

Studying the Effect of Fiber Architecture and Alkalization on
Mechanical, Physical and Morphological Behavior of Banana Fiber
Reinforced Polymer Matrix Composite



Gezahgn Gebremaryam Badabo

A Thesis submitted in partial fulfillment of the requirements for the degree of
Master's in Manufacturing Engineering
Department of Mechanical Engineering

School of Mechanical Chemical and Materials Engineering
Office of Graduate Studies
Adama Science and Technology University

February, 2023

Adama, Ethiopia

Studying the Effect of Fiber Architecture and Alkalization on Mechanical,
Physical and Morphological Behavior of Banana Fiber Reinforced Polymer
Matrix Composite

Gezahgn Gebermayam Badabo

Advisor: - Dr. Kiran Shahapurkar

A Thesis submitted in partial fulfillment of the requirements for the degree of
Master's in Manufacturing Engineering
Department of Mechanical Engineering
School of Mechanical Chemical and Materials Engineering
Office of Graduate Studies
Adama Science and Technology University

February, 2023

Adama, Ethiopia

DECLARATION

I declare that this thesis/dissertation proposal entitled “Studying the Effect of Fiber Architecture and Alkalization on Mechanical, Physical and Morphological Behavior of Banana Fiber Polymer Composite” is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Name of student

Signature

Date

RECOMMENDATION OF ADVISOR

I, the major advisor/supervisor of this research proposal, hereby certify that I have closely advised/supervised the student while developing this proposal and read the draft thesis/dissertation proposal entitled “Studying the Effect of Fiber Architecture and Alkalization on Mechanical, Physical and Morphological Behavior of Banana Fiber Reinforced Polymer matrix Composite” prepared under my guidance by _____. Therefore, I recommend the submission of the proposal to the department for further review and evaluation.

Major advisor

Signature

Date

APPROVAL OF BOARD OF EXAMINERS

I/we hereby certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated into the final thesis work entitled “Studying the Effect of Fiber Architecture and Alkalization on Mechanical, Physical and Morphological Behavior of Banana Fiber reinforced Polymer matrix Composite” by

Advisor

Signature

Date

Co-advisor

Signature

Date

We, the undersigned, members of the Board of Reviewers of the thesis open defense by Gezahgn Gebremaryam Badabo have read and evaluated the thesis entitled “Studying the Effect of Fiber Architecture and Alkalization on Mechanical, Physical and Morphological Behavior of Banana Fiber reinforced Polymer matrix Composite” and assisted the understanding of candidate about the thesis research. This is, Therefore, to certify that the thesis.

Chairperson

Signature

Date

Reviewer 1

Signature

Date

Reviewer 2

Signature

Date

Finally, approval and acceptance of the thesis research is contingent upon submission of its copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate (DGC) and School Graduate Committee (SGC).

Department Head

Signature

Date

School Dean

Signature

Date

Office of Postgraduate Studies, Dean

Signature

Date

ACKNOWLEDGEMENT

First I would like to thank my God, he keeps and encourage me throughout the research work and let me to complete it successfully.

I would like to offer my most profound thanks and sincere gratitude to my advisor Dr. Kiran Shahapurkar, for his valuable support, continuous follow-ups, guidance encouragement, crucial remarks, priceless suggestion, and comments throughout the thesis. His enthusiasm, vision, sincerity and motivation have deeply inspired me. Besides my advisor, I would like to extend my sincere thanks to Dr. C. Venkatesh, and to my thesis committee: Dr. Moera Gutu, Dr. Belete Sirhabizu, and Dr. Esmael Adem for their encouragement, important comments.

I never forget to thank my families and my wife Wubit Matias; who supported, asked, and motivated me in circumstancetances of my life. Your pray haven't been cut off still now. I wish long life and health for you with all good things. I would also like to express my sincere and genuine gratitude to my friend Tamirat Lamaro and others for their help, comments, and valuable suggestion during documentation. I am also grateful for technical lab assistant and those who contributed their effort directly or indirectly while conducting this thesis. I am thankful for Wolaita Sodo University who has awarded me with a full scholarship to conduct my study.

Finally, I would like to thank the ASTU mechanical engineering department for all supports and facilities during my study.

TABLE CONTENTS

DECLARATION	ii
RECOMMENDATION OF ADVISOR	iii
APPROVAL OF BOARD OF EXAMINERS	iv
ACKNOWLEDGEMENT	v
TABLE CONTENTS.....	vi
LIST OF TABLES	x
LIST OF FIGURES	xi
NOMENCLATURE	xiii
ACRONYMS.....	xiv
ABSTRACT.....	xv
CHAPTER ONE	1
INTRODUCTION	1
1.1 Background of the study	1
1.2 Problem statement	5
1.3 Objective of the study	6
1.3.1 General Objective	6
1.3.2 Specific objective	6
1.5 The scope of the study.....	7
1.6 Challenge and limitation of the study	7
1.7 Thesis organization.....	7
CHAPTER TWO	8
LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Natural fibers.....	8
2.2.1 Plant fiber	9
2.2.2 Animal fibers	10
2.3 Fiber architecture.....	10
2.3.1 Woven fiber	10
2.4.2 Short fiber	11
2.4.3 Continuous fiber	12

2.5 Physical and mechanical properties of banana fiber	12
2.6 Chemical composition of banana fiber.....	13
2.7 Bio and thermal degradation of banana fiber	14
2.8 Treatment of banana fiber	14
2.8.1 Physical treatment.....	14
2.8.2 Chemical treatment.....	15
2.9 Polymer matrix.....	16
2.9.1 Properties of polymer resins	17
2.9.2 Epoxy resin	18
2.9.3 Unsaturated Polyester	18
2.9.4 Phenolic Resin	18
2.9.5 Polyethylene	19
2.10 Mechanical behavior of short fiber polymer composite.....	19
2.11 Mechanical behavior of woven natural fiber composite	19
2.13 Fiber weight fraction	20
2.14 Water absorption behavior	22
2.14.1 kinetic of water absorption	22
2.15 Production methods of fiber reinforced polymer composite.....	23
2.15.1 Hand lay-up	23
2.15.2 Compression moulding.....	23
2.15.3 Pultrusion moulding	23
2.15.4 Injection moulding.....	23
2.12 Application of natural fiber composite in industry	23
2.16 Summary of literatures	24
2.17 Research gap	25
CHAPTER THREE	26
MATERIALS AND METHODS.....	26
3.1 Introduction	26
3.2 Materials.....	27
3.2.1 Banana fiber.....	27
3.2.2 NaOH.....	28

3.2.3 Distilled water.....	28
3.2.4 Polyester resin.....	28
3.2.5 Hardener	28
3.3 Methods.....	29
3.3.1 Fiber preparation procedures	29
3.3.2 Volume and weight fraction determination.....	31
3.3.3 Theoretical density calculation.....	32
3.3.4 Mold preparation	33
3.3.5 Composite fabrication.....	33
3.3.6 Characterization of composite	37
CHAPTER FOUR.....	44
RESULT AND DISCUSSION	44
4.1 Introduction	44
4.2 Tensile test result.....	44
4.2.1 The effect fiber architecture on tensile strength	44
4.2.2 The effect of alkaline treatment on tensile strength	45
4.3 Tensile modulus	47
4.3.1 The effect of fiber architecture on elastic modulus	47
4.3.2 The effect of alkaline treatment on tensile modulus.....	48
4.4 Impact test result	49
4.4.1 The effect of fiber architecture on impact strength	49
4.4.2 The effect alkaline treatment on impact strength	50
4.5 Flexural test result	52
4.5.1 The effect fiber architecture on flexural strength	53
4.5.2 The effect of alkaline treatment on flexural strength	54
4.6 Flexural modulus.....	55
4.6.1 The effect of fiber architecture on flexural modulus.....	56
4.6.2 The effect of alkaline treatment on flexural modulus.....	56
4.7 Hardness test result.....	57
4.7.1 Effect of fiber architecture on harness value	58
4.7.2 Effect of alkaline treatment on impact strength.....	58

4.8 Density and void fraction	60
4.8.1 The effect fiber architecture on void content.....	61
4.8.2 The effect alkaline treatment of fiber void content	61
4.9 Water absorption test result.....	63
4.9.1 Kinetic of water absorption	65
4.10 Scanning electron micrographs analysis	68
4.11 Comparison with pervious study.....	70
CHAPTER FIVE	72
CONCLUSION AND RECOMMENDATION.....	72
5.1 Conclusions	72
5.2 Recommendation.....	74
References.....	75
Appendix A.....	84
Appendix B.....	85
Appendix C	86

LIST OF TABLES

Table 2.1 Physical and mechanical behavior of banana fiber.....	13
Table 2.2 Chemical composition of banana fiber (Bhatnagar et al., 2015).	13
Table 3.1 Physical, mechanical, and chemical properties of banana (Bhatnagar et al., 2015; Subagyo & Chafidz, 2020).	27
Table 3.2 Property of polyester resin (Chandgude & Salunkhe, 2021)	28
Table 3.3 Composition of banana fiber.....	37
Table 4.1 Tensile strength result.....	44
Table 4.2 Tensile modulus of banana fiber reinforced polyester composite	47
Table 4.3 Impact test result.....	49
Table 4.4 Flexural test result.....	53
Table 4.5 Flexural modulus of banana fiber polyester composite.	56
Table 4.6 Hardness test result	58
Table 4.7 Density and void content result	60
Table 4.8 Dry mass of water absorption test specimens.....	63
Table 4.9 Percentage of water gain.....	63
Table 4.10 kinetic parameter banana fiber polyester composite.....	66
Table 4.11 Diffusion coefficient of banana fiber polyester composite.....	68
Table 4.12 Comparison with existing work.....	70

LIST OF FIGURES

Figure 2.1 Classification natural fibers. (Jawaid et al., 2017; Parashar & Chawla, 2020)	8
Figure 2.2 a) plain woven fabric b) twill woven fabric c) stain woven fabric. (Hasan et al., 2021)	11
Figure 2.3 End effect A. continuous fiber B. short fiber (Monfared, 2020)	12
Figure 2.4 Classification of polymer resin. (“Building Plastic,” 2011).....	17
Figure 3.1 Methodology followed to achieve research objective.	26
Figure 3.2 Photographs of (a) banana plant (b) pseudo stem (c) fiber extraction (d) fiber.	27
Figure 3.3 Polyester resin b) sodium hydroxide flake c) harder and d) distilled water.	29
Figure 3.4 a) NaOH treatment b) washing fiber c) Drying under sunlight.....	29
Figure 3.5 a) Customized handloom b) Warp and weft yarns of plain woven banana fabric	31
Figure 3.6 Chopped banana fiber.....	31
Figure 3.7 the mold b) mold cover.....	33
Figure 3.8 Illustrated flowchart represent production process of treated woven fiber composite.	35
Figure 3.9 a) Weighted fiber b) weighted resin	35
Figure 3.10 Clamped mold for proper curing.	36
Figure 3.11 CAD model untreated/treated a) short fiber composite b) woven fiber four layers composite c) short fiber mid layer and woven fiber faces composite.....	36
Figure 3.12 Banana fiber polyester composite samples.....	37
Figure 3.13 Specimen under tensile test.	38
Figure 3.14 Tensile test Specimens before and after test.....	38
Figure 3.15 Specimen under flexural test.	39
Figure 3.16 Flexural test specimens before and after test.....	39
Figure 3.17 Specimen under impact test.....	40
Figure 3 18 Specimens before and after impact test.	40
Figure 3.19 Hardness test samples.....	41
Figure 3.20 Specimens for void content determination.	42
Figure 3.21 Specimens for water absorption test and under test.	43
Figure 4.1 The effect of fiber architecture on tensile strength.....	45
Figure 4.2 The effect of alkaline treatment on tensile strength.	46
Figure 4.3 Tensile Strength of composite.	47

Figure 4.4 The effect fiber architecture of tensile modulus of banana fiber reinforced polyester composite.	48
Figure 4.5 the effect alkaline treatment on tensile modulus	48
Figure 4.6 The effect of fiber architecture on impact behavior	49
Figure 4.7 The effect of alkaline treatment on impact behavior.....	51
Figure 4.8 Impact properties of composites.....	52
Figure 4.9 The effect of fiber architecture on flexural strength.....	53
Figure 4.10 The alkaline treatment on flexural strength.....	54
Figure 4.11 Flexural behavior of composite.....	55
Figure 4.12 the effect of fiber architecture on flexural strength.	56
Figure 4.13 the effect of alkaline treatment of flexural modulus of banana fiber polyester composite.	57
Figure 4.14 The effect of fiber architecture on hardness value	58
Figure 4.15 The effect of alkaline treatment on hardness value	59
Figure 4.16 Hardness properties of composites.....	59
Figure 4.17 The effect of fiber architecture on void fraction.	61
Figure 4.18 The effect of alkaline treatment on void fraction.	62
Figure 4.19 Void content of composite.....	62
Figure 4.20 Plot of water gain verses time curve.....	65
Figure 4.21 Figure linear fitted absorption curve.	66
Figure 4.22 Plot of M_t/M_s verse square root time curve	67
Figure 4.23 Scanning electron micrographs of tensile tested (a) TSB (b) TWB and (c) TWSWB.	69

NOMENCLATURE

ρ_a	Actual/measured density of composite
ρ_c	Density of composite
ρ_f	Density of fiber
ρ_m	Density of matrix
ρ_t	Theoretical density
ρ_w	Density of water
m_c	Mass of composite
m_f	Mass of fiber
m_m	Mass of matrix
F	Applied force for indentation
b	Width of the sample
d	Thickness of the sample
D	Indentation surface
d	Depth of the specimen
L	Length
w_f	Weight fraction of fiber
w_f	Weight fraction of matrix
$S_1, S_2, S_3, \dots$	specimen1, specimen2...
v_f	Fiber volume fraction
v_m	Matrix volume fraction
v_v	Void content
W_a	Weight of the sample in air
W_f	Final weight of sample after immersed
W_i	Initial weight of sample before immersed
$W_t \%$	Weight percentage
W_w	Weight of the sample in water
CaCO_3	Calcium carbonate
MPa	Mega Pascal
m	Meter
NaOH	Sodium hydroxid

ACRONYMS

ASTM	America Society for Testing and Material
ASTU	Adama Science and Technology University
CAS	Central Statistical Agency
CMMS	Ceramic Matrix Composites
FRPMC	Fiber Reinforced Polymer matrix composite
GFRPC	Glass Fiber Reinforced Polymer composite
GPa	Giga Pascal
hr	Hour
HV	Vickers hardness number
MMCs	Metal Matrix Composites
NFRPC	Natural fiber reinforced polymer composite
NFs	Natural fibers
PMCs	polymer matrix composites
TSB	Treated short banana fiber
TWB	Treated woven banana fiber
TWSWB	Treated woven short woven banana fiber
UTSB	Untreated short banana fiber
UTWB	Untreated woven banana fiber
UTWSWB	Untreated woven short woven banana fiber
UTM	Universal Testing Machine
UPR	Unsaturated Polyester Resin
UTS	Ultimate tensile strength or peak stress
UV	Ultraviolet radiation
SEM	Scanning electron microscopy

ABSTRACT

In developing countries, huge agricultural biomass with the intrinsic potential lingo-cellulosic fiber is removed as waste after harvesting. Effective utilization of those natural fibers is one of the ways to ensure a sustainable economy and minimize environmental pollution related to synthetic fiber. Currently, significant studies have been carried out on natural fiber-reinforced composite for substituting classical materials in various applications such as vehicle, aerospace, medical and agricultural sectors. In this investigation, the effect of fiber architecture and alkaline treatment on the mechanical, physical and morphological behavior of banana fiber reinforced polyester composite were carried out. Six composite samples, chemically treated/untreated short fiber composite, chemically treated/untreated woven fiber composite and chemically treated/untreated short fiber mid-layer sandwiched by woven fiber faces were prepared by a hand layup method with fixed fiber to matrix weight ratio 40:60. The prepared composite samples were tested for its mechanical, physical and morphological behaviors with the set of standard and condition. The maximum tensile strength, flexural strength, impact strength and hardness values 64.95MPa, 172.52MPa, 24.37KJ/m² and 70.75HV respectively were perceived by chemically treated woven banana fiber polyester composite. Introduction of woven fiber in top and bottom faces improves mechanical and physical properties short fiber composite. Chemically treated woven banana fiber composite, possessed minimum void fraction and hold less amount of water at equilibrium state. The diffusion mechanism of water molecules into composite structures was analyzed that chemically treated and untreated woven banana fiber composite and treated short fiber mid layer sandwiched by woven fiber faces composite behave Fickian diffusion mechanism while the rest samples deviated from Fickian diffusion mechanism. Scanning electron micrographs of test specimens were analyzed to correlate the structure and properties. Based on obtained result chemical treated woven banana fiber polyester matrix composite showed improved mechanical properties, denser, and less sensitive to moisture compared with the rest samples.

Keyword: *fiber architecture, Banana fiber, polyester resin, hand layup*

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Currently, there were increased demand for materials thus industries produce more and more materials. As a result of industrial processing, carbon dioxide is emitted into the atmosphere and contributes significantly to global warming. Additionally, most industrial byproducts are non-biodegradable, and their uncontrolled disposal causes landfills and unhygienic environments. International Panel on Climate Change has a plan to reduce carbon dioxide emissions by 70% in 2050 (Rwawiire et al., 2015). One way to implement such strategies is utilizing sustainable and biodegradable materials rather than manmade materials that can contribute a lot to environmental pollution. Consequently, renewable and green materials should be used in product manufacturing to reduce environmental pollution and minimize dependence on petroleum-based products (Chandramohan & Bharanichandar, 2014). Composites are one of the engineering materials and are widely consumed in the high-performance application that needs lightweight materials but is strong enough to resist dynamic work environments and loading conditions. In particular, composite materials are used in vehicles components such as car bodies, panels, and engine covers and aeronautical parts such as tails, wings, fuselages, and propellers. The intrinsic properties of composite materials are achieved because of their constituents (Ramesh et al., 2017).

Composite materials produced from two or materials through physical mixing. Intentionally, these materials have strong load carrying strengthening material embedded in weaker matrix materials. The major component of composites has a continuous phase which is the important part of material that is termed as matrix. Primary role of matrix material is to transfer loads between reinforcing fibers and to protect them from mechanical damage ("Composite Material", 2003a). Composites are basically classified based on the type of matrix material used. The three basic kinds of composites are polymer matrix composites, metal matrix composites, and ceramic matrix composites (Sharma et al., 2020).

Metal matrix composite: Composites consisting of metal matrix such as magnesium, aluminum, iron, copper, and titanium within which reinforcement phase either metals like steel or ceramics such as alumina or silicon carbide are dispersed in it. They behave well with stiffness, low density,

and high corrosion resistance as compared with other metals. Several benefits such as low cost, low specific weight make it a major point of attentiveness for various applications (Gopi Krishna et al., 2017; Kumar et al., 2020).

Ceramic matrix composite: The composite which contains a ceramic mixed with a ceramic continuous phase. Since, the accessibility of new manufacturing methods increases the interest for high performance products. The major problem with ceramic matrix composite is limitation to regain ductility (Chawla, 2013; Diaz et al., 2019).

Polymer matrix composite: Extensively used and in demand composites due to its benefits such as high strength, low cost, inexpensive manufacturing method. Matrix used in polymer composite is resins used to grip and bind together the reinforced components with the aid of surface link (Material, 2003b; Plueddemann, 2016). The most commonly used resin in polymer processing are polyester, epoxy, vinyl ester and phenolic (Ramakrishnan et al., 2022).

Fiber reinforced polymer composite

Despite its light weight and easy formability polymers have low strength and low heat resistance. Introducing high strength fiber such as fiberglass, carbon fiber and Kevlar fiber as reinforcement increasing load bearing capacity (“Decorative Plastics,” 2011). The output materials had high strength than polymer resin. However, the fabrication of fiberglass and carbon fiber emitted carbon dioxide to environments and at the end of service life the fiber was not decomposed biologically (Thyavihalli Girijappa et al., 2019a). To mitigate such problem utilizing fibers from natural source those are sustainable, environmentally friendly and biodegradable (Crosky et al., 2013).

Natural fiber reinforced polymer composite

The increased demand for composite materials make the new trend on investigation of natural fiber reinforced polymer composite. Nowadays scientist and engineer made a lot effort to exploit the effective utilizing the fibers obtained from agricultural waste. Natural fiber preferred over synthetic because high specific strength, biodegradable, sustainable, low cost of processing and green house free. The drawback of natural fiber in polymer composite processing are variable quality, water absorption and poor wettability (Jawaid et al., 2017; Y. Li & Dai, 2006). Poor wettability and water sensitivity of natural fiber alleviated by chemical treatment. Chemical treatments improve fiber-polymer interface adhesion by removing wax, lignin and hemicellulose. Alkalizing natural fiber reduce hydroxyl group of cellulose, while the newly formed cellulose

function group is hydrophobic as the result compatible with polymer matrix and less sensitive to water.

Natural fiber for polymer composite may exist in the form of short, continuous or woven structure. Short fiber is one of interested fiber form in polymer composite due to high creep resistance, out of plane rigidity and ease for automated production system (Monfared, 2020). The reinforcing effect short fiber depend on the source of fiber and matrix material. The draw back with short fiber in composite processing are agglomeration and difficult of controlling orientation. Woven fabric is one of an interested fiber architecture that used in production bio based laminated composite. There are three basic types of weave structure used in production of fiber reinforced polymer composite. Those are plain, twill and stain woven fabric. The interlock of warp and weft yarns in weave structure keep the fabric in per specified appearance and impart strength to composite. Woven fabrics are comfort for handling and positioning during composite processing (Hasan et al., 2021). When we deal green fiber from agricultural residue banana pseudo stem fibers are plenty and underutilized resources.

Banana pseudo stem fiber

Banana (*Musa Sap*) is one of the most widely cultivated food fruit through the world. The most common production of banana has been done in tropic and subtopic region. It is one of the leading world food fruit crops that provide to cash and house hold consumption (I.O. Jideani, 2020). Banana plant applicable in several foods and nonfood related solicitations i.e. flavor, stain, nutrient, fertilizers, fiber, livestock etc. (Padam et al., 2014). Furthermore, the leaf of banana plant applicable in food preparation, packing, etc. According to statistical information the yearly production of lingo-cellulosic fiber from food crop was four billion ton in the world, While the annual production of steel and plastic was 0.7 billion and 0.1 billion ton respectively. Thus proper uses of those fibers provide enormous economic advantage (K. Li et al., 2010). Nearly, 72.5 billion ton of banana fruit are harvested in the world. It estimated to be four ton of biomass waste is produced from every one ton banana fruit harvested. Other study showed that approximately 220 ton of agricultural biomass produced from every hector of banana plantation. The literature Confer that annual production of banana fiber was extended to 100,000 ton in the world. The production was about 97,000 ton in the year 1960 and 99,320 ton in the year 2002 (Subagyo & Chafidz, 2020).

