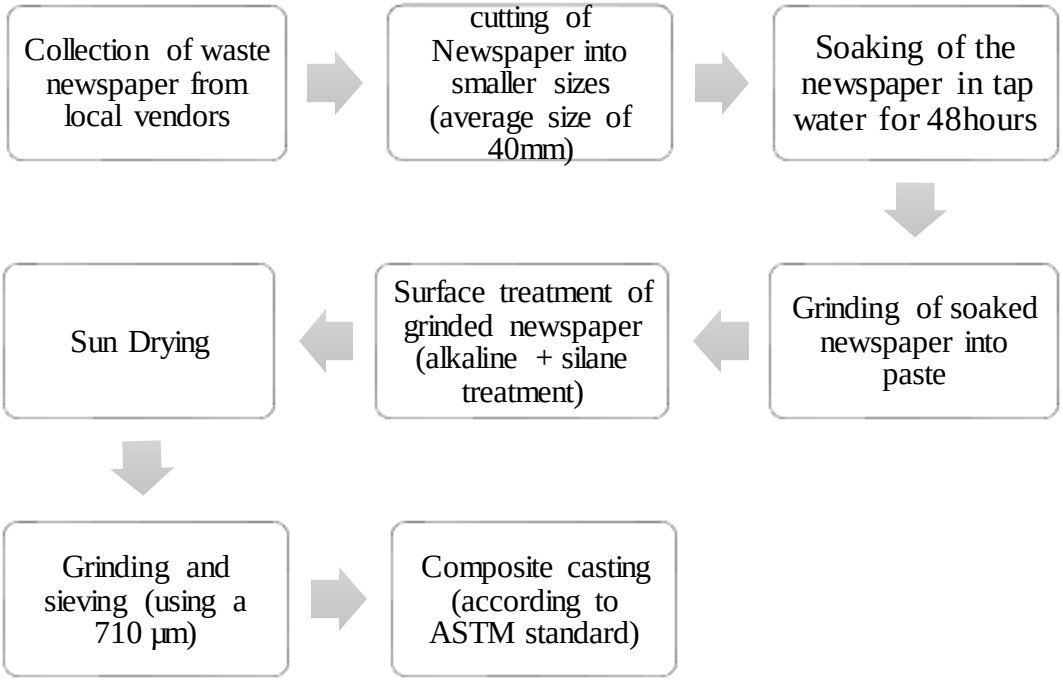


Figure 3. 1 Flow Chart of Composite Development.

3.3.5 Determination of Mechanical Properties Test

The tested mechanical properties of the material were tensile, compressive, flexural/bending, impact strength and hardness. Test samples were produced according to ASTM specifications (D638 for tensile, D368 for compressive, D790 for flexural, A370 for hardness and D7136 for impact test).

3.3.5.1 Tensile

Tensile test samples were produced according to ASTM D638 specification with a gauge length of 35mm. The samples were mounted on a Monsanto Tensometer Motor Drive testing machine (with a serial No of 4612 and a load capacity of 20 kN) and then subjected to tensile loading. The force applied and the corresponding extension were recorded and used in the calculation tensile properties such as stress and strain. The test was carried out at the department of mechanical engineering, Ahmadu Bello University, Zaria. Five samples were produced for each composition of particulate filler reinforcement and the average reading was calculated and reported.

3.3.5.2 Compressive

Compressive strength of the composite was tested using ENPAC Universal Testing Machine (Cat.Nr.261) with a 100 kN load capacity was used. The test was done according to ASTM D368 standard. Five samples each for all the different filler composition having a dimension of 20 mm by 20 mm by 20 mm were cast. Test samples were mounted on the testing machine and a compressive force was applied until the sample fails. The compressive force at the failure of the sample was recorded and used in equation (2.3) to calculate the compressive strength of the composite material.

3.3.5.3 Flexural Strength

Five test samples for each composition were cast according to ASTM D790 specifications (5 mm x 40 mm x 100 mm) and tested for flexural strength. The samples were mounted on the testing machine at a span distance of 40 mm. Flexural load was applied on the material until it fails at which the failure load of the material was recorded. The average load value of five samples for

each of the different composition was recorded and used in equation (2.4) and (2.5) for further analysis of the flexural strength.

3.3.5.4 Impact Strength

Toughness of the composite material was tested for using the Charpy impact testing. Five samples each for the different proportion of the filler reinforcement were cast according to ASTM D7136 standard with length, width and thickness as 90 mm x 10 mm x 10 mm respectively. The samples were V- notched with at angle of 45^0 and depth of 2 mm ± 0.5 mm. the test samples were mounted on the stationary clamps of the machine and a pendulum hammer released to hit the mounted sample at an average speed of 1.5 m/s and a falling angle 60^o. The impact force that breaks the material was recorded.

3.3.5.5 Hardness

VICKERS Hardness Testing Machine [MVI-PC, Model: 8187.5 LKV (B)] was used in determining the hardness property of the composite material according to ASTM E 18-15 standard. For the material being polymer composite, the hardness scale of F was used. The indenter was steel ball of 1/16inch (1.6mm) diameter. The samples were subjected to a preload and total load of 10kg and 60kg respectively. The average reading of five different surface locations on the material were taken for each of the particulate filler composition.

3.3.6 Tribology

Test samples were produced according to ASTM G99 specification with a thickness of 10 mm and a diameter of 20 mm and mounted on a tribo testing machine (Anton Paar 6.1.19 Tribotester). The sample was subjected to a load of 5 N, arm distance of 32 mm, 5 mm radius of ball from disc centre, and turning speed of 200 rpm for 5 minutes. The weight of the sample before and after the test were recorded and used in equations (2.8), (2.9) and (2.10) to calculate the specific wear of the samples.

3.3.7 Thermal properties

3.3.7.1 Thermal Conductivity

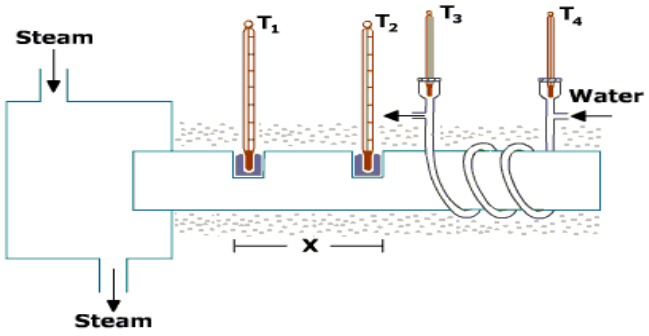


Figure 3. 2 Schematic set-up of thermal conductivity test

.

The figure shown above is that of the Searle's apparatus was used to measure the thermal conductivity of the developed composite. The thermal conductivity of the composite samples were determined using Searle's apparatus at the laboratory of the Physics department, Ahmadu Bello University, Zaria. Heat was supplied to one end of a copper bar by means of electrical power. Water from a reservoir was supplied to the heated copper bar to one end at a constant rate until heat energy in the copper bar reached an equilibrium. Two thermometers T_h and T_c measure the inlet and outlet temperature of the water into the apparatus, while two other thermometers T_3 and T_4 were positioned on the set-up to measure the heat at those positions. The current and voltage causing the heating effect were recorded. The heat flow is governed by the equation:

$$Q_{in} = VI \text{----------} 3.1$$

Heat in and out was governed by the equation

$$Q_{out} = KA(T_h - T_c)/t \text{----------} 3.2$$

Where Q is the heat transfer (W)

K is the thermal conductivity material (W/m-k)

A is the cross sectional area of the heat transfer region (m^2)

$T_h - T_c$ is the difference in temperature between the hot and cold region of the bar (K)

The composite sample is placed in the heat transfer region to measure the heat transfer of the material. The sample was cast according to the ASTM E1530 with a thickness of 8mm and a diameter of 40mm. Equation 3.1 to 3.3 were used to compute the heat conductivity of the composite material.

$$K = \frac{VIT}{A(Th - Tc)} \text{ ----------3.3}$$

3.3.7.2 Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analyzer DMA 242E Artmis was employed at Mechanical Engineering Department, Ahmadu Bello University, Zaria to determine the storage modulus (E′), loss modulus (E′′), damping factor (tan δ) and glass transition temperature curves of the developed composite samples according to the ASTM D4065 standard. Test samples were cast (50 mm by 12 mm by 4 mm) and tested under loading frequencies of 2.5Hz, 5Hz and 10Hz using a dual cantilever configuration. The samples were heated with a heating ratio of 6 K/min from 24 ^{o}C to 130 ^{o}C and a deformation amplitude of 60µm. The obtained results of E′, E′′, tan δ and glass transition temperature were determined to evaluate the effect of WNP and its reinforcement variation on the mechanical behavior on polyester resin.

After a particular test, the test machine was allowed to cool down to a temperature of 24 ^{o}C before another sample was loaded onto the machine. The E′, E′′ and tan δ were recorded as the temperature changes, the obtained results are summarized in table 4.9.

3.3.8 Scanning Electron Microscopy (SEM)

The micro structure of the produced composite was observed under a SEM. Composite sample of 10mm by 10mm dimension (with different percentage reinforcement) were developed to examine the morphology and fibre-matrix interaction. Phenom ProX (PhenomWorld, SN: MVE01570775, Model No: 800-07334.) SEM machine was used in the observation.

3.3.9 Physical Properties

3.3.9.1 Water Absorption

The water absorption tests of WNP composites were performed as per ASTM D570. For the water absorption test, the test samples were sun dried in an oven for a period of 42 hours, allowed to cool and cleaned with a clean cotton material. The weight of the samples were taken using an electron weighing machine. The samples were then immersed in water at for a period of 24 hours, then removed and cleaned of water using a dry cotton material, and then weighed again. The ssamples were then immerse in water, removed from the water after another 24 hours, cleaned and weighed. This procedure was repeated for 192 hours at 24 hours interval. The water absortiop of the material was expressed using equation (2.6). Five samples for each composition were used and the average value was reported.

3.3.9.2 Density

Samples of 20 mm by 20 mm by 20 mm were cast and weighed using an electronic weighing machine. The volum;e of the material was evaluated by measuring the height, width and length of the material.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Fourier Transform Infrared Spectroscopy (FTIR) Analysis of Newspaper

The FTIR analysis of newspaper sample was carried out and the obtained result is shown in Figure 4.1 and 4.2 denoting four (4) and five (5) major peak bands signifying lower molecular weight by the material are presented by the waste newspaper and the treated newspaper respectively.

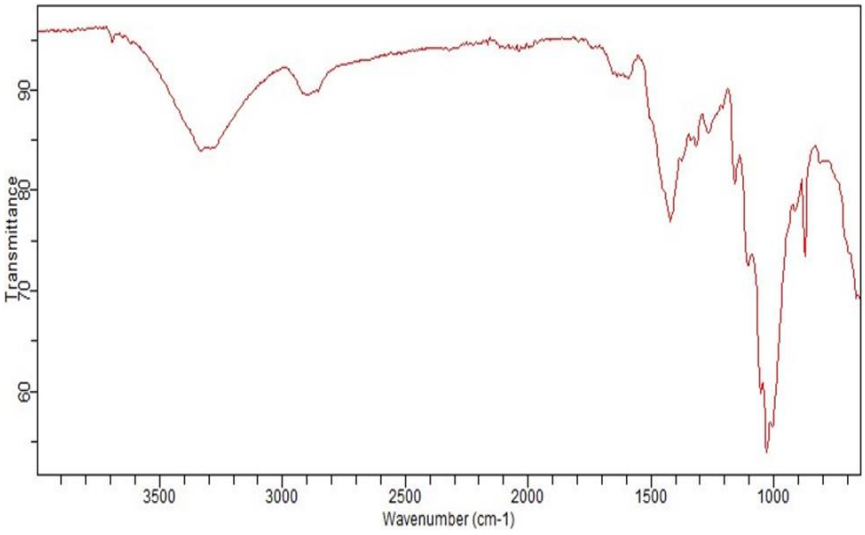


Figure 4. 1 Fourier Transform Infrared Spectroscopy (FTIR) analysis of WNP.

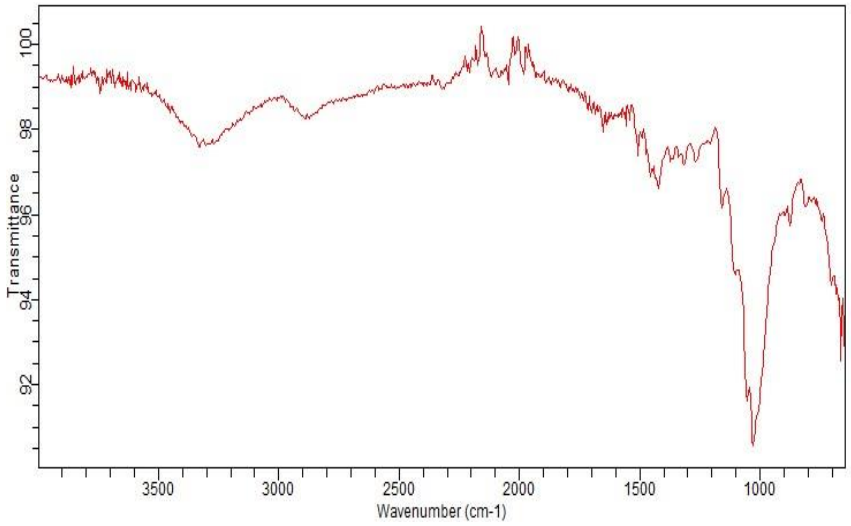


Figure 4. 2 Fourier Transform Infrared spectroscopy (FTIR) analysis of Treated WNP.

The major absorption bands in the FTIR highlights the lignocellulosic components in the paper composing of aromatic alkynes and oxygen functional groups. The presence of broad band absorbent peak around 3693 – 3338 cm^{-1} is associated with the –OH stretching of the hydroxyl group in both the

treated and untreated paper filler. The band at 2899cm^{-1} corresponds to C-H stretching of non-aromatic compounds which is again visible in the graphs of the untreated and treated paper filler. In the treated fillers, a broad peak absorbent band was noticed in the range of 2348.2 – 2117.1 cm^{-1} which is responsible for O=C=O strong stretching. This functional group noticed at this region may be as a result of the additional hydrogen-carbon molecules from the silane compound used in the surface treatment of the fibres. The peak band at 2094cm^{-1} is attributed to C=C=C medium stretching. The absorbent peak range 1595 – 1423cm^{-1} in both the untreated and treated samples corresponds to asymmetrical stretching of N-O. 1982.2 – 16651.2 cm^{-1} absorption band in the treated sample is responsible for a weak C-H bonding indicating the presence of an over tune aromatic compound. Another peak was observed in the range of 1267 – 1028cm^{-1} is responsible for the stretching of C-O.

4.2 X-Ray Florescence (XRF)

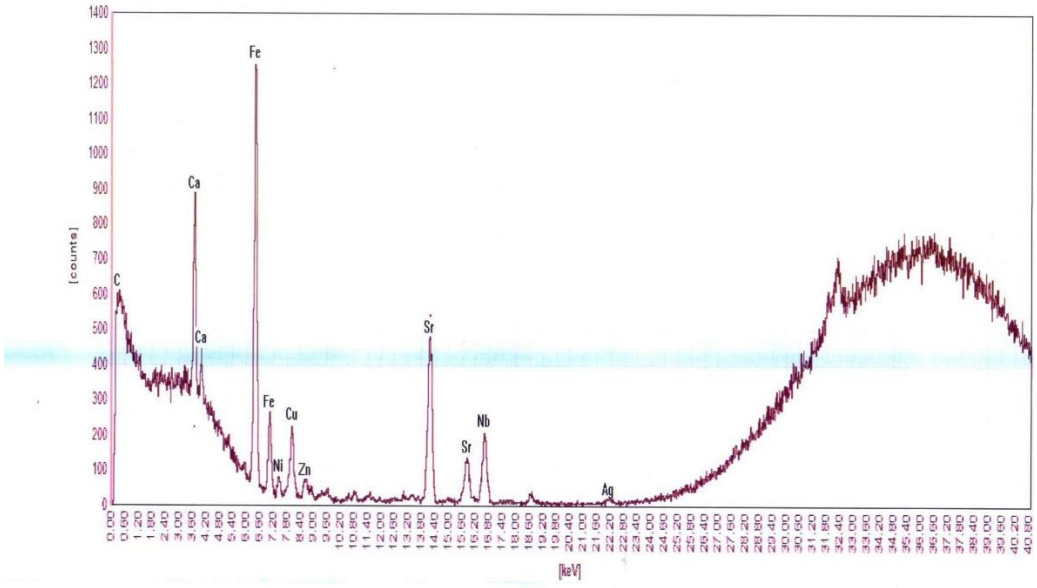


Figure 4. 3 X-Ray Florescence of the produced Treated WNP.

The figure above shows the result X-Ray Fluorescent of WNP which reveals Ca to have the highest percentage composition of 2.7357%, followed by Ce with 2% concentration, then Si with 1.9332%, Al

with 0.308%, then 0.2876%, K with 0.0941%. The presence of Ca and Fe might be as result of the surface treatment and grinding process of the paper paste.

4.3 Scanning Electron Microscopy (SEM)

Scanning electron microscope images of the developed composite were taken to observe the microstructure of the composite and for a clear understanding behind the increase and decrease in the strength of the material. Plate 4.1, 4.2, 4.3 and 4.4 shows the microscopic images of 0, 5, 10 and 15wt% of Waste Newspaper Particulate Composite (WNPC) samples. It is clearly visible there is good adhesion existing between the matrix and the reinforcement. Also filler cluster was not evident in the images. This explains why the strength of the material increase with the addition of WNP into polyester at lower percentages.

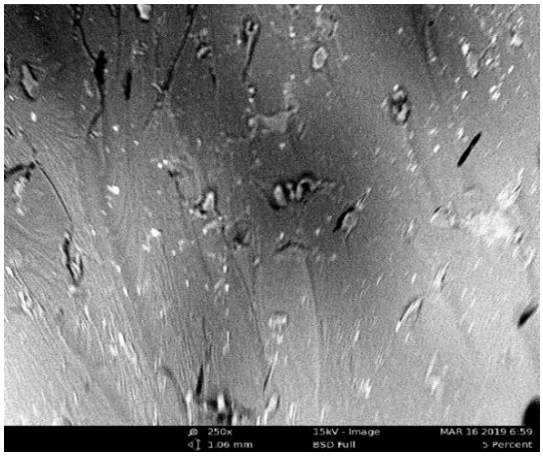


Plate 4 1: SEM Micrograph of neat polyester resin at 20kv operating voltage of 250X magnification.

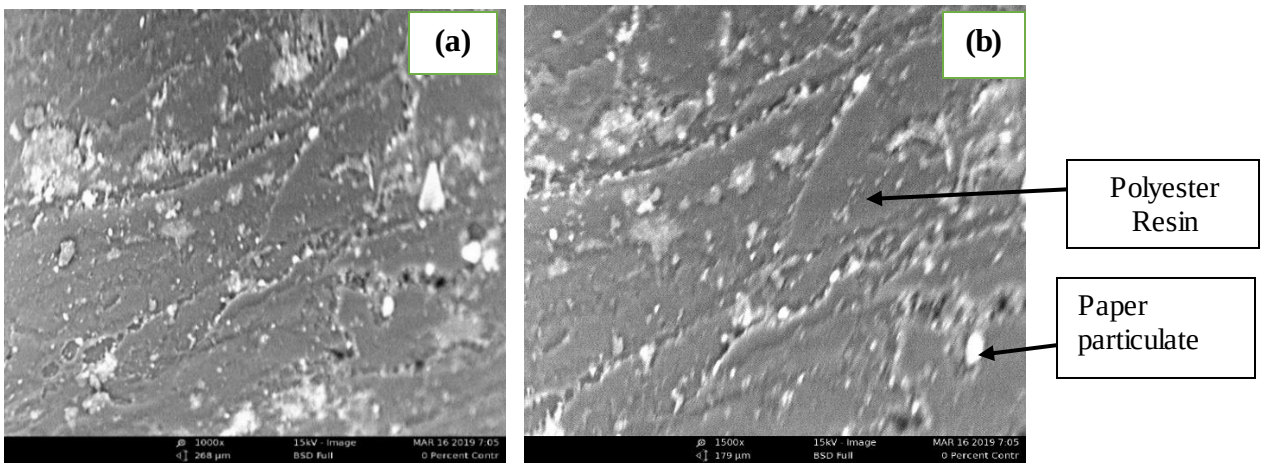


Plate 4 2: SEM Micrograph of 5wt% WNPRC sample at 20kv operating voltage at a) 1000X and b) 1500X magnification.