In Ethiopia banana farm cover 53,956.13 hector and 478,251.04 ton of banana fruit harvested in annual base (Ambisa, 2019). The most banana plantation has been done in southern and southwestern part of the country such as south nation nationality and people regional state and Oromia regional state. In southern district Arba Minch is the most banana production area contribute major share to domestic market (Gebre et al., 2020). In Ethiopia, modern banana farming was started at the beginning of 21 century with introduction of large scale farm and sugarcane planation.

According to central statistical agency report in Ethiopia 48% of total banana production used for house hold consumption, 49% used for commercial purpose, no more than 1% used for livestock food and no more than 3% used for other purpose (CSA, 2018). Banana pseud stem can cause sires environmental pollution if not carefully managed. However, proper use of this biomass can provide big economic advantage. The fiber extracted form banana pseud stem is applicable as strengthen material in polymer matrix, textile, marine rope, high quality sanitary product, coffee and tin packing bag (Subagyo & Chafidz, 2020) .

Banana pseudo stem fiber composite

Natural fiber composite are used in automotive, sport, furniture, building construction, etc. Different parts are made from natural fiber composite like roof sheet, indoor panel, laminate sheet, wallpaper, door frame, door and window. Many investigation were undertaken on fabrication of jute door frames, coir fiber reinforced cement roofing panes, sisal/glass hybrid fiber epoxy sheet sisal fiber polyester composite roof panel (Singh B, Gupta M 2005). The banana fiber is an appropriate reinforcement for replacing the existing fibers because of its high cellulose content (63–64%) and lignin content (5%) (Ibnu & Adityarini, 2019).

The study was undertaken to investigate the mechanical behavior hybrid composite fabricated from flax/banana /industrial waste tea leaf fibers and polyester matrix composite. The fiber was alkaline treated by 5% NaOH concertation and the samples prepared by manual compression mold method with fixed fiber to matrix weight ratio 40:60 fiber to matrix ratio by fixed flax volume 10% and varying the weight percentage of banana and tea leaf fiber. The test were carried as per ASTM standard and the investigation shown that improved mechanical strength obtained with chemical treated fiber composite compared with untreated one. The maximum tensile, flexural and impact strength obtained The tensile, flexural and impact strength increase with fiber volume of banana and maximum strength obtained at 25 wt.% of banana fiber (Prabhu et al., 2021).

1.2 Problem statement

Engineering plays a vital role in conducting research to ensure a continuous supply of material in advance to achieve sustainable development goals (SDG) (Amrose et al., 2021). In this line researchers around the world work a lot to balance the increased demand for materials and the environmental impact related to the production, use, and disposal of those materials. Currently, fiber-reinforced polymer matrix composites are in great need due to their important properties such as high strength, high stiffness, lightweight, good corrosion resistance, and high dimensional stability compared with conventional materials such as aluminum and steel. Natural fiber from agriculture residues is an alternative material that can replace petroleum-based fiber used in polymer matrix composite production. Banana pseudo-stem is one of the huge agricultural biomass with intrinsic potential lingo-cellulosic fiber. The fiber extracted from banana stems is a natural fabric that has good mechanical strength, is gas permeable, and biocompatible. The introduction of banana fiber in the polymer matrix improves the load-bearing capacity of the composite. In addition to this utilizing banana fiber as reinforcement material in the polymer composite, reduce agricultural waste, increase the income of farmers in developing countries, and reduce carbon dioxide emission and energy for the production of synthetic fiber. The drawback of banana fiber in polymer composite is its poor interfacial bond and moisture sensitivity. The literature confirmed various chemical treatments method available that improve natural fiber by removing sensitive constituents such as wax, lignin, and hemicellulose (Aravindh et al., 2022). In addition to this fiber architecture and volume fraction also affect load-bearing capacity composite. This investigation was conducted to study the mechanical, physical, and morphological behavior of banana fiber reinforced polymer composite which is eco-friendlily, bio-degradable, and lightweight material for various household and industrial applications.

1.3 Objective of the study

1.3.1 General Objective

To study the effect of fiber architecture and alkalization on mechanical, physical and morphological behavior of banana fiber reinforced polymer matrix composite.

1.3.2 Specific objective

- To modify banana fiber by alkaline treatment and preparing plain woven fabric.
- To fabricate composite from polyester resin and alkaline treated/untreated short fiber, woven fiber and short fiber mid layer sandwiched by woven fiber faces.
- To determine physical properties of composite such as density and void content.
- To investigate water absorption behavior of composite.
- To investigate mechanical properties of composite such as tensile, flexural, impact and hardness behavior.
- To analyze microstructure of composite by using scanning electron microscope (SEM).

1.4 Significance of the study

Banana pseudo stems are huge agricultural waste in developing countries like Ethiopia even though it is the source of dense, strong and bi-compatible fibers. This investigation pursues to expose novel uses for materials found in plenty among those communities, In this regard, this study provides the following importance in terms of material want and green economy.

- Reduce carbon dioxide emission during synthesis of man-made fiber.
- Inspire sustainable supply material with reduced cost.
- Reduce environmental hazard during synthesis and after disposal of man-made fiber composite.
- Reduce energy related to fabrication synthetic fiber.
- Pursue effective utilization of agricultural waste.

1.5 The scope of the study

This investigation is designed to study the effect of banana fiber architecture (woven, short, and their combination) and chemical treatment on the mechanical, physical, and morphological properties of banana fiber polyester composite. First, short, and woven fiber composites were prepared independently, and then other set of composite prepared by combining both fiber structures to analyze how composite properties changed accordingly.

1.6 Challenge and limitation of the study

Single fiber pullout and interlaminar shear strength tests are basic tests to determine interface behavior and interlayer strength, but they were not performed because they require special fixtures and testing conditions that are not available in our country. In addition to this the fiber for this investigation was extracted manually due to the unavailability of a fiber-extracting machine as well as the fabric was prepared with the aid of a customized handloom those tasks are very difficult and time-consuming.

1.7 Thesis organization

The thesis was organized into five chapters, the first chapter presents the background of the study, the problem statement, the objective of the study, significance, scope, and limitations of the study. The second chapter discusses the theoretical concept and empirical review regarding natural fiber, fiber architecture, polymer matrix, natural fiber reinforced polymer matrix composite, the fabrication method of fiber reinforced polymer composite and application of polymer matrix composite. the third chapter describes the methods and material used in thesis work. The fourth chapter presents results and discussion. The last chapter presents the conclusions from conducted test and forward what will be done in the future as recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this section, the theoretical and empirical review has been carried out to acquire general concepts regarding natural fiber, source of natural fiber, polymer matrix and different types of fiber architecture (short, woven and continuous) used in polymer composite fabrication. Intensive surveys were undertaken on the mechanical, chemical and morphological properties of banana fiber, various chemical and psychical modifications of banana fiber, physical and mechanical behavior of banana fiber reinforced polymer composite, different composite processing techniques and the application of natural fiber in current industries were discussed.

2.2 Natural fibers

Fiber is material that has very small diameter and the ratio of length to diameter not less than 100. Natural fiber is one of plenty resource while not utilized well. Nowadays scientist and engineer made a lot effort to exploit the effective utilizing those fibers. Natural fiber preferred over synthetic because high specific strength, biodegradable, sustainable, low cost of processing and green house free. The drawback of natural fiber is variable quality, water absorption and poor wettability (Jawaid et al., 2017; Y. Li & Dai, 2006).

Natural fiber used as reinforcement in polymer composite obtained from animal, plant and mineral.

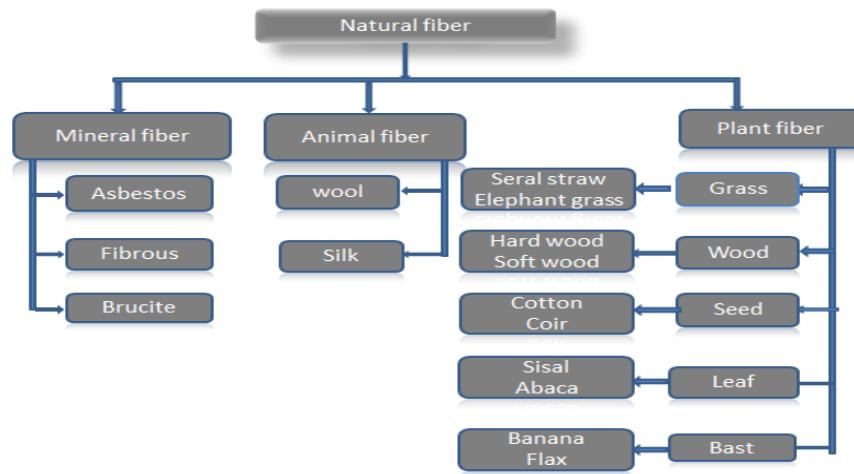


Figure 2.1 Classification natural fibers. (Jawaid et al., 2017; Parashar & Chawla, 2020)

2.2.1 Plant fiber

It is the fiber extracted from different part plant such as leaf, bast, seed, fruit and wood. Fiber that obtained from plant is lingo cellulosic, biodegradables and has good compatibility with polymer resin (Thyavihalli Girijappa et al., 2019a).

2.2.1.1 Sisal fiber

Fiber is extracted from the aged Sisal Ana plants. Sisal fiber is mostly used in polymer composite material for reinforcement. It is applicable in construction, automotive and shipping industries. Sisal fiber is a versatile fiber and can be used with various resins in short or in long-form (Thyavihalli Girijappa et al., 2019b).

2.2.1.2 Coir fiber

Coir fiber is collected from coconut shell. These coconut strands are strong, light and adequately resist heat and salt water. When compared with other plant fiber coir fiber higher constitutes lignin and lower hemicellulose and cellulose. These properties provide coir fiber high wear resistance, high extension at break and damping resistance (Santhanam et al., 2020).

2.2.1.3 Jute fiber

It is obtained from genus Corchorus plants. Jute filaments are extricated from the strip of the stem. It is utilized as bundling material (sacks), ropes, and yarns and in numerous other improving things.

2.2.1.4 Cotton fiber

It is a seed hair collected from the boll of the cotton plant. The cotton fiber is mainly composed of cellulose and highly crystalline structure with numerous strong hydrogen bonds. Cotton is the most significant fiber utilized in the material business. Correlation with other normal filaments, cotton is for the most part utilized in the manufacturing of garments, covers and carpets (Sathees Kumar et al., 2021).

2.2.1.5 Bamboo fiber

The fiber is arranged in longitudinal direction bamboo plant. Traditional bamboo plant is used for house constructions, bridge making, musical instrument, etc... Nowadays bamboo fiber used as strengthen material in polymer resin. Bamboo fiber strengthen polymer composite used in various industrial sector such as automotive, building construction, sport, etc. (Zakikhani et al., 2014).

2.2.2 Animal fibers

The fiber collected from long-haired animals or produced by glands. Animal fiber mainly composed proteins such as collagen, keratin and fibroin (Chitosan et al., n.d.).

2.2.2.1 Wool

It is fiber refers obtained from animal such as sheep, camels, oxen, and hairy animals. Wool was one of the first fibers to be spun into yarn and woven into fabric. Wool fiber is mainly composed protein named keratin (Chitosan et al., n.d.; Erdogan et al., 2020).

2.2.2.2 Silk

It is a tiny, strong, unbroken filament produced by the young insect, mainly the silkworm, when making their sheaths. Silk is fiber mainly composed of protein called fibroin (Thyavihalli Girijappa et al., 2019b).

2.3 Fiber architecture

Natural fiber as reinforcement in polymer resin can be existed in three form short, continuous and woven fiber.

2.3.1 Woven fiber

Woven fabrics are produced by interlocking warp and weft yarns in a repeated weaving pattern. The weaving structure provides stability of fiber through mechanical interlocking (Hasan et al., 2021). In fiber reinforced composite three basic types' woven fabrics are mostly employed. Those are plain, twill and stain woven fabric. Plain woven fabrics are the simplest woven fabric structure where the weft yarns are alternately passed over and under a warp yarn. Warp yarns pleased zero degree while weft is filling yarns pleased 90 degree with the respect to warp yarn. Plain weave fabrics are considered structurally symmetrical, having good porosity and stability.

Twill woven fiber is fabric made by one or more weft strand pass over and under more than one warp strand in a repeated pattern to form twill woven fabrics. The fiber woven in such way a straight or broken diagonal rib structure appears on the surface fabric. When compared with pain woven fabric has superior wettability and drapability, however less stable than plain woven fabric.

Satin weaves are produced through the use of the floating yarns by weaving operations. It is basically twill weaves used to form a lesser amount of warp and weft crossing. Stain woven fabric have higher drape and wettability but less fiber integrity compared with plain and twill woven fabric.

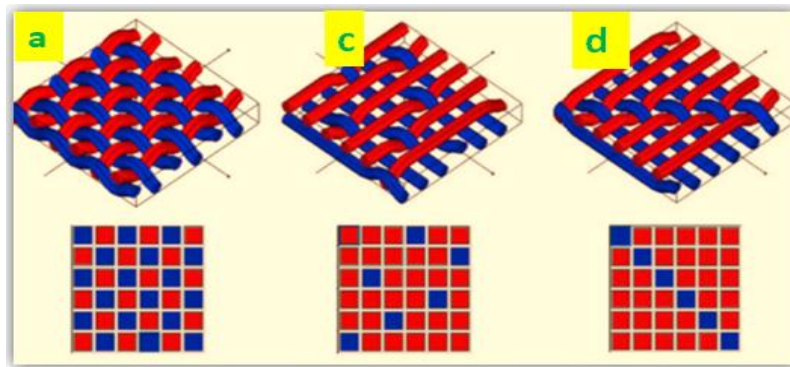


Figure 2.2 a) plain woven fabric b) twill woven fabric c) stain woven fabric. (Hasan et al., 2021)

2.4.2 Short fiber

It is one of interested fiber form in polymer composite due to high creep resistance, out of plane rigidity and ease for automated production system. When we dialed with the term “short fiber” there is no specific length however there is clear difference from continuous fiber. The strengthen effect short fiber depend on the source of fiber and matrix material. The short fiber may be prepared in the form of randomized mat. The composite made from random oriented short fiber mat has uniform in plane mechanical property. the short fiber embedded in polymer matrix was characterized by end effect. When the aspect ratio (l/d) length to diameter ratio of the fiber decreases, the end effect become more significant and strengthens and stiffening effect of fiber was decreases. The large shear stress at the end produces unwanted result such “interfacial shear deboned”, “cohesive failure of matrix or fiber” and “matrix yielding”. For short fiber the stress distribution varies along the length of fiber and maximum stress happen away from the end of fiber (Monfared, 2020). The main weakness of short fiber in polymer composite was difficulty to control distribution and direction fiber.

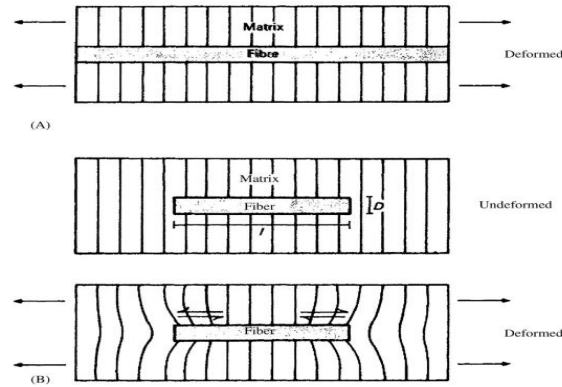


Figure 2.3 End effect A. continuous fiber B. short fiber (Monfared, 2020)

2.4.3 Continuous fiber

The continuous natural fiber were used as reinforcemet enhance the mechanical properties of polymer composites (Wongsriraksa et al., 2013). The direction continuous fiber can manipulated during composite processing to obtain desired mechanical strength in specific direction. Continuous fiber can made into fabric by mechanical and chemical means or by infusion of different solvents. The adhesive substrate are applied by spraying, coating, printing, or saturation techniques for chemical bonding to produce nonwoven fabrics to keep the fibers together (Hasan et al., 2021).

2.5 Physical and mechanical properties of banana fiber

Surface of natural fiber is rough with number of intermodal point connect individual cell. Chemical composition and microfibrillar angle are factor determine mechanical strength natural fiber. Relatively fiber with higher constitute of cellulose and smaller microfibrillar angle behave better mechanical strength. Banana fiber is strong moisture sensitive due to hydrophilic nature of cellulose and hemicellulose. Physical and mechanical properties of natural fiber can be improved by chemical treatment (Kalia et al., 2011).

Morphological study of banana fiber shown that, it is a multicellular fiber, resembling other vegetable fibers. SEM image analysis showed that diameter of single cell nearly $10\mu\text{m}$ and average length about $4.5\mu\text{m}$. The hollow structure of the banana pseudo-stem suggests that the fiber will have good insulation and absorbance properties (Subagyo & Chafidz, 2020).

Table 2.1 Physical and mechanical behavior of banana fiber

Width or diameter (μm)	Density (kg/m^3)	Microfibrillar angle (degree)	Initial modulus (GPa)	Tensile strength (MPa)	Cell L/D Ratio	Elongation (%)
10 – 450	1350	10 ± 1	7.2 – 20.0	54 – 754	150	10.35

2.6 Chemical composition of banana fiber

Natural fiber mainly composed of cellulose, hemicellulose and lignin. Among those composition celluloses are semi-crystalline while, lignin and hemicellulose are amorphous. Cellulose constitutes the major content in natural fiber with repeated linear chain of β - D - .glucopyranose. Hemicellulose is branched chain formed from 5 ring and 6 ring carbon polysaccharide with lower degree polymerization compared with cellulose. Lignin is a phenolic compound that provides rigidity to the natural fiber (Bismarck et al., 2005).

Crystalline region of cellulose interconnected by thread like structure called cellulose microfibrillar. Microfibrillar itself formed from large number of interconnected cellulose molecules. It is arranged at angle with respect to fiber axis. Microfibrillar angle determine mechanical strength of natural fiber. Fiber with higher constitute of cellulose and small microfibrillar angle behave better mechanical strength.

The cell wall of natural fiber consists primary and secondary cell wall with central hollow tube called lumen. Lumen is responsible to hold water. The cell wall of natural fiber is composite with cellulose microfibrillar (reinforcement phase) dispersed in hemicellulose and lignin matrix (Kalia et al., 2011). Cellulose contain a number of $-\text{OH}$ group that form hydrogen bond with water, however crystallinity of cellulose reduce the extent of hydroxyl group expose to water.

Table 2.2 Chemical composition of banana fiber (Bhatnagar et al., 2015).

Constituents	Cellulose	hemicellulose	Lignin	Pectin	Ash	Extractive
Contribution from 100%	60-65	6-19	5-10	3-5	1-3	3-6

2.7 Bio and thermal degradation of banana fiber

Albertson and Karlsson defined biodegradation is the result happened by action of enzyme or chemical decay related with living thing such as bacteria, fungi, yeast and insect or by their secretion product. Biodegradability investigation can be done by putting the fiber on the ground. Microorganisms grow on buried fiber and secrete cellulose enzyme. The enzyme decomposes cellulose continuously. The soil burial test showed that tensile strength decreased nearly 21.8% after three day. The decay of banana fiber by microbial action changes the strength and elongation condition of the fiber (Subagyo & Chafidz, 2020)

Natural fibers have low heat resistance that limits it for high temperature application. William et.al, 2011 carried out fiber burn-off test to determine optimal operating temperature for banana fiber. Based on this investigation, instantaneous loss in weight observed at temperature close to 200°C. Thermal stability can be improved by chemical treatment that reduce amorphous component (Gupta & Tiwari, 2020).

2.8 Treatment of banana fiber

The major weakens natural fiber in polymer composite is poor interfacial bonding and water absorption. Water intake capacity of natural fiber polymer composite is increases with fiber loading because of increased hydroxyl group. The fiber-polymer interfacial adhesion is strongly affected by surface nature of fiber and polymer chemical composition. The hydrophilic nature of cellulose and lignin result with high affinity to water. Treatment of natural fiber increase compatibility with polymer matrix by removing unwanted waste from fiber surface, as coupling agent, by creating free radical, or by formation of new functional group.

There are several methods available to modify natural fiber, those methods generally categorized in to chemical or physical method.

2.8.1 Physical treatment

Physical treatment changes the surface and structure of fiber without altering chemical composition. It improves mechanical adhesion between fiber and matrix. The most common methods physical treatments are ultrasound, ultra-violet and plasma treatment.

Plasma treatment use gas consists of ions and neutral particle with zero charge density that injected into the surface of fiber (Kalia et al., 2011). It improves fiber by removing unwanted surface layers and/or by formation of free radical. Depending on temperature used plasma treatment can be classified into thermal or non-thermal. It may be undertaken at vacuum or atmospheric pressure. Based on nature of gas used, cold plasma treatment improves natural fiber by surface crosslink.

Ultrasound modification of natural fiber enhances fiber-polymer adhesion by removing lignin, hemicellulose and other surface impurity by ultrasound vibration. It improves thermal stability and moisture absorption of natural fiber. Ultraviolet treatment is other method of physical modification change chemical and mechanical behavior natural fiber. UV treatment increase tensile strength, impact strength and tensile module of natural fiber reinforced polymer composite (Gholampour, 2020).

2.8.2 Chemical treatment

Chemical treatments improve fiber-polymer interface adhesion by removing wax, lignin and hemicellulose. In addition to this hydrophilic nature of banana fiber is reduced by reaction of hydroxyl group of cellulose with chemical reagent, while the newly formed cellulose function group is hydrophobic as the result compatible with polymer matrix. Same of chemical treatment methods involve by using coupling agent that form bridge between fiber and matrix. The most commonly use chemical treatment methods are discussed below.