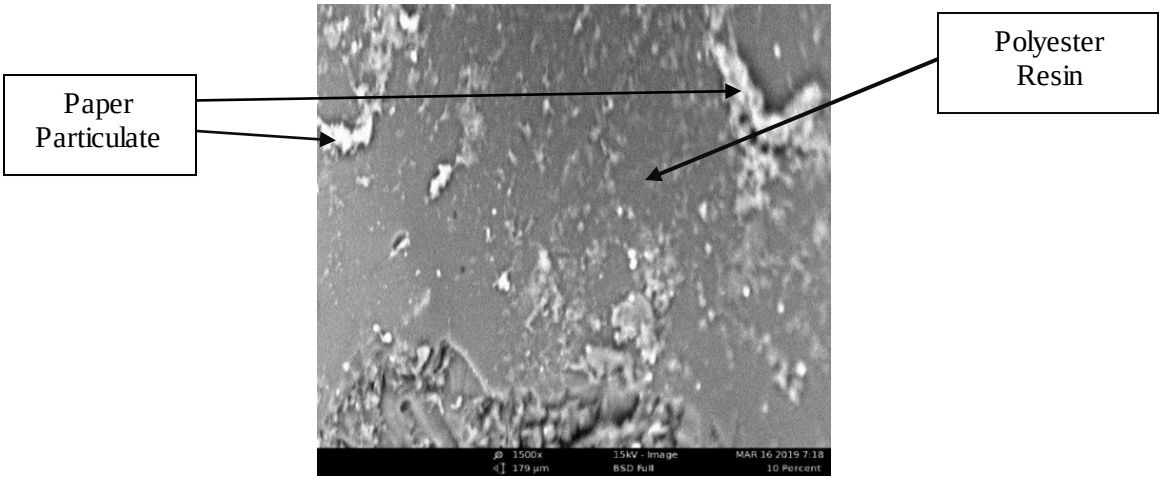


Plate 4 3: SEM Micrograph of 10wt% WNPRC sample at 20kv operating voltage at 1500X magnification

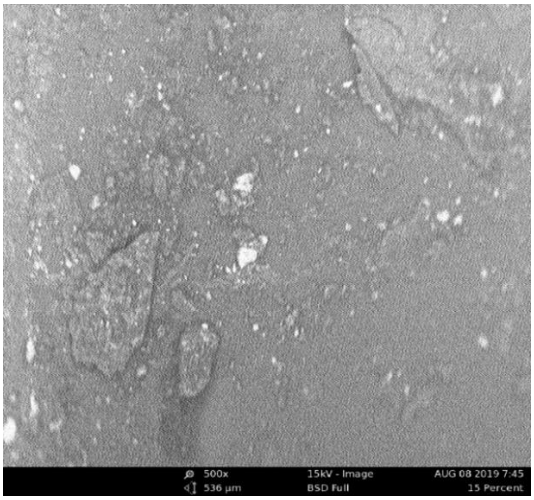


Plate 4 4: SEM Micrograph of 15wt% WNPRC sample at 20kv operating voltage at a) 1000X magnification.

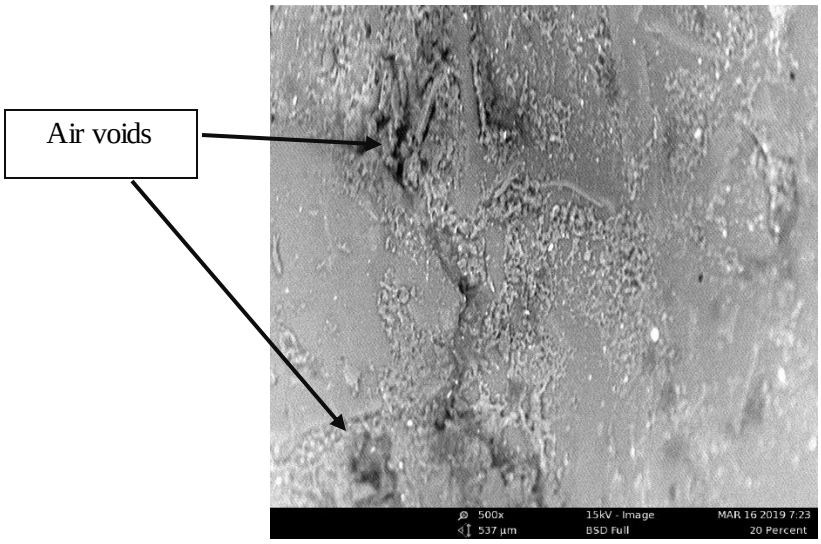


Plate 4 5: SEM Micrograph of 20wt% WNPRC sample at 20kv operating voltage at 500X magnification.

In plate 4.5, little formation of air voids and filler agglomeration was observed. However, the voids formation and filler agglomeration are not as much as those seen in Plate 4.6 (a and b). Nonetheless, this defects in the sample are enough to cause reduction in the material strength as seen in the results of the material obtained.

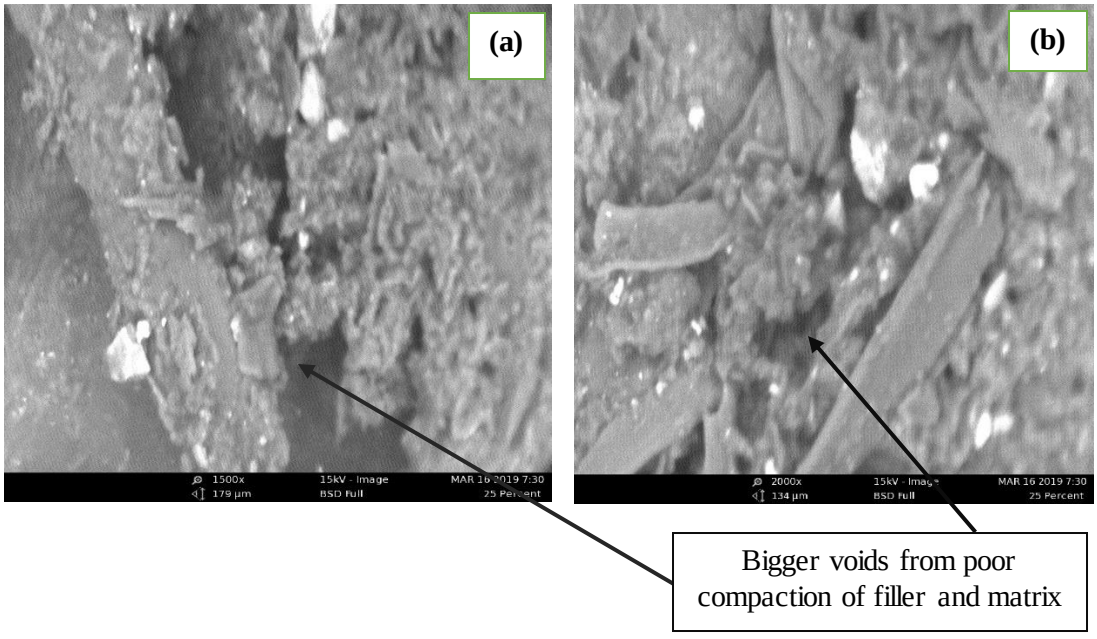


Plate 4 6: SEM Micrograph of 25wt% WNPRC sample at 20kv operating voltage at (a) 1500X and (b) 2000X magnification.

Observing Plate 4.6(a), formation of air voids are clearly visible. These air voids cause reduction in the strength of the material. Again, poor filler distribution in the polyester resin leading to filler agglomeration are visible in Plate 4.6(b). This poor dispersion of filler at higher percentages of filler loading is another reason for the strength reduction at higher percentages through non-uniform stress transfer. Gopinatha, *et al.*, 2014 made similar observation in their research.

The formation of air voids, poor dispersion of WNP in matrix agglomeration and nature WNP-matrix bonding are all influential factors that can increase or reduce the strength of fibre matrix reinforced composite material.

4.4 Tensile Strength Test

Figure 4.4 shows the variation of the tensile strength (TS) of the developed WNP Reinforced Composite at varied filler loading. The tensile strength of the sample was observed to be increase with the addition of the waste newspaper particulate from 30.97 to 32.5MPa up to 20wt% filler loading.

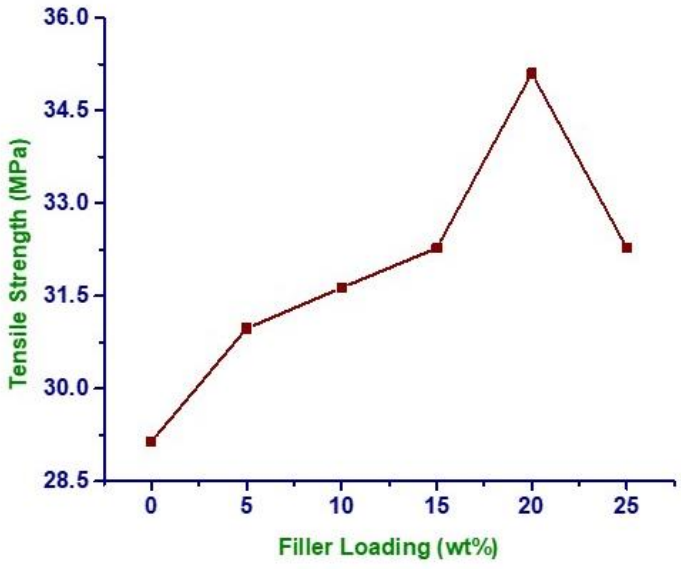


Figure 4. 4 Variation of Tensile Strength with Percentage Weight of Particulate Filler Reinforcement.

However, further addition of the particulate beyond 20wt% resulted in decreased TS. The increase in the TS value maybe due to the adhesion between filler and the polyester resin as a result of the alkaline + silane surface treatment of the filler. The decrease in TS beyond 20wt% filler loading may be due to poor or uneven dispersion of the filler within the polyester matrix. Another reason may be due to the increased formation of the micro space (voids) in the composite at higher filler loading. These research findings are similar to previous findings by Adhikaria & Gowda, (2017); Prabu *et. al.,* (2017) and Tabatabai, *et. al.,* (2017). Comparing the neat polyester sample with its composite samples, it indicates that the addition of filler increases the tensile strength of polyester with filler loading up to 20wt%.

Tensile Modulus

Figure 4.5 shows the variation of the Tensile Modulus (TM) of the developed composite material. The highest Tensile Modulus (TM) of the composite material was found to be 224.7 at 20wt% filler loading. It is evident that the addition of WNP improved the TM of the composite by 34.95%. The improvement in the TM is must noticeable in 15wt% and 20wt% samples (where the maximum TM is exhibited by the material). Samples with 15wt% and 20wt% WNP loading showed an increase in TM relative to the control sample by about 18.6% and 30.8% respectively.

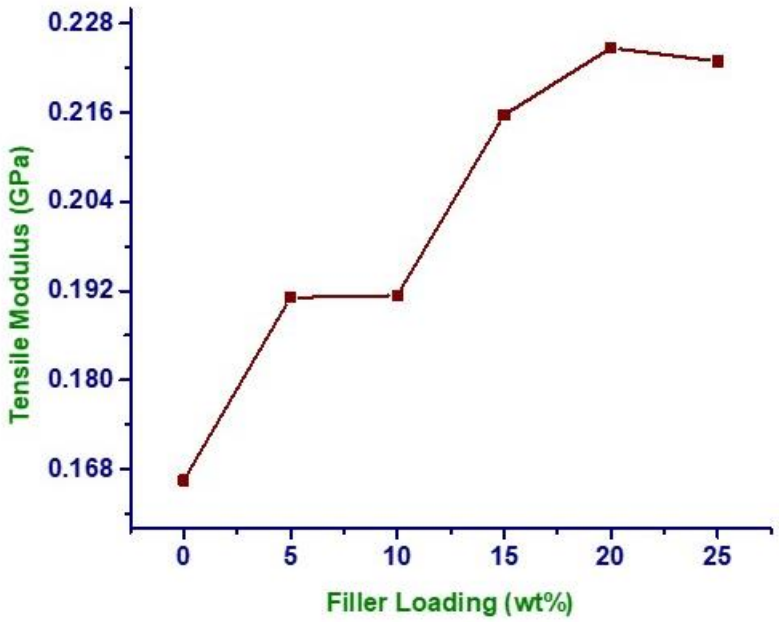


Figure 4. 5 Variation of Tensile Modulus with percentage of Particulate Reinforcement.

The increase in TM is likely due to detention in deformation of the polyester resin which brings about a reduction in tensile strain (Islam, *et al.*, 2017). The tensile properties (TS and TM) are expected to be on the increase with increase in the percentage of fller loading due to good interfacial bonding between the WNP and the polymer matrix. The increase is expected to a certain limit at which it will be decreasing as observed in samples with the 25wt% filler loading. This decrease is may be due to poor wetting and formation of micro pores which is associated with composite at higher percentages of reinforcement (Fu & Lauke, 1997; and Thomason & Vlug, 1995).

4.5 Compressive Strength Test

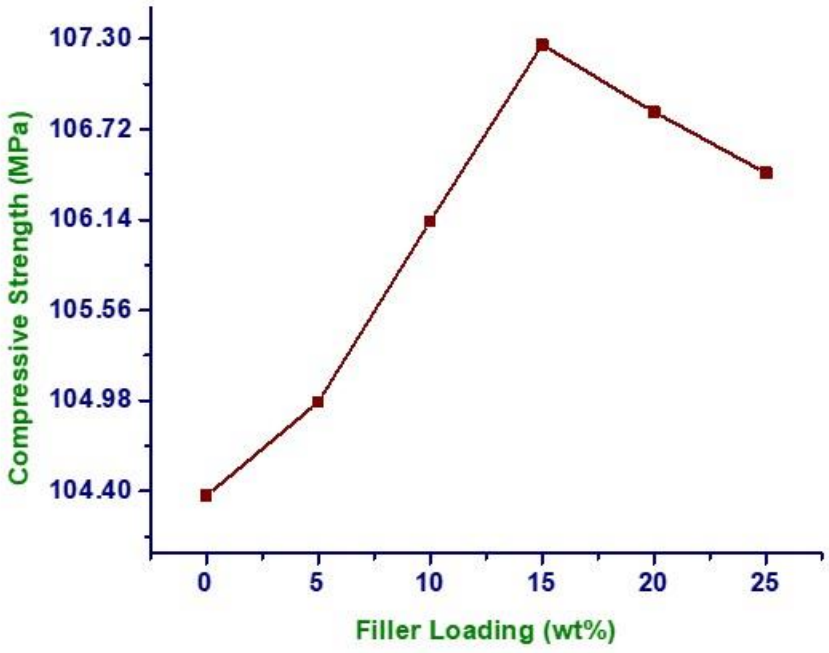


Figure 4. 6 Compressive strength (MPa) against percentage of Particulate Reinforcement.

Figure 4.6 shows the variation of the compressive strength with the percentage weight of filler loading. The compressive strength at 0, 5, 10, 15, 20 and 25wt%of WNP loading is 104.37, 104.97, 106.13, 107.26, 106.83 and 106.44MPa respectively. The vital factor in optimizing the compressive properties of a filler matrix composite is a good interfacial bonding between the filler and the matrix as reported by (Mylsamy & Rajendran, 2011). This explains the slight increase in the compressive strength of the developed material relative to neat polyester specimen resulting from the good interfacial bonding achieved from the surface treatment of the filler.

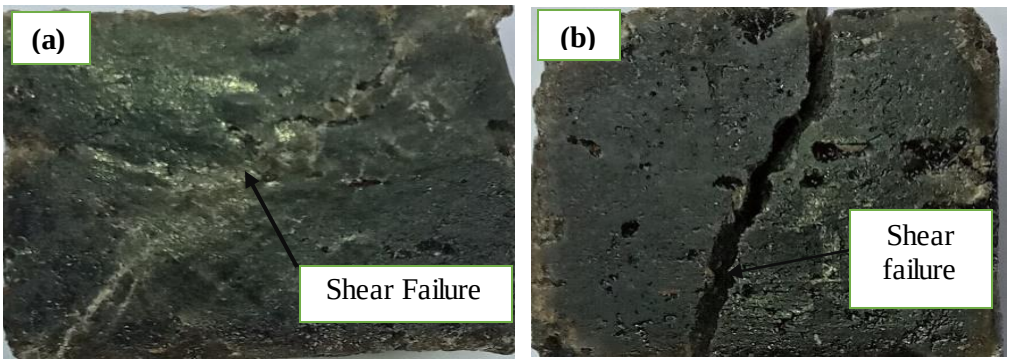


Plate 4 7: Compressive failure mode of the developed material. (a) 15wt% sample (b) 20wt% sample.

In plate 4.7, the nature of the compressive failure of the material can be observed to occur in shear mode. In shear mode failure of composite material, buckling of filler occurs in phase with one another causing the material to buckle. This is very common with composite materials and occurs as the percentage filler loading increases which eventually leads to a decrease in the compressive strength of a material (Chandramohan , 2019). This explains the decrease in compressive strength of the material at higher percentage of fibre loading.

4.6 Flexural Strength Test

The Figure 4.7 shows the variation of the flexural strength (FS) and flexural modulus (FM) of the composite of varied filler loading. It can be observed that the FS of the composite sample decreased from 63.71 to 46.21MPa as the filler loading increased up to 25wt%. On the other hand, the FM of the composite was also observed to decrease from 32.09MPa at 5wt% to 25.37MPa as the composition of filler loading is increased up to 25wt%. Sigley, *et al.*, (1991) reported that polyester resins are usually brittle under tensile and flexural loading, hence the decrease in the FS of the developed composite relative to that of the polyester resin maybe due increase in the brittleness and reduction in the ductility property in the composite leading to a decrease in the FS value. This also validate the low deflection observed in the composite material.

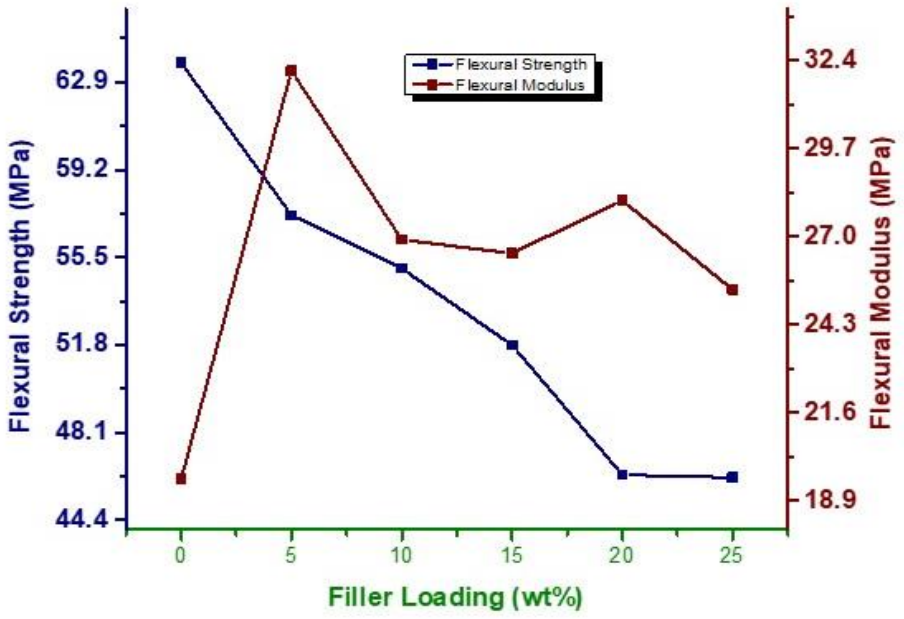


Figure 4. 7 Variation of Flexural strength (MPa) and Flexural Modulus with percentage of Particulate Filler Reinforcement loading.

At higher percentages of the WNP, the decrease may also be due to formation of voids, poor filler/matrix interactions as higher filler percentages and uneven dispersion of particulates in the matrix. The flexural behavior shown by the composite material is similar to the findings of García, *et al.,* (2018) and Choudhury, *et al.,* (2017). For polymer matrix composite, with a decrease in the either the tensile or flexural/bending strength, the tensile and flexural modulus is expected to increase which will be as a result of the restrain deformation caused by the filler (Islam, *et al.*, 2017).

4.7 Hardness Test Result

The hardness test result of the fabricated composite is presented in the Table 4.1 above, clearly shows the increase in the harness value of the composite material as the percentage weight of the particulate reinforcement increases. The hardness value obtained at 5wt%, 10wt% and 15wt% were 31.6, 38.7 and 44.6 respectively. Further addition of the particulate filler at 20wt% and 25wt% resulted in a decrease in the hardness value to 37.08 and 37.7 respectively.

Table 4. 1 Results obtained for the Hardness analysis of the material.

Fibre Loading (wt %)	Hardness Value (HRF)
0	29.60
5	31.60
10	38.70
15	44.60
20	37.03
25	37.70

The maximum value was obtained at 15wt% while the minimum was at 5wt%. With the least hardness value obtained, an improvement in the value obtained for the hardness value of the control sample (pure unsaturated polyester) with about 25%. Good compaction between the reinforcing particulate fibres and the resin maybe the reason behind the improvement in the hardness value and also the good and ease in the mixing of the resin and matrix at these percentages. However, the decrease observed at 20wt% and 20wt% maybe attributed to air collection during composite fabrication between the composite and the walls of the mould before setting. SEM micrographs of the 20wt% and 25wt% can justify the presence of air voids in the samples. Vaghasia & Rachchh (2018) made similar observations.

4.8 Impact Strength Test

Impact test was conducted to determine the amount of energy that would be absorbed by the material before failure when subjected to impact loading. Figure 4.7 shows the variation of impact energy of matrix with that of composite at varying percentage loading of waste newspaper particulate. The result showed an increase in the impact energy of the composite as the percentage of particulate reinforcement filler increases from 5wt% up to 15wt%.

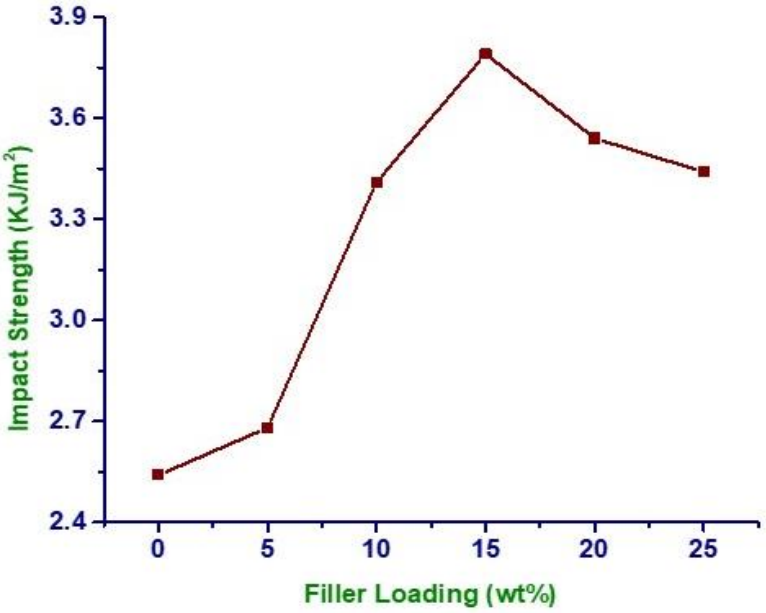


Figure 4. 8 Variation of Impact Strength (kJ/m^2) with percentage weight of WNP Filler Reinforcement.

However, for further increase in the particulate filler composition at 20wt% and 25wt%, the impact energy decreased to 3.23 KJ/m^2 and 3.07 KJ/m^2 respectively. Highest impact energy was observed to be 3.79 KJ/m^2 at 15wt% filler loading. The decrease in the impact energy of the composite material maybe as a result of increased voids formation associated with higher percentages of filler loading in composite compounding leading to a decrease in the impact energy. Another reason may be as a result of the poor compaction of the matrix and reinforcement at higher percentages. Similar result findings are obtained by (Farzi, *et al.*, 2019, Pradhan, *et al.*, 2019, Islam, *et al.*, 2017 and Munawara, *et al.*, 2017).

4.9 Thermal Analysis

4.9.1 Thermal Conductivity

Figure 4.9 presented the result of the thermal conductivity of the composite material. It is observed that the thermal conductivity of the material increases with increase in the percentage of fibre loading. The good compaction of the resin and the matrix can add to reason of the thermal conductivity of the material as there is no spacing between them to serve as interfacial thermal resistance.

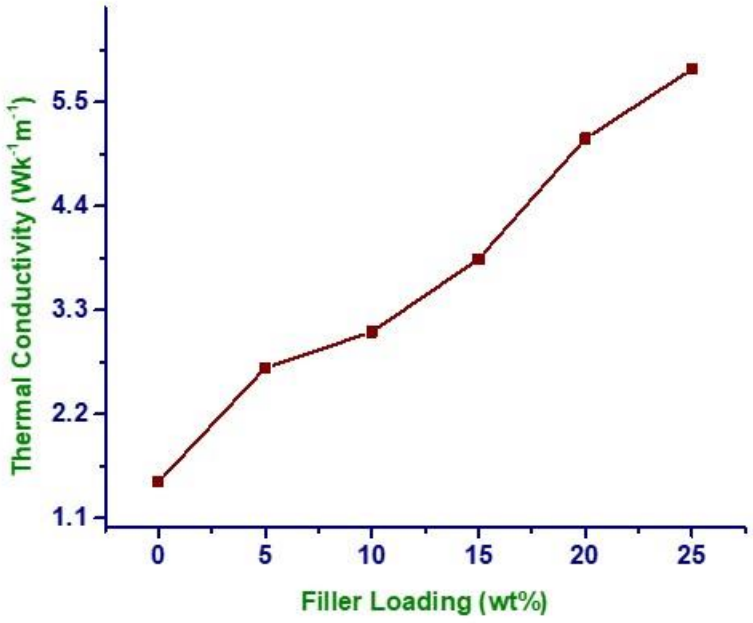


Figure 4. 9 Variation of thermal conductivity with percentage weight of Waste Newspaper Particulate Filler Reinforcement.

The alkaline and silane treatment of the fibres improves the conductivity effect of the material as reported by some researchers (Choudhury, *et al*, 2012; Irwin, *et al*, 2003 and Agarwal, *et al.*, 2006). Surface treatment also leads to the elimination of possible impurities in the fibres which will eventually leads to the increase in the conductivity of the material with certain percentage of filler reinforcement in comparison to that of the net polyester sample. This is as a result more vibrating phonons in the samples which are the carriers of thermal energy (Sair, *et al.*, 2017).

4.9.2 Dynamic Mechanical Analysis (DMA)

Table 4.2 presents a summary of the DMA results recorded at different percentages of fibre loading at 10Hz. A summary of the storage and loss modulus, damping factor (tan δ), glass transition temperature (T_g) and the activation energy of the material are presented in the table.

Table 4. 2 Summary DMA results of polyester and developed composite material.

Fibre loading (wt %)	E´ (MPa)	E´´(MPa)	Tan δ	T_g (ºC)	Activation Energy (KJ/mol)
0	2600	396	0.774	49.2	264.193
5	2620	273	0.619	62.9	361.599
10	2550	275	0.631	64.0	404.311
15	2850	328	0.591	67.7	422.661
20	4000	388	0.555	65.9	355.772
25	2600	325	0.542	60.6	312.986

4.9.2.1 Temperature Effect on Storage Modulus E´ with varied weight percentage of fibre loading.

Storage Modulus (E´) is the most major property to approach the load bearing ability of a material (Reddy & Reddy, 2014).

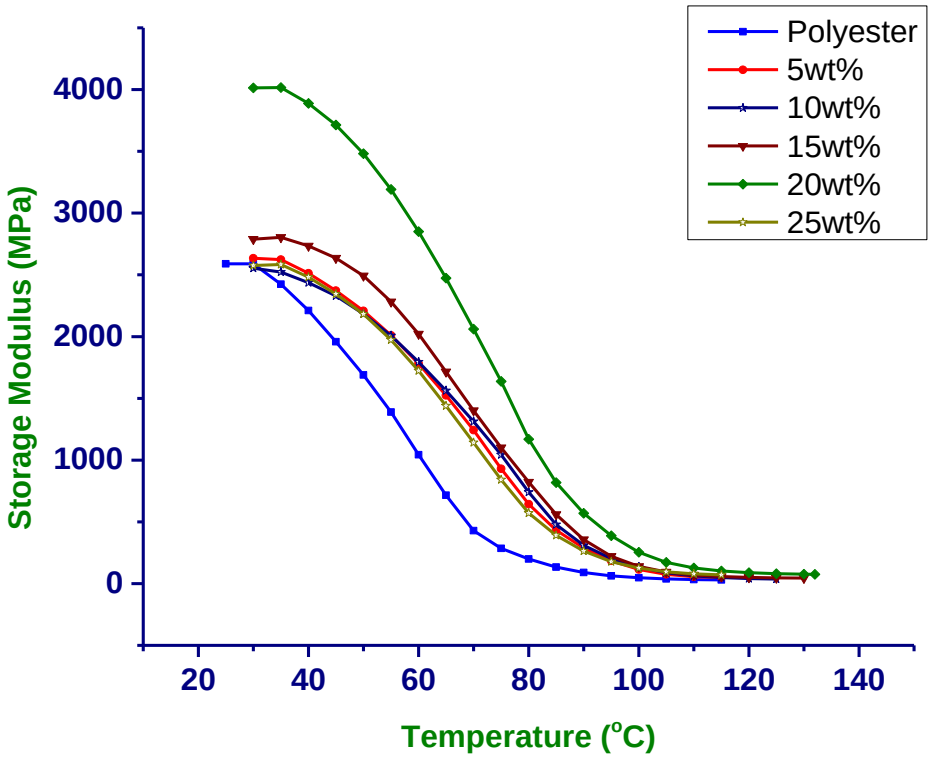


Figure 4. 10 Variation of Storage Modulus (E´) with temperature of the developed composite at different Particulate Filler Reinforcement composition.

From the result presented in figure 4.10 above, the value of E´ were very close at lower percentages of the fibre loading, then increases with further addition of the WNP before a decrease was again observed at higher percentage (25wt%). the sharp decrease of E´ value for 25wt% composite may have the probably resulted from improper/ poor compaction between the WNP and the polyester in which similar trend was seen in the mechanical property result s of the developed material. As the temperature rises, the storage modulus in all the composite composition decreases and a sharp decrease noticed around the glass transition temperature region. This may be based on less impact WNP has at elevated temperature resulting again in stiffness loss between WNP and the polyester

More also, value of E´ increases as the frequency increase. Hence, highest value of E´ in all the composite samples developed was at 10Hz, the 5Hz and 2.5Hz has the least value respectively.

4.9.2.2 Effect of Temperature on Loss Modulus E´´ and Glass Transition Temperature (T_g) With Varying Weight Percentage of Fibre Loading.

Loss Modulus E´´ is the quantity of energy dissipated as heat per cycle under deformation i.e. viscous response of the material (Ornaghi, *et.al*, 2010).

Glass transition temperature is the temperature region at which the material changes from glassy solid to a more flexible, elastomeric solid. T_g is the sudden change in elastic modulus and an attendant peak in the tan δ curves (Reddy & Reddy, 2014). The variation of loss modulus with temperature for the different composition of the fibre loading is presented in the Figure.

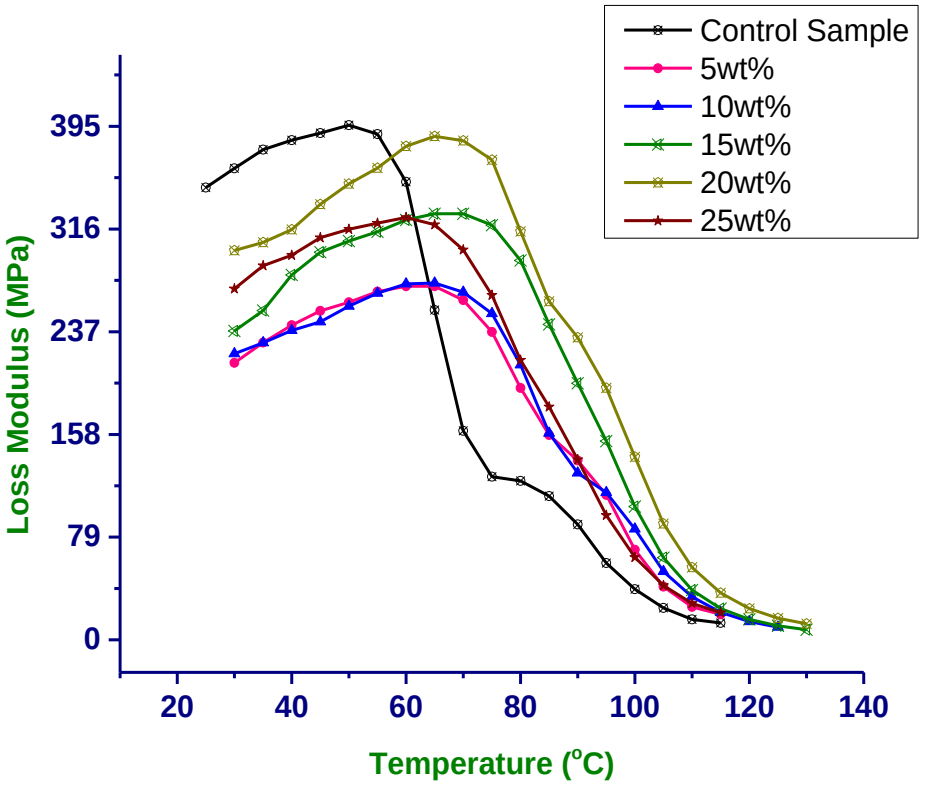


Figure 4. 11 Variation of Loss Modulus (E´) with temperature of the developed composite at different Particulate Filler Reinforcement composition.

Figure 4.11 shows the nature of variation of loss modulus for the different composite samples developed (with varied weight percentage of fibre loading) with temperature and at frequency of 10Hz. It could be easily observed from the figures that E´´ value increases as the temperature increases, having

a peak value at the glass transition temperature region and then decreases as the temperature increases in all the composition of the composite. The incorporation of the WNPF into the polyester resin increases the stiffness of the material, hence making it require more heat to bring about the movement of the molecules of the material. As observed, variation in frequency varies the E´´ value in all composite samples which is similar to results obtained in the storage modulus of the material. The increase in the loss modulus of the material with frequency may be due to more molecular mobility with the increase in frequency. The peak values of E´´ were recorded at 15wt% (328MPa) and 20wt% (388MPa) respectively. This is property of the material also supports the findings of the tensile modulus of the material. Similar observations were made by (Negawo, *et al.*, 2018).

4.9.2.3 Effect of Fibre loading on Glass Transition Temperature Tg.

Glass transition is a reversible change that occurs between the rubbery and the glassy state as the temperature of a changes. The T_g is measured as the peak temperature in the E´´ curve (Deepthi, *et al.*, 2019; Negawo, *et al.*, 2018). Other researchers measure glass transition temperature as the peak of the tan δ curve or the onset drop at storage modulus E´ curve. But however, the real Tg of a material can be determined by running a multi-frequency scan and calculating the activation energy of the material. The activation energy for a true/real T_g value should roughly be in the region of 300 - 400KJ/mol.

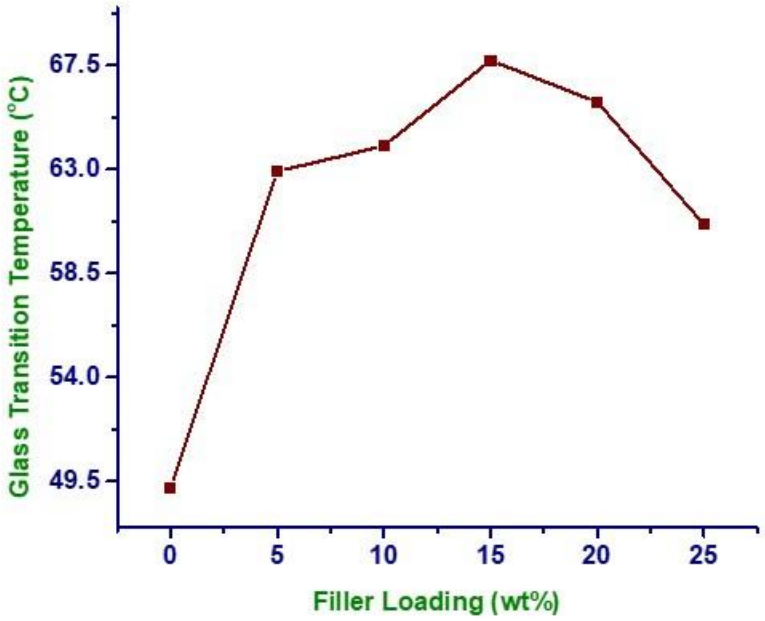


Figure 4. 12 Variation of Glass Transition Temperature with of the developed composite with percentage of particulate filler reinforcement.

As observed from table 4.2 and figure 4.12, the T_g of the composite increases as the percentages of fibre loading increases with a maximum T_g of 67.7°C at 15wt% fibre loading. A decreasing temperature was observed at 20 and 25wt% fibre loading. T_g was increase as a result of the increase in the stiffness the material experiences from the reinforcing action of WNPF which restricts free movement of polyester molecules as the temperature increases. At 20wt% and 25wt%, fibre loading, poor compaction/mixing of the fibre and polyester gave rise to the formation of voids, as such causing a decrease in the T_g value at these percentages of fibre loading.

4.9.2.4 Variation of Damping Factor with Temperature at Varied Weight Percentage of Fibre Loading.

The damping factor (tan δ) is the ratio of loss to storage modulus. It is simply a measure of the energy lost and represents the mechanical damping of a material (Oboh, *et al.*, 2018). High value of damping factor implies that a material possess high non-elastic strain component while a lower value indicate a high elasticity, as the molecular chains mobility get decreases at the fiber/matrix interface *(Negawo, et al.*, 2018). The variation of tan δ with temperature for different fibre loading composition is shown below in Figure 4.12.

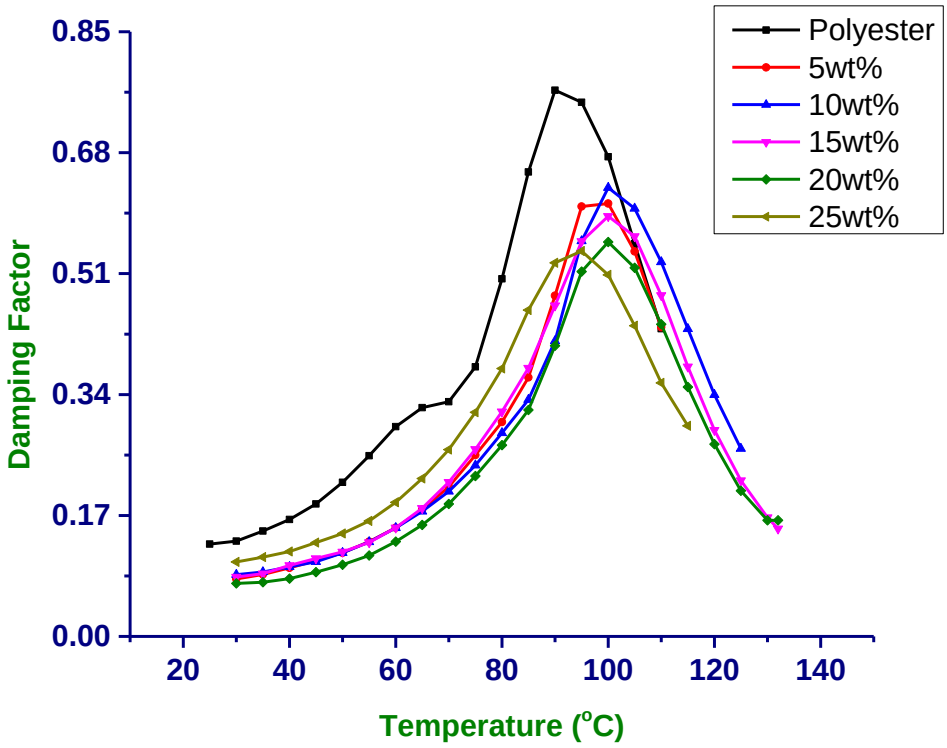


Figure 4. 13 Variation of Loss Modulus (E´´) with temperature for the developed composite samples at different reinforcement composition.

The highest value of the damping factor is attained at the peak the tan δ curve or at the highest value of E´´ curve which is equally the glass transition temperature of the material. From the figure, the samples with lower percentage of fibre loading attained highest damping factor due to free mobility of the polyester molecules as the temperature increases. The obtained Tan δ values of composites at 5, 10,

15, 20, and 25wt% were 0.6190, 0.6314, 0.5906, 0.5545 and 0.5421 respectively. Sample with 10wt% loading exhibited lower damping value confirming the result in Figure 4.13 where the sample had the highest storage and loss modulus among the rest of the samples. Sample 15wt% showed better thermal stability at 100°C T_g temperature with a damping factor of 0.5906 as a result of more restriction in molecular movement. Smaller values of tan δ are more preferable (as with samples 20 and 25wt %) but, putting into account the transition temperature (95°C for sample 20wt% and 90°C for sample 25wt %), the sample 15wt% will be more thermally stable as it can absorb more heat than other samples.

4.9.2.5 Temperature Effect on Damping Factor (tan δ) with Varying Weight Percentage of Fibre Loading.

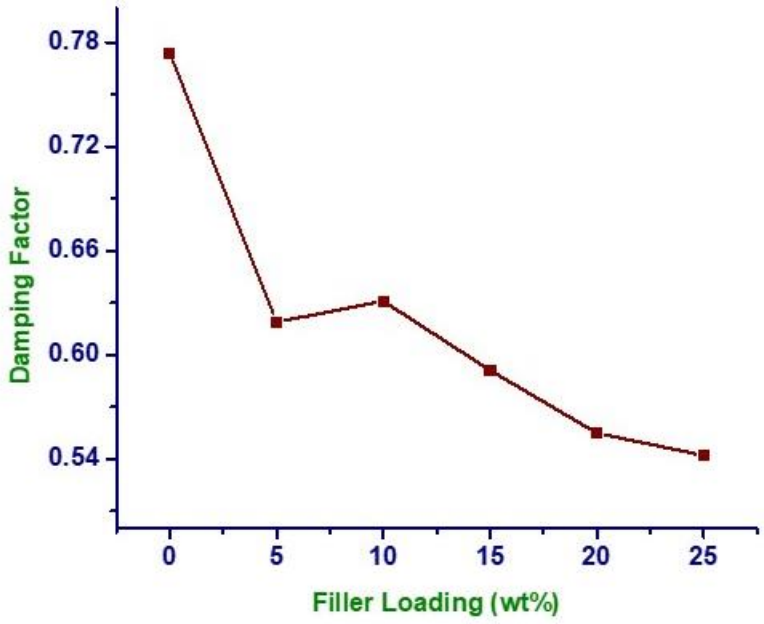


Figure 4. 14 Effect of particulate filler reinforcement (wt %) on damping factor of the composite material.

The damping factors for pure polyester resin, 5, 10, 15, 20 and 25wt% at a frequency of 10Hz are 0.774, 0.619, 0.631, 0.591, 0.555 and 0.542 respectively. As clearly seen in Figure 4.14, the damping factor in all the composite composition increases as the temperature increases through a peak at the glass transition region, then decreases through the rubbery region. the damping capabilities of the material

is low in the rubbery region because the chain segment of the material are frozen, which makes the deformation mainly elastic, bringing about a molecular slip in the viscous to be low. The damping factor in all the samples developed decreases as the percentage of the fibre loading increases. This lowering effect of the damping factor may probably be due to the restriction in movement of the resin (polyester) molecules caused by the addition of the WNPF which increases the rigidity of the material. The decrease in the damping factor is an indication of good bonding between the WNPF and the polyester resin which is caused by the surface treatment of the fibres. (Reddy & Reddy, 2014) Made similar finding in their research work.