Alkali treatment

It is the most common and effective method to improve natural fiber. Alkalization held by soaking the fiber with known concentration of sodium hydroxide in water. Modification of natural fiber by NaOH removes amorphous constitute such as lignin, pectin and hemicellulose thus water sensitive nature of natural fiber is reduced and interfacial adhesion with polymer matrix enhanced. The improvements of interfacial bonding allow uniform transfer of stress within composite thereby improved tensile, flexural and impact strength obtained (Aravindh et al., 2022). Zafra Mejía et al., 2012 carried an experimental investigation to study the effect of alkalization on mechanical and morphological properties of banana fiber. Banana fiber was treated by 5% sodium hydroxide and when compared with untreated one reduced diameter and rougher surface was obtained. Negawo et al., 2019 investigated the effect different alkali concentration (NaOH 2.5%, 5% and 7.5%) on

mechanical and morphological behavior of Ethiopia Enset plant pseud stem fiber. They conclude that improved mechanical and dynamic-mechanical properties obtained with 5% NaOH treated banana fiber. Aravindh et al., 2022 they carried out Carried out comprehensive review to identify the effect of various chemical treatment on renewable bio-fiber composite and they conclude that 5% alkali treated composite provide good mechanical strength and it is the most effective and inexpensive treatment provide better bonding between matrix and reinforcement.

Benzoyl treatment

It involve introduction of benzoyl group followed by alkalization of natural fiber. Benzoylization reduce hydrophilicity of natural fiber thereby compatibility with polymer matrix increased. Benzoyl modification improves thermal stability by increasing crystallinity of sisal (Boopathi et al., 2012). Benzoyl modification improve mechanical strength and physical behavior such as dimensional stability and water uptake by natural fiber. Benzoylization of banana fiber significantly improve thermal conductivity, increase tensile strength and modulus however not as good as alkali and silane treated fiber (Sampathkumar et al., 2012).

Acetyl treatment

Acetyl treatment esterifies natural fiber i.e. – OH group substituted by acetyl group, which make fiber hydrophobic and enhance compatibility with polymer matrix. In general acetylation improve physical, chemical and mechanical properties of natural fiber thus better fiber strengthen polymer composite obtained when compared with untreated one (Bhatnagar et al., 2015).

2.9 Polymer matrix

It is resin used in fiber reinforced composite processing. Polymer bind the fiber with aid surface link and protect it from mechanical damage. Polymer resin classified based on method of synthesis; poly-addition and poly-condensate resin. Poly-addition resins are polymerized resins made from monomer units with double or triple bonds. Based on response to heat polymer resins are classified into thermosetting and thermoplastic resins. Thermoplastic resin softens when it is heated and then hardens when it cools down. This process can be continual for several times without starving the property and form of the material (“Decorative Plastics,” 2011).

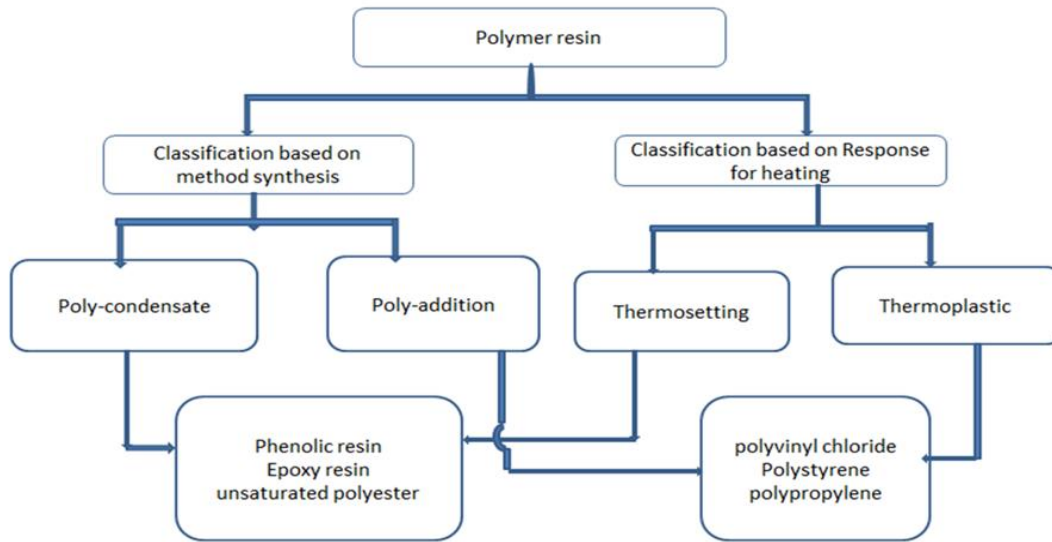


Figure 2.4 Classification of polymer resin. (“Building Plastic,” 2011)

2.9.1 Properties of polymer resins

Density of polymer resin is typically varies from 0.8-2.2 g/cm² nearly, one fifth of the density of steel, half of aluminum, one third concrete, and comparable to the density of wood. This property of polymer resin allows it typically selected for light weight application especially, in aerospace and automotive industry that need product with reduced dead weight to minimize fuel consumption. The specific strength of plastic materials is close to or even beyond that of steel. It is a kind of impressive material with lightweight and improved strength (Dodiuk, 2021).

The thermal conductivity of polymer varies from 0.020-0.046 W/(mK) hence, it is an ideal heat insulating material. In addition to this polymer can be molded into products with different shapes without using complicated processes. This property allows it easy to carry out automated mass production (“Building Plastic,” 2011).

Polymer material can be easy tinted and can stay for long time without fading its color. By using photogravure copy, polymer can printed into texture of natural materials, in such way it’s hard to identify the candid from the fake. Although, the advantages listed above, polymer has many weak sides, such as get old easily, flammability, low temperature resistance, and feeble stiffness. The aging of polymer can be improved by adding a certain amount of stabilizer and extra ordinary

quality colorant. Flame retard property can be enhanced by introducing same inorganic filler material. The strength and stiffness can be enhanced greatly by adding fiber reinforced polymer (“Decorative Plastics,” 2011). The most commonly used resin in polymer processing are polyester, epoxy, vinyl ester and phenolic.

2.9.2 Epoxy resin

It is thermosetting resin, before mixed with curing agent, it exist in liquid state or brittle solid, and easily soluble in solvents like xylene and acetone. When mixed with hardening agent, it gets solid at ambient or high temperature. Ethylene polyamine likes diethylene tri-amine and tri-ethylene tetra-amine cause it cure at room temperature, while o-dicarboxylic anhydride and acid anhydride are high temperature curing agent. The important behavior of epoxy resin, it form strong bonding with diverse material, this happen since after cure it had different types of polar group such as -OH group, ether bond and epoxy group in its structure. Epoxy exhibit little shrinkage rate during curing, and even though at extreme shrinkage, the resin is partial in gel state and behave same fluidity; hence it had low residual stress (Sukanto et al., 2021).

2.9.3 Unsaturated Polyester

Polyester is types of thermosetting resin, before curing; it exists in liquid state with high viscosity. It cures at ambient temperature, requiring hardening substrate and accelerant to aid curing. There are several types starting material, in such way that polyester with different level performance is produced by implementing desired material, formulas or methods to meet varied requirements. Unsaturated polyester made easily, that means it is easily processed, it can be cast under low compression force or with no such load. Its drawback is when it is cured; its volume reduction is high, 7 - 8%. It is largely implemented to produce fiber reinforced polymer products (Dodiuk, 2021).

2.9.4 Phenolic Resin

Phenolic is thermoset resin produced by polymerizing phenol and aldehyde by influence of acidic or alkaline catalyst. Phenolic resin has better cohesion strength, light resistance, water resistance, heat resistance, corrosion resistance, and electrical insulation. However, it has poor stiffness. Phenolic resin, added by filling material and curing agent, can be made into phenolic plastic.

Phenolic plastic is smooth, strong, durable, and cheap. It has become a type of commonly used plastic (Engineers, 2007).

2.9.5 Polyethylene

Polyethylene is thermoplastic polymer made by polymerization vinyl monomer. It is linear chain crystalline polymer. Degree of crystallinity depends on number of monomer unit engaged in the formation polymer. Higher density of monomer unit related with high degree of crystallinity. Polyethylene is wax-like light radiant appearance, good chemical resistance and good elasticity despite, its low heat and impact resistance it had much better properties than those of polyvinyl chloride (“Decorative Plastics,” 2011).

2.10 Mechanical behavior of short fiber polymer composite

Haghighatnia et al., 2017 studied the effect of fiber length, fiber loading and alkalization on mechanical behavior of hemp fiber reinforced polyurethane composite. The fiber length was selected by applying the concept of critical fiber length. The investigation was shown enhanced mechanical properties was obtained with composite sample having 40 vol% fiber loading and 15mm fiber length. Rana et al., 2017 investigated mechanical behavior sisal fiber reinforced epoxy composite. The samples was prepared by hand layup method with variable fiber length (5, 10, 15 and 20mm) and fixed fiber loading 30 wt.%. The investigation was shown that improved mechanical properties were obtained with sample made by 15mm fiber length.

2.11 Mechanical behavior of woven natural fiber composite

Woven natural fiber used in production of bio-based laminated composite. When compared with short fiber composite, the wave structure allows easily manipulating the fiber direction in woven composite. Woven fabrics are comfort for handling and positioning during composite processing. Randomized short fiber composite have improved out plain rigidity and strength however it is difficult to control fiber direction and distribution. Ratim et al., 2012 study the mechanical properties plain, twill woven and non-woven mat of kenaf fiber reinforced polyester composite and use net polyester as control. Based on this investigation woven fiber composite behave better mechanical behavior when compared with non-woven composite and control. Alavudeen et al., 2015 studied the effect of woven (plain and twill) and random oriented banana fiber, kenaf fiber and there hybrid on mechanical behavior of polyester matrix composite. The investigation show

plain woven fiber composite behave improved mechanical strength than both twill and random oriented fiber composite. Furthermore hybridization enhances mechanical properties polyester composite due to addition of kenaf fiber. Hamdan et al., 2016 investigated the effect woven and short kenaf fiber on flexural and tensile behavior kenaf fiber epoxy composite. the samples was manufactured 30:70 wt.% matrix to fiber ratio with three laminated layer by changing warp and weft direction and chopped fiber composite as control. The investigation was shown that improved flexural and tensile strength obtained with woven fabric composite compared with control.

Sapuan & Maleque, 2005 the telephone stand was designed and fabricated from woven banana fiber epoxy matrix composite. The design and production steps follow sires of product design specification from market need to sale of actual product. The telephone stand was manufactured by using concerts mold laminated by plastic layer. Final fabricated stand was golden brown, pleased to look, light weight and it is ideal material to substitute conventional product from metal and non-metal.

2.12 Laminated composite

Laminated composite fabricated from two or more stacking layers. The stacking layer may or may not be made from the same material. The mechanical behavior of laminate composite affected by laminate stacking layers, laminate orientation and properties of matrix material (Hasan et al., 2021). The investigation was done to study the effect of number staking layer (1, 3, 5 and 7), fiber direction (0^0 and 45^0) and cutting direction (0^0 and 45^0) on mechanical behavior jute fabric reinforced epoxy composite (Abdellaoui et al., 2015). The investigation was shown that mechanical strength increase with stacking layer and maximum strength was obtained with five layer laminated composite and with 0^0 fibers orientation and cutting direction.

2.13 Fiber weight fraction

Fiber loading one of the factor determine mechanical and physical behavior of natural fiber polymer matrix composite. Based on (Gairola et al., 2020) investigated on non-woven banana fiber epoxy matrix composite, the study was done with variable fiber content 10-50wt.%. The samples were manufactured using hand layup method followed by applying static compressive load. The tensile and flexural test was performed as per ASTM D3039 and ASTM D790 respectively. The impact energy was estimated as per ASTM D256 and hardness test as per ASTM E-92. The

investigation was shown that maximum tensile and flexural strength were obtained with samples having 30% fiber load while; maximum impact energy and hardness were obtained with samples having 40% fiber content. Consequently, they reported 40wt.% fiber loading as optimum content provide good mechanical properties.

Characteristics, (1997) carried out an investigation to study the effect of fiber loading, fiber length and chemical treatment on mechanical behavior of banana fiber polyester composite. The investigation revealed that 30mm and 40mm fiber length and 40wt% fiber content provide improved mechanical strength of composite. The study was done to analyze the effect NaOH treated and untreated sugar palm fiber loading on mechanical properties polyester composite (Norizan et al., 2018). The samples were prepared with variable fiber load (10, 20, 30, 40 and 50 wt. %) and The maximum tensile strength and tensile modulus, flexural strength and flexural modulus were observed at 30 wt. % of fiber loading, while highest impact strength was observed at 40 wt. % of fiber loading.

Kenned et al., (2020) banana fiber was needle punched and composite was manufactured using unsaturated polyester matrix. The thermal and mechanical of behavior needle punched banana fiber composite was compared with random oriented glass and banana fiber composite. the investigation was shown that optimal thermo-mechanical properties was acquired with 40 wt.% fiber load for all composites, while better thermo-mechanical properties was found with needle punched banana fiber composite that compared with random oriented banana fiber composite and comparable properties with random oriented glass fiber composite. SEN image was revealed that minimum fiber pull out and matrix yield with sample 40 wt.% fiber load when compared with samples having lesser fiber content.

Da Cunha et al., (2021) studied physical and mechanical property of titica vine fiber reinforced epoxy composite. The composite was manufactured with variable titica vine fiber volume, 10, 20, 30 and 40 vol.%. In addition to variation of fiber content, the fiber was chemical treated with sodium carbonate as one variable and calcium lingo-sulfonate as another. When compared with untreated titica vine fiber composite of 40 vol.% fiber loading, sodium carbonate treated fiber composite absorbs more water while calcium lingo-sulfonate uptakes less amount of water with

equal fiber load. Regardless the effect chemical treatment highest impact strength was obtained with 40 vol.% titica vine fiber reinforced epoxy composite.

2.14 Water absorption behavior

The water molecules absorbed by natural fiber composite affect the structure of fiber and fiber-matrix interface thus, it act as debonding agent. The water molecules moves by capillary action between the fiber and matrix hence weaken the interfacial bond even initiate micro crack. Due to variable weather condition of the working environment, natural fiber composite may behave cyclic Swelling and shrinking, freezing and unfreezing cause microbial growth and failure of interfacial bond. This characteristic significantly reduces mechanical behavior of composite (Gupta & Tiwari, 2020). Gairola et al., (2020) studied water absorption behavior non-woven banana fiber epoxy composite. The composite was prepared with variable fiber loading (10, 20, 30, 40 and 50 wt.%). The investigation was shown that water uptake rate increase with time and fiber content. Badyankal et al., (2019) studied compression and water uptake behavior banana/sisal fiber hybrid polymer composite with fixed fiber to matrix ratio 40:60%. The samples were prepared with contribution of banana fiber 25, 37.5, 50 and 62.5% and the rest was sisal fiber. Based on this study chemical treated fiber with less contribution of sisal fiber behave composites were lesser sensitive to water molecules. Venkateshwaran et al., (2011) investigated water absorption behavior of woven jute/banana fiber hybrid composite. The laminated composite with three layers was manufactured by hand layup method and water absorption test was carried out as per ASTM D570. The experimentation was shown that hybrid composite with banana fiber outer layers absorb less amount water compared with jute fiber outer face. Pure banana fiber composite less sensitive to moisture compared with jute fiber and jute/banana fiber hybrid composite.

2.14.1 kinetic of water absorption

The diffusion of water into composite structure is initiated by void in polymer structure, crack on the surface of composite and by capillary action between fiber and matrix (Graham-Jones & Summerscales, 2015). The diffusion behavior in polymer determined by relative mobility of penetrant and polymer segment. Based on that there were three diffusion mechanism; Fickian diffusion were the movement of penetrant less than polymer segment mobility, case II (super case) were the movement penetrant greater than polymer segment mobility and non-Fickian

diffusion were polymer segment mobility comparable with polymer segment mobility (Kushwaha et al., 2009).

2.15 Production methods of fiber reinforced polymer composite

Production method selections depend on the basis of lowest cost which will produce the sample to meet the specific requirements.

2.15.1 Hand lay-up

It is the most common and cost effective method to produce fiber reinforced thermoset matrix composite. The general steps followed to fabricate the samples are; treat the mould surface with releasing substrate, skinny plastic layers placed on mould to get flat surface, stepwise the resin and fiber alternative layers added to get pre-specified thickness, while after placing new fiber layer roll the surface to remove entrapped air bubbles (Crosky et al., 2013).

2.15.2 Compression moulding

In this method, matched dice are employed to produce composite items. The lower plate is secure whereas the top plate is moveable to apply force. Fiber and matrix are placed in the bottom mold and the whole mixture is kept in the middle of the pressure decay. The required force applied by hydraulic or mechanical means (Huda et al., 2006).

2.15.3 Pultrusion moulding

In this method, fibers or fabric are soaked in a resin bath and pulled through a heated die. It is limited to long fiber reinforced polymer composite (Tzounis et al., 2014).

2.15.4 Injection moulding

This system is employed for the progression of plastic parts with uncommon measurement precision. This method is suitable to produce short fiber reinforced polymer composite (Santhanam et al., 2020).

2.12 Application of natural fiber composite in industry

There are ongoing increases using renewable material in industry to minimize dependence on Petroleum based products to reduce environmental pollution (Chandramohan & Bharanichandar, 2014) Nowadays reducing carbon dioxide emission is a global issue and manufacturing industries

should be concerned toward achieving the goal of minimizing its emission to 70% in 2050 (Rwawiire et al., (2015)). In Europe, auto industries are using natural fabric extracted from hemp, abaca and flax reinforced polymer composite for automotive accessories (Kalia et al., 2011) The drive force for application natural fiber in current industry is environmental aspect such as biodegradability and green house free, economic aspect such as low cost of processing, sustainability and availability. Natural fiber polymers composite have relatively low cost of production, low specific weight, high resistance to corrosion and high thermal and sound insulation compared with man-made fiber composite.

Many car making companies around the world have made an effort to apply natural fiber polymer composite for both interior and exterior parts in their model. German auto company Mercedes Benz uses natural fiber polymer composite to make the interior parts like door panel, glove box, instrumental panel, seat basket surface and trunk panel (Davoodi et al., 2012). Toyota makes parts from natural fiber composite such as floor mats, spare tire cover, door panels, and seat backs. Natural fiber composite is applicable other than Auto Company such as sport, furniture, building construction etc. Different parts are made from natural fiber composite like roof sheet, indoor panel, laminate sheet, wallpaper, door frame, door and window. Studies were undertaken on fabrication of jute door frames, coir fiber reinforced cement roofing panes, sisal/glass hybrid fiber epoxy (Bismarck et al., 2005)

2.16 Summary of literatures

A comprehensive literature survey was carried out regarding natural fiber, natural fiber polymer composite, and fabrication methods. Natural fibers obtained from animals and plants are green, biodegradable, and sustainable. The introduction of natural fiber in a polymer matrix improves the mechanical strength of the polymer and the resulting composite are had higher specific strength and inexpensive than synthetic fiber composite, thus natural fibers are potential candidates to replace synthetic fiber. The drawback of natural fibers in polymer composite are poor interfacial bonding and moisture absorption. The literature described various physical and chemical treatment methods available to improve natural fiber hence it becomes compatible with polymer resin and less sensitive to moisture. Among different method of chemical treatment literature confirmed that alkaline treatment of fiber by 5% NaOH concentration is cost-effective and provide better mechanical properties. Fiber architecture is another factor that affects the mechanical properties of natural fiber composite. short fiber widely used in automated polymer composite processing.

Random oriented short fiber composite had out-of-plane rigidity and high creep resistance. Woven (plain, twill and stain) natural fibers are used in the production of bio-based laminated composite. In woven fiber composite, the interlock of fiber in the weave structure provides additional strength to the composite. In addition to this fiber weight percentage is another factor that affects composite physical and chemical properties. Based on the literature survey most of the mechanical strength increases with fiber until 40 wt.%. Among different methods fiber reinforced polymer composite production, hand layup is a simple and cost-effective technique to fabricate natural fiber reinforced polymer composite. Natural fiber polymer matrix composites are applicable in automotive, sports, and construction industries that need lightweight and strong materials.

2.17 Research gap

Most of the researches that have been done on banana fiber reinforced polymer composite involve either woven or short fiber but not their combined effect on mechanical and physical properties of composite.

This investigation carried out to study the effect fiber architecture (woven and short fiber their combined effect) and chemical treatment on mechanical, physical and morphological behavior of banana fiber reinforced polyester matrix composite.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the materials used and methods followed when conducting the research. The material used for composite preparation were banana pseudo stem fiber, sodium hydroxide flax, distilled water, waxy releasing agent, and unsaturated polyester resin. The composite samples were fabricated by the hand layup method. The prepared composite samples were tested for mechanical, physical, and morphological behavior as per ASTM standards and a set of conditions. Generally, the procedures were followed to achieve the stated objective.

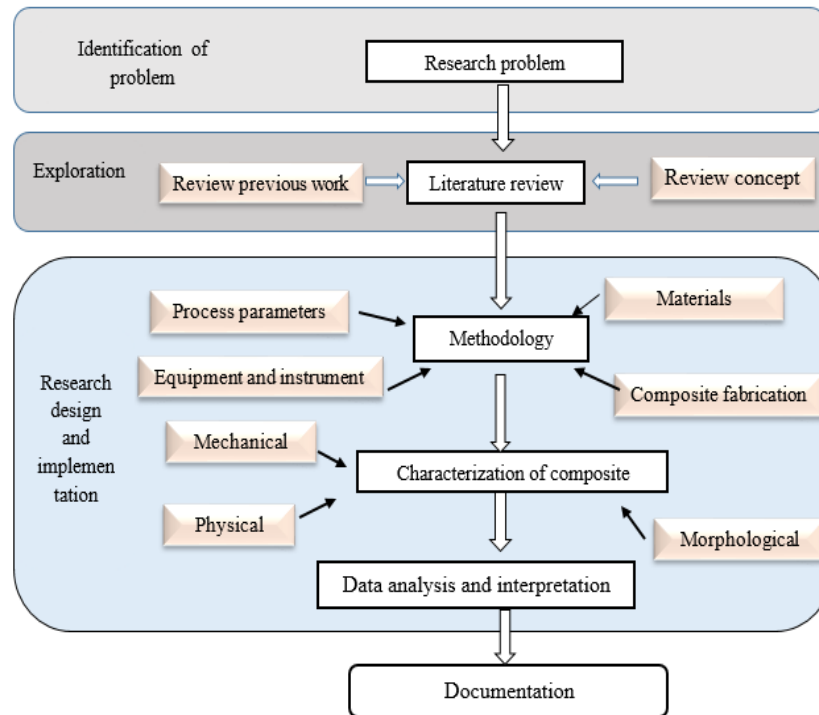


Figure 3.1 Methodology followed to achieve research objective.