4.10 Moisture Absorption Test

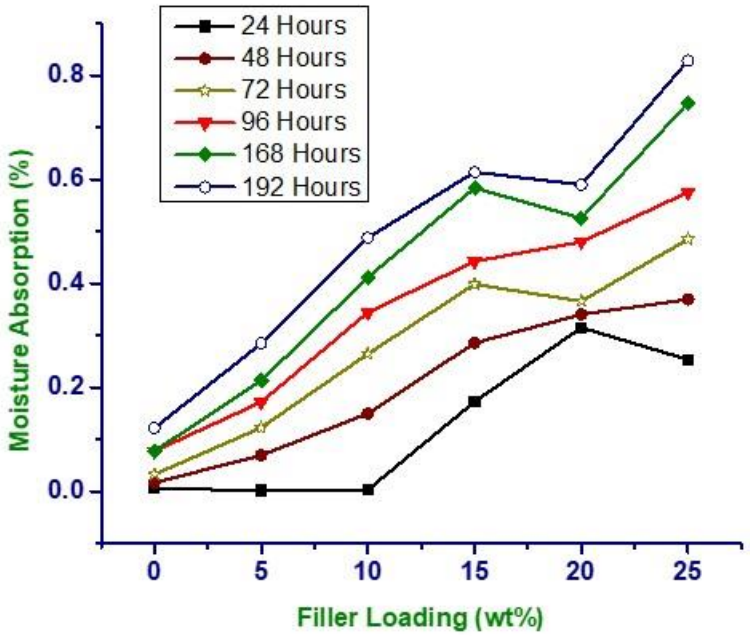


Figure 4. 15 Variation of Moisture Absorption of the composite with percentage composition of particulate filler reinforcement over a period of 192 hours.

Water absorption behavior of the developed composite at different percentages of fibre loading shown in the figure 4.15 above. A small increase can be observed in the percentage of water absorption with increase in the percentage of fibre loading.

(Wirawan, *et al.,* 2012 and Ashori, *et al.,* 2010) Reported that the cellulosic content in newspaper to be around 76.3%. this can explain why there is still a small amount of water absorption by the developed composite due to the fact that cellulose molecule contain hydroxyl group which in turn attract water molecules due to the presence of hydrogen bond. Poor compaction and void content at higher percentage of fibre loading is usually associated with polymer composites, this can be a reason why the percentage of water absorption of the developed composite at higher percentage of fibre loading is higher relative to the samples of lower composite samples. Water molecules are absorbed into the voids and flaws between the polyester resin and the newspaper fibres through capillary action. Other mechanism of water absorption in polymer composite as reported by (Masoodi & Pillai, 2012) are capillary transportation of water into micro cracks arising from fibre swelling, diffusion of water molecules into the fibre structure forming hydrogen bonds with fibre hydroxyl group and diffusion of water molecules into the gaps between polymer molecules chain. The obtained result is in line with the published results of (Das, 2017).

The higher moisture intake of the higher reinforcement composition is due to the presence of voids mostly associated with polymer composite during casting and poor compaction of matrix with fibre at higher percentage. Though the result showed an increased moisture absorbed by the composite, the alkaline and silane surface treatment of the fibre improved the hydrophilic nature of the fibre resulting in low percentage of moisture intake (Srinivasa, Udaya, & Prahlada, 2017).

4.11 Density

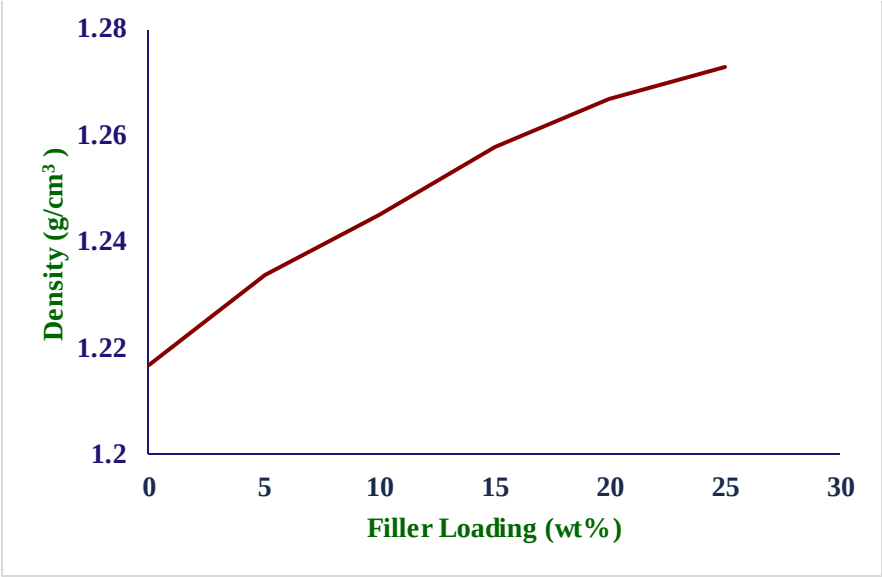


Figure 4. 16 Variation of density of developed composite with weight percentage of particulate filler.

Figure 4.16 shows the values of the density for various percentage weight composition of the particulate filler in the matrix. The density of WNP-Polyester composite can be observed to be higher than that of the control sample. It also be observed from the SEM micrographs when there is an increase in the percentage of reinforcement, there is good bonding between the matrix and the reinforcement, which in turn led to an increase in the mass of the composite within an unchanged volume matrix, as such, increasing the density of the composite material. When percentage increase in density of the composites at higher and lower percentages of reinforcement are compared with respect to the control, it can be observed that the increase is higher at lower than higher percentage of reinforcement with respect to the control sample. This is because of the void formation at higher percentages (20 and 25 wt%) of the reinforcement with the voids making it possible for lesser mass of the reinforcement to be to be mixed with the matrix. hence the little increase in the density of the composite at higher percentages of reinforcement. This analysis is in par with other authors' analysis (Joseph & Sivaganesan, 2020; Alamgir et al., 2015 & Hassan, Aigbodion, & Patrick, 2012).

4.12 Tribology

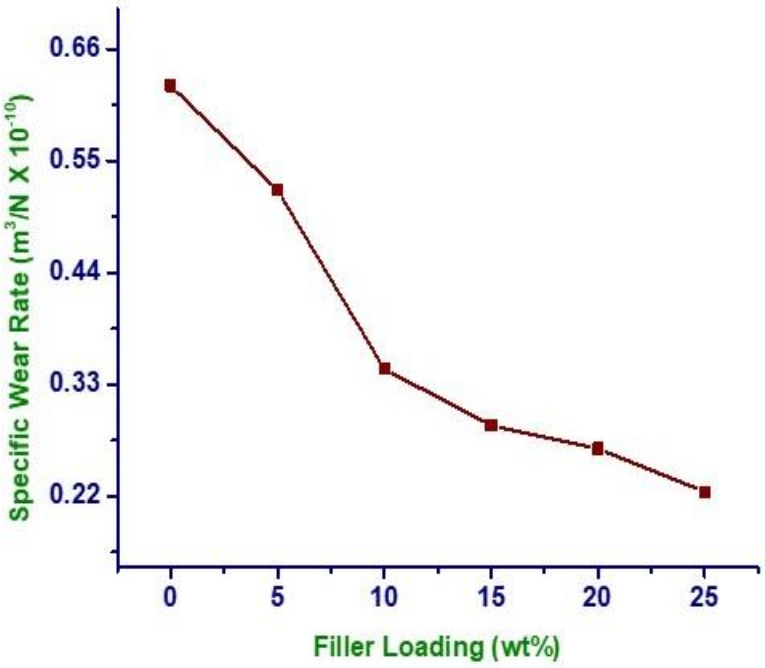


Figure 4. 17 Variation of Specific Wear Rate with percentage composition of waste newspaper particulate filler reinforcement.

.

Wear rate of a material affects the service life of the material and hence, its application. The wear rate of a material relies on the component and manufacturing process used (among which can include fire as reinforcing material and interfacial bonding with the matrix material.

Figure 4.15 shows the relationship between wear rate and the percentage weight of fire loading. 0.6242, 0.5214, 0.3453, 0.2896, 0.2669 and 0.2242 x $10^{-10}m^3/N$ as the wear rate for neat polyester sample, 5, 10, 15, 20 and 25wt% samples. As observed in the figure, the wear rate of the composite decreases with increase in the percentage of the WNP. In comparison either the near polyester sample, 16.47% decrease in 5wt% sample was observed. Similarly, a decrease of 44.68%, 53.6%, 57.24% and 64.25% decrease was observed by 10%, 15%, 20% and 25wt% samples relative to the neat polyester sample. This reduction in the wear rate may be ascribed to the increased content of the silane+alkaline treated WNP. Similar trend was reported by (Pradhan *et al.*, 2019 and Liu *et al.*, 2018).

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

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

i. Particulate cellulose filler from waste newspaper were developed. Surface treatment of the produced cellulose filler was possible using sodium hydroxide solution and 3-(Trimethoxy silyl) propyl methacrylate treatment to modify the surface of the filler so as to improve adhesion between matrix and filler, thereby enhance the properties of the developed composite material.

ii. Fourier transform infrared spectroscopy (FTIR) of newspaper carried out shows the presence of the –OH (hydroxyl) functional responsible for the water absorption by the developed composite material. C=C=C, N-O and C-O functional groups were also found to be present in the newspaper used. Also X-Ray Florescence (XRF) was carried out to characterize the produce particulate filler. Obtained result showed the filler to contain Fe and Ce as major constituent of the filler.

iii. Polymer composite material was developed using the modified particulate filler of waste newspaper at varying weight percentage (5, 10, 15, 20 and 25wt) with unsaturated polyester.

iv. Mechanical properties results showed that tensile strength, tensile modulus, compressive strength, flexural strength, flexural modulus, hardness, impact strength were 35.79 MPa at 20wt%, 0.2298 GPa, at 107.26 MPa at 15wt%, 57.29 MPa at 5wt%, 32.09 GPa at 5wt%, 44.6HRF at 15wt% and 3.79 kJ/m^2 at 15wt% for impact strength respectively. Water absorption of the composite material showed increased water absorption in the material with increase in percentage of fibre loading and immersion time up to 192hours. The maximum percentage of water absorption was 0.8285% at 25wt% fibre loading after 192hours. The density of the material was found to be highest at 25wt% with a density of 1.273 g/cm^3.

v. The tribological properties of the material were determined. The specific wear rate and depth of penetration of the material were found to be decreasing as the percentage of the fibre increases. Maximum of $0.6242m^3/N \times 10^{-10}$ was found to be the highest specific wear rate at 5wt% of fibre reinforcement. Highest penetration depth of 2.44×10^{-3} (μm) on the material was equally recorded 5wt%.

vi. The thermal conductivity and DMA were carried out. The thermal conductivity of the material increases with increase in the percentage of fibre loading due to the method of surface treatment used. Storage modulus, dynamic modulus, damping factor and the glass transition temperature of the material were equally determined. Sample with 20wt% was found to be more thermally stable with a storage modulus of 4000MPa, loss modulus of 388MPa and a damping factor of 0.5550.

vii. The microstructure of the material was studied using SEM which shows good interfacial bonding between the fibre and the matrix.

viii. From the obtained result, and making comparison with manufacturing standard and previous

5.2 Recommendations

The following are the recommendations for future research:

i. Different resins and waste papers forms should be used as reinforcement and compare the results to find a suitable engineering application for the developed material.

ii. Performance of newspaper hybrid composite should be carried out with different resins.

iii. As environmental controls measure, solid waste (papers and others) should be used in developing new and better engineering materials.

iv. Future research should be conducted using different waste papers sizes with different resins and results should be compared.

v. Also, future research should investigate interface and weathering characteristics of the polyester-WNP composite.

ix. From literatures available on materials developed for nonstructural/ interior application in automotive. The tensile strength of the material is within the permissible range of tensile strength of a material considered for automotive dashboard application. The permissible range is 20 – 40MPa (Susilowati & Sumardiyanto, 2018) based on ABS plastics for automotive. According to (Sapuan, *et al.*, 2011) the recommended range is 20 – 30 MPa. Also the developed material can be recommended for the following;

a. Car Door Map Pocket

b. Internal Door Panel

5.3 Contributions to Knowledge

i. The research findings provided a characterize properties of a composite material developed from waste newspaper particulate filler and unsaturated polyester resin. It equally showed that newspaper as a form of solid waste can be turned into wealth. The material also promising properties for use as reinforcement in polymer composite material.

ii. Based on the characterize properties of the developed composite, a new material for automotive interior application have been developed. The material can be used for dashboard, internal door panel and door map pocket.

REFERENCES

Abilash, N., & Sivapragash, M. (2013). Environmental benefits of eco-friendly natural fiber reinforced polymeric composite material. *International Journal of application or innovation in Engineering and management (IJAIEM), 2 (1)*(2319-4847), 53-59.

Adhikaria, R., & Gowda, B. (2017). Exploration of mechanical properties of banana/jute hybrid polyester composite. *Materials Today: Proceedings 4*, 7171–7176.

Agarwal, R., Saxena, N., Sharma, K., Thomas, S., & Pathon, L. (2006, October). Thermal Conduction and Diffusion Through Polyester Resin. *Indian Journal of Pure and Applied Pyhsics*, 746 - 750.

Akinwumi, a. I., Olatunbosun, O. M., Olofinnade, O. M., & Awoyera., P. O. (2014). Structural Evaluation of Lightweight Concrete Produced Using Waste Newspaper and Office Paper. *Civil and Environmental Research, 6*(7), 160.

Ali, A., Hashmi, H., & Baig, N. (2013). Treatment of the paper mill effluent – A review. *Annals of Faculty Engineering Hunedoara - International Journal of Engineering, 3*(11), 337-340.

Angela, H., Nicolas, F., Samuele, G., Elke, H. J., Melanie, N., Rudolf, R., . . . Markus, S. (2013, January). Thermal Analysis of Polymers. *Applications handbook: Thermal Analysis of Polymers*. Switzerland: Global MarCom Switzerland.

Ankita, P., Dibakar, B., & Tapan, K. (2014, May). Fabrication and Mechanical Properties of BisGMA/Amine Functionalized Paper Pulp Composites. *International Journal of Innovative Research in Science, Engineering and Technology, 3*(5), 12718-12723.

Appusamy, A., Eswaran, P., Subramani, M., & Sadaiappan, S. (2018). Experimental studies on Mechanical properties and Characterization of Parthenium Short Fibre Reinforced Polymer Matrix Composites. *International Journal of Engineering and Advanced Technology (IJEAT), 8*(2S), 94-97.

Aramide, F., Atanda, P., & Olorunniwo, O. (2012). Mechanical Properties of a Polyester Fibre Glass Composite. *International Journal of Composite Materials, II*(6), 147-151. doi: 10.5923/j.cmaterials.20120206.06

Ashby, M. F. (1987). *Philosophical Transactions of the Royal Society of London*.

Ashori, A., & Sheshmani, S. (2010). Hybrid composites made from recycled materials: Moisture absorption and thickness swelling behavior. *Bioresource Technology*, 4717–4720. doi:10.1016/j.biortech.2010.01.060

Ataguba, & Clement, O. (2016, February 02). Properties of Ceiling Boards Produced From a Composite Waste Paper and Rice Husk. *International Journal of Advances in Science Engineering and Technology*(2321-9009), 117.

Avci, A., Arikan, H., & Akdemir, A. (2013). . Fracture behaviour of glass fibre reinforced polymer composite. *Cement Concrete Res, III*(34), 429-434.

Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., & White, R. (2011). Coir Fiber Reinforced Polypropylene Composite Panel for Automotive Interior Applications. *12*(7), 919-926. doi:10.1007/s12221-011-0919-1

Bako, A. (2014, June). *Municipal Solid Waste Re-use And Recycling For Wealth Creation And Sustainable Environment in Zaria, Kaduna State, Nigeria*. Zaria.

Bongarde, U., & Shinde, V. (2014). Review on natural fiber reinforcement polymer composites. *International Journal of Engineering Science and Innovative Technology (IJESIT), 3*(2), 431-432.

Bower, A. (2009). *Applied Mechanics of Solids.* CRC Press.

Campbell, F. (2010). Introduction to Composite Materials. In F. Campbell, *Structural Composite Materials* (p. 1).

Chandramohan, D., & Marimuthu, K. (2011, August). A Review on Natural Fibers. *IJRRAS, 8*(2), 195-195.

Chandramohan, N. (2019). Variation in compressive and flexural strength of the carbon epoxy composites with the addition of various fillers to the epoxy resin. *Materials Today: Proceedings*. doi:10.1016/j.matpr.2019.06.731

Choudhury, M., Mohanty, S., Nayak, S., & Aphale, R. (2017, July 22). Preparation and Characterization of Electrically and Thermally Conductive Polymeric Nanocomposites. *Journal of Minerals and Minerals Characterization and Engineering*, 744 - 756.

Das, S. (2017). Mechanical and water swelling properties of waste paper reinforced unsaturated polyester composites. *Construction and Building Materials*, 469–478. doi:10.1016/j.conbuildmat.2017.02.041

Deepthi, P., Raju, S., & Reddy, M. (2019). Dynamic mechanical analysis of banana, pineapple leaf and glass fibre reinforced hybrid polyester composites. *Materials Today: Proceedings*. doi:https://doi.org/10.1016/j.matpr.2019.06.484

Elia, E. (2003). *Practical Hardness Testing Made Simple.*

Eskezia, E., Abera, A., & Tilahun, D. (2017). Finite Element Analysis of Internal Door Panel of a Car by Cons idering Bamboo Fiber Reinforced Epoxy Composite. *Journal of Applied Mechanical Engineering, 6*(1), 1-6. doi:10.4172/2168-9873.1000247

Fadila, R., Suleiman, M. Z., & Noordin., N. M. (2008). Paper Fibre Reinforced Foam Concrete Wall Paneling System. *2nd International Concrete On Built Environment In Developing Countries (ICBEDC2008)*, (p. 528). Pulua Pinang, Malaysia.

Farsi, M. (2012). Thermoplastic Matrix Reinforced with Natural Fibers: A Study on Interfacial Behavior. In M. Farsi, & D. J. Wang (Ed.), *Some Critical Issues for Injection Molding* . Shanghai, China: InTech.

Farzi, G., Lezgy-Nazargah, M., Imani, A., Eidi, M., & Majid Darabi, M. (2019). Mechanical, Thermal and Microstructural Properties of Epoxy-OAT. *Construction and Building Materials*, 0950-0618. doi:https://doi.org/10.1016/j.conbuildmat.2018.11.202

Fu, S., & Lauke, B. (1997). Characterization of tensile behaviour of hybrid short glassfibre/calcite particles/ABScomposites. *Composite part A, 29*(5-6), 575-583. doi:doi.org/10.1016/S1359-835X(97)00117-6

García, P., Ramírez-Aguilar, R., Torres, M., Franco-Urquiza, E., & May-Crespo, J. (2018). Mechanical and thermal behavior dependence on graphite and oxidized graphite. *Polymer*. doi:10.1016/j.polymer.2018.06.069.

Gaurav, A., Amar, P., & Rajesh, K. (2013). Parametric Optimization and Three-Body Abrasive Wear Behavior of Sic Filled Chopped Glass Fiber Reinforced Epoxy Composites. *International Journal of Composite Materials, III*(2), 32-38. doi:10.5923/j.cmaterials.20130302.02

Goodman, I. (1988). Encyclopedia of Polymer Science and Engineering. In I. Goodman, *Encyclopedia of Polymer Science and Engineering* (2nd ed., Vol. 12). New York: Wiley.

Gopinatha, A., Kumar, S., & Elayaperumal., A. (2014). Experimental Investigations on Mechanical Properties Of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices. *Procedia Engineering*, 2052–2063. doi:10.1016/j.proeng.2014.12.448

Grayson, M., & Eckroth, D. (1985). Encyclopedia of Chemical Technology. In M. Grayson, & D. Eckroth, *Encyclopedia of Chemical Technology* (3rd ed., Vol. 18, p. 575). John Wiley and Sons.

Gupta, G., Gupta, A., Dhanola, A., & Raturi, A. (2016). Mechanical behavior of glass fiber polyester hybrid composite filled with natural fillers. *IOP Conference Series: Materials Science and Engineering*, (pp. 1-8). doi:10.1088/1757-899X/149/1/012091

Guptaa, M., & Singha, R. (2018). Flexural and Dynamic Mechanical Analysis (DMA) of Polylactic Acid (PLA) Coated Sisal Fibre Reinforced Polyester Composite. *Materials Today: Proceedings 5*, 6109–6114.

Hanamanagouda, Gowda, K., Easwara Prasad, G., & Velmurugan, R. (2016). Mechanical Properties of Raw Jute Polyester Composite. *International Journal of Fiber and Textile Research, 6*(1), 20-24.

Huda, M., Drzal, L., Mohanty, A., & Misra, M. (2008). Effects of fibre surface-treatments on the properties of laminated biocomposites from poly(lactic acid) (PLA) and kenaf fibres. *Composites Science and Technology*, 424-432. doi:10.1016/j.compscitech.2007.06.022

Hughes, M. (2011). Defects in natural fibres: their origin, characteristics and implications for natural fibrereinforced composites. *Journal of Materials Science*, 1-11.

Irena, Ž., Karlo, K., & Josip, Ž. (2015). Thermal Properties Of Waste Paper Composites . *International Conference, MATRIB 2015*, (pp. 419-420). Vela Luka, Croatia.

Irwin, P., Cao, Y., Bansal, A., & Schadler, L. (2003). Thermal and Mechanical Properties of Polyimide Nanocomposites. *IEEE Conference. El.*, (pp. 120-123). Albuquerque, New Mexico, USA,.

Islam, M., Das, C., Saha, J., Debasree Paul, D., Islam, M., Rahman, M., & Khan, M. (2017). Effect of Coconut Shell Powder as Filler on the Mechanical Properties of Coir-polyester Composites. *Chemical and Materials Engineering, 5*(4), 75-82. doi:10.13189/cme.2017.050401

Jeyanthi, S., & Janci, J. (2012). Improving Mechanical Properties by KENAF Natural Long Fiber Reinforced Composite for Automotive Structure. , *Journal of Applied Science and Engineering, 15*(03), 275280.

Kanungo, B., Rohit, K., & Thakar, G. (2017, June). Unkwonwibgly Accepting Health Hazards in Daily Routine Life. *Industrial Engineering Journal, X*(6), 29-33.

Khurmi, R., & Gupta, J. (2008). *Machine Design*. New Delhi: S, Chand and Company.

Kim, H., Hong, S., & Kim, S. (2001). On the rule of mixtures for predicting the mechanical properties of composites with homogeneuosly distributed soft and hard particles. *Journal of Material Processing Technology*, 109-113.

Kodre, K., Attarde, S., Yendhe, P., Patil, R., & Barge, V. (2014, July 28). Differential Scanning Calorimetry: A Review. *Research and Reviews: Journal of Pharmaceutical Analysis, III*(3), 11-12.

Krishnaprasad, R., Veena, N., Maria, H., Rajan, R., Skrifvars, M., & Joseph, K. (2009). Mechanical and thermal properties of bamboo microfibril reinforced polyhydroxybutyrate biocomposites. *Journal of Polymers and the Environment*(17), 109-114.

Li, X., Tabil, L., & Panigrahi, S. (2007). Chemical treatments of natural fibre for use in natural fibre-reinforced composites. *Journal of Polymers and the Environment*(15), 25-33. doi:10.1007/s10924-006-0042-3

Liu, W., Mohanty, A., Drzal, L., & Misra, M. (2005). *Novel biocomposites from native grass and soy based bioplastic: Processing and properties evaluation. Industrial & Engineering Chemistry Researc*. doi:10.102/ie050257

Liu, W., Mohanty, A., P, A., Drzal, L., & Misra, M. (2007). Influence of fiber surface treatment on properties of Indian grass fiber reinforced soy protein based biocomposites. Polymer . *Journal of Polymers and the Environment* , 7589-7596.

Liu, Y., Xie, J., Wu, N., Wang, L., Ma, .., & Tong, J. (2018). Influence of silane treatment on the mechanical, tribological and morphological properties of corn stalk fiber reinforced polymer composites. *Tribology International*. doi:10.1016/j.triboint.2018.11.004

Lópeza, J., Mutjéb, P., Carvalho, A., Curveloa, A., & Gironèsb, J. (2013). Newspaper fiber-reinforced thermoplastic starch biocomposites obtained by melt processing: Evaluation of the mechanical, thermal and water sorption properties. *Industrial Crops and Products*, 300-305. doi:10.1016/j.indcrop.2012.11.020

Mallick, P. (2007). *Fibre-Reinforced Composites; Materials, Manufacturing and Design*. (3rd ed.). New York: CRC Press.

Masoodi, R., & Pillai, K. (2012). A study on moisture absorption and swelling in bio-based jute-epoxy composites. *Journal of Reinforced Plastics and Composites*, 285–294. doi:10.1177/0731684411434654

McKinney, R. (1995). Technology of paper recycling. In *Technology of paper recycling*. London: Blackie.

Mishra, H., Dash, B., Tripathy, S., & Padhi, B. (2000). A Study On Mechanical Performance Of Jute-Epoxy Composites. *Polymer-Plastics Technology and Engineering,*, *39*(1), 187-198. doi:http://dx.doi.org/10.1081/PPT-100100023

Morgan, P. (1965). Condensation Polymers; By Interfacial and Solution Methods. In P. Morgan, *Condensation Polymers; By Interfacial and Solution Methods*. New York: Inerscience Publishers.

Muhammad Azeem Munawara, d. D., Schuberta, D., Khand, S., Atiq, M., Rehman, U., Gulld, N., . . . Muhammad Shafiqd. (2017). Investigation of functional, physical, mechanical and thermal properties of TiO2 embedded polyester hybrid composites: A design of experiment (DoE). *Progress in Natural Science: Materials International*. doi:https://doi.org/10.1016/j.pnsc.2017.12.005

Mylsamy, K., & Rajendran, I. (2011). Influence of alkali treatment and fibre length on mechanical properties of short agave fibre reinforced epoxy composites. *32*, 4629-4040.

NDT Resource Center. (2016, March). Retrieved from NDT Resource Center: www.ndt_ed.org/EducationResources/CommunityCollege/Materials/Structure/composite_class

Neale, M., & Gee, M. (2001). *Guide to wear problems and testing for industry*. New York, U.S.A.: William Andrew Publishing.

Negawo, T., Polat, Y., Buyuknalcaci, F., Kilic, A., Saba, N., & Jawaid, M. (2018). Mechanical, Morphological, Structural and Dynamic Mechanical Properties of Alkali Treated Ensete Stem Fibers Reinforced Unsaturated Polyester Composites. *Composite Structures*. doi:https://doi.org/10.1016/j.compstruct.

Nishino, T., Hirao, K., Kotera, M., Nakamae, K., & Inagaki, H. (2003). Kenaf reinforced biodegradable composite. *Composites Science and Technology*, 1281-1286. doi:10.1016/S0266-3538(03)00099-X

Noryani, M., Sapuan, S., Mastura, M., Zuhri, M., & Zainudin, E. (2018). Material Selection Criteria for Natural Fibre Composite in Automotive component: A review. *The Wood and Biofiber International Conference (WOBIC 2017)* (pp. 1-16). IOP Publishing. doi:10.1088/1757-899X/368/1/012002

Oboh, J. O., J., O., Okafor, J., Kovo, A., & Abdulrahman, A. (2018, July). Dynamic Mechanical Properties of Crosslinked Natural Rubber Composite Reinforced with Cellulosic Nanoparticles. *Nigerian Journal of Technology, 37*(3), 668-673. doi:2467-8821

Ochi, S. (2008). Mechanical properties of kenaf fibres and kenaf/PLA composites. *Mechanics of Materials, 40*, 446-452. doi: 10.1016/j.mechmat.2007.10.006

Oriyomi, M., & Oluwatobi, J. (2014). Assessment of the Suitability of Paper Waste as an Engineering Material. *Engineering, Technology & Applied Science Research, IV*(6), 724-725. Retrieved July 2017

Ornaghi, H., Bolner, A., Fiorio, R., Zattera, A., & Amico, S. (2010). Mechanical and Dynamic Mechanical Analysis of Hybrid Composites Molded by Resin Transfer Molding. *Journal of Applied Polymer Science, 118*, 887–896. doi:10.1002/app.32388

Pandiatmi, P., Dyah, E., & Watoni, S. (2019). Polyester Composite Bending Strength Optimization Strengthened with Coastal Cottonwood Tree Bark Fiber and Fly Ash Filler. *International Conference on Mechanical Engineering Research and Application* (pp. 1-8). IOP Publishing. doi:10.1088/1757-899X/494/1/012010

Panthapulakkal, S., & Sain, M. (2007). Studies on the Water Absorption Properties of Short Hemp – Class Fiber Hybrid Polyproylene Composites. *Journal of Composite Materials, 41*(15), 1871 – 1883.

Piyoosh, T., Pawan, S., & Manish,B. (2013, December). An Approach of Composite Materials in Industrial Machinery: Advantages, Disadvantages and Application. *International Journal of Research in Engineering and Technology, 02*(12), 354. Retrieved April 2017

Prabu, V., & Johnson, R. (2017). Usage Of Industrial Wastes As Particulate Composite For Environment Management: Hardness, Tensile And Impact Studies. *Journal of Environmental Chemical Engineering*. doi:http://dx.doi.org/10.1016/j.jece.2017.02.007

Pradhan, S., Rajkonwar, A., & Acharya, S. (2019). Study of mechanical and abrasive wear properties of lantana camara. *Materials Today: Proceedings*, 2214-7853. doi:https://doi.org/10.1016/j.matpr.2019.07.206

Rachchha, N., Ujeniyab, P., & Misrac, R. (2014). Mechanical characterisation of rattan fibre polyester composite. *Procedia Materials Science, 6*, 1396-1404. doi:10.1016/j.mspro.2014.07.119

Rahyan, F., Mohd, Z., & Norizal, M. (2008). Paper Fibre Reinforced Foam Concrete Wall Paneling. *2nd International Conference on Built Environment in Developing Contries (ICBEDC 2008)*,(pp. 528-529). Pulau, Pinang.

Rajput, R. (2008). *Strength of Materials.* New Delhi: S Chand and Company Ltd.

Rakesh, K., Sangeeta, O., & Aparna, S. (2011). Chemical modifications of natural fiber for composite material. *Der Chemica Sinica, 2*(4), 220-221. Retrieved from www.pelagiaresearchlibrary.com

Reddy, M., & Reddy, V. (2014, September). Dynamic Mechanical Analysis of Hemp Fiber Reinforced Polymer Matrix Composites. *International Journal of Engineering Research & Technology (IJERT), III*(3),410-415.

Reis, J. D., Cardosob, J., & Castrob, P. (2014). Mechanical Properties of Recycled Kraft Paper Residue Polyester Composites. *Materials Reseach*.

Rezaei, F., Yunus, R., Ibrahim, N., & Mahdi, E. (2008). Development of Short-Carbon-Fiber-Reinforced Polypropylene Composite for Car Bonnet. 351-357. doi:10.1080/03602550801897323

Richardson, T. (1987). Composite-a design guide . In T. Richardson, *Composite-a design guide* (p. 200). New York: Industrial Press Inc,Maidson Avenue .

Ru-Min, W., Shui-Rong, Z., & Ya-Ping, Z. (n.d.). Application of composite materials. In W. Ru-Min, Z. Shui-Rong, & Z. Ya-Ping, *Polymer Matrix Composites and Technology* (pp. 9-12). WoodHead Publishing, Science Press.

Sair, S., Oushabi, A., Kammouni, A., Tanane, O., Abboud, Y., Oudrhiri Hassani, F., . . . El Bouari, A. (2017). Effect of surface modification on morphological, mechanical and thermal conductivity of hemp fiber: Characterization of the interface of hemp Polyurethane composite. *Case Studies in Thermal Engineering*. doi:10.1016/j.csite.2017.10.012

Sangrutsamee, V., Panya, S., & Nuchthana, P. (2012). Re-pulped waste paper–based composite building materials with low thermal conductivity. *Journal of Asian Architecture and Building Engineering, XI*, 147-151.

Sapuan, S., Mun, N., Hambali, A., Lok, H., Fairuz, A., & Ishak, M. (2011). Prototype expert system for material selection of polymeric composite automotive dashboard. *International Journal of the Physical Sciences, 6*(25), 5988-5995. doi:10.5897/IJPS11.939

Senthiil, P., & Sirsshti, a. (2014, 2November 20). Studies on Material and Mechanical Properties of Natural Fiber Reinforced Composites. *The International Journal Of Engineering And Science, III*(2), 18-27.

Serrano, A., Espinach, F., Julian, F., Del Rey, R., Mendez, J., & Mutje, P. (2013). Estimation of the interfacial shears strength, orientation factor and mean equivalent intrinsic tensile strength in old newspaper fiber / polypropylene composites. *Composite Part B: Engineering*, 232-238. doi:10.1016/j.compositesb.2013.02.018

Shafiur Rahman, G., Muhammad Abdullah Al Mamun, Bashar, M. S., Mostafa, M., Farhad Ali, M., & Mubarak, A. (2015, February 22). A Study on Comparison Between Recycled Waste Paper Reinforced Polymer Composite and Hardboard. *Rajshahi University Journal of Environmental Science*, 11.

Shah, A., & Lakkad, S. (1981). Mechanical properties of jute-reinforced plastics. *Fibre Science and Technology, 15*(01), 41-46.

Shan Ren, H., & David, N. (1993). Newspaper Fiber-Reinforced Polypropylene Composite. *Journal Of Reinforced Plastics And Composites,, 12*, 1311-1322.

Shinji, O. (2008). Mechanical properties of kenaf fibers and kenaf/PLA composites. In O. Shinji, *Mechanics of Materials* (pp. 446-452).

Sigley, R., Wronski, A., & Parry, T. (1991). Three-parameter yield criterion for a brittle. *Journal of Master Science, 26*(15), 3985-3990.

Singleton, A., Baillie, C., Beaumont, P., & Peijs, T. (2003). On the mechanical properties, deformation and fracture of a natural fibre/recycled polymer composite. 519-526. doi:10.1016/S1359-8368(03)00042-8

Srinivasa, K., Udaya, K., & Prahlada, R. (2017). Effect of Fiber Surface Treatments on Mechanical Properties of Sisal Fiber Polymer Composites–A Review. *International Journal of Advanced Research in Science, Engineering and Technology, 4*(8), 4412-4413.

Susilowati, S., & Sumardiyanto, D. (2018). Assessing Mechanical Properties of Pineapple Leaf Fibre (PLF) Reinforced Composites for Automotive Applications. *International Journal of Composite Materials, 8*(3), 57-63. doi:10.5923/j.cmaterials.20180803.02

Tabatabai, H., Janbaz, M., & Nabizadeh, A. (2017). Mechanical and thermo-gravimetric properties of unsaturated polyester. *Construction and Building Materials*, 438–445. doi:https://doi.org/10.1016/j.conbuildmat.2017.12.041

Tangimul Islam, M., Das, S., Saha, J., Paul, D., Islam, M., Rahman, M., & Khan, M. (2017). Effect of Coconut Shell Powder as Filler on the Mechanical Properties of Coir-polyester Composites. *Chemical and Materials Engineering, 5*(4), 75-82. doi:10.13189/cme.2017.050401

Thomason, J., & Vlug, M. (1995). Influenece of fibre length and concentration on the properties glass fibre reinforced polypropylene 1: Tensile and Flexural properties. *Composite Part A*, 477-484. doi:doi.org/10.1016/1359-835(X)00065A

Vachira S, Panya, S., & Nuchthana, P. (2012). Re-pulped waste paper- Based composite building materials with low thermal conductivity. *Asian Architecture and Building Engineering*, 151.

Vaghasia, B., & Rachchh, N. (2018). Evaluation of Physical and Mechanical Properties of Woven Bamboo Glass Polyester Hybrid Composite Material. *Materials Today: Preceedings, 5*(2), 7930–7936. doi:doi.org/10.1016/jmatpr.2017.11.475

Velev, P., Takev, M., & Samichkov, V. (2014). Physicomechanical Properties of Biodegradeble Composites Based on Polypropylene Ans Paper from Old Newspsper. *Journal of Chemical Technology and Metallurgy, 49*(4), 363-369.

Verma, D., Gope, P., Shandilya, A., Gupta, A., & Maheshwari, M. (2003). Coir Fiber Reinforcement and Application in Polymer Composites: A Review. *Journal of Material Environment science, 4*, 263-276.

Vijaya, K., Sarcar, M., & Ramji, K. (2014, February). Investigation of Dielectric Properties of Industrial Waste Reinforced Particulate Polymer Composites. (L. Nicolais, Ed.) *AdvancesinMaterialsScienceandEngineering*, 1-6. doi:10.1155/2014/319741

Warner, S. (1995). Fibre Science. In S. Warner, *Fibre Science* (pp. 5-6). New York: Prentice Hall, Engle wood Cliffs.

Wirawan, R., Sapuan, S., Yunus, R., & Abdan, K. (2012). Density and Water Absorption of Sugarcane Bagasse-Filled Poly(vinyl chloride) Composites. *Polymers & Polymer Composites,, 20*(7), 659-664.

Witold, B., Vera, K., Domagoj, V., & Jenna, W. (2010). Tribology of Polymers and Polymer-Based Composites . *Journal of Materials Education, 32*(5-6), 273-290.

Xie, Y., Hill, C., Xiao, Z., Militz, H., & Mai, C. (2010). Silane coupling agents used for natural fibre/polymer composites. 806–819.

Yeny, D., & Yulinah, T. (2012). Solid Waste Management in Asian Developing Countries: Challenges and Opportunities. *Journal of Applied Environmental Biological Science, II*(7), 329-335.

Yuhazri, M., Amirhafizan, M., Abdullah, A., Yahaya, S., Lau, S., & Kamarul, A. (2018). Kenaf Fibre Composites as Promising Green-Composites for Automotive Car Door Map Pocket Application. *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 18*(2), 15-21.

APPENDICES

APPENDIX A: TENSILE STRENGHT CALCULATIONS

A 1 Tensile Test Result of Neat Polyester Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{11}	7.3	7.0	6.6	1.3	25.44	0.165	0.1542
A_{12}	7.4	7.6	6.6	1.6	28.45	0.165	0.1724
A_{13}	7.0	7.4	7.8	1.7	32.82	0.195	0.1683
A_{14}	7.0	7.2	6.0	1.5	29.76	0.510	0.1984
A_{15}	7.4	7.4	8.4	1.6	29.22	0.210	0.1391
Average	**7.22**	**7.32**	**7.08**	**1.54**	**29.14**	**0.177**	**0.1665**

A 2 Tensile Strength Test Result of 5wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{21}	7.3	7.1	6.6	1.65	31.83	0.17	0.1872
A_{22}	7.3	7.3	5.4	1.4	26.27	0.15	0.1751
A_{23}	7.2	7.3	6.0	1.6	30.44	0.16	0.1903
A_{24}	7.4	7.0	5.6	1.6	30.89	0.14	0.1817
A_{25}	7.5	6.4	4.8	1.7	35.42	0.15	0.2214
Average	**7.34**	**7.02**	**5.68**	**1.59**	**30.97**	**0.16**	**0.1911**

A 3 Tensile Strength Test Result of 10wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{31}	7.3	7.1	6.6	1.53	22.83	0.17	0.1712
A_{32}	7.2	7.3	7.2	2.0	37.54	0.17	0.2208
A_{33}	7.4	7.3	7.2	1.6	25.58	0.15	0.2002
A_{34}	7.4	7.0	10.8	1.7	34.72	0.17	0.1877
A_{35}	7.4	6.4	6.2	1.64	23.42	0.16	0.1847
Average	**7.34**	**7.02**	**7.6**	**1.66**	**31.63**	**0.164**	**0.1929**

A 4 Tensile Strength Test Result of 15wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{41}	7.3	7.2	6.0	1.7	32.34	0.15	0.2156
A_{42}	7.3	7.3	6.6	1.5	28.15	0.16	0.1759
A_{43}	7.2	7.4	7.2	1.8	33.78	0.18	0.1877
A_{44}	7.2	7.3	5.4	1.6	30.44	0.14	0.2174
A_{45}	7.2	7.2	4.2	1.9	36.65	0.13	0.2819
Average	**7.24**	**7.32**	**5.88**	**1.70**	**32.27**	**0.152**	**0.2157**

A 5 Tensile Strength Test Result of 20wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{51}	7.0	7.4	6.0	1.8	34.75	0.15	0.2317
A_{52}	7.1	7.3	6.6	1.5	34.34	0.14	0.2544
A_{53}	7.5	7.2	7.2	1.7	35.19	0.18	0.1955
A_{54}	7.0	7.5	5.4	1.67	37.14	0.14	0.2751
A_{55}	7.3	7.3	7.8	1.65	37.53	0.195	0.1925
Average	**7.18**	**7.34**	**6.36**	**1.66**	**35.79**	**0.159**	**0.2298**

A 6 Tensile Strength Test Result of 25wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Extension (mm)	Load (KN)	UTS (MPa)	Strain	Young Modulus (GPa)
A_{61}	7.3	7.2	6.6	1.72	32.73	0.165	0.1107
A_{62}	7.4	7.2	6.4	1.67	31.34	0.160	0.1331
A_{63}	7.2	7.3	5.4	1.62	30.82	0.135	0.1372
A_{64}	7.3	7.2	4.8	1.80	34.25	0.120	0.1574
A_{65}	7.2	7.2	3.0	1.73	33.37	0.175	0.2223
Average	**7.28**	**7.22**	**5.24**	**1.67**	**32.50**	**0.147**	**0.1521**

A 7 Average Tensile Strength Test Result of Developed Composite.

Filler Loading (wt%)	Width (mm)	Thickness (mm)	Extension	Load (KN)	Strain	Tensile Strength (MPa)	Tensile Modulus (GPa)
Neat Polyester	7.22	7.32	7.08	1.54	0.177	29.14	0.1665
5	7.34	7.02	5.68	1.59	0.160	30.97	0.1911
10	7.42	7.30	7.60	1.66	0.174	31.63	0.1914
15	7.28	7.44	5.88	1.70	0.152	32.27	0.2157
20	7.18	7.34	6.36	1.83	0.159	35.10	0.2247
25	7.40	7.32	5.24	1.67	0.147	32.27	0.2229

APPENDIX B: COMPRESSIVE STRENGTH CALCULATIONS

B 1 Compressive Strength Test Result of Neat Polyester Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{11}	20.40	21.00	47.08	109.90
B_{12}	21.50	21.00	48.92	108.35
B_{13}	21.00	21.40	46.08	102.54
B_{14}	21.60	21.40	47.60	102.53
B_{15}	21.40	21.70	45.75	98.52
Average	**21.18**	**21.30**	**47.59**	**104.37**

B 2 Compressive Strength Test Result of 5wt% Particulate Filler Reinforcement Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{21}	21.40	21.20	48.26	106.37
B_{22}	21.00	21.20	47.79	107.35
B_{23}	21.00	21.70	47.81	104.89
B_{24}	21.40	21.40	48.22	105.29
B_{25}	21.70	21.40	46.87	100.93
Average	**21.30**	**21.38**	**38.41**	**104.97**

B 3 Compressive Strength Test Result of 10wt% Particulate Filler Reinforcement Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{31}	21.00	21.60	48.09	106.02
B_{32}	21.50	21.00	46.54	103.08
B_{33}	21.20	21.20	47.91	106.60
B_{34}	21.30	21.00	49.22	110.04
B_{35}	21.30	21.40	47.82	104.91
Average	**21.26**	**21.25**	**47.92**	**106.13**

B 4 Compressive Strength Test Result of 15wt% Particulate Filler Reinforcement Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{41}	21.50	20.20	47.43	109.21
B_{42}	20.40	21.20	46.34	107.15
B_{43}	21.30	20.30	45.88	106.11
B_{44}	21.00	21.40	48.34	107.57
B_{45}	21.00	21.20	47.31	106.27
Average	**21.04**	**20.86**	**47.06**	**107.26**

B 5 Compressive Strength Test Result of 20wt% Particulate Filler Reinforcement Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{51}	21.40	21.50	48.82	106.11
B_{52}	21.40	21.30	47.82	104.91
B_{53}	21.40	21.40	49.61	108.83
B_{54}	21.40	21.20	48.01	105.82
B_{55}	21.20	21.30	49.20	108.96
Average	**21.36**	**21.40**	**48.69**	**106.83**

B 6 Compressive Strength Test Result of 25wt% Particulate Filler Reinforcement Sample

SAMPLE	Length (mm)	Breath (mm)	Force (KN)	Compressive Strength (MPa)
B_{61}	21.40	21.20	49.72	109.59
B_{62}	21.40	21.20	48.37	106.62
B_{63}	21.60	21.30	48.37	105.13
B_{64}	21.30	21.60	47.29	102.79
B_{65}	22.50	21.40	49.95	103.74
Average	**21.78**	**21.74**	**48.74**	**105.57**

B 7 Average Compressive Strength Test Result of Developed Composite.