3.2 Materials

3.2.1 Banana fiber

The natural fiber used for this investigation was extracted from a banana pseud stem that is one of massive agricultural waste in southern Ethiopia. It was obtained from 7°14'N 37°32'E Bohe. The fiber was extricated from the pseud stem manual by removing the pulp that holds them together. After extraction, the fiber allowed for sunlight for about 12 hours. It is common practice used by this community to prepare kocho (traditional food in Ethiopia) from false bananas, however it is less common with banana plant to prepare fiber.

Table 3.1 Physical, mechanical, and chemical properties of banana (Bhatnagar et al., 2015; Subagyo & Chafidz, 2020).

Width or diameter (μm)	Density (kg/m ³)	Micro-fibrillar angle (degree)	Initial modulus (GPa)	Tensile strength (MPa)	Cell L/D ratio	Elongation (%)
10 – 450	1350	10±1	7.2 – 20.0	54 - 754	150	10.35
Constituents	Cellulose	Hemicellulose	Lignin	Pectin	Ash	Extractive
Contribution%	60-65	6-19	5-10	3-5	1-3	3-6

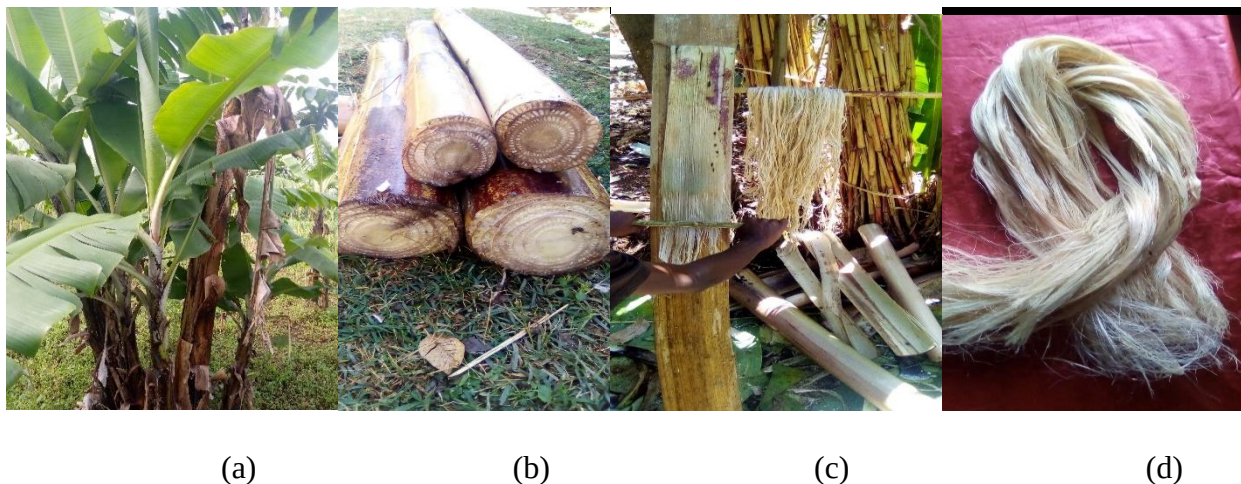


Figure 3.2 Photographs of (a) banana plant (b) pseudo stem (c) fiber extraction (d) fiber.

3.2.2 NaOH

Alkali substance used to modify fiber Modification of natural fiber by NaOH removes amorphous constitute such as lignin, pectin and hemicellulose thus water sensitive nature of natural fiber is reduced and interfacial adhesion with polymer matrix enhanced. The improvements of interfacial bonding allow uniform transfer of stress within composite thereby improved mechanical properties. It was obtained from Addis Ababa, Atomic Educational Materials supply PLC.

3.2.3 Distilled water

It is purified water manly contain hydrogen and oxygen atoms. Purification of water remove dissolved mineral such as sodium, calcium, and potassium and contaminants like bacteria, algae, lead, rust, etc.. in this thesis work distilled water employed to dissolve NaOH flax. It purchased from Addis Ababa, Atomic Educational Materials supply PLC.

3.2.4 Polyester resin

It is a type of thermosetting resin, before curing; it exists in a liquid state with high viscosity. It cures at ambient temperature, requiring a hardening substrate and accelerant to aid curing. Unsaturated polyester can be moulded under low compression force or without such loading, so it can be easily processed. The important behavior of polyester resin is it forms strong bonding with diverse material. it had good interfacial bond with natural fiber. The general purpose unsaturated polyester resin was obtained from supplier World Fiber Glass and Waterproofing Engineering, Addis Ababa, Ethiopia..

Table 3.2 Property of polyester resin (Chandgude & Salunkhe, 2021)

Thermoset resin	Density (g/cm ³)	Tensile strength (MPa)	Compressive (MPa)	Young's modulus (GPa)	Impact strength (J/s)
Polyester	1.2–1.5	40–90	90–250	3	0.15–3.2

3.2.5 Hardener

It is a curing agent responsible for reacting with the function groups contained in the polyester resin. The reaction of curing agent with polyester resins results in hardening, thermoset materials. It obtained from local market Word Fiberglass and Waterproof Engineering.



Figure 3.3 Polyester resin b) sodium hydroxide flake c) harder and d) distilled water.

3.3 Methods

A description of the methods used during fiber preparation, mold making, and composite fabrication was presented in this sub-section.

3.3.1 Fiber preparation procedures

3.3.1.1 Alkaline treatment

The dried fiber was alkaline treated by soaking it in a 5% NaOH solution (it is an optimum concentration according to the literature (Ibnu & Adityarini, 2019; Zafra Mejía et al., 2012) for an hour followed the same procedure with (Ibnu & Adityarini, 2019). Sodium hydroxide flake was mixed in distilled water to create free Na^+ ions that react with hydroxyl group in the fiber. The treated fiber was washed with run water to remove excess alkali solution and dried well in sunlight for 48 hour before composite fabrication.

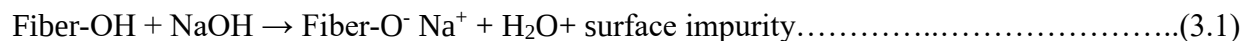


Figure 3.4 a) NaOH treatment b) washing fiber c) Drying under sunlight.

3.3.1.2 Fabric preparation

The banana fiber was woven in to plain fabric manually by using handloom with 0/90° fiber adjustment (Hasan et al., 2021). The woven pattern consist weft and warp yarns. Warp yarns placed zero degree while weft is filling yarns placed 90 degree with the respect to warp yarn. In order to make the fabric the following procedure was followed.

3.3.1.3 Carding/combing

The treated and untreated banana fibers were combed by using commercially available human hair comb. This was done to remove short fiber as well as to get straight and parallel fiber.

3.3.1.4 Yarn making

Yarn is the strand of fiber that used to make fabric. It is one of the factors that determine the properties of the fabric. According to the definition of textile yarn is the strained of fiber having considerable length and a relatively small cross-section with or without twisting (Y. Li & Dai, 2006). The twist angle an angle measured from the axis yarn. The extent of twist affects the yarn strength. Tensile strength increase with twist angle. When the twist angle increases, the most component of applied tensile force is distributed in the radial direction and the friction between fiber increase thus reduce the slip of fiber one over another. However when twist angle increase more torsional stresses in individual fiber hence reduce yarn strength (Aisyah et al., 2021).

The influence of the extent of twist angle on tensile strength of flax fiber composite was studied by (Goutianos et al., 2006). They study showed that the porousness of the strand declined by increasing the extent of twist and the strength was reduced in response to fiber obliquity, hence upsetting the competence of orientation. High twist angle humble the wettability of fiber as well as poor fiber-matrix interface. To sustain adequate wettability and to reduce fiber obliquity in this thesis work minimum twist angle was used.

3.3.1.5 Weaving

The weaving process was done by using customized handloom that consist evenly spaced pin used to tight the warp yarns. Bi-functional heald and reed comb was used to keep the space between warp yarns, reed the fill yarn to position and govern the warp yarn to open shed.

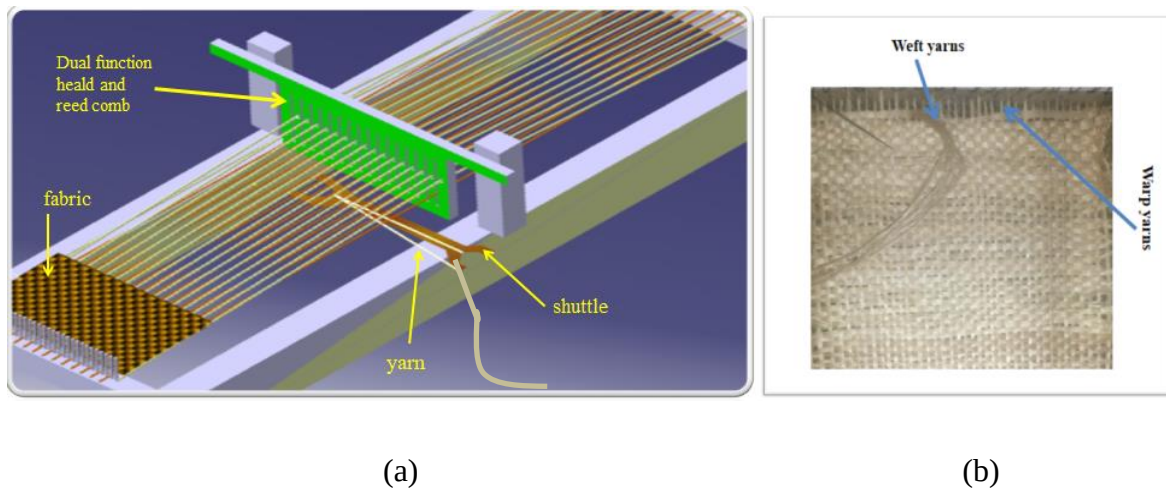


Figure 3.5 a) Customized handloom b) Warp and weft yarns of plain woven banana fabric

3.3.1.5 Chopped fiber

Both chemical treated and untreated fiber was chopped into 15mm length (Haghighatnia et al., 2017; Rana et al., 2017). Before chopping the fiber, it was combed to make it parallel and to avoid unnecessary disordered fiber.



Figure 3.6 Chopped banana fiber.

3.3.2 Volume and weight fraction determination

Volume fraction of fiber and matrix pre specified before fabricating the specimen. Volume fraction of fiber is the ratio of fiber to total volume of composite.

$$V_f = \frac{\text{fiber volume}}{\text{total volume}} \dots\dots\dots 3.2$$

The volume fraction of matrix calculated as:

$$V_m = \frac{\text{volme of matrix}}{\text{total volme}} \dots\dots\dots 3.3$$

The sum of two ratios expressed as:

$$V_m + V_f = 1 \dots\dots\dots 3.4$$

$$V_C = V_m + V_f \dots\dots\dots 3.5$$

The above formulas are valid based on the assumption that there is on void space in composite. In the manner to volume fraction, the weight fraction is a ratio of the ingredient to entire weight of composite.

$$W_f = \frac{\text{fiber weight}}{\text{total weight}} \dots\dots\dots 3.6$$

$$W_m = \frac{\text{matrix weight}}{\text{total weight}} \dots\dots\dots 3.6$$

The sum of two ratios expressed as:

$$W_m + W_f = 1 \dots\dots\dots 3.7$$

The above formulas are valid based on the assumption there is no foreign particle; this means the composite only made from the weight fiber and matrix.

3.3.3 Theoretical density calculation

Theoretical density of composite was estimated by averaging rule. It involves computing a weighted average of the component material density. The mass of composite determined by mixture rule;

$$m_c = m_f + m_m \dots \dots \dots 3.8$$

$$\rho_c = \rho_m v_m + \rho_f v_f \dots \dots \dots 3.9$$

$$w_f = \frac{\rho_f}{\rho_c} v_f \dots \dots \dots 3.10$$

$$v_f = \frac{w_f / \rho_f}{w_f / \rho_f + w_m / \rho_m} \dots \dots \dots 3.11$$

Where; m stand for mass, ρ stand for density, V stand for volume, v stand for volume fraction and the subscript m and f stands for matrix and fiber respectively.

3.3.4 Mold preparation

The mold for sample production was manufactured from plywood with a dimension of 170mm×400mm and the upper cover with a dimension of 178mm×398mm that transfer pressure.



Figure 3.7 the mold b) mold cover

3.3.5 Composite fabrication

The composite samples were manufactured by using hand layup technique with fixed fiber to matrix weight ratio 40:60. It is an optimum composition provide better mechanical strength based on resent report (Gairola et al., 2020; Kenned et al., 2020; Norizan et al., 2018). Before putting the resin and reinforcement in the mold, the plywood mold was assembled by using bolts and nuts. Then the mold surface as well as mold cover was shielded by polyethylene plaster to avoid contact between composite and plywood during processing and curing. The releasing agent was slightly

and uniformly applied on mold surface to smooth samples surface and facilitate demolding. Flowchart depicting the composite preparation was presented in Figure 3.8.

The volume of composite was specified from standard thickness of composite sample and mold dimension. The volume fraction of fiber and matrix calculated using above formula 11 and based on this volume fraction, the weight of matrix and fiber was determined.

Standard tackiness of samples taken for this study $t = 3.5 \text{ mm}$

Rectangular mold dimension $L \times W = 160\text{mm} \times 400\text{mm}$

$$V_c = L \times W \times t = 160\text{mm} \times 400\text{mm} \times 3.5\text{mm}$$

$$V_c = 224000\text{mm}^3 = 224\text{cm}^3$$

$$v_f = \frac{w_f / \rho_f}{w_f / \rho_f + w_m / \rho_m} \quad v_f = \frac{0.4 / 1.35}{0.4 / 1.35 + 0.6 / 1.19}$$

$$= 0.37$$

$$V_m + V_f = 1 \text{ from equation (3.4)}$$

$$v_m + 0.37 = 1$$

$$v_m = 0.63$$

$$m_f = \rho_f V_c v_f = 1.35 \text{ g/cm}^3 * 224\text{cm}^3 * 0.37$$

$$= 111.89\text{g}$$

$$m_m = \rho_m V_c v_m = 1.192 \text{ g/cm}^3 * 224\text{cm}^3 * 0.63$$

$$= 168.21\text{g}$$

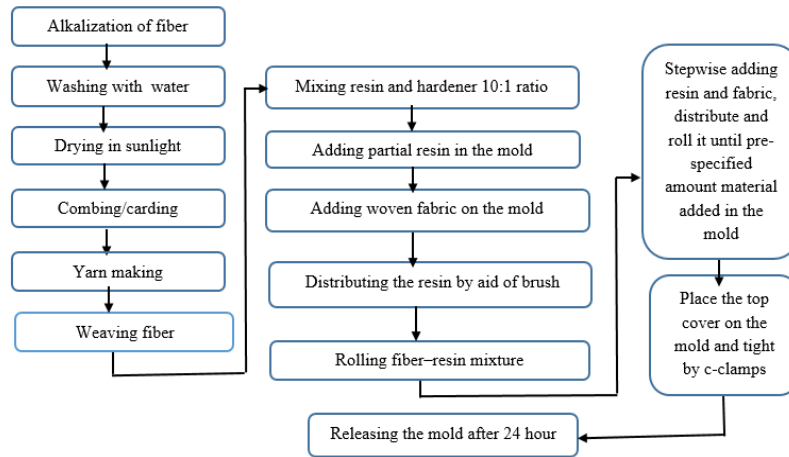


Figure 3.8 Illustrated flowchart represent production process of treated woven fiber composite.



(a)

(b)

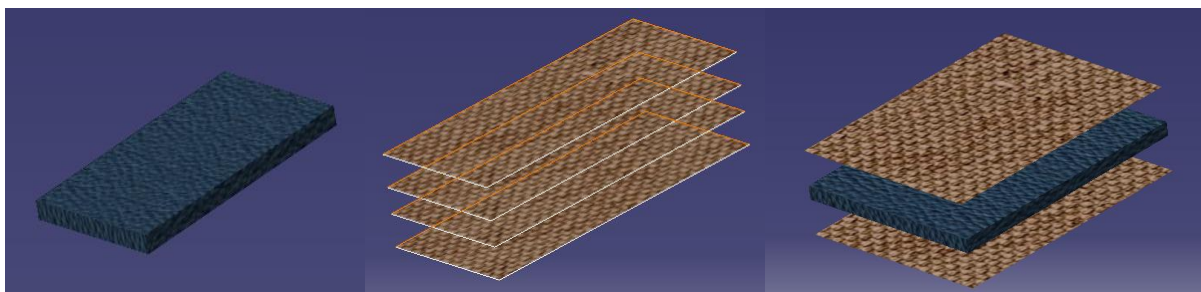
Figure 3.9 a) Weighted fiber b) weighted resin

The hardener was mixed with resin at a 10:1 weight ratio and properly stirred for 2min. The production process was done by pouring resin on the mold surface then proportional amount of fiber added on it. To ensure proper distribution resin and fiber brush was used. In case of woven fiber composite processing, the brush was used to facilitate uniform distribution of the resin. The roller was used to avoid entrapped air, to join the laminate, to ensure uniform wetting of the reinforcement. The process was continued until per specified amount of material counted in composite.



Figure 3.10 Clamped mold for proper curing.

After completing the lamination process, the cover was placed on the mold and tightened by c-clamps that applied uniform pressure during curing. Compressive pressure used to avoid further entrapped air and enhance proper consolidation of composite. In case of combined short and woven banana fiber polyester composite, the short fiber was placed at the middle and woven fiber on the faces depicted in figure 3.11 (c). This simplifies composite processing as well as provides more appearance to composite compared with short fiber polymer composite. In addition to this, weaving is a complex and time consuming task despite its good mechanical properties, easy to process and handling. Thus putting short fiber in the middle reduces time and cost that incurred with the weaving process. Six samples were manufactured with the following composition and laminate layers.



(a)

(b)

(c)

Figure 3.11 CAD model untreated/treated a) short fiber composite b) woven fiber four layers composite c) short fiber mid layer and woven fiber faces composite

Table 3.3 Composition of banana fiber

S. No.	Samples nomenclature	Wt.% of resin	Wt.% of fiber	Contribution of woven fiber (%)	Contribution of short fiber (%)
1	Untreated short banana fiber (UTSB)	60	40	0	100
2	Treated short banana fiber (TSB)	60	40	0	100
3	Untreated woven banana fiber (UTWB)	60	40	100	0
4	Treated woven banana fiber composite (TWB)	60	40	100	0
5	Untreated woven/short/woven banana fiber composite (UTWSWB)	60	40	50	50
6	Treated woven/short/woven banana fiber composite (UTWSWB)	60	40	50	50



Figure 3.12 Banana fiber polyester composite samples.

3.3.6 Characterization of composite

The composite specimen were tested for mechanical, physical and morphological behaviors discussed below.

3.3.6.1 Tensile strength test

The test was performed to determine how much load a composite sample can bear before it fractures. Tensile tests machine directly measure ultimate tensile strength, maximum load and

maximum elongation. The output of test result tensile load verse elongation graph, tensile stress verse strain graph and their respective data were generated by aid of computer interface. The test was performed by using universal testing with capacity of 50 KN in Federal Defense Engineering University College, Bishoftu Ethiopia. The composite specimens were prepared as per ASTM D638-14 with dimension of 165×19×3.5 mm (ASTM D638-14, 2014). During the test, the cross speed of the machine was adjusted to 2 mm/min.

As a first step, the computer connected to the machine needs to be set with parameters such as gauge length and specimen width before the test specimen was loaded. Having prepared the computer for recording the data and providing the necessary output. Tensile tests were then performed on the specimens until they fractured by applying the tensile load. Then the required outputs were obtained. Three specimens were taken from each composite sample and the average tensile strength was reported as properties of corresponding sample.



Figure 3.13 Specimen under tensile test.



Figure 3.14 Tensile test Specimens before and after test.

3.3.6.2 Flexural Strength Test

Flexural strength test was performed to know how composite samples behave under transverse compressive load. The test was performed by using universal testing (UTM) with capacity of 50 KN. The sample placed horizontally over two supports and the load applied at middle. The forces gradually increase until permanent failure of the sample. Flexural test specimen experience stress at different section, tensile stress at the top, compressive at the bottom and shear stress at the middle. The test was held as per ASTM D790 with samples dimension 130mm×13mm×3.5mm (ASTM D790 – 17, 2002). The test was conducted in Mechanical department lab, Adama Science and Technology University, Ethiopia. Three specimens were tested from each samples. During the test, the cross head speed of the machine was adjusted to 2 mm/min and three specimens were tested form each sample.

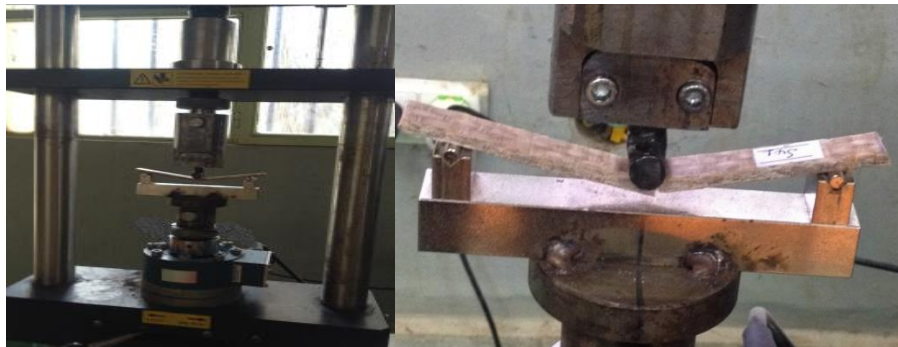


Figure 3.15 Specimen under flexural test.



Figure 3.16 Flexural test specimens before and after test.