Filler Loading (%)	Length (mm)	Breath (mm)	Load (KN)	Compressive Strength (MPa)
0	21.18	21.30	47.59	104.37
5	21.30	21.38	47.79	104.97
10	21.26	21.24	47.53	106.13
15	21.04	20.86	47.06	107.26
20	21.36	21.40	48.69	106.83
25	21.78	21.74	49.14	106.44

APPENDIX C: FLEXURAL STRENGTH CALCULATIONS

C 1 Flexural Strength Test Result of Neat Polyester Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (GPa)
			Initial	Final			
C_{11}	40.0	6.7	14.63	12.01	0.81	54.14	21.954
C_{12}	39.6	6.8	14.54	11.53	0.81	53.09	21.954
C_{13}	40.0	6.7	14.98	10.64	0.91	60.82	14.947
C_{14}	39.0	6.0	14.65	9.98	0.99	84.62	19.327
C_{15}	40.0	6.0	14.99	11.41	0.79	65.87	19.615
Average	**39.72**	**6.44**	**14.76**	**11.11**	**0.862**	**63.714**	**19.559**

C 2 Flexural Strength Test Result of 5wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (MPa)
			Initial	Final			
C_{21}	39.0	7.0	16.56	14.02	0.84	52.75	22.154
C_{22}	39.0	7.0	16.70	14.87	1.02	64.05	37.332
C_{23}	38.0	7.2	15.68	13.58	0.80	48.73	24.754
C_{24}	39.0	7.6	15.56	13.42	1.01	53.81	26.817
C_{25}	40.5	7.0	16.97	15.52	1.11	67.12	49.376
Average	**39.1**	**7.16**	**16.294**	**14.282**	**0.956**	**57.29**	**32.087**

C 3 Flexural Strength Test Result of 10wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (MPa)
			Initial	Final			
C_{31}	39.3	6.3	18.07	15.79	0.71	54.62	25.222
C_{32}	39.0	6.0	16.10	14.01	0.75	64.10	32.717
C_{33}	39.5	6.8	17.86	15.61	0.75	49.27	23.361
C_{34}	39.2	6.4	14.90	12.69	0.70	52.32	25.250
C_{35}	38.9	6.0	16.43	14.34	0.64	54.84	27.990
Average	**39.18**	**6.3**	**16.672**	**14.482**	**0.71**	**55.03**	**26.908**

C 4 Flexural Strength Test Result of 15wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (GPa)
			Initial	Final			
C_{41}	39.00	7.0	18.04	15.66	0.88	55.30	24.766
C_{42}	39.60	7.6	15.20	13.60	0.72	37.77	25.182
C_{43}	38.00	7.1	15.93	13.97	0.80	50.12	27.274
C_{44}	38.40	7.2	16.39	13.88	1.00	60.29	25.618
C_{45}	38.60	7.1	16.41	14.41	0.90	55.50	29.601
Average	**38.72**	**7.2**	**16.39**	**14.30**	**0.86**	**51.796**	**26.488**

C 5 Flexural Strength Test Result of 20wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (GPa)
			Initial	Final			
C_{51}	38.0	7.5	15.78	14.08	0.88	49.40	30.998
C_{52}	39.5	7.0	15.46	13.95	0.72	44.64	31.535
C_{53}	38.0	7.3	16.31	14.31	0.81	48.00	25.600
C_{54}	38.5	7.5	15.85	14.11	0.75	41.56	25.476
C_{55}	38.8	7.4	16.10	14.42	0.85	48.01	30.480
Average	**38.56**	**7.34**	**15.90**	**14.174**	**0.802**	**46.322**	**28.818**

C 6 Flexural Strength Test Result of 25wt% Particulate Filler Reinforcement Sample

SAMPLE	Width (mm)	Thickness (mm)	Deflection (mm)		Load (KN)	Flexural Strength (MPa)	Flexural Modulus (MPa)
			Initial	Final			
C_{61}	38.0	7.4	16.05	14.30	0.75	42.11	25.663
C_{62}	40.0	7.4	17.09	15.03	0.95	52.04	26.949
C_{63}	39.0	7.0	16.54	14.43	0.70	43.96	22.221
C_{64}	39.0	7.3	16.32	14.56	0.80	45.71	27.995
C_{65}	38.5	7.4	16.56	14.46	0.83	47.24	24.000
Average	**38.9**	**7.32**	**16.512**	**14.556**	**0.806**	**46.212**	**25.366**

C 7 Average Flexural Strength Test Result of Developed Composite.

Filler Loading (wt %)	Width (mm)	Thickness (mm)	Deflection (mm)		Δl (mm)	Load (KN)	Flexural Strength (MPa)	Flexural Modulus (GPa)
			Initial	Final				
0	39.72	6.44	14.76	11.11	3.65	0.860	63.71	19.56
5	39.10	7.16	16.29	14.28	2.01	0.96	57.29	32.09
10	39.18	6.30	16.67	14.82	2.19	0.71	55.03	26.91
15	38.72	7.20	16.39	14.03	2.09	0.86	51.80	26.49
20	38.56	7.34	15.90	14.17	1.73	0.80	46.32	28.12
25	38.90	7.32	16.51	14.56	1.96	0.81	46.21	25.37

APPENDIX D: IMPACT STRENGTH ANALYSIS

D 1 Impact Strength test result for Neat Polyester Sample

Fibre Loading (wt %)	Area (m^2) X 10^{-6}	Impact Energy (J)	Impact Strength (kJ/m^2)
D_{11}	132.00	0.3	2.27
$D1_2$	133.44	0.25	1.87
D_{13}	143.00	0.32	2.24
D_{14}	143.00	0.40	2.80
D_{15}	141.36	0.50	3.54
Average	**138.56**	**0.35**	**2.54**

D 2 Impact Strength test result for 5wt% Particulate Filler Reinforcement Sample

Filler Loading (5wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
D_{21}	139.2	0.30	2.16
D_{22}	132.00	0.40	3.03
D_{23}	132.00	0.40	3.03
D_{24}	144.00	0.36	2.50
D_{25}	138.10	0.37	2.68
Average	**137.06**	**0.37**	**2.68**

D 3 Impact Strength test result for 10wt% Particulate Filler Reinforcement Sample

Filler Loading (10wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
D_{31}	146.96	0.70	4.76
D_{32}	150.00	0.42	2.80
D_{33}	151.20	0.45	2.98
D_{34}	148.80	0.48	3.23
D_{35}	132.00	0.43	3.26
Average	**145.79**	**0.50**	**3.41**

D 4 Impact Strength test result for 15wt% Particulate Filler Reinforcement Sample

Filler Loading (wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
D_{41}	145.10	0.60	4.14
D_{42}	132.00	0.46	3.48
D_{43}	143.90	0.48	3.34
D_{44}	145.10	0.53	3.65
D_{45}	115.20	0.51	4.34
Average	**132.26**	**0.52**	**3.79**

D 5 Impact Strength test result for 20wt% Particulate Filler Reinforcement Sample

Filler Loading (20wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
D_{51}	151.20	0.48	3.17
D_{52}	148.80	0.51	3.43
D_{53}	153.60	0.49	3.19
D_{54}	132.00	0.60	4.55
D_{55}	140.80	0.47	3.34
Average	**142.28**	**0.51**	**3.54**

D 6 Impact Strength test result for 25wt% Particulate Filler Reinforcement Sample

Filler Loading (25wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
D_{61}	146.40	0.49	3.35
D_{62}	132.00	0.48	3.64
D_{63}	132.00	0.45	3.41
D_{64}	136.40	0.44	3.23
D_{65}	132.00	0.47	3.56
Average	**141.50**	**0.42**	**3.44**

D 7 Average Impact Strength Test Result of Developed Composite

Filler Loading (wt %)	**Area (m^2) X 10^{-6}**	**Impact Energy (J)**	**Impact Strength (kJ/m^2)**
Neat Polyester	138.56	0.35	2.54
5	137.06	0.37	2.68
10	144.79	0.43	3.41
15	132.26	0.47	3.79
20	142.28	0.34	3.54
25	141.50	0.33	3.44

APPENDIX E: TRIBOLOGY TEST RESULT

E 1Tribology Test Result of Neat Polyester Sample.

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 5.00 [mm]
- Lin. Speed: 10.47 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

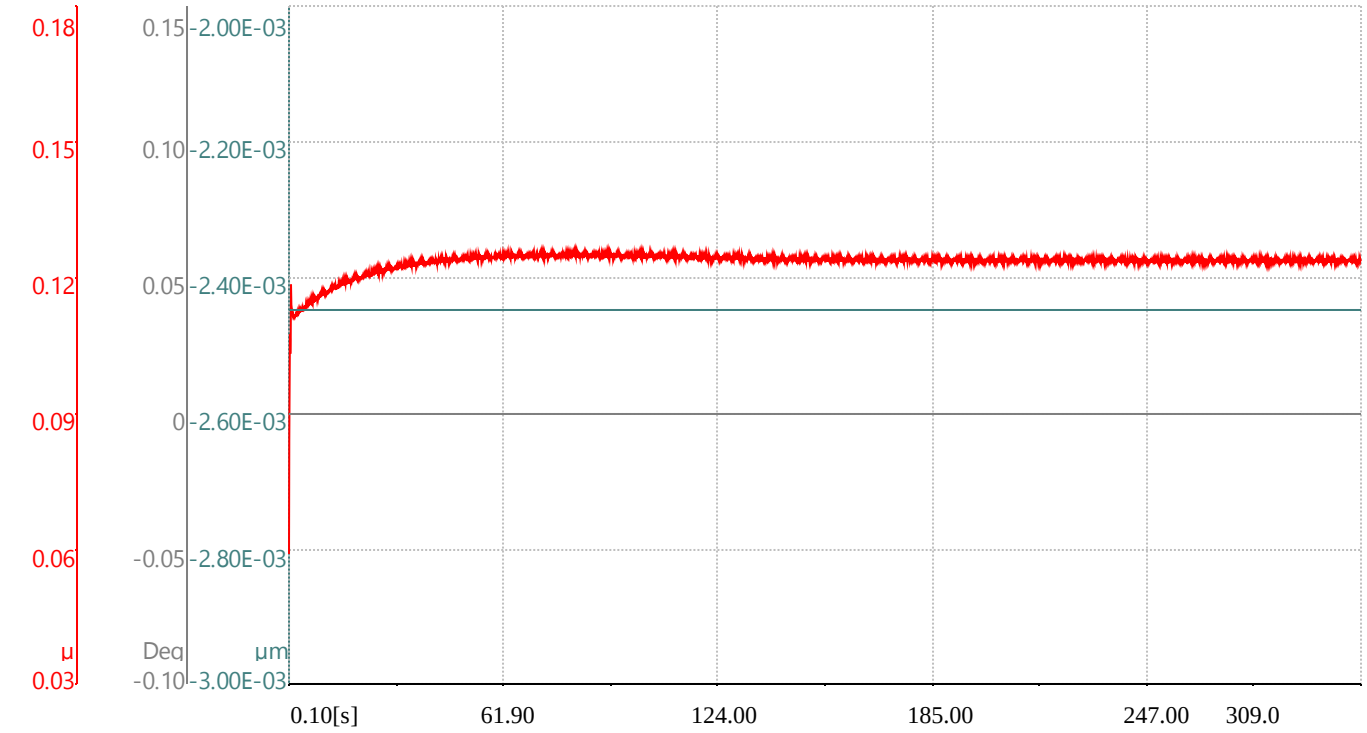
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 11:22:40 AM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : 0.059 min : 0.059 max : 0.126 mean : 0.123 std. dev. : 0.003



E 2 Tribology Test Result of 5wt% Particulate Filler Reinforcement Sample

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 4.99 [mm]
- Lin. Speed : 10.45 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

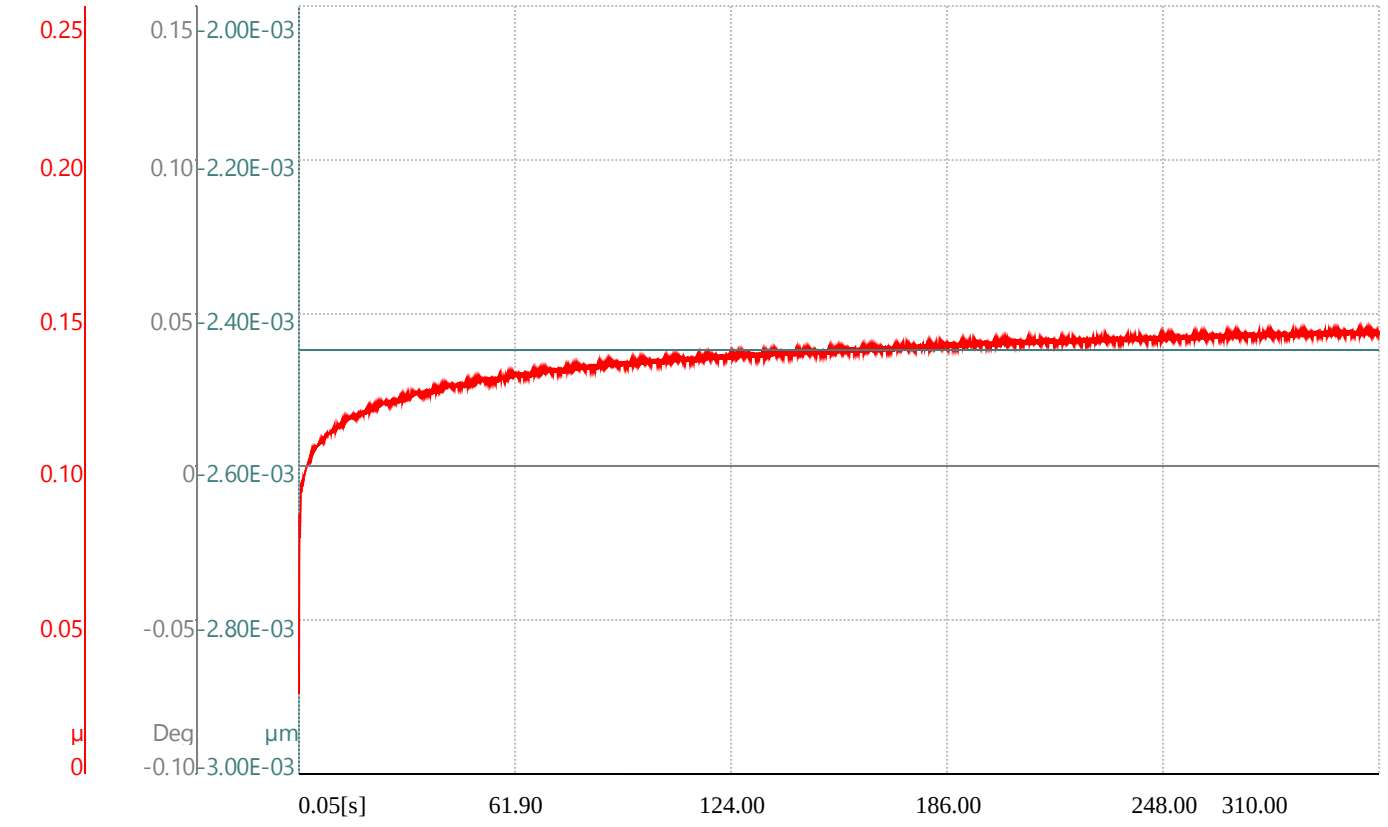
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 11:51:57 AM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : 0.026 min : 0.026 max : 0.145 mean : 0.135 std. dev. : 0.009



E 3 Tribology Test Result for 10wt% Particulate Filler Reinforcement Sample

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 5.00 [mm]
- Lin. Speed : 10.47 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

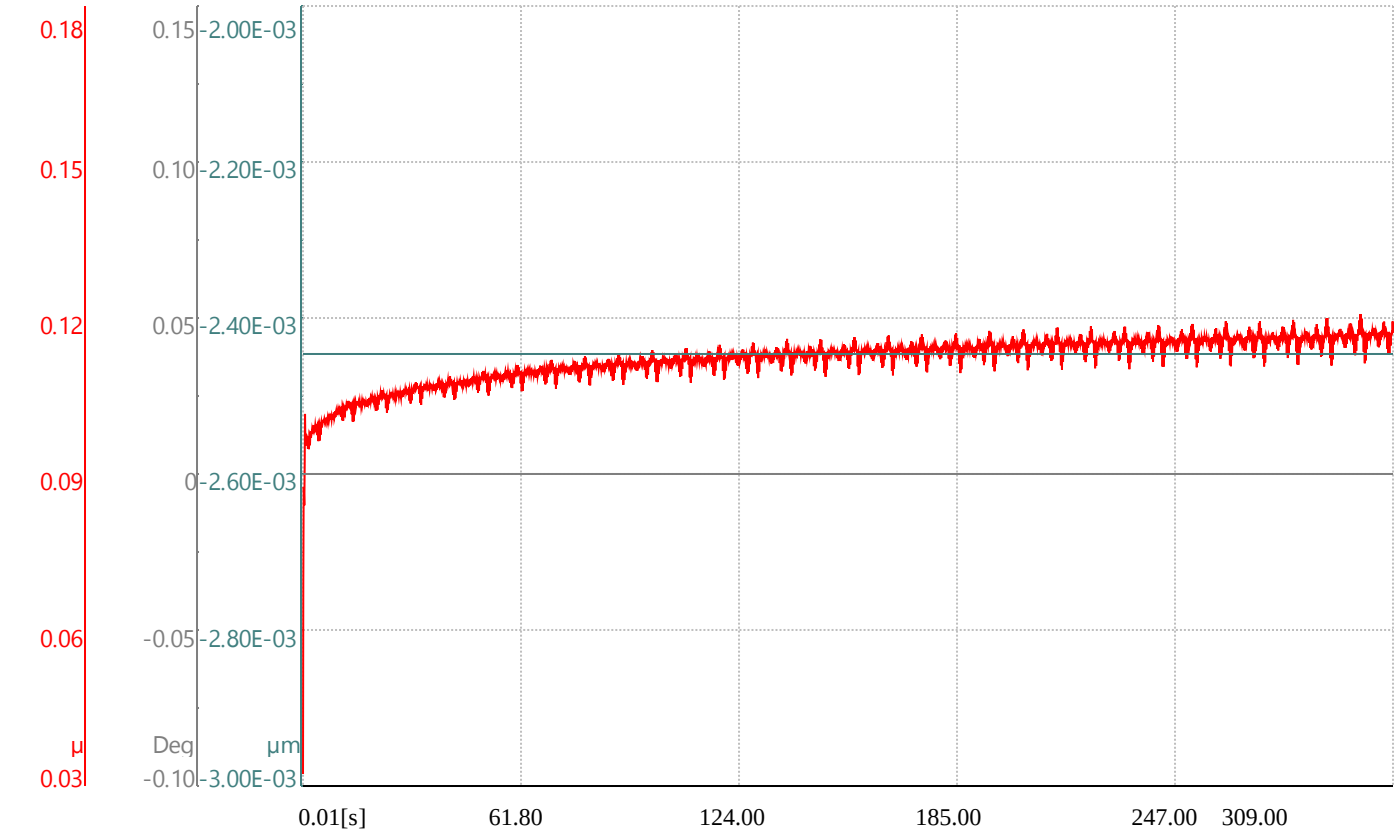
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 12:14:54 PM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : 0.032 min : 0.032 max : 0.121 mean : 0.112 std. dev. : 0.005



E 4 Tribology Test Result of 15wt% Particulate Filler Reinforcement Sample

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 5.00 [mm]
- Lin. Speed : 10.47 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