3.3.6.3 Impact Strength Test

Generally, a pointer on a calibrated dial attached to the testing machine indicates how much energy has been absorbed in breaking the specimen. This energy is equal to the difference in energy that was in the pendulum hammer at impact and the energy that remains in it after the specimen has been broken. The specimen prepared in such a way it had a rectangular shape with a notch in one side. The notch was act as per specified crack initiator. The test was conducted as per ASTM D6110-10 with specimen dimension $55 \times 12.7 \times 3.5$ mm having notch depth 2.54 mm (Astm-D6110-10, 2010). The test machine had a 294 N weight mounted pendulum, with the hammer impacts speed 3.8 m/s. A specimen should have its notch cut in the opposite direction of the striker. Three specimens were tested from each samples and the average strength was reported as properties of corresponding sample. Impact tests can be used to quantify the amount of energy required to fracture materials. The test was conducted Defense engineering university collage, Bishoftu, Ethiopia.



Figure 3.17 Specimen under impact test.



Figure 3 18 Specimens before and after impact test.

3.3.6.4 Vickers hardness test

Hardness test was conducted to measure composite resistance to localized plastic deformation (indentation). The test involves measuring of indentation dimension lifted on the sample after application of constant loaded indenter for specific time. The hardness of the specimens was measured by Vickers hardness testing machine (HVS-50) with test force of 10kgf and 10 sec of dwelling time. The diagonal length imprinted on surface the specimen was measured by upright optical device. Load during hardness test is 10 kg (99.1N), two measurement was taken for each specimen at different position and the average value was reported.

$$HV = \frac{\text{constant} \times \text{test force}}{\text{surface of indentation}}$$

$$= \frac{0.102 \times 2F(\sin \frac{136^\circ}{2})}{d^2} \dots\dots\dots 3.12$$

Where: - HV - Vickers hardness value, F - Load in kgf

d - Arithmetic mean of the two diagonals $\frac{(d1+d2)}{2}$, d1and d2 in mm.



Figure 3.19 Hardness test samples.

Two indentions were done on two positions and the average value was taken. All the experimental data is illustrated in table below. The experiment was conducted at material science department, ASTU, Ethiopia.

3.3.6.5 Density determination

Density the composite specimen was determined as per ASTM D720-20 standard. The test was conducted by using water as immersion media at room temperature. The specimen weight

measured in air, then it immersed in the water and apparent weight upon immersion was determined.

$$\rho_a = s_g \times \rho_w \dots\dots\dots 3.13$$

Where; ρ_a is actual density, s_g is relative density of specimen, and ρ_w is density of water.

The relative density is the ratio the weight of test specimen in air to the weight of displaced volume of water up on immersion.

$$s_g = \frac{\varphi_a}{\varphi_a - \varphi_w} \dots\dots\dots 3.13$$

Where; φ_a is weight specimen in air and φ_w is the weight specimen in the water.

3.3.6.6 Void content determination

The void in the composite structure was determined as per ASTM D2734 having specimen dimension 25.4x25.4x3.5 mm. It expressed as ratio of division between theoretical and actual density to theoretical density. Void in composite structure hinder mechanical properties composite and reduces product life span.

$$v_r = \frac{\rho_t - \rho_a}{\rho_t} \dots\dots\dots 3.14$$

Where, ρ_a is the actual density, ρ_t is theoretical density and v_r is void fraction.



Figure 3.20 Specimens for void content determination.

3.3.6.7 Water absorption test

Water absorption test was performed how composite behave in wet environment. The test was performed as per ASTM D570 having specimens dimension 76.2×25.4×3.5mm. The test specimens placed in glass beaker containing normal water. The specimens were removed from the water after 24 hours, the surface water wiped off with a dry cloth, and weighed with digital balance having an accuracy 0.0001 g immediately. The test was conducted for eight day duration.

$$\partial_{\%} = \frac{\phi_1 - \phi_2}{\phi_1} \times 100 \dots \dots \dots 3.15$$

Where; $\partial_{\%}$ is percentage of water absorption, ϕ_1 is initial weight of sample before immersed and ϕ_2 is final weight of sample after immersed.



Figure 3.21 Specimens for water absorption test and under test.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

In this chapter numeric and analytic data obtained from experimentation have been discussed. The conducted test in terms of mechanical tests; tensile, flexural, impact, and hardness tests while in terms of physical tests such as density, void fraction, and water absorption test results were presented and discussed. Scanning electron microscopy images were analyzed and their relationship with structure and properties was discussed.

4.2 Tensile test result

The tensile test result of short/woven banana fiber polyester matrix composite was depicted in the table below. For tensile test three specimens were taken from each samples and the average maximum tensile stress was taken as representative strength of the sample.

Table 4.1 Tensile strength result

No	Samples Name	Tensile strength (MPa)				Maximum Force (N)			
		S1	S2	S3	Average	S1	S2	S3	Average
1	UTSB	26.37	26.37	30.1	27.61	1200	1200	1370	1256.67
2	TSB	34.72	37.14	31.86	34.57	1580	1690	1450	1573.33
3	UTWB	49.67	58.46	59.56	55.90	2260	2660	2710	2543.33
4	TWB	65.93	63.5	65.43	64.95	3000	2890	2980	2956.67
5	UTWSWB	40.44	34.07	38.24	37.58	1840	1550	1740	1710.00
6	TWSWB	44.17	38.9	38.68	40.58	2010	1770	1760	1846.67

4.2.1 The effect fiber architecture on tensile strength

The minimum tensile strength 27.61 MPa was obtained with untreated short banana fiber composite (UTSB), this showed 102.46% decline in tensile strength compared with untreated woven fiber composite which bear 59.56 MPa. The average tensile strength of untreated short fiber mid-layer sandwiched by woven fiber faces composite (UTWSWB) was 37.58 MPa, when compared with untreated woven banana fiber composite (UTWB), it showed 48.75% decline in tensile strength while 36.11% increment in strength compared with untreated short fiber composite.

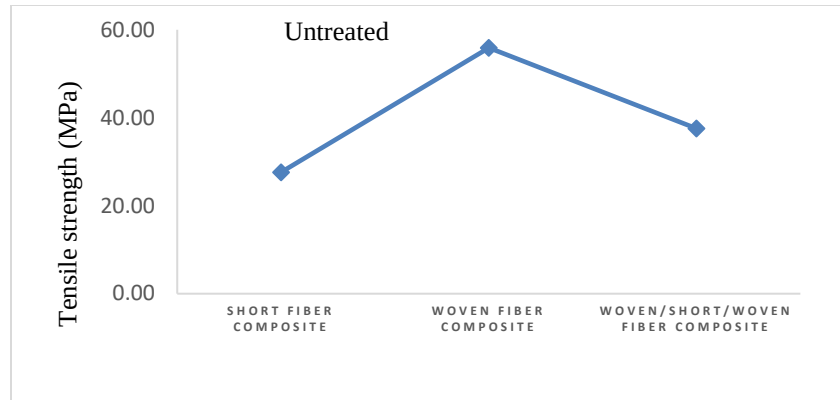


Figure 4.1 The effect of fiber architecture on tensile strength.

The fiber architecture is the significant factor that affects the tensile strength of banana fiber polyester composite. Minimum tensile strength is exhibited with chopped fiber polyester composite. This may happen due to ineffective stress transfer within the composite along the load direction. Relatively, maximum tensile strength perceived by woven fiber composite. This investigation has a good correlation with (Alavudeen et al., 2015), the study showed that randomly oriented banana fiber had lower tensile strength than woven fiber composite having equal fiber loading (40 wt.%). The integrity and interlace of fiber in weave architecture provide structural strength to the fabric (Aisyah et al., 2021). The fabric strength coupled with fiber-matrix adhesion allows uniform transfer stress within the composite structure hence woven fiber composite withstands high tensile load compared with short fiber composite and woven/short/woven fiber composite. In addition to this comfortability of fabric to handle and position during composite processing permits an even distribution of resin and minimalizing void formation. The composite prepared from untreated short fiber middle and woven fiber skin showed improved tensile strength than untreated short fiber composite while lower tensile strength than untreated woven fiber composite.

4.2.2 The effect of alkaline treatment on tensile strength

As seen in figure 4.2 below, composite having same fiber architecture, alkaline treated banana fiber reinforced polyester composite had better tensile strength than untreated one.

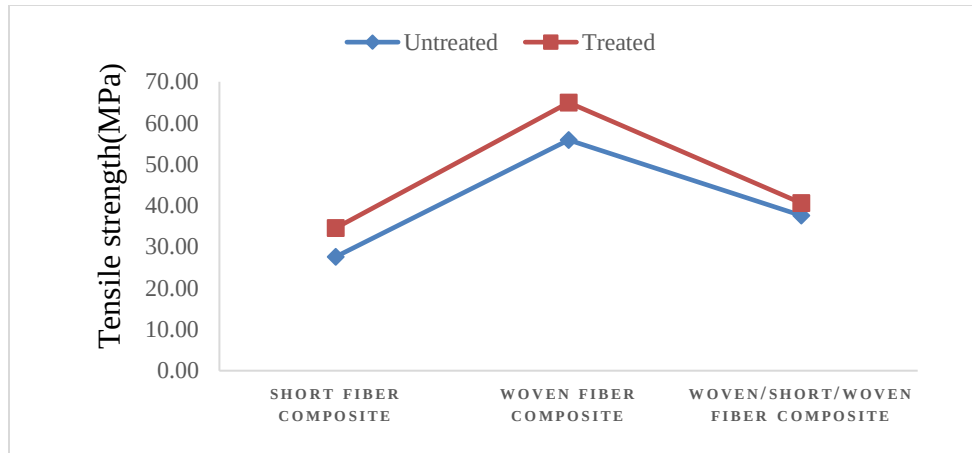


Figure 4.2 The effect of alkaline treatment on tensile strength.

The tensile strength for untreated short banana composite (UTSB) was 27.61MPa while the average tensile strength of treated short fiber composite (TSB) was 34.57MPa. When compared with untreated short fiber composite, treated short fiber composite showed 25.21% increment in tensile strength. The maximum average tensile strength 64.95MPa was obtained with a chemically treated woven banana fiber polyester composite (TWB) while untreated woven banana fiber polyester composite (UTWB) had average tensile strength 55.59MPa. When compared with untreated woven banana fiber polyester composite, treated woven fiber composite showed 16.84% increment in tensile strength. The tensile strength of untreated woven/short/woven fiber composite (UTWSWB) was 37.58 MPa, while the tensile strength of treated woven/short/woven banana fiber polyester composite was 40.58MPa. When compared with UTWSWB, TWSWB composite showed 7.899% increment in tensile strength.

When comparing composites having the same fiber architecture, alkaline treatment brings a major improvement in tensile strength to short fiber composite while minor improvements to woven/short/woven fiber. In general, composite prepared from treated banana fiber improved tensile strength than untreated counterpart. Since NaOH treatment enhances the interfacial bond between the polyester resin and banana fiber by degrading the waxy layers, and amorphous content such as lignin and hemicellulose (Faruk et al., 2012). Alkalization of banana fiber provides rougher fiber that provides anchor points to aid the bond formation with the polymer resin (Zafra Mejía et al., 2012).

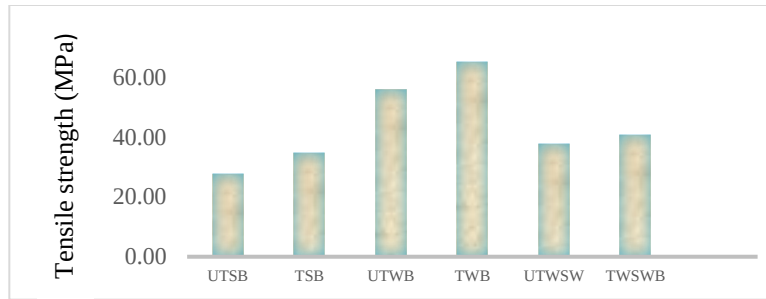


Figure 4.3 Tensile Strength of composite.

Generally, the fiber structure is a significant factor that affects the tensile strength of banana fiber polyester composite. Woven banana fiber composite had higher tensile strength compared with short fiber and short fiber mid-layer sandwiched by woven fiber face composite regardless of the effect of chemical treatment. TWB fiber polyester composite withstands maximum tensile load, this may happen due to the alignment of warp yarns in the direction of external load, interlock of warp and weft yarns in a weave structure may provides structural integrity to woven fiber composite (Othman et al., 2018) and improved fiber-matrix bonding due to chemical treatment (Ibnu & Adityarini, 2019).

4.3 Tensile modulus

The tensile elastic modulus of chemically treated/untreated banana fiber reinforced polyester composite depicted in the table 4.7. the tensile modulus obtained from slope of elastic region of stress versus strain curve.

Table 4.2 Tensile modulus of banana fiber reinforced polyester composite

Samples name	Flexural modulus (Gpa)			
	s1	s2	s3	average
UTSB	1.48	1.49	1.77	1.58
TSB	1.81	1.19	2.03	1.68
UTWB	1.33	1.53	2.08	1.64
TWB	2.26	2.05	2.04	2.12
UTWSWB	1.46	1.49	1.92	1.62
TWSWB	1.89	1.73	1.43	1.68

4.3.1 The effect of fiber architecture on elastic modulus

Figure 4.4 illustrated the effect fiber architecture on tensile modulus of banana fiber polyester composite. The minimum tensile modulus 1.58 GPa was perceived by untreated short fiber

composite. Tensile modulus of untreated woven fiber composite was 1.64GPa, when compared with untreated short fiber composite it possessed 3.79% more tensile modulus. This showed continuity of fiber and weave structure improve tensile modulus of banana fiber polyester composite. Untreated short fiber mid-layer and woven outer faces composite possessed improved tensile modulus than short fiber composite while lesser modulus than woven fiber composite.

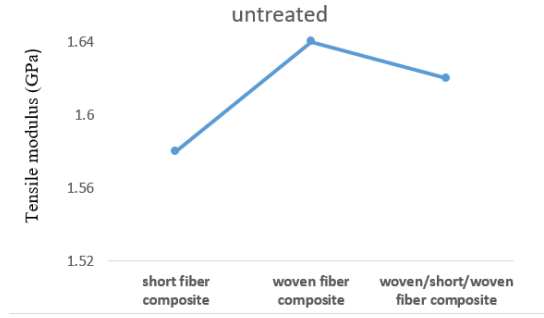


Figure 4.4 The effect fiber architecture of tensile modulus of banana fiber reinforced polyester composite.

4.3.2 The effect of alkaline treatment on tensile modulus

Figure 4.5 illustrated the effect of alkaline treatment on tensile modulus of banana fiber polyester composite. As seen on the figure chemically treated banana fiber composite had better tensile modulus untreated fiber composite irrespective the effect fiber architecture. Chemically treated short fiber composite had 1.68 GPa tensile modulus, when compared with untreated short fiber composite it showed 3.64% improvement in tensile modulus. The tensile modulus of treated woven fiber composite had 2.12 GPa and it exhibited 29.27% enhancement in tensile modulus. Chemically treated short fiber mid layer and woven fiber outer faces perceived 1.68 GPa and it showed 3.7% improvement in tensile modulus compared with untreated counterpart.

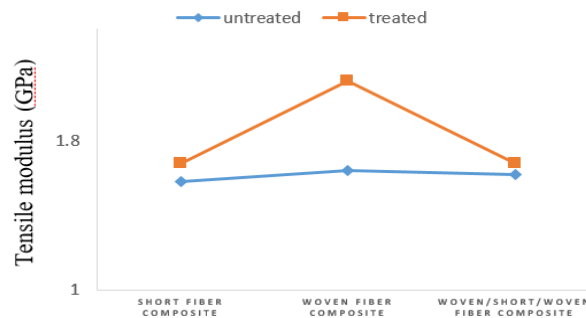


Figure 4.5 the effect alkaline treatment on tensile modulus

Generally, chemically treatment of fiber brings significant improvement on tensile modulus to woven fiber composite and the minor improvement to short fiber mid-layer sandwiched by woven fiber faces.

4.4 Impact test result

Impact test indicate the amount of energy absorbed by material before failure. The impact behavior of composite material is mainly affected by fiber-matrix adhesion, inter-laminar bond and fiber architecture. Three specimens were tested from each samples and the average impact energy was taken as representative energy absorbed by corresponding sample.

Table 4.3 Impact test result

Samples Name	Energy absorbed in J				Impact strength (KJ/m ²)			
	S1	S2	S3	Average	S1	S2	S3	Average
UTSB	0.5	0.6	0.5	0.53	14.06	16.87	14.06	15.00
TSB	0.7	0.6	0.7	0.67	19.69	16.87	19.69	18.75
UTWB	0.7	0.7	0.8	0.73	19.69	19.69	22.50	20.62
TWB	0.9	0.8	0.9	0.87	25.31	22.50	25.31	24.37
UTWSWB	0.7	0.6	0.7	0.67	19.69	16.87	19.69	18.75
TWSWB	0.8	0.7	0.9	0.80	22.50	19.69	25.31	22.50

4.4.1 The effect of fiber architecture on impact strength

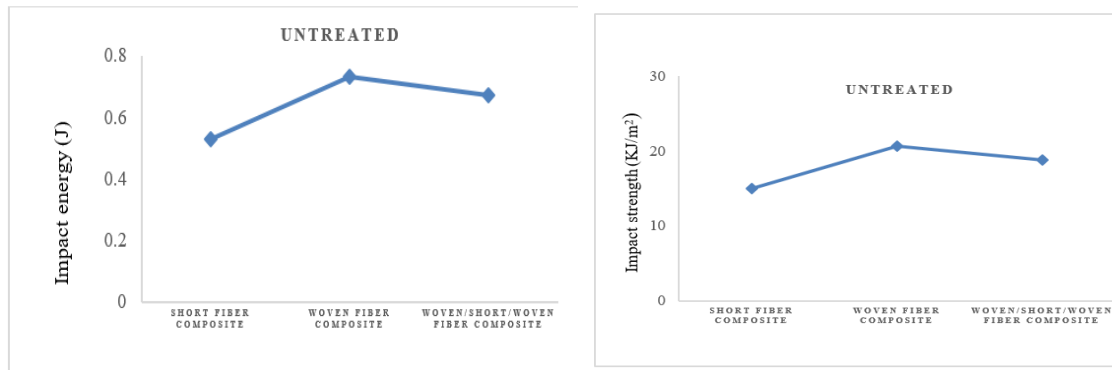


Figure 4.6 The effect of fiber architecture on impact behavior

The minimum impact strength 15.0KJ/m² was perceived by untreated short fiber composite and it absorbed 0.53J energy. The impact strength of untreated woven banana fiber composite (UTWB) was 20.62KJ/m² and it absorbed 0.73J energy. When compared with untreated short banana fiber

composite, untreated woven fiber composite showed 37.73% increment in impact strength and absorbed 32.07% more energy. The impact strength of untreated woven/short/woven banana fiber composite (UTWSWB) was 18.75KJ/m² and it absorbed 0.67J energy. When compared with untreated woven fiber composite, untreated woven/short/woven fiber composite showed 9.97% decline in impact strength and it absorbed 8.95% lesser energy while it showed 25.0% increment in impact strength and absorbed 26.41% more energy compared with untreated short fiber composite.

When we analyze the fiber architecture on impact behavior of banana fiber reinforced polyester composite, minimum impact strength was perceived by short fiber composite. This may happen due to random orientation fiber, there is a low probability of aligned fibers along the specimen longitudinal direction to resist applied impact load in the transverse direction. (Beg & Pickering, 2008) states energy intake capacity of discontinuous fiber polymer composite is impeded because the large number of fiber end act as stress concentration points. Woven fiber composite had improved impact strength than both short and woven/short/woven fiber composite. This may happen due to the integrity and interlace warp and weft filament in the weave structure providing strength to woven fabric. The structural stability of fabric induces additional strength to composite (Hasan et al., 2021). In addition to this, the alignment of warp yarns along the specimen's longitudinal direction increases the number of individual fibers that bear the impact load applied in the transverse direction (Rahman et al., 2018).

4.4.2 The effect alkaline treatment on impact strength

Figure 4.5 indicted the effect of alkaline treatment on impact strength of banana fiber reinforced polyester composite with variable fiber architecture. Alkalized banana fiber composite had improved strength than untreated counterpart having the same fiber architecture.

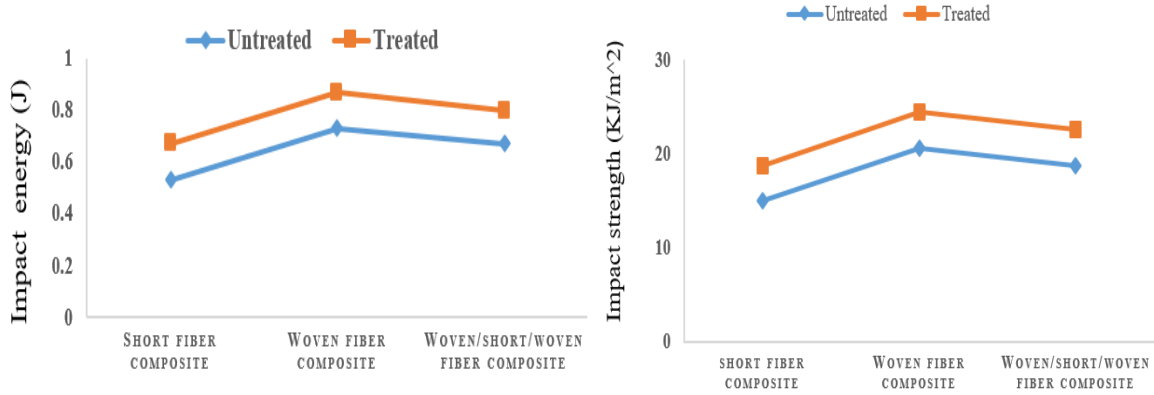


Figure 4.7 The effect of alkaline treatment on impact behavior.

The minimum average impact strength 15 KJ/m² was perceived by untreated short fiber polyester composite (UTSB) and it absorbed 0.53J energy. The average impact strength for treated banana fiber composite (TSB) was 18.75KJ/m² and it absorbed 0.67J. When compared with untreated short fiber composite, 25 % increment in impact strength was obtained by TSB composite. The average impact strength of untreated woven fiber composite (UTWB) was 20.62KJ/m² and it absorbed 0.73J energy. While the average impact strength of treated woven banana fiber composite (TWB) was 24.37KJ/m² and it absorbed 0.87J. When compared with untreated woven fiber composite (UTWB), treated woven fiber composite showed 37.50% increment in impact strength. The average impact strength of untreated woven/short/woven banana fiber polyester composite (UTWSWB) was 18.75KJ/m² and it absorbed 0.67J while the average impact strength of treated woven/short/woven banana fiber composite (TWSWB) was 22.50KJ/m² and it absorbed 0.80J energy. When compared with untreated woven banana fiber composite (UTWSWB), treated woven banana fiber composite showed 20.0% increment in impact strength. Chemically treated short, woven and woven/short/woven banana fiber reinforced polyester composite showed 25.0%, 37.50% and 20% increment in impact strength respectively, compared to untreated counterparts. Paul et al., (2010) point out that fiber pull-out and fiber-matrix debonding were the main energy dissipation mechanism that contributes to the impact strength of short banana fiber polymer composite. In case untreated short banana fiber polyester composite had high fiber pull-out and fiber-matrix debonding, however, it absorbs less amount energy compared with treated short fiber composite behave brittle fracture and less fiber pullout. The reason behind this was good fiber-matrix adhesion hinders crack initiation and propagation before fracture. This implies interfacial

bonding contributes to major energy share rather than energy acquired during fiber matrix-debonding and pullout. Hence, alkaline-treated banana fiber reinforced polyester matrix composite had improved impact strength than untreated counterparts having the same fiber architecture.

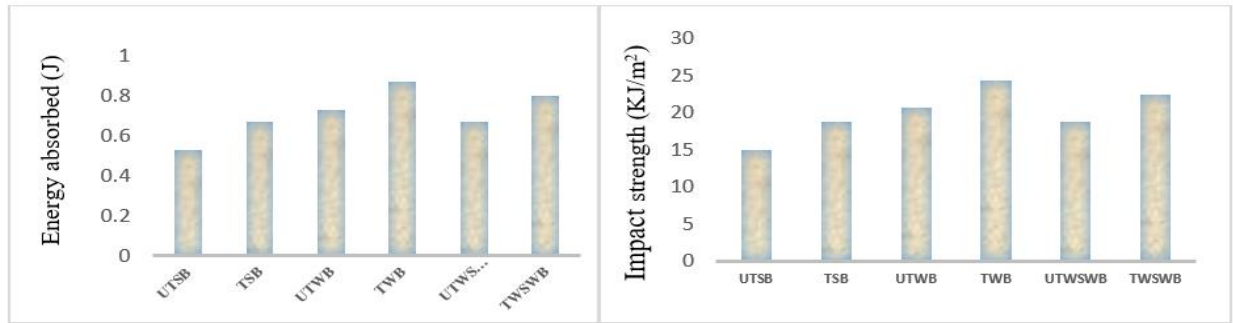


Figure 4.8 Impact properties of composites.

Generally, the impact strength of banana fiber-reinforced polyester composite was affected by fiber architecture and alkaline treatment. The maximum impact strength perceived by treated woven fiber composite. This may happen due to the alkaline treatment of fiber and the integrity of fiber in the weave structure. Composite fabricated from woven face and short fiber mid-layer had higher impact strength than short fiber composite regardless of the effect of chemical treatment. This implies the partial replacement of short fiber by woven fiber improves the impact strength of short banana fiber polymer composite. This in good agreement with (Dress et al., 2021) reported that 0/90° woven sisal fiber treated by 5% NaOH polyester composite absorbs 0.91J having equal fiber load. Little improvement for sisal fiber composite may happen due to the higher crystallinity of sisal fiber compared with banana fiber. Alavudeen et al., (2015) reported plain woven banana fiber treated with 10% NaOH and 40% fiber loading epoxy matrix composites had an impact strength of 18KJ/m², while in case higher impact strength was perceived by TWB polyester composite.

4.5 Flexural test result

The test was performed how composite behave under three point bending load. Three test specimens were taken from each samples and the average flexural strength was taken as representative strength of corresponding samples.

Table 4.4 Flexural test result

No	Samples Name	Flexural strength (MPa)				Maximum load (N)			
		S1	S2	S3	Average	S1	S2	S3	Average
1	UTSB	57.43	52.75	42.2	50.79	55	50	40	48.33
2	TSB	72.79	105.55	105.55	94.63	70	100	100	90.00
3	UTWB	116.05	116.05	116.05	116.05	110	110	110	110.00
4	TWB	126.6	126.6	116.05	123.08	120	120	110	116.67
5	UTWSWB	137.15	137.15	137.15	137.15	130	130	130	130.00
6	TWSWB	168.8	168.8	179.35	172.32	160	170	170	166.67

4.5.1 The effect fiber architecture on flexural strength

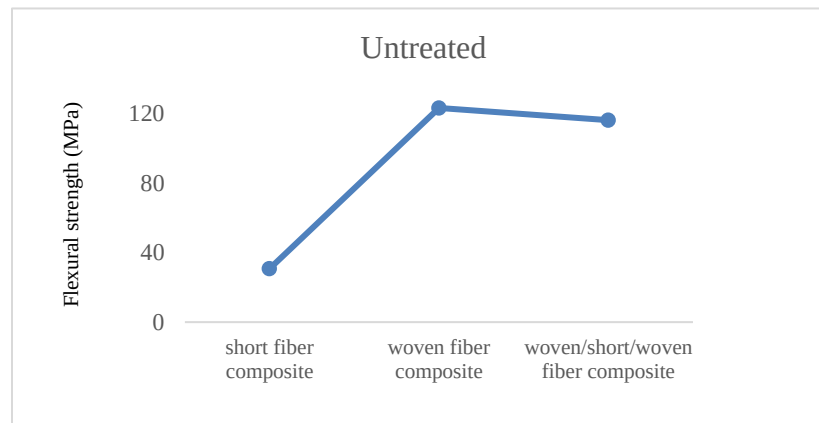


Figure 4.9 The effect of fiber architecture on flexural strength.

Minimum flexural strength 30.7 MPa was perceived by untreated short fiber composite (UTSB), while the flexural strength of untreated woven fiber composite (UTWB) was 123.03 MPa. When compared to untreated short fiber composite, woven fiber showed 300 % increment in flexural strength. This implies flexural strength is significantly affected by fiber structure. In woven fiber, the warp and weft yarns interlock one over the other. Hence, friction developed between the yarn keeps the fabric in a pre-designed structure and the structure integrity induces strength to fabric-based laminated composite (Aisyah et al., 2021). The flexural strength of untreated woven/short/woven fiber composite was 116.03 MPa, it shown 277.9 % increment in flexural strength compared with untreated short fiber composite. This implies introducing short fiber in the mid significantly improves the flexural behavior of banana fiber polyester composite compared with untreated short fiber composite. This may happen due to different load-bearing sections of

samples under bend load. This means tensile at the bottom, shear at the middle and compressive at the top. Literature conformed adding short fiber between the laminate layers improves flexural strength. Wang et al., (2022) infer short fiber toughing is one of the mechanisms that alleviate the delamination effect by adding a short fiber layer between laminar. Zhengcai et al., (2017) introduced short ramie fiber between carbon fiber layers of epoxy composite, and they concluded short fiber improves interlayer strength by obstructing crack propagations and increasing the bending strength of the composite. Jeong & Cheong, (2013) applied the short silk fiber layer between carbon fiber strengthened epoxy composite, the investigation was shown that short fiber toughed composite had improved inter-laminar strength compared with un-toughened composite. Introduction of chopped fiber middle layer form three dimensions interlinked structures that stacks directional crack movement and sliding of laminate layer one over the other.

4.5.2 The effect of alkaline treatment on flexural strength

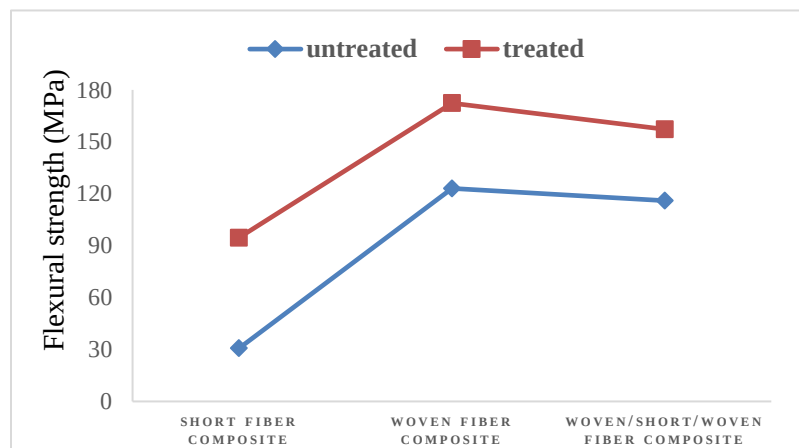


Figure 4.10 The alkaline treatment on flexural strength.

The flexural strength of untreated short banana fiber reinforced polyester composite (UTSB) was 30.7 MPa while the flexural strength of treated banana fiber composite (TSB) was 94.63 MPa. When compared with untreated short fiber composite, alkalized short banana fiber composite showed 208.24% increment in flexural strength. The flexural strength of untreated woven banana fiber composite was 123.08 MPa and the flexural strength of treated woven banana fiber composite (TWB) was 172.32 MPa. Treated woven banana fiber composite revealed 39.42 % improvement in flexural strength compared with untreated woven fiber composite. The flexural strength of untreated woven/short/woven banana fiber reinforced polyester matrix composite (UTWSWB)

was 123.08 MPa, while the flexural strength of treated woven/short/woven banana fiber composite (TWSWB) was 157.15 MPa. Alkalized woven/short/woven banana fiber composite shown 21.67% increment in flexural strength compared with untreated one.

When we analyzed the effect of alkalizations on the flexural strength of banana fiber polyester composite, treated fiber composite had better strength than untreated counterparts having same fiber architecture. Specifically, alkaline treatment significantly improves the flexural strength of short fiber composites, less so for woven fiber composites, and a minor improvement for woven/short/woven fiber composites.

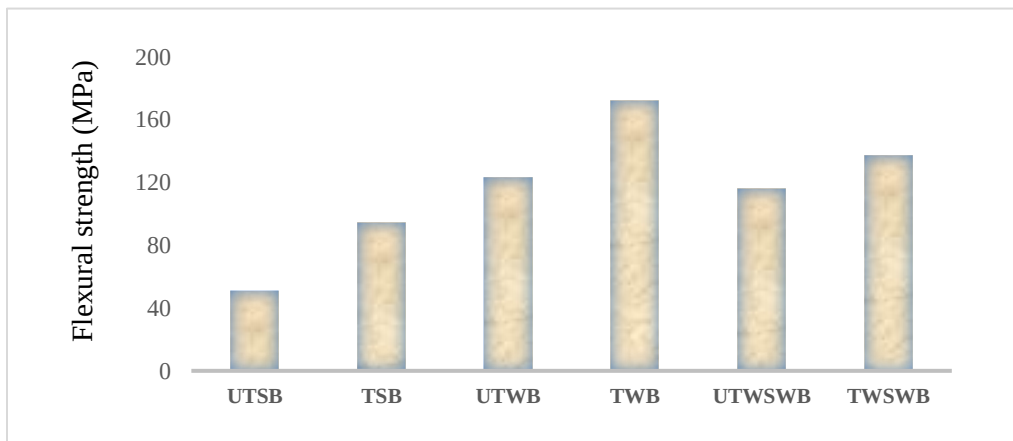


Figure 4.11 Flexural behavior of composite.

In general maximum flexural strength was perceived by treated woven fiber reinforced polyester composite and it showed significant improvement in untreated woven fiber composite. Chemically treated woven/short/woven fiber composite (TWSWB) had improved flexural strength than the rest samples despite treated woven fiber composite. This implies the introduction of short fiber in the mid-section significantly improves flexural strength, especially compared with short fiber composite.

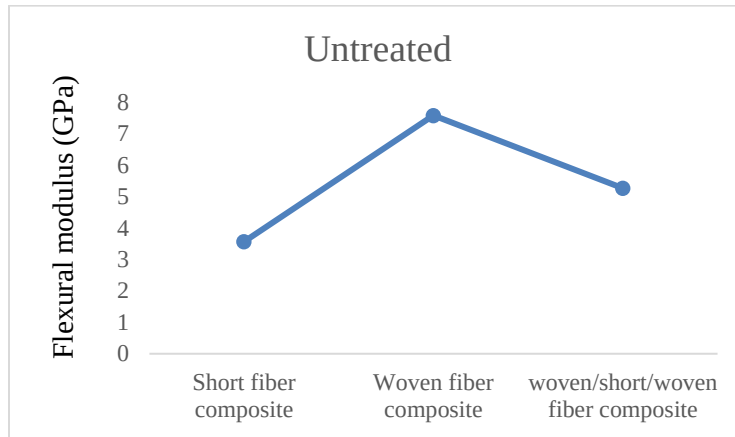
4.6 Flexural modulus

Modulus elasticity of chemically treated/untreated woven/short banana fiber reinforced polyester composite was depicted in table below. It was obtained from slope of stress strain graph in elastic region.

Table 4.5 Flexural modulus of banana fiber polyester composite.

S. name	Flexural Modulus (GPa)			
	s1	s2	s3	Average
UTSB	2.91	3.11	4.65	3.56
TSB	4.47	4.33	5.76	4.98
UTWB	6.12	10.03	6.57	7.57
TWB	12.21	9.74	9.11	10.35
UTWSWB	5.52	5.01	4.60	5.26
TWSWB	11.21	8.47	6.99	8.89

4.6.1 The effect of fiber architecture on flexural modulus



The effect of fiber architecture on flexural strength.

Figure 4.10 illustrates how fiber structure affects the flexural modulus of banana fiber composites. A minimum flexural modulus 3.56 GPa was perceived by the short fiber composite. This may happen due to the random orientation of fiber causing ineffective stress transfer within fiber and matrix. A local maximum flexural modulus 7.57 GPa was obtained by untreated woven fiber composite. Woven banana fiber polyester composite showed improved flexural modulus due straightening of yarn ought to result in stiffening materials and the effect of interlocking warp and fill yarn. Composite prepared from short fiber mid layer and woven fiber outer faces had better flexural modulus than short fiber composite.

4.6.2 The effect of alkaline treatment on flexural modulus

The flexural modulus of chemically treated and untreated banana fiber composite dissected in figure 4.11 below.



Figure 4.12 the effect of alkaline treatment of flexural modulus of banana fiber polyester composite.

As seen in figure 4.11 chemical treatment of fiber enhance the flexural modulus of the composite for all fiber architecture. Chemical-treated short fiber composite perceived 4.89GPa flexural modulus. It showed 37.35% improvement in flexural modulus compared with untreated short fiber composite. The flexural modulus of treated woven fiber composite was 10.33GPa, when compared with untreated woven fiber composite it showed 36.45% improvement in flexural modulus. The flexural modulus of treated woven/short/woven fiber composite was 8.89 GPa, while untreated short/woven/short fiber composite was 5.26 GPa. Hence treated woven/short/woven fiber composite revealed 69.01% improvement in flexural modulus untreated counterpart.

Generally, for composite samples having the same fiber architecture, alkaline treatment of fiber brings significate improvement in flexural modulus to short fiber mid-layer sandwiched by woven fiber faces composite followed by woven fiber composite and the minor to short fiber composite.

4.7 Hardness test result

Nondestructive test show how material resist localized plastic deformation (indentation). Composite material contains reinforcement and base material. So the hardness of composite depends on the properties constituent material and compatibility among them. Uniform dispersion of reinforcement phase through composite structure also affects hardness value reinforced composite.

Table 4.6 Hardness test result

No	Samples name	Hardness value (HV)		
		Indention 1	Indention 2	Average
1	UTSB	32.3	32.7	32.5
2	TSB	38.7	41.1	39.9
3	UTWB	48.9	45.8	47.35
4	TWB	70.5	71	70.75
5	UTWSWB	40.9	42.5	41.7
6	TWSWB	67.6	58	62.8

4.7.1 Effect of fiber architecture on harness value

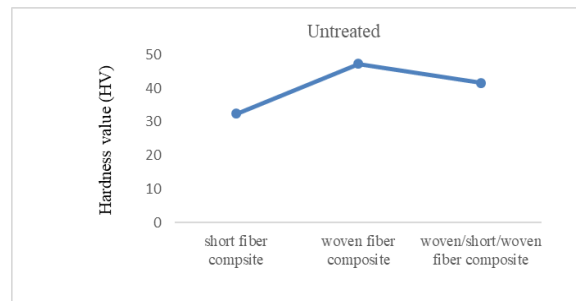


Figure 4.13 The effect of fiber architecture on hardness value

The minimum hardness value of 32.5 HV was perceived by untreated short banana fiber composite. The hardness value of untreated woven banana fiber composite was 47.35 HV. When compared with untreated short fiber composite, treated short fiber composite showed 45.69 % increment in hardness value. This implies hardness value of banana fiber polyester composite was affected by fiber architecture. The hardness value of untreated woven/short/woven fiber composite was 41.7 HV, when compared with untreated short fiber composite, it showed 28.3 % increment in hardness value while 13.54 % decline in hardness value compared to untreated woven fiber composite. This implies the introduction of woven fiber outer faces improves the harness value of short fiber composite.

4.7.2 Effect of alkaline treatment on impact strength

As seen in figure 4.11 alkaline treated banana fiber reinforced polyester composite had improved hardness value compared with untreated counterpart having same fiber architecture.

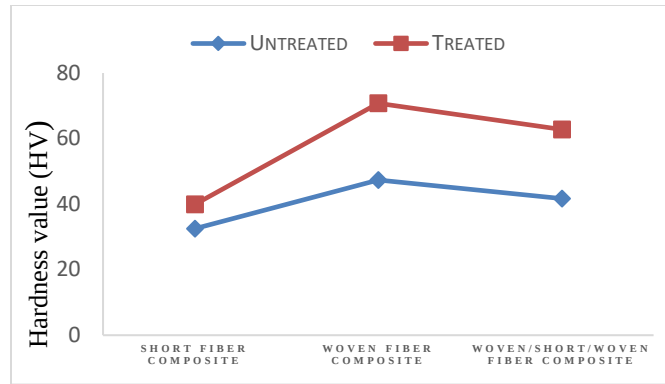


Figure 4.14 The effect of alkaline treatment on hardness value

The hardness value of untreated short banana fiber reinforced polyester composite (UTSB) was 32.5 HV while treated short fiber composite (TSB) perceived 39.9 HV. Alkalized short banana fiber showed 22.77 % increment in hardness value compared with its untreated counterpart. The maximum hardness value of 70.25HV perceived by TWB composite, when compared with untreated woven fiber (UTWB) composite, TWB showed 49.4 % increment in hardness value. The hardness value of untreated woven/short/woven banana fiber composite (UTWSWB) was 41.70HV whereas the hardness value TWSWB composite was 62.8 MPa. TWSWB showed 50.59 % increment in hardness value compared with UTWSWB composite.

Hence, alkalizing banana fiber brings a significant improvement in harness value to woven/short/woven fiber composite followed by woven fiber composite and less improvement to short fiber composite.

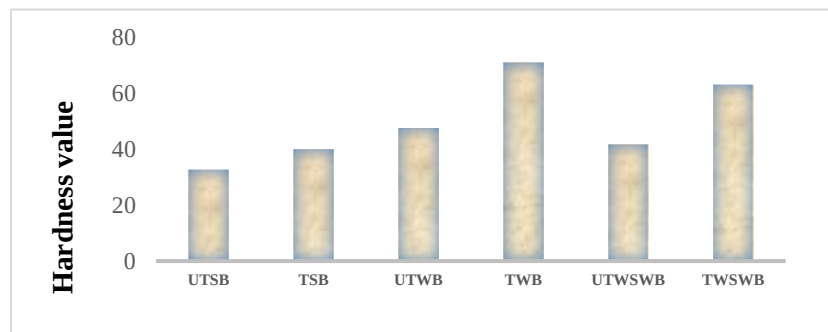


Figure 4.15 Hardness properties of composites.

Generally, treated woven banana fiber composite had maximum hardness value compared with the rest samples, this may happen due to good interfacial adhesion between fiber and matrix coupled with fabric strength enhancing TWB composite had improved ability to resist localized plastic deformation. In woven fiber laminated composite, the fabric architecture allows uniform distribution of fiber thus there was a low probability of agglomeration and void formation. This may also impart strength to woven fiber composite. This work is in good agreement with (Singh et al., 2020), who reported the maximum hardness of 70HV perceived by a jute-coconut fiber hybrid epoxy composite with 85% jute fiber contribution.

4.8 Density and void fraction

Void is inherited behavior of reinforced composite so it is difficult to have composite with void free. However it needs to be in limited range, because slight increases in void fraction significantly affects mechanical behavior of reinforced composite. Two specimens were taken from each sample and their void fraction was calculated by comparing theoretical and measured density composite then the average value was depicted in the table below.

Table 4.7 Density and void content result

Samples Name	Theoretical density	Experimental density			Void fraction		
		S1	S2	Average	S1	S2	Average
UTSB	1.25	1.211	1.212	1.224	3.12	3.04	3.08
TSB	1.25	1.213	1.214	1.226	2.96	2.88	2.92
UTWB	1.25	1.212	1.217	1.226	3.04	2.64	2.84
TWB	1.25	1.215	1.218	1.228	2.8	2.56	2.68
UTWSWB	1.25	1.214	1.214	1.226	2.88	2.88	2.88
TWSWB	1.25	1.216	1.215	1.227	2.72	2.8	2.76

4.8.1 The effect fiber architecture on void content

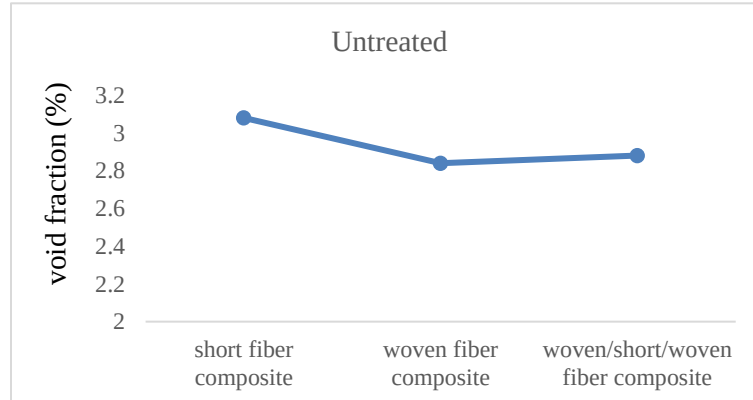


Figure 4.16 The effect of fiber architecture on void fraction.

The maximum void fraction 3.2 % was perceived by untreated short fiber composite. The common problem with short fiber composite is an agglomeration of fiber during composite processing (Monfared, 2020). This may contribute its part to the maximum void content of short fiber composite. The void fraction of untreated woven fiber composite was 2.84 %, when compared with untreated short fiber composite it had a 12.67 % lesser void fraction. In woven fiber composite, the weave architecture allows easy handling and positioning of fiber during composite processing thus void related to the agglomeration of fiber was minimized. The void fraction of untreated woven/short/woven fiber composite was 2.88 %, when compared with untreated short fiber composite it had 11.11 % lesser void fraction and 1.41 % more void fraction than untreated woven fiber composite. This implies the partial replacement of short fiber by woven fabric minimized the void in pure short fiber composite.

4.8.2 The effect alkaline treatment of fiber void content

Untreated short banana fiber polyester composite (UTSB) had a maximum void fraction of 3.08%, this implies it was the most porous compared with the rest samples. Alkaline treated short banana fiber composite (TSB) had 2.92% void fraction, when compared with treated short banana fiber composite showed 5.5% lesser void fraction than untreated short fiber composite. Alkalized woven fiber composite perceived a minimum void fraction compared with the rest samples. While compared with UTSB, it had 5.9% lesser void content. Untreated woven/short/woven fiber composite (UTWSWB) had 2.88% void fraction whereas treated woven/short/woven (TWSWB)

perceived 2.76% void fraction. When compared with untreated woven/short/woven fiber composite, alkaline treated woven/short/woven showed 4.35% lesser void fraction.

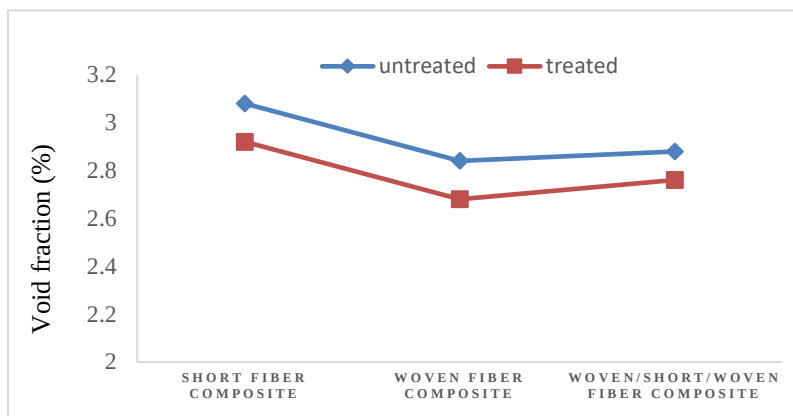


Figure 4.17 The effect of alkaline treatment on void fraction.

Figure 4.14 shows, alkaline treated banana fiber composite had lesser void content than its untreated counterpart. This may happen due to the alkaline treatment of banana fiber changing its hydrophilic nature to hydrophobic thus it become compatible with polymer resin, in addition, the surface of treated natural fiber is rougher and provides more surface area for fiber-matrix linkage.

Thus, alkalization of banana fiber minimized void primarily in woven fiber composites, followed by short fiber composites, and less improvement in woven/short/woven fiber composites.

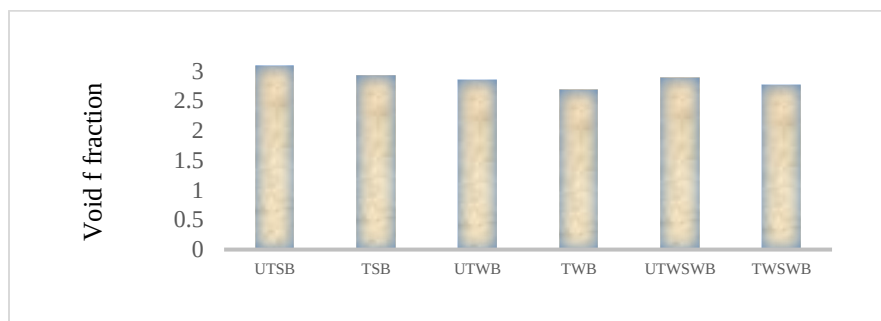


Figure 4.18 Void content of composite.

Generally, the amount of void in composite structure was affected by fiber architecture and chemical treatment of fiber. Treated woven fiber composite (TWB) had a minimum void fraction compared with the rest specimens. In woven fiber composite, the void-related agglomeration of fiber is minimized. In addition to this alkaline treatment of fiber enhance the bond between fiber

and matrix, which make the treated woven banana fiber composite very sound and denser than the rest samples. Composite prepared from woven fiber face and chopped fiber middle layer had lower void fraction than chopped fiber composite whereas higher void fraction than woven fiber composite counterpart. The mechanical behaviors of composites decreased with increasing void fraction thus, voids may act as crack initiation points and cause early failure of the composite.

4.9 Water absorption test result

The water molecules absorbed by natural fiber composite affect the structure of fiber and fiber-matrix interface thus, it impede composite strength. Two specimens were taken from each sample and the average value of moisture gain was taken and depicted in the table below.

Table 4.8 Dry mass of water absorption test specimens

Sample name	UTSB	TSB	UTWB	TWB	UTWSWB	TWSWB
Dry mass of s1 (g)	10.858	10.829	9.8243	10.245	10.000	9.149
Dry mass of s2 (g)	11.874	10.503	10.000	10.872	10.001	9.156

Table 4.9 Percentage of water gain

Sample s Name	Time									
		0	24	48	72	96	120	146	172	196
UTSB	%w S1	0	2.402	3.533	4.102	4.602	5.513	5.941	6.398	6.399
	%w S2	0	2.411	3.541	4.126	4.601	5.514	6.053	6.412	6.412
	aver	0	2.406	3.537	4.114	4.601	5.513	5.997	6.405	6.405
TSB	%w S1	0	2.021	2.251	3.931	4.314	4.901	5.523	6.131	6.131
	%w S2	0	2.056	3.261	3.942	4.231	5.101	5.53	6.132	6.132
	aver	0	2.0385	2.756	3.936	4.272	5.001	5.526	6.131	6.131
UTWB	%w S1	0	3.257	4.631	4.723	5.011	5.544	5.681	5.681	5.681

	S2	0	3.458	4.632	4.741	5.021	5.546	5.682	5.682	5.682
	aver	0	3.358	4.632	4.732	5.016	5.545	5.682	5.682	5.682
TWB	%w S1	0	3.082	4.131	4.363	4.751	5.301	5.453	5.453	5.453
	%w S2	0	3.091	4.132	4.362	4.743	5.302	5.452	5.452	5.452
	aver	0	3.086	4.131	4.362	4.747	5.301	5.452	5.452	5.452
UTWS W	%w S1	0	3.373	4.316	4.557	4.941	5.422	5.521	5.902	5.902
	%w S2	0	3.372	4.315	4.558	4.934	5.421	5.524	5.901	5.901
	aver	0	3.372	4.315	4.557	4.937	5.421	5.522	5.901	5.901
TWSW	%w S1	0	2.812	3.831	4.031	4.413	5.104	5.471	5.691	5.691
	%w S2	0	2.811	3.821	4.027	4.426	5.205	5.482	5.691	5.691
	aver	0	2.811	3.826	4.029	4.419	5.154	5.476	5.691	5.691

Less amount of water was absorbed by NaOH treated fiber composite compared with counterparts having the same fiber architectures. This happened due to good interfacial bond between fiber and resins. Alkalizing banana fiber reduces amorphous content which was more suspected to moistures. Due to the presence of more –OH ions in untreated fibers, they had a high affinity for water molecules and therefore were incompatible with hydrophobic polyester resins. Poor compatibility with resin result with weak interfacial bond hence water molecules easily moved through composite structure along the fiber (Gupta & Tiwari, 2020; Kalia et al., 2011).

Diffusion of water molecules by banana fiber polyester composite was also affected by fiber architecture. Initially, woven fibers composite absorbed more water than chopped fiber composites, but they reached saturation state quickly. Short banana fiber polyester composite absorb more water at equilibrium irrespective of the effect chemical treatment. In short fiber composite difficult of fiber for handling and distribution during composite processing may cause increased void formation compared with woven fiber composite. In addition to this a large number

fiber end in chopped fiber polyester composite may contribute for increased water holding at saturation point.

TWB composite absorbed minimum amount of water at saturation state compared with the rest specimen while maximum amount of water was absorbed by UTSB composite.

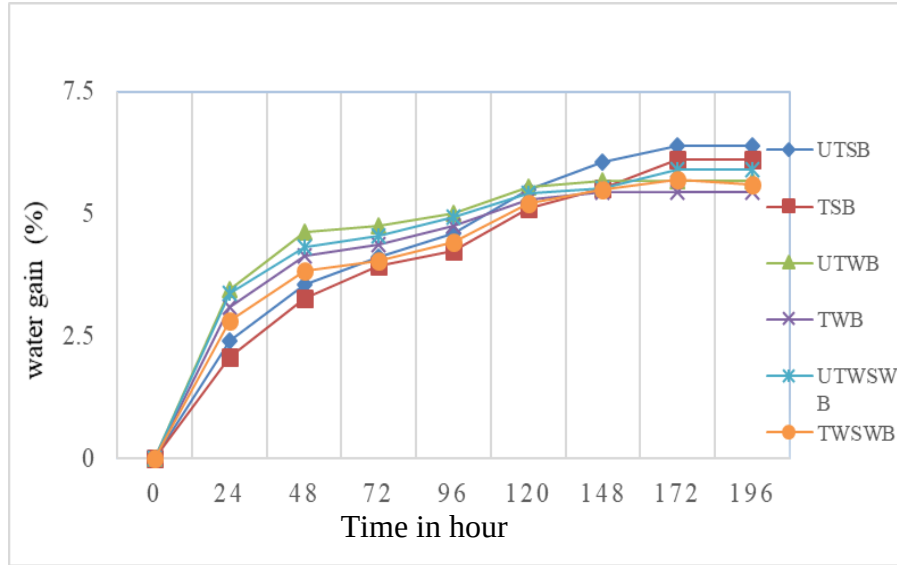


Figure 4.19 Plot of water gain verses time curve.

4.9.1 Kinetic of water absorption

The diffusion behavior by composite material can be analyzed mathematically from shape of absorption curve (Akintayo et al., 2017).

$$\frac{M_t}{M_s} = kt^n \dots\dots\dots 4.1$$

Where; M_t is water gain at any time t , M_s is water gain at saturation point, k is the slope of $\frac{M_t}{M_s}$ verse $\sqrt{t}$ curve, n is constant. The value of coefficient n shows diffusion behavior exhibited by material. Three cases diffusion mechanism; Fickian diffusion corresponding to $n = 1/2$, Case II $n = 1$ and for Non-Fickian diffusion n in-between ($0.5 < n < 1$). The value of k gives information about the interaction between penetrant and material. In order to get the value of kinetic parameter k and n from experimental data the above equation rearranged as follows.

$$\log\left(\frac{M_t}{M_s}\right) = \log k + n \log(t) \dots\dots\dots 4.2$$

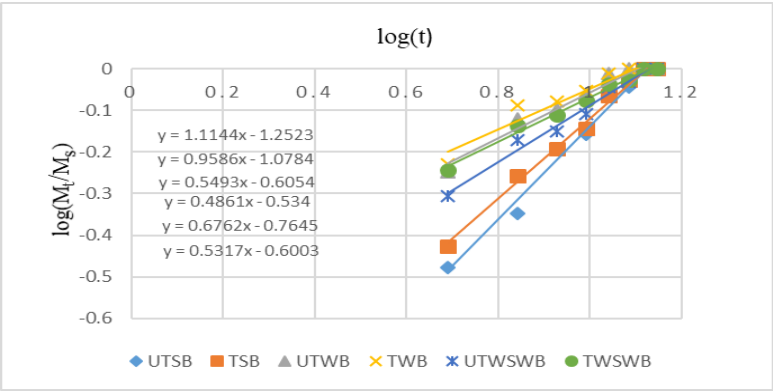


Figure 4.20 Figure linear fitted absorption curve.

The value n and k obtained from curve fitting of water absorbed by banana fiber polyester composite depicted in the table 4.7.

Table 4.10 kinetic parameter banana fiber polyester composite.

Sample name	UTSB	TSB	UTWB	TWB	UTWSWB	TWSWB
Slope (n)	1.105	0.959	0.549	0.486	0.676	0.532
Intercept (k)	1.246	1.078	0.605	0.534	0.764	0.600

The diffusion exponent n for UTWB, TWB and TWSWB composite close to 0.5 thus they behaved Fickian diffusion mechanism. The n value for UTWSWB in between 0.5 and 1, It behave non-Fickian mechanism while for UTSB and TSB n approach to 1 they are in case-II diffusion mechanism. The value k lower for NaOH treated banana fiber composite compared with untreated composite having the same fiber architecture. This implies untreated banana fiber composite had good interaction with water molecules compared with treated composite counterpart. Generally the value k lower for woven fiber composite and short fiber mid layer sandwiched by woven fiber face, this implies short banana fiber composite good interaction with water molecules compared with woven fiber composite and short fiber mid layer sandwiched by woven fiber outer face.

Diffusion coefficient (D) is an important factor that tells us the amount of water molecules can pass unit area per unit time. It obtained from initial slope of $\frac{M_t}{M_s}$ verse square root of time curve.

$$\frac{M_t}{M_s} = \frac{4}{h} \left(\sqrt{\frac{D \cdot t}{\pi}} \right) \dots\dots\dots 4.3$$

Where h is the thickness of specimen. From experimental data $\frac{M_t}{M_s}$ was calculated and corresponding graph was sketched below.

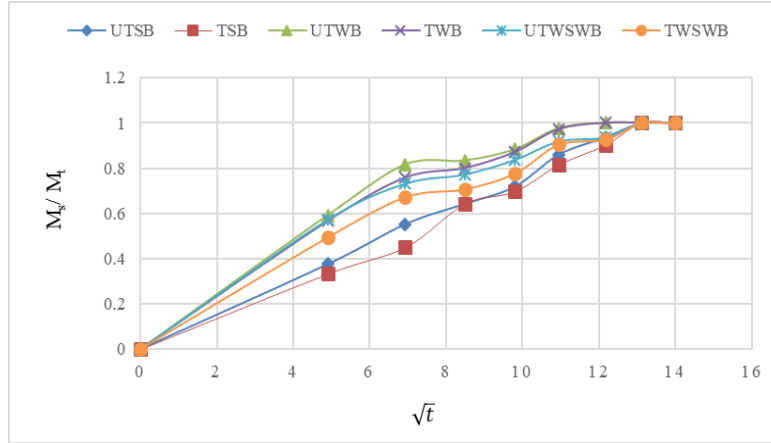


Figure 4.21 Plot of M_t/M_s verse square root time curve

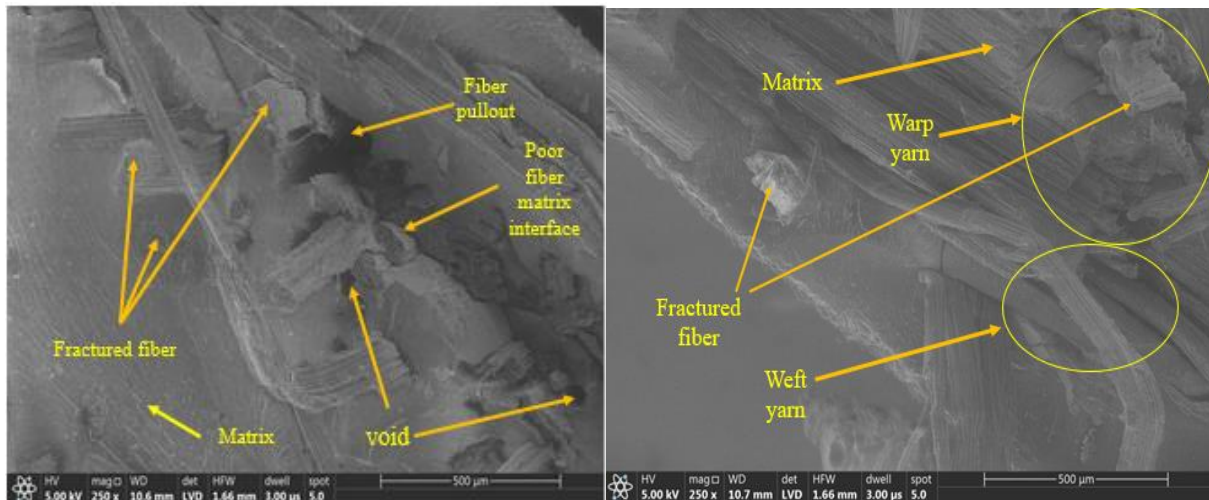
The value D calculated from initial slope of $\frac{M_t}{M_s}$ and displayed on the table 3.8. it is in good agreement reported by other author (Panthapulakkal & Sain, 2007) where the value D for natural fiber composite within range of 10^{-8} to $10^{-9} \text{cm}^2/\text{s}$. Untreated banana fiber composite had higher diffusion coefficient compared with chemical treated fiber composites having the same fiber architecture. This implies lesser amounts water molecules can pass unit area per unit time for treated fiber composite. Treated fiber composites had good interfacial bond with matrix and less amount –OH ions this may reduce affinity to moisture. Woven fiber composite had higher value diffusion coefficient compared with short fiber, this implies large amount water molecules can penetrated in to woven fiber composite structure initially (Tang et al., 2005). Maximum diffusion coefficient exhibited by UTWB fiber composite, this may happen due the structure and hydrophilic properties of untreated fiber. The diffusion coefficient of short fiber mid layer sandwiched by woven banana fiber outer face comparable with woven composite, this may imply diffusion of water molecules in composite mainly influenced by outer face.

Table 4.11 Diffusion coefficient of banana fiber polyester composite.

Samples Name	UTSB	TSB	UTWB	TWB	UTWSWB	TWSWB
Diffusion Coefficient ($\text{cm}^2 \text{s}^{-1}$)	3.95×10^{-8}	3.16×10^{-8}	9.72×10^{-8}	8.94×10^{-8}	9.09×10^{-8}	7.01×10^{-8}

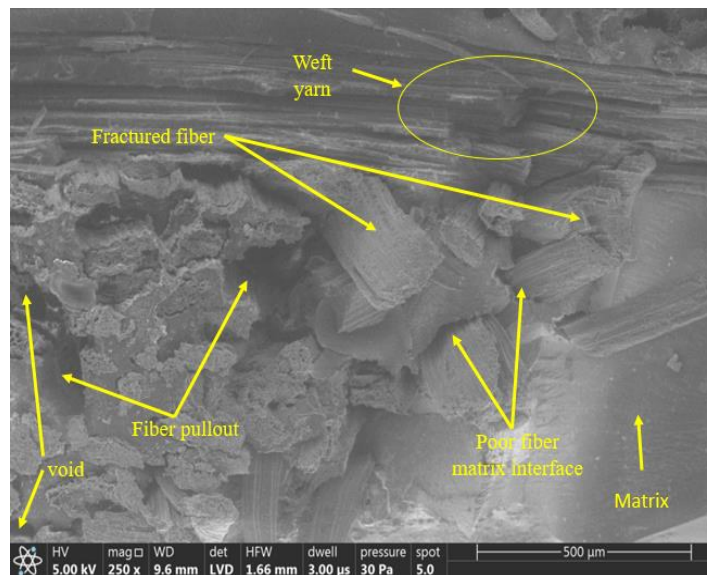
4.10 Scanning electron micrographs analysis

Scanning electron micrographs of tensile-tested specimens for different banana fiber-reinforced polyester composites are presented in figure 4.10. Figure 4.10 (a) shows the chopped banana fiber composites wherein the chopped banana fibers can be clearly seen in the micrographs. These chopped fibers provide adequate strength to the matrix during loading due to their random orientation. There was seen in the macrograph, the fiber was evenly distributed and had good fiber matrix addition however fiber pullout and voids were seen at the same. Figure 4.10 (b) depicted the woven banana fiber composites wherein the woven fiber above the matrix can be clearly seen. Woven banana fibers unlike chopped fibers provide strength due to their weaving pattern that provides more resistance to loading mainly attributed to the good bonding between constituents and good inter-fiber strengths. There was seen in the macrograph, a good bond between fiber and matrix and less fiber pullout. Figure 4.10 (c) shows the composites prepared by utilizing short and woven fibers. It can be clearly observed that the short fibers and woven fibers are properly mixed with the matrix. The combined effect of short and woven fibers is very advantageous and provides better mechanical strength than pure short fiber composite.



(a)

(b)



(c)

Figure 4.22 Scanning electron micrographs of tensile tested (a) TSB (b) TWB and (c) TWSWB.

4.11 Comparison with pervious study

Table 4.12 Comparison with existing work.

s. N	Authors	Reinforce ment	Matri x	Fabrication method/composition	Finding
1	Arun et al., (2016)	Short Banana and coir fiber	Epoxy	Hand layup 40/0, 15/25, 20/20, 25/15 and 0/40 wt.% banana/coir fiber and 60wt% epoxy resin	Maximum tensile strength 14.705MPa perceived by 0/40 wt.% banana/coir fiber composite Maximum flexural strength 34.11 MPa obtained with 40/0 wt. banana/coir fiber composite.
2	Gairola et al., (2020)	Non-woven Banana fiber	Epoxy	Hand layup The sample prepared with 10, 20, 30, 40, and 50 wt.% banana fiber	Maximum flexural and tensile strength 65.6 MPa and 38.1 MPa, respectively were obtained with 30wt. banana fiber composite. Maximum impact and hardens value 2.8 Joules and 45.6 HV respectively was perceived by 40 wt. % banana fiber composite.
3	Kenned et al., (2020)	Needle punched and non-woven banana fiber	Polye ster	Hand layup The samples prepared with 0, 10, 20, 30, 40 and 50 wt.% needle punched and random fiber banana fiber	Maximum tensile and flexural strength obtained with needle punched banana fiber with 40 wt. % fiber loading while Random oriented banana fiber with 30 wt.% fiber loading possess maximum harness value.
4	Pothan et al., (2012)	Short banana fiber	Polye ster	Hand layup Samples prepared with 10, 20, 30 and 40 mm fiber length and 10, 20, 30 and 40 wt.% fiber loading.	Maximum tensile and flexural strengths strength 57 MPa and 58 MPa were obtained with sample 40wt.% fiber loading 30 mm length respectively while maximum impact strength 37 KJ/m ² perceived by sample having 40 wt.% fiber loading and 40mm length.