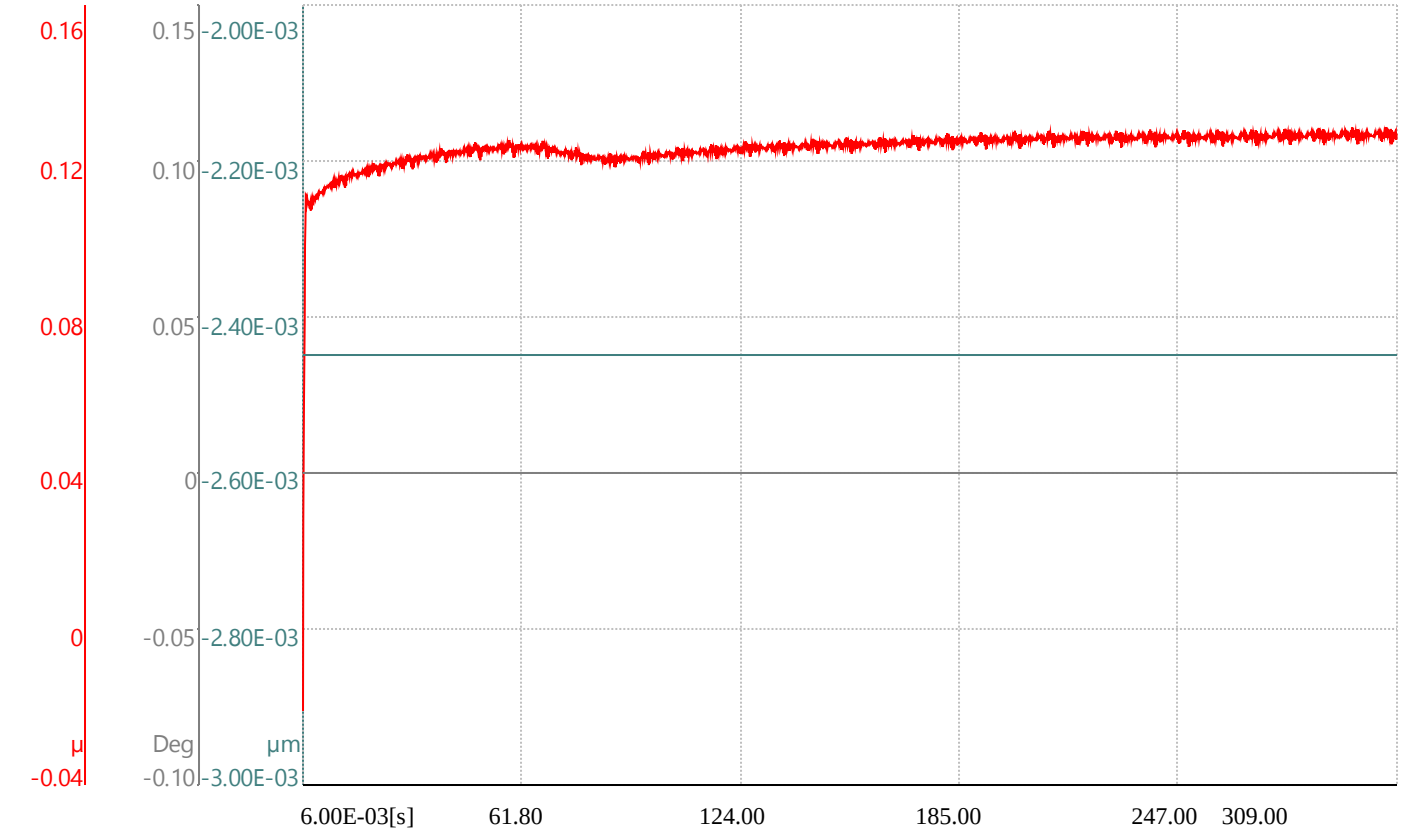
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 12:22:31 PM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : -0.021 min : -0.021 max : 0.129 mean : 0.123 std. dev. : 0.005



E 5 Tribology Test Result for 20wt% Particulate Filler Reinforcement Sample

Tribo measurement1

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 5.00 [mm]
- Lin. Speed : 10.47 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

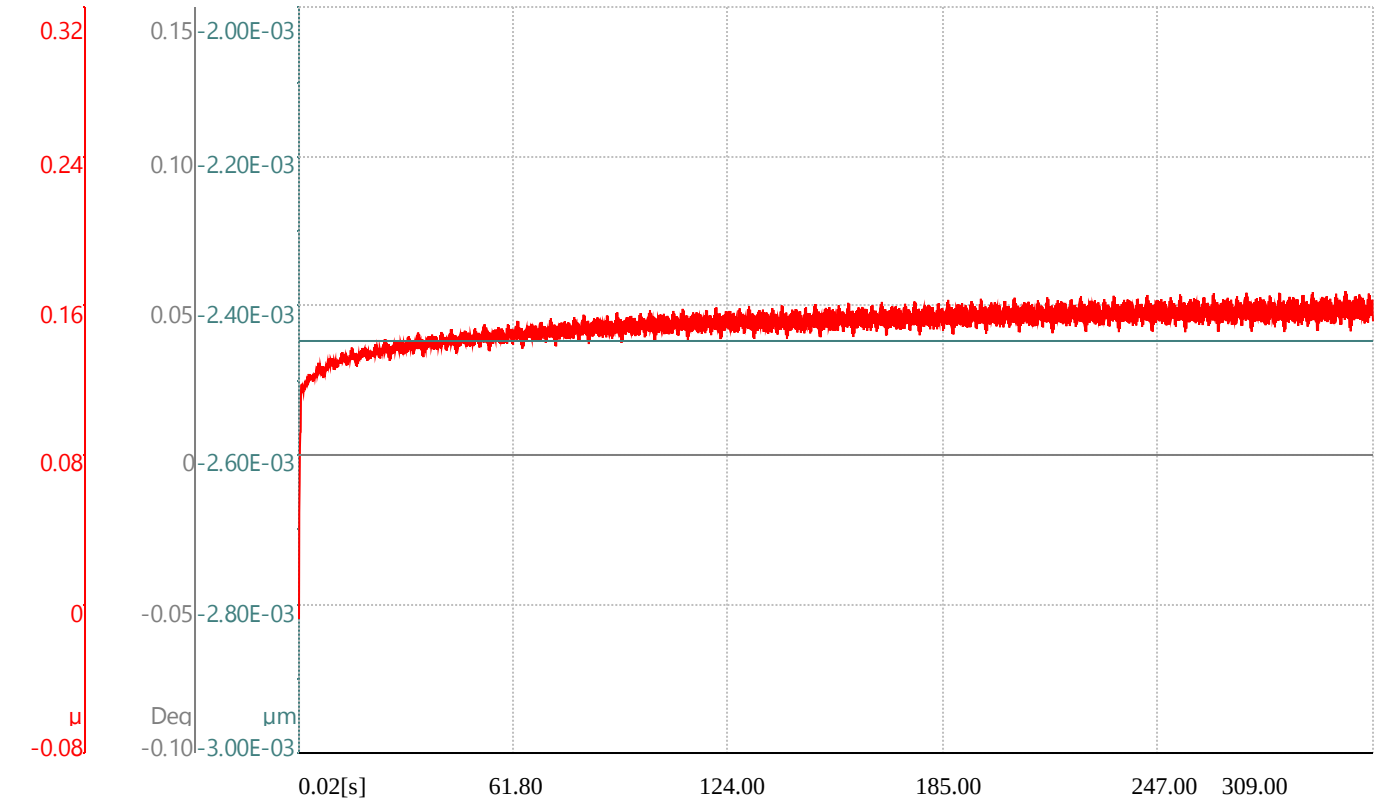
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 12:38:32 PM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : -0.008 min : -0.008 max : 0.168 mean : 0.149 std. dev. : 0.010



E 6 Tribology Test Result for 25wt% Particulate Filler Reinforcement Sample

Tribo parameters

- Tribometer : Standard tribometer
- serial : 0000-0000-0000-0000

Sequencer information
- pause : 0 [s]
- Load Unload : False
- homing : False
- Nb sequence : 1

Acquisition
- Radius : 5.00 [mm]
- Lin. Speed : 10.47 [cm/s]
- Normal load : 8.00 [N]
- Stop condit. : 32.00 [m]
- Effective Stop : Meters
- Acquisition rate : 10.0 [hz]
- Cycles sampled : 1/1 [cycles]

Sample
- Cleaning : IPA
- Supplier : AP

Static partner
- Coating : Steel
- Substrate : Steel
- Supplier : AP
- Dimension : 6.00 [mm]
- Geometry : Ball

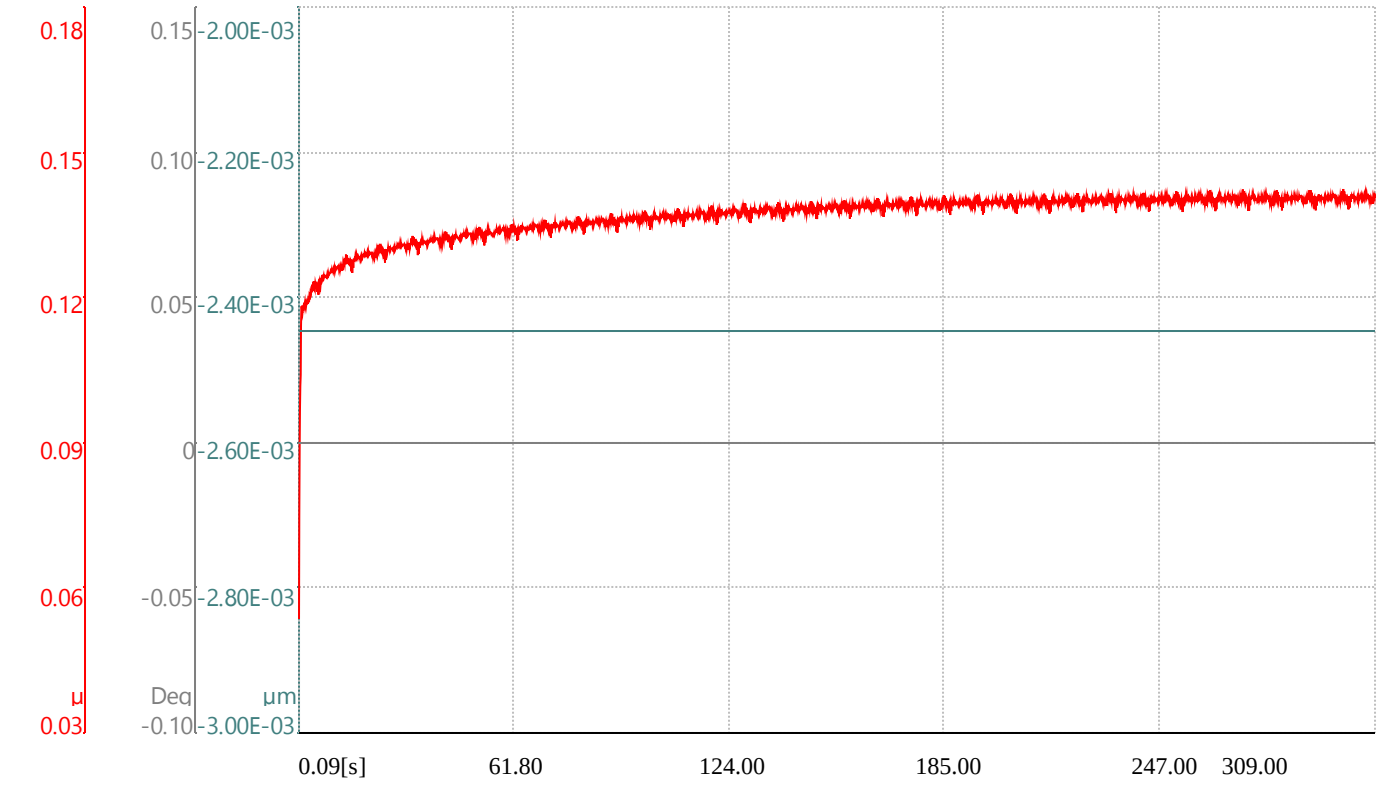
Environment
- Temperature : 23.00 [°C]
- Humidity : 55.00 [%]

Lubricant :
- Volume : 0.00 [ml]

Version:
- Tribometer / Version 6.1.19
- Date : 12/19/2018 12:55:12 PM

Sample	Static partner	Calculations
Worn track section : 0.0 µm2	Worn cap diameter : 0.0 µm	Sample wear rate : 0 mm3/n/m
Young's modulus : 0.0 gpa	Young's modulus : 0.0 gpa	Partner wear rate : 0 mm3/n/m
Poisson ratio : 0.000	Poisson ratio : 0.000	Max Herzian stress : 0 gpa

Start : 0.053 min : 0.053 max : 0.142 mean : 0.137 std. dev. : 0.005

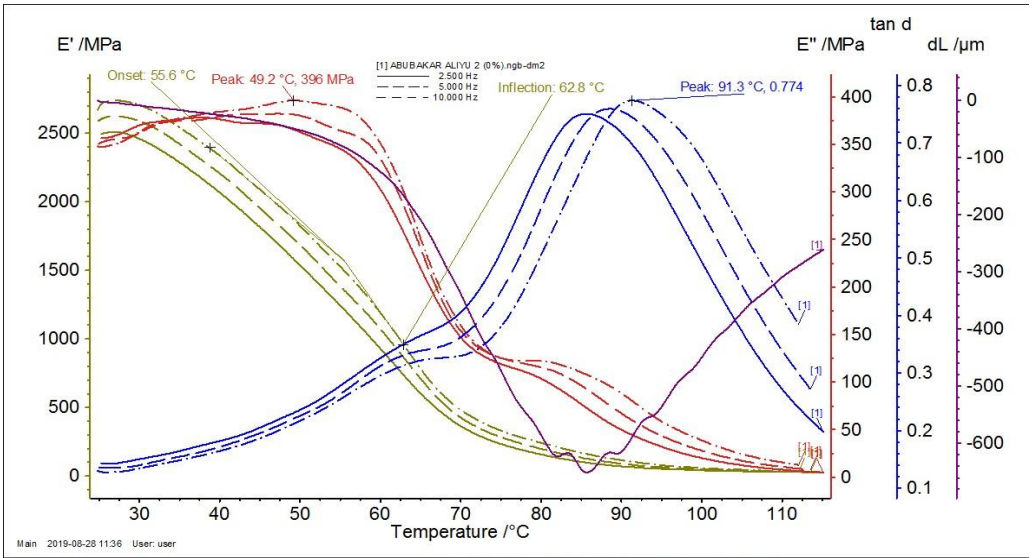


E 7 Tribology Test Result of the Developed Particulate Reinforced Composite Sample

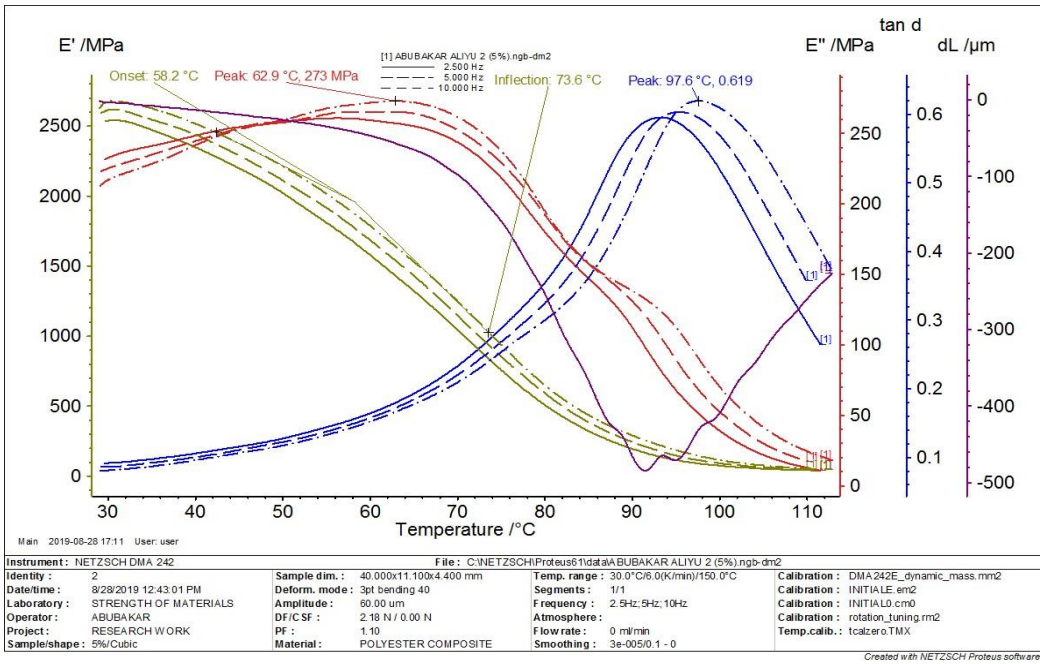
Filler Loading (wt %)	W_1 (g)	W_2 (g)	ΔW $[W_1 - W_2]$ X 10^{-7} (kg)	Height (m)	ρ (Kg/m^3)	Ws (m^3/N) X 10^{-10}	Penetration Depth -X 10^{-3} (µm)	µ
Neat Polyester	5.1911	5.1906	4.5	0.0128	1265.41	0.6242	2.44	0.1260
5	4.6038	4.6032	6.0	0.0113	4223.32	0.5214	2.36	0.1475
10	4.6933	4.6933	3.0	0.0730	0745.84	0.3453	2.42	0.1185
15	4.8925	4.8923	2.5	0.0136	3357.87	0.2896	2.30	0.1360
20	5.5612	5.5597	3.3	0.0133	1844.20	0.2669	2.34	0.1340
25	5.0459	5.0452	7.0	0.0122	1207.40	0.2244	2.23	0.1500

APPENDIX F: DYNAMIC MECHANICAL ANALYSIS (DMA)

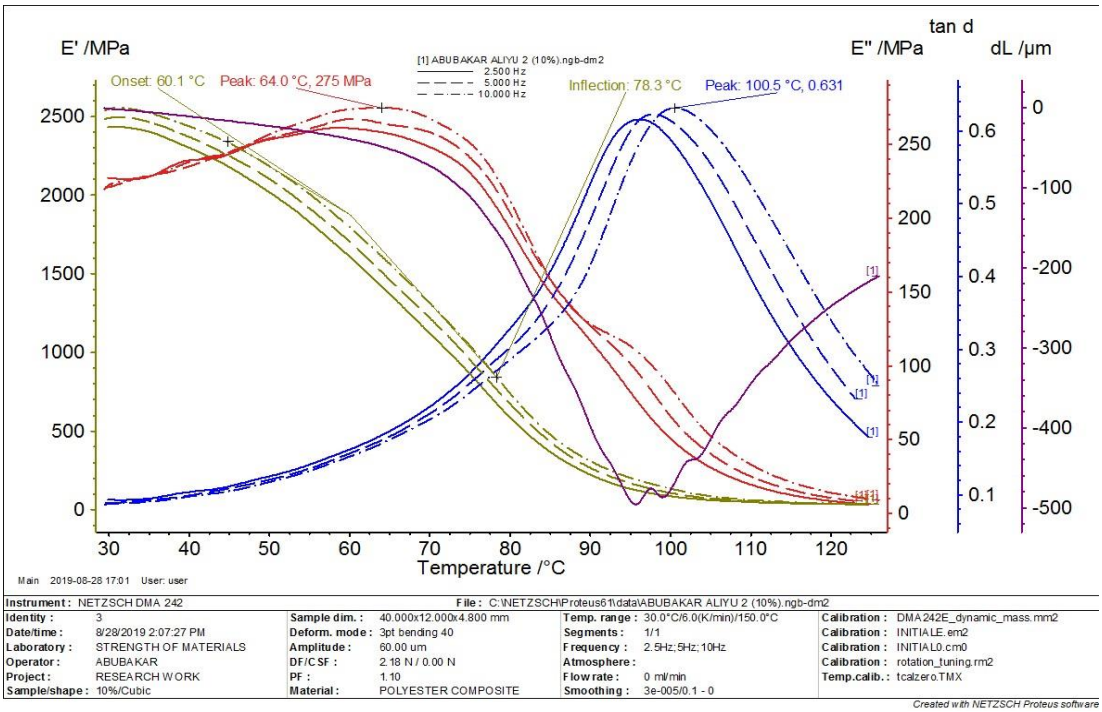
F 1 Dynamic Mechanical Analysis result of Neat Polyester Sample



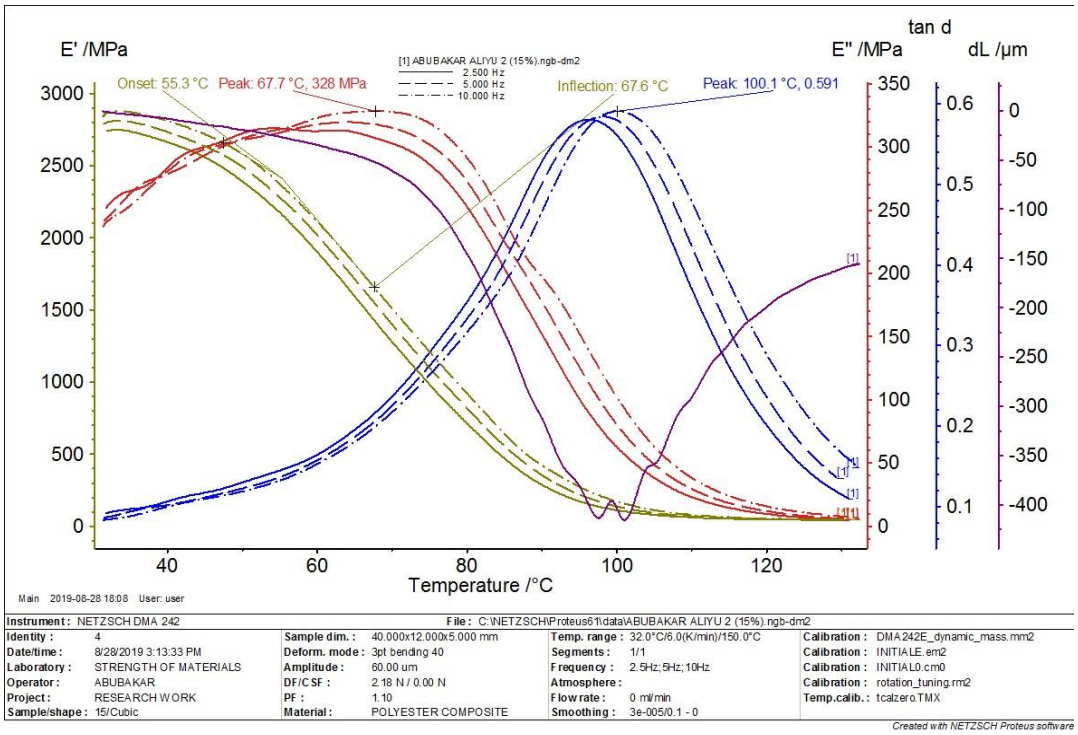
F 2 Dynamic Mechanical Analysis result of 5wt% Particulate Filler Reinforcement Sample