6	Alavud een et al., (2015)	NaOH treated/unt reated random and woven banana/ke naf fiber	Polye ster	Hand layup Samples prepared from plain/twill woven, random oriented banana, kanaf fiber their hybrid with 40:60 fiber to matrix ratio.	Plain woven fiber structure provide better mechanical strength than both twill woven and random oriented fiber composite. Hybridization Improve tensile, flexural and impact strength of composite.
7	Ratim et al., (2012)	Plain, twill and random oriented mat kenaf.	Polye ster	Hand layup Composite prepared with fixed fiber volume ratio 30 vol. %.	Twill woven kenaf fiber reinforced composite provide better flexural strength than both plain woven and random oriented mat composite.
8	Haghig hatnia et al., (2017	Short hemp fiber	Polyu rethane	Hand layup Composite prepared with 10, 20, 30 and 40 fraction and 6, 15 and 40 mm fiber.	Maximum tensile and flexural strength 27.23 MPa and 22.14 MPa respectively was obtained by alkaline treated hemp fiber composite having 40 vol% fiber load and 15mm length.
9	(Porras et al., 2016)	Manicaria Saccifera palm fiber	Poly- lactic acid	Compression mold Fixed fiber-matrix ratio 40:60 and net PLA	Maximum tensile, flexural and impact strength 54.36 MPa, 113.55 MPa and 17.04 KJ/m ² respectively were perceived by Manicaria Saccifera palm fiber poly- lactic acid composite.
10	Present work	Alkaline treated/unt reated woven/short banana fiber	Polye ster	Hand layup Samples fabricated with fixed fiber matrix weight ratio 40:60.	Maximum tensile, flexural, impact strength and hardness value 64.95 MPa, 172.52MPa, 24.37 KJ/m ² and 70.25 HV respectively were obtained with by chemical treated woven banana fiber composite.

The current work was compared with the recent reports done on natural fiber polymer matrix composite. Comparatively, this work had improved flexural and tensile strength than composite prepared with the same procedure and base material. This may happen due to well-designed fiber preparation steps and strong fabric structure. Following the hand layup technique, static pressure was applied during composite preparation to minimize voids. This may make composite samples sounder and allow them to resist more load.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

In this research work mechanical, physical and morphological properties of woven/short banana fiber polyester composite have been successfully investigated. The fiber was extracted from banana pseudo-stem, one of abundant agricultural biomass and less utilized in our country status. This work is also an endeavor and figure print that adds scientific knowledge in the use of eco-friendly and sustainable green fiber which is a potential candidate to substitute synthetic fiber.

The composite was manufactured by hand lay-up method, with fixed fiber to matrix 60:40 weight ratio. The fiber architecture and chemical treatment were taken as process parameter and the following conclusion were made:

- ✓ Woven banana fiber polyester composites had improved mechanical strength compared with short banana fiber composite regardless of the effect of chemical treatment.
- ✓ Composite made by mercerized banana fiber had enhanced mechanical properties, less sensitive to moisture, and minimum void fraction compared with untreated counterparts.
- ✓ Maximum tensile, flexural, impact strength and hardness value 64.95MPa, 172.32MPa, 24.37KJ/m² and 70.75HV respectively, were perceived by chemical treated woven banana polyester composite.
- ✓ Tensile strength significantly affected by alignment of fiber in external load direction.
- ✓ Water absorption behavior of composite specimens were affected by fiber architecture, and chemical treatment of fiber. Alkalized fiber composite absorbed less amount water at equilibrium state compared with counterpart having the same fiber structure. Woven fiber composite absorbed more water initial and quickly reached the equilibrium state.
- ✓ The diffusion mechanism of water molecules in to composite structure was analyzed that treated and untreated woven banana fiber and treated short banana fiber mid layer sandwiched by woven fiber face behave Fickian diffusion mechanism while untreated short fiber mid layer sandwiched by woven fiber faces behave non-Fickian mechanism. Both

chemically treated and untreated short banana fiber composite were in case-II diffusion mechanism.

- ✓ Treated woven banana fiber composite had minimum void fraction hence improved mechanical properties whereas untreated short banana fiber composite experience maximum void fraction and it had inferior mechanical properties.

In general, chemically treated banana fiber composite had showed significant improvements and better results in terms of mechanical properties (tensile strength, flexural strength and hardness value), less suspected moisture and minimum void fraction compared with chemically untreated banana fiber composite. In terms of fiber architecture, woven banana fiber has improved mechanical property and less suspected to moisture compared with chopped fiber composite counterpart. Finally, composite prepared from chopped fiber mid layer and sandwiched by woven faces showed improved mechanical strength than short fiber composite counterparts. Based on result obtained, chemically treated woven fiber composite had enhanced mechanical property compared with the rest samples.

5.2 Recommendation

Banana fiber polyester composite was manufactured and tested for its physical and mechanical properties. Based on experimental result, limitation of the study and challenge faced during entire research work the following task has to be performed in future.

- ✓ Banana fiber has to be extracted by an aid machine.
- ✓ Manual weaving of fabric is difficult and time consuming task thus it is better has to be performed by aid machine.
- ✓ Rather than hand layup method other techniques has to be used to prepare samples in order to get better surface finish and minimum void content.
- ✓ Metal or ceramics particulates have to be introduced to enhance mechanical properties.
- ✓ Tribiological, dynamic mechanical and inter-laminar shear strength can be investigated.
- ✓ Further experimental variable can be added in exiting parameter and taguchi optimization method applied to get optimum process parameter.

References

- Abdellaoui, H., Bensalah, H., Echaabi, J., Bouhfid, R., & Qaiss, A. (2015). Fabrication, characterization and modelling of laminated composites based on woven jute fibres reinforced epoxy resin. *Materials and Design*, 68, 104–113. <https://doi.org/10.1016/j.matdes.2014.11.059>
- Aisyah, H. A., Paridah, M. T., Sapuan, S. M., Ilyas, R. A., Khalina, A., Nurazzi, N. M., Lee, S. H., & Lee, C. H. (2021). A comprehensive review on advanced sustainable woven natural fibre polymer composites. *Polymers*, 13(3), 1–45. <https://doi.org/10.3390/polym13030471>
- Akintayo, O. S., Adewole, T. A., & Talabi, H. K. (2017). *Mechanical Properties and Water Absorption Behaviour of Polyester/Soil-Retted Banana Fibre (Srbf) Composites*.
- Alavudeen, A., Rajini, N., Karthikeyan, S., Thiruchitrambalam, M., & Venkateshwareen, N. (2015). Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation. *Materials and Design*, 66(PA), 246–257. <https://doi.org/10.1016/j.matdes.2014.10.067>
- Ambisa, Z. (2019). Review on the Production and Marketing of Banana in Ethiopia. *World Journal of Agriculture and Soil Science*, 2(1), 1–9. <https://doi.org/10.33552/wjass.2019.02.000529>
- Aravindh, M., Sathish, S., Ranga Raj, R., Karthick, A., Mohanavel, V., Patil, P. P., Muhibbullah, M., & Osman, S. M. (2022). A Review on the Effect of Various Chemical Treatments on the Mechanical Properties of Renewable Fiber-Reinforced Composites. *Advances in Materials Science and Engineering*, 2022. <https://doi.org/10.1155/2022/2009691>
- Arun, A. S., Sathyaseelan, R., Tamilselvan, M., Gowtham, M., & Karthikeyan, A. (2016). *Influence of Weight Fractions on Mechanical , Water Absorption and Corrosion Resistance Behaviors of Untreated Hybrid (Coir / Banana) Fiber Reinforced Epoxy Composites*. 9(05), 932–940.
- Astm-D6110-10. (2010). Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics. *Astm*, April, 17. <https://doi.org/10.1520/D6110-10.1>
- ASTM D638-14. (2014). Método de prueba estándar para las propiedades de tracción de los plásticos. In *Astm D638-14*. [https://repositorio.uisek.edu.ec/bitstream/123456789/2628/1/ASTM D638-14.pdf](https://repositorio.uisek.edu.ec/bitstream/123456789/2628/1/ASTM%20D638-14.pdf)
- ASTM D790 – 17. (2002). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. D790. *Annual Book of ASTM*

- Standards*, i, 1–12. <https://doi.org/10.1520/D0790-17.2>
- Badyankal, P. V., Manjunatha, T. S., Vaggar, G. B., & Praveen, K. C. (2019). Compression and water absorption behaviour of banana and sisal hybrid fiber polymer composites. *Materials Today: Proceedings*, 35(June), 383–386. <https://doi.org/10.1016/j.matpr.2020.02.695>
- Bao, L. R., & Yee, A. F. (2002). Moisture diffusion and hygrothermal aging in bismaleimide matrix carbon fiber composites: Part II-woven and hybrid composites. *Composites Science and Technology*, 62(16), 2111–2119. [https://doi.org/10.1016/S0266-3538\(02\)00162-8](https://doi.org/10.1016/S0266-3538(02)00162-8)
- Beg, M. D. H., & Pickering, K. L. (2008). Mechanical performance of Kraft fibre reinforced polypropylene composites: Influence of fibre length, fibre beating and hygrothermal ageing. *Composites Part A: Applied Science and Manufacturing*, 39(11), 1748–1755. <https://doi.org/10.1016/j.compositesa.2008.08.003>
- Bhatnagar, R., Gupta, G., & Yadav, S. (2015). A Review on Composition and Properties of Bagasse Fibers. *International Journal of Scientific & Engineering Research*, 6(5), 49–52. <http://www.ijser.org>
- Bismarck, A., Mishra, S., & Lampke, T. (2005). Plant fibers as reinforcement for green composites. In *Natural fibers, biopolymers, and biocomposites* (pp. 52–128). CRC Press.
- Boopathi, L., Sampath, P. S., & Mysamy, K. (2012). Investigation of physical, chemical and mechanical properties of raw and alkali treated Borassus fruit fiber. *Composites Part B: Engineering*, 43(8), 3044–3052.
- Building Plastic. (2011). *Building Materials in Civil Engineering*, 289–423. <https://doi.org/10.1533/9781845699567.289>
- Chandgude, S., & Salunkhe, S. (2021). In state of art: Mechanical behavior of natural fiber-based hybrid polymeric composites for application of automobile components. *Polymer Composites*, 42(6), 2678–2703. <https://doi.org/10.1002/pc.26045>
- Chandramohan, D., & Bharanichandar, J. (2014). Natural fiber reinforced polymer composites for automobile accessories. *American Journal of Environmental Sciences*, 9(6), 494–504. <https://doi.org/10.3844/ajessp.2013.494.504>
- Characteristics, A. (1997). *Journal of Reinforced Plastics and Composites*. <https://doi.org/10.1177/073168449701600806>
- Chawla, K. K. (2013). *Ceramic matrix composites*. Springer Science & Business Media.
- Chitosan, C., Keratin, C., Moisture, P., Industrial, A., Biomaterial, N., & External, R. (n.d.).

Natural fiber Animal fibers.

Composite material. (2003a). In *Medical Textiles* (Issue JANUARY, p. 9).

Composite material. (2003b). *Medical Textiles*, JANUARY, 9.

Crosky, A., Soatthiyanon, N., Ruys, D., Meatherall, S., & Potter, S. (2013). Thermoset matrix natural fibre-reinforced composites. In *Natural Fibre Composites: Materials, Processes and Applications*. Woodhead Publishing Limited. <https://doi.org/10.1533/9780857099228.2.233>

CSA. (2018). Agricultural sample survey. Report on area and production of crops of 2018/2019. Statistical bulletin 1:592. Addis Ababa, Ethiopia. *October, I*(October), 125.

da Cunha, J. D. S. C., Nascimento, L. F. C., da Luz, F. S., Monteiro, S. N., Lemos, M. F., da Silva, C. G., & Simonassi, N. T. (2021). Physical and mechanical characterization of titica vine (*Heteropsis flexuosa*) incorporated epoxy matrix composites. *Polymers*, 13(23). <https://doi.org/10.3390/polym13234079>

Davoodi, M. M., Sapuan, S. M., Aidy, A., Abu Osman, N. A., Oshkour, A. A., & Wan Abas, W. A. B. (2012). Development process of new bumper beam for passenger car: A review. *Materials and Design*, 40(December), 304–313. <https://doi.org/10.1016/j.matdes.2012.03.060>

Decorative Plastics. (2011). *Building Decorative Materials*, 228–262. <https://doi.org/10.1533/9780857092588.228>

Diaz, O. G., Luna, G. G., Liao, Z., & Axinte, D. (2019). The new challenges of machining Ceramic Matrix Composites (CMCs): Review of surface integrity. *International Journal of Machine Tools and Manufacture*, 139, 24–36.

Dodiuk, H. (2021). *Handbook of thermoset plastics*. William Andrew.

Dress, G. A., Woldemariam, M. H., & Redda, D. T. (2021). Influence of Fiber Orientation on Impact Resistance Behavior of Woven Sisal Fiber Reinforced Polyester Composite. *Advances in Materials Science and Engineering*, 2021. <https://doi.org/10.1155/2021/6669600>

Engineers, N. B. C. (2007). Phenolic Resins Technology Handbook. *NIIR Project Consultancy Services*.

Erdogan, U. H., Seki, Y., & Selli, F. (2020). Wool fibres. In *Handbook of Natural Fibres: Second Edition* (Vol. 1). Elsevier Ltd. <https://doi.org/10.1016/B978-0-12-818398-4.00011-6>

Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000-2010. *Progress in Polymer Science*, 37(11), 1552–1596.

- <https://doi.org/10.1016/j.progpolymsci.2012.04.003>
- Gairola, S. P., Tyagi, Y. K., Gangil, B., & Sharma, A. (2020). Fabrication and mechanical property evaluation of non-woven banana fibre epoxy-based polymer composite. *Materials Today: Proceedings*, 44(xxxx), 3990–3996. <https://doi.org/10.1016/j.matpr.2020.10.103>
- Gebre, G. G., Rik, E., & Kijne, A. (2020). Analysis of banana value chain in Ethiopia: Approaches to sustainable value chain development. *Cogent Food and Agriculture*, 6(1). <https://doi.org/10.1080/23311932.2020.1742516>
- Gholampour, A. (2020). Review A review of natural fiber composites : properties , modification and processing techniques , characterization , applications. In *Journal of Materials Science* (Vol. 55, Issue 3). Springer US. <https://doi.org/10.1007/s10853-019-03990-y>
- Gopi Krishna, M., Praveen Kumar, K., Naga Swapna, M., Babu Rao, J., & Bhargava, N. R. M. R. (2017). Metal-metal Composites-An Innovative Way For Multiple Strengthening. *Materials Today: Proceedings*, 4(8), 8085–8095. <https://doi.org/https://doi.org/10.1016/j.matpr.2017.07.148>
- Goutianos, S., Peijs, T., Nystrom, B., & Skrifvars, M. (2006). Development of flax fibre based textile reinforcements for composite applications. *Applied Composite Materials*, 13(4), 199–215. <https://doi.org/10.1007/s10443-006-9010-2>
- Graham-Jones, J., & Summerscales, J. (2015). *Marine applications of advanced fibre-reinforced composites*. Woodhead Publishing.
- Gupta, U. S., & Tiwari, S. (2020). Study on the Development of Banana Fibre Reinforced Polymer Composites for Industrial and Tribological Applications: A Review. *IOP Conference Series: Materials Science and Engineering*, 810(1). <https://doi.org/10.1088/1757-899X/810/1/012076>
- Haghighatnia, T., Abbasian, A., & Morshedian, J. (2017). Hemp fiber reinforced thermoplastic polyurethane composite: An investigation in mechanical properties. *Industrial Crops and Products*, 108(June), 853–863. <https://doi.org/10.1016/j.indcrop.2017.07.020>
- Hamdan, A., Mustapha, F., Ahmad, K. A., Mohd Rafie, A. S., Ishak, M. R., & Ismail, A. E. (2016). The Effect of Customized Woven and Stacked Layer Orientation on Tensile and Flexural Properties of Woven Kenaf Fibre Reinforced Epoxy Composites. *International Journal of Polymer Science*, 2016. <https://doi.org/10.1155/2016/6514041>
- Hasan, K. M. F., Horváth, P. G., & Alpár, T. (2021). Potential fabric-reinforced composites: a

- comprehensive review. *Journal of Materials Science*, 56(26), 14381–14415.
<https://doi.org/10.1007/s10853-021-06177-6>
- Huda, M. S., Drzal, L. T., Mohanty, A. K., & Misra, M. (2006). Chopped glass and recycled newspaper as reinforcement fibers in injection molded poly(lactic acid) (PLA) composites: A comparative study. *Composites Science and Technology*, 66(11–12), 1813–1824.
<https://doi.org/10.1016/j.compscitech.2005.10.015>
- I.O. Jideani, A. (2020). Introductory Chapter: Banana Nutrition - Function and Processing Kinetics. *Banana Nutrition - Function and Processing Kinetics*, 1–5.
<https://doi.org/10.5772/intechopen.85884>
- Ibnu, R. M. D., & Adityarini, H. (2019). *Effect of NaOH Concentration Treatment on Tensile Strength , Flexure Strength and Elasticity Modulus of Banana Fiber Reinforced Polyester Resin*. 961, 10–15. <https://doi.org/10.4028/www.scientific.net/MSF.961.10>
- Jawaid, M., Sapuan, S. M., & Alotman, O. Y. (2017). *Green Biocomposites Manufacturing and Properties*. 409. <https://doi.org/10.1007/978-3-319-46610-1>
- Jeong, J.-S., & Cheong, S.-K. (2013). Interlaminar fracture toughness of CFRP laminates with silk fibers interleave. *Journal of Mechanical Science and Technology*, 27(12), 3651–3656.
<https://doi.org/10.1007/s12206-013-0910-4>
- Kalia, S., Kaith, B. S., & Kaur, I. (2011). *Cellulose fibers: bio-and nano-polymer composites: green chemistry and technology*. Springer Science & Business Media.
- Kenned, J. J., Sankaranarayanassamy, K., Binoj, J. S., & Chelliah, S. K. (2020). Thermo-mechanical and morphological characterization of needle punched non-woven banana fiber reinforced polymer composites. *Composites Science and Technology*, 185, 107890.
<https://doi.org/10.1016/j.compscitech.2019.107890>
- Kumar, S., Singh, R., & Hashmi, M. S. J. (2020). Metal matrix composite: a methodological review. *Advances in Materials and Processing Technologies*, 6(1), 13–24.
- Kushwaha, P. K., Kumar, R., Kushwaha, P. K., & Kumar, R. (2009). *Studies on Water Absorption of Bamboo-Polyester Composites : Effect of Silane Treatment of Mercerized Bamboo Studies on Water Absorption of Bamboo-Polyester Composites : Effect of Silane Treatment of Mercerized Bamboo*. 2559. <https://doi.org/10.1080/03602550903283026>
- Li, K., Fu, S., Zhan, H., Zhan, Y., & Lucia, L. A. (2010). Analysis of the chemical composition and morphological structure of banana pseudo-stem. *BioResources*, 5(2), 576–585.

- Li, Y., & Dai, X. Q. (2006). Clothing comfort and compression therapy. In *Biomechanical Engineering of Textiles and Clothing*. <https://doi.org/10.1533/9781845691486.2.145>
- Monfared, V. (2020). Problems in short-fiber composites and analysis of chopped fiber-reinforced materials. In *New Materials in Civil Engineering*. INC. <https://doi.org/10.1016/B978-0-12-818961-0.00031-4>
- Negawo, T. A., Polat, Y., Buyuknalcaci, F. N., Kilic, A., Saba, N., & Jawaidd, M. (2019). Mechanical, morphological, structural and dynamic mechanical properties of alkali treated Ensete stem fibers reinforced unsaturated polyester composites. *Composite Structures*, 207, 589–597. <https://doi.org/10.1016/j.compstruct.2018.09.043>
- Norizan, M. N., Abdan, K., Salit, M. S., & Mohamed, R. (2018). The effect of alkaline treatment on the mechanical properties of treated sugar palm yarn fibre reinforced unsaturated polyester composites reinforced with different fibre loadings of sugar palm fibre. *Sains Malaysiana*, 47(4), 699–705. <https://doi.org/10.17576/jsm-2018-4704-07>
- Othman, Z., Saiman, M. P., Hamid, M. F. A., & Talibin, M. N. (2018). The application of 2D woven kenaf reinforced unsaturated polyester composite in automotive interiors. *IOP Conference Series: Materials Science and Engineering*, 368(1). <https://doi.org/10.1088/1757-899X/368/1/012032>
- Padam, B. S., Tin, H. S., Chye, F. Y., & Abdullah, M. I. (2014). Banana by-products: an under-utilized renewable food biomass with great potential. *Journal of Food Science and Technology*, 51(12), 3527–3545. <https://doi.org/10.1007/s13197-012-0861-2>
- Panthapulakkal, S., & Sain, M. (2007). Studies on the water absorption properties of short hemp-glass fiber hybrid polypropylene composites. *Journal of Composite Materials*, 41(15), 1871–1883. <https://doi.org/10.1177/0021998307069900>
- Parashar, S., & Chawla, V. K. (2020). A systematic review on sustainable green fibre reinforced composite and their analytical models. *Materials Today: Proceedings*, 46(xxxx), 6541–6546. <https://doi.org/10.1016/j.matpr.2021.03.739>
- Paul, S. A., Joseph, K., Mathew, G., Pothen, L. A., & Thomas, S. (2010). Preparation of polypropylene fiber/banana fiber composites by novel commingling method. *Polymer Composites*, 31(5), 816–824.
- Plueddemann, E. P. (2016). *Interfaces in Polymer Matrix Composites: Composite Materials*, Vol. 6 (Vol. 6). Elsevier.

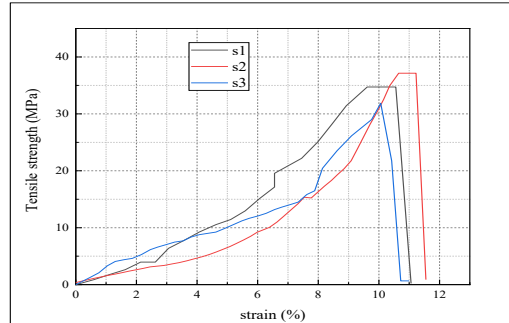