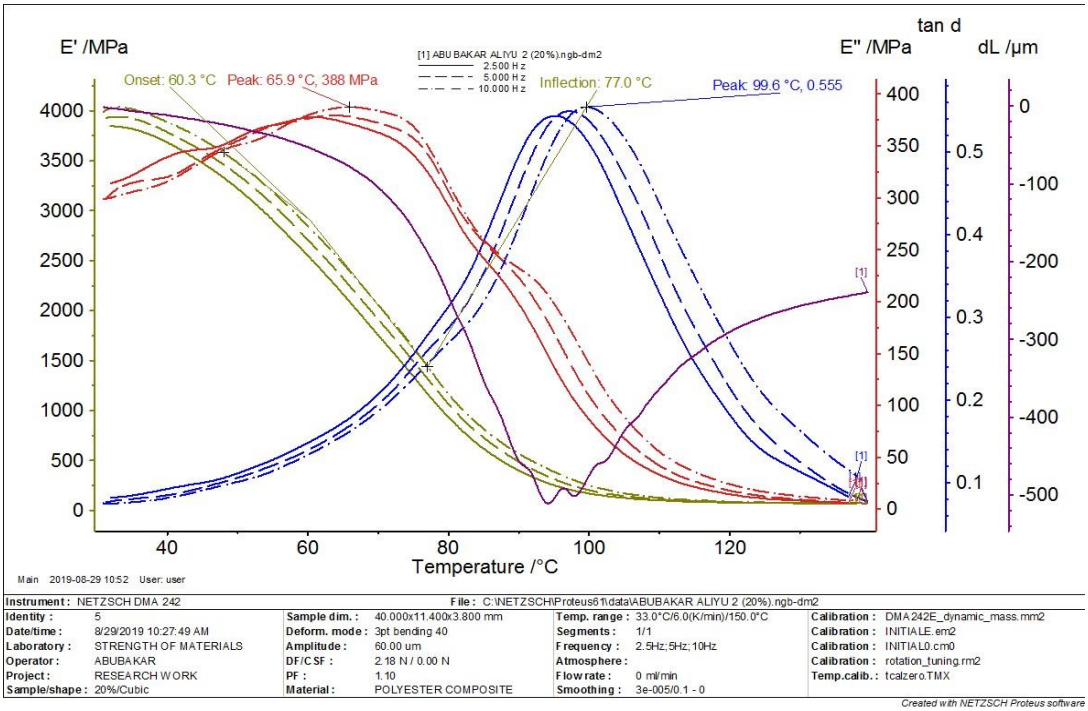
F 3 Dynamic Mechanical Analysis result of 10wt% Particulate Filler Reinforcement Sample



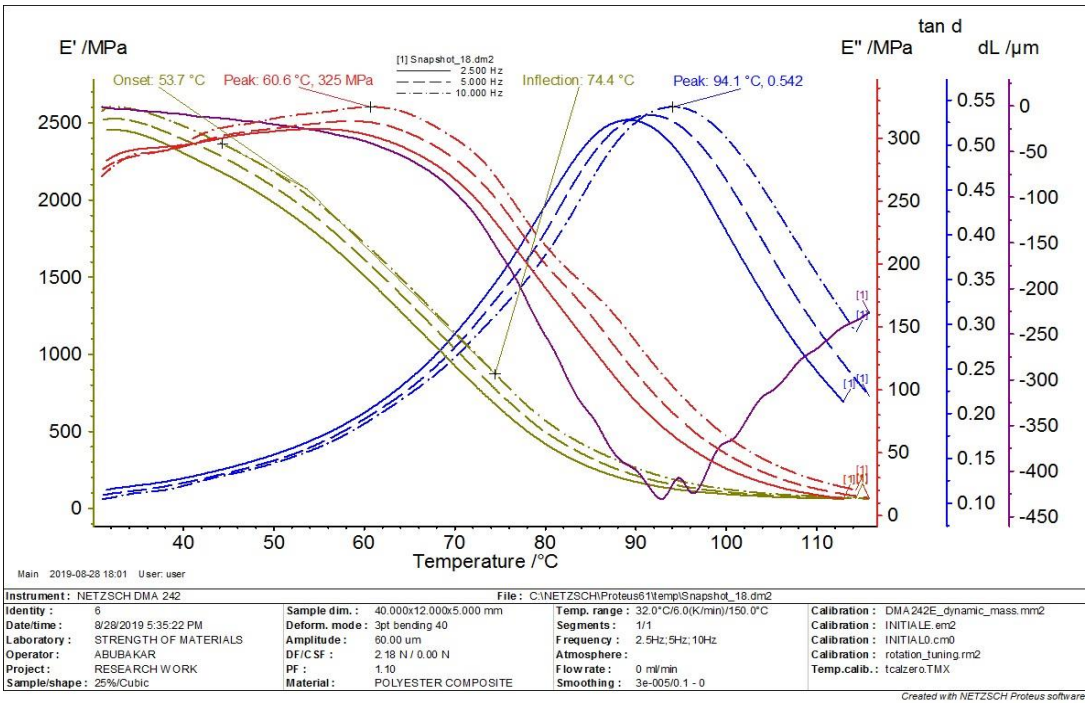
F 4 Dynamic Mechanical Analysis result of 15wt% Particulate Filler Reinforcement Sample



F 5 Dynamic Mechanical Analysis result of 20wt% Particulate Filler Reinforcement Sample



F 6 Dynamic Mechanical Analysis result of 25wt% Particulate Filler Reinforcement Sample



APPENDIX G: MOISTURE ABSORPTION TEST

G 1 Moisture Absorption Test of the Developed Waste Newspaper Particulate Composite.

Filler Loading (wt %)	Moisture Absorption (%)					
	24 Hours	48 Hours	72 Hours	96 Hours	168 Hours	192 Hours
Neat Polyester	0.0065	0.0172	0.0329	0.0776	0.0776	0.1220
5	0.0016	0.0695	0.1228	0.1721	0.2133	0.2845
10	0.0035	0.1499	0.2646	0.3445	0.4117	0.4878
15	0.1728	0.2857	0.3986	0.4426	0.5834	0.6139
20	0.3149	0.3405	0.3661	0.4801	0.5255	0.5898
25	0.2536	0.3692	0.4851	0.5753	0.7474	0.8285

APPENDIX H 1: Thermal Conductivity Test Result of the Developed Waste Newspaper Particulate Filler Composite

Filler Loading (wt %)	Area (m^2)	Thickness (m)	Temp. Diff. (^oC)	Thermal Conductivity. ($Wk^{-1}m^{-1}$)
Neat Polyester	0.5539	0.008	4	1.482819
5	0.5806	0.007	3	2.686439
10	0.5501	0.008	2	3.068014
15	0.5631	0.0095	1.5	3.839634
20	0.5979	0.0075	1.5	5.111412
25	0.6078	0.01	1	5.845552

APPENDIX I: DENSITY CALCULATIONS

I 1 Density test result for Control Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
A	21..0	21.0	21.0	9.261	1.270
B	21.0	21.0	21.0	9.702	1.195
C	2.15	21.0	21.5	9.707	1.185
Total	**21.1**	**21.0**	**21.5**	**9.557**	**1.217**

I 2 Density test result for 5wt% Particulate Filler Reinforcement Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
A	21.0	21.5	21.0	9.481	1.274
B	22.0	22.0	21.0	10.164	1.213
C	21.5	21.8	21.0	9.843	1.215
Total	**21.5**	**21.77**	**21.00**	**9.830**	**1.234**

I 3 Density test result for 10wt% Particulate Filler Reinforcement Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
A	21	22.0	21.0	9.702	1.263
B	21	21.5	21.5	9.707	1.248
C	21	21.8	21.5	9.843	1.223
Total	**21.00**	**21.77**	**21.50**	**10.286**	**1.242**

I4 Density test result for 15wt% Particulate Filler Reinforcement Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/m^3)
A	21.0	22.0	21.0	9.798	1.239
B	21.0	21.5	21.5	9.570	1.264
C	21.0	21.8	21.5	9.640	1.247
Total	**21.0**	**21.77**	**21.5**	**9.641**	**1.250**

I5 Density test result for 20wt% Particulate Filler Reinforcement Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
A	21.0	21.5	21.0	9.933	1.247
B	21.5	21.0	21.0	9.482	1.286
C	21.0	21.5	21.5	9.707	1.266
Total	**21.17**	**21.5**	**21.5**	**10.166**	**1.267**

I 6 Density test result for 25wt% Particulate Filler Reinforcement Sample

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
A	22.0	21.0	21.50	9.933	1.261
B	21.0	21.3	21.60	9.662	1.287
C	21.0	21.5	21.76	9.825	1.270
Total	**22.0**	**21.5**	**21.75**	**10.266**	**1.273**

I 7: Average Density Test Result of Developed Composite Samples 1 XRF Analysis of Treated WNP Filler

Sample	Length (mm)	Breath (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
Control	21.10	21.00	21.50	9.261	1.270
5wt%	21.50	21.77	21.00	9.830	1.234
10wt%	22.00	21.77	21.50	10.286	1.242
15wt%	21.00	21.35	21.50	9.641	1.250
20wt%	22.00	21.50	21.50	10.166	1.267
25wt%	22.00	21.50	21.75	10.266	1.273

J1: XRF ANALYSIS OF WNP FILLER

Sample List: Standard Method EDXRF Umaru Musa Yar'adua University Katsina
Analysis Technique: Linear
Method File: C:\...\@Geological Calibration Element in air updated.mth

Analyzed: Thu May 6 10:35:23 2021
Last Calibrated: Thu May 6 10:11:51 2021
Software version: 10.3.0.159

Comments:

Conditions

Mid Zb

Voltage	20 kV	Current	Auto
Livetime	60 seconds	Counts Limit	0
Filter	Pd Medium	Atmosphere	Air
Maximum Energy	40 keV	Count Rate	Medium
Warmup time	0 seconds		

Low Za

Voltage	4 kV	Current	Auto
Livetime	60 seconds	Counts Limit	0
Filter	No Filter	Atmosphere	Air
Maximum Energy	40 keV	Count Rate	Medium
Warmup time	0 seconds		

Low Zc

Voltage	12 kV	Current	Auto
Livetime	60 seconds	Counts Limit	0
Filter	Al	Atmosphere	Air
Maximum Energy	40 keV	Count Rate	Medium
Warmup time	0 seconds		

High Za

Voltage	40 kV	Current	Auto
Livetime	60 seconds	Counts Limit	0
Filter	Cu Thin	Atmosphere	Air
Maximum Energy	40 keV	Count Rate	Medium
Warmup time	0 seconds		

High Zb

Voltage	50 kV	Current	Auto
Livetime	100 seconds	Counts Limit	0
Filter	Cu Thick	Atmosphere	Air
Maximum Energy	40 keV	Count Rate	Medium
Warmup time	0 seconds		

Results

Element	Concentration	Peak(cps/mA)
EDXRF Analyzer UMYU Katsina- Abu Sadiq EDXRF		
Fe	0.2876 %	1527
Si	1.9332 %	305
Al	0.308 %	9
Mg	0 %	0
P	0 %	0
S	0.04510 %	130
Ti	0.01047 %	62
Mn	0.04878 %	190
Ca	2.7357 %	5720
K	0.0941 %	119
Cu	0.02832 %	113
Zn	0.01385 %	94
Cr	0.00031 %	4
V	0.00048 %	6
As	[0.0009] %	0
Pb	[0.00115] %	1
Rb	0.000263 %	1
Ga	0 %	0
Ni	0.00128 %	9
Cl	0.01570 %	23
Zr	[-0.02000] %	2
Ta	0.0282 %	37
W	0.046 %	12
Br	[0.000129] %	1
Sr	0.110 %	39
Ce	2 %	0
Th	0 %	0
Y	0.001172 %	0

Nb	[-0.0100] %	14
I	0 %	0
Ag	0.00041 %	1
Sn	[-0] %	0
U	[-0] %	0
Bi	0.00235 %	1
Ge	0.00038 %	2
Sb	[-0] %	0
La	[-0.0010] %	6
Co	0 %	0
Cd	[-0] %	0
Ba	0.02223 %	32
Cs	0.000358 %	16

PLATES

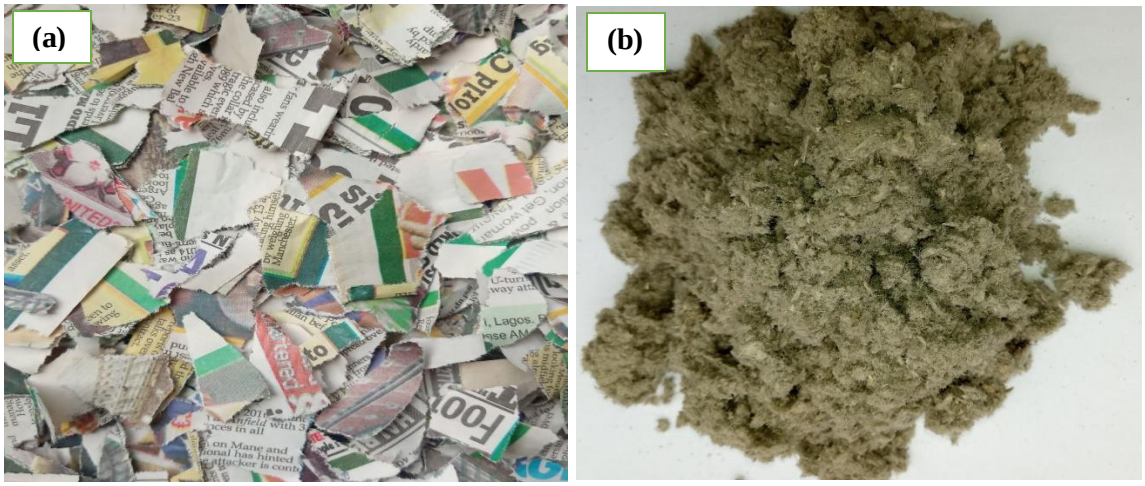


Plate 1: Modified waste newspaper particulate

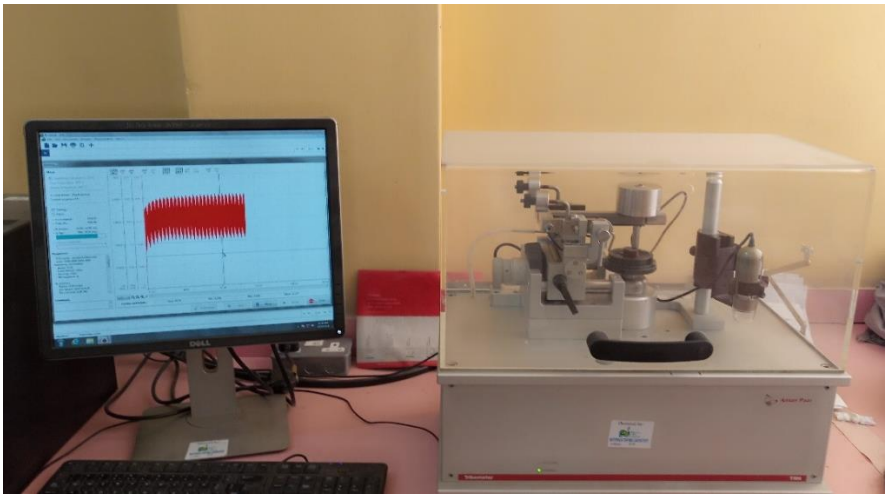


Plate 2: Tribometer (Anton Paar 6.1.19 Tribotester)

Plate 3: Thermal conductivity test samples

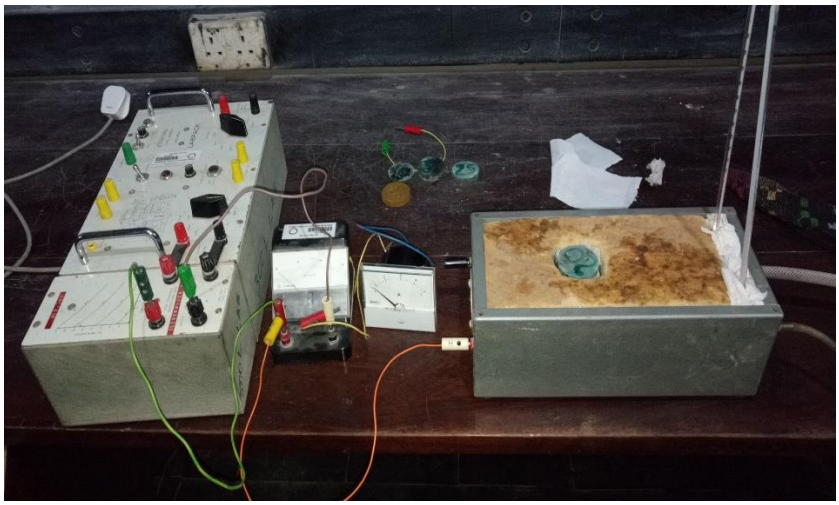


Plate 4: Thermal conductivity test set-up

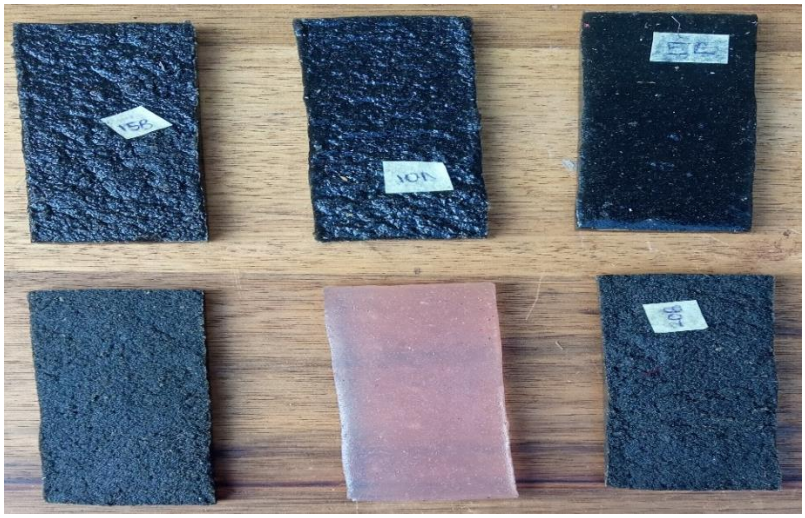


Plate 5: Flexural strength test samples

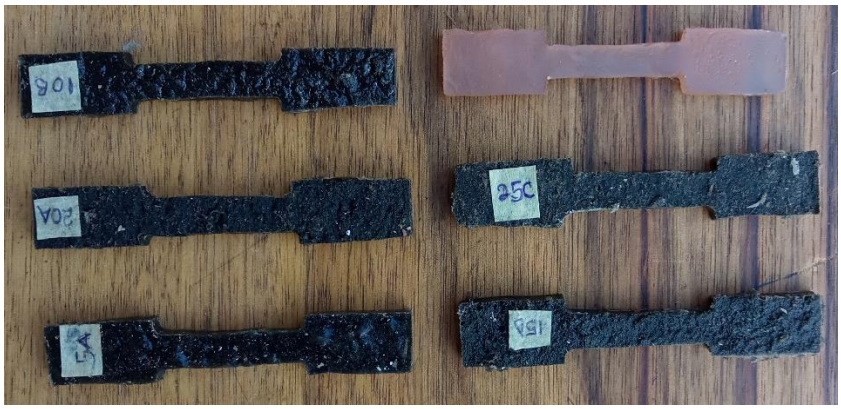


Plate 6: Tensile strength test samples

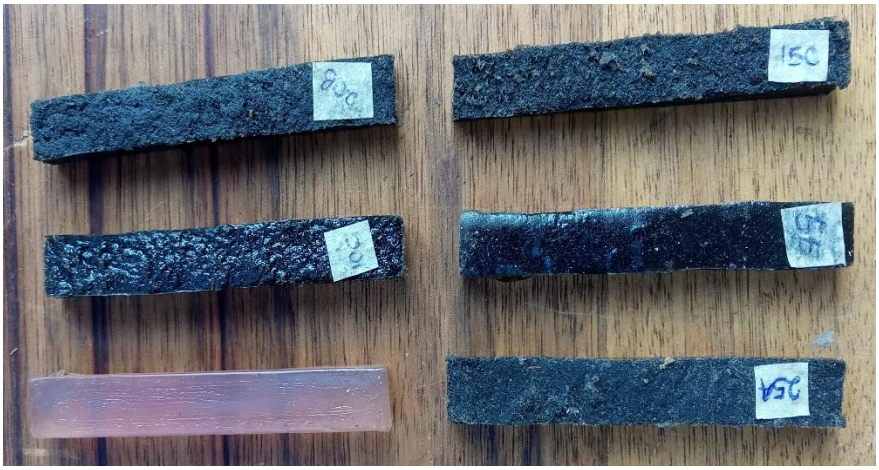


Plate 7: Impact strength test samples

Plate 8: Dynamic Mechanical Analyzer (DMA 242E, Artmis)

Plate 9: Compressive strength test samples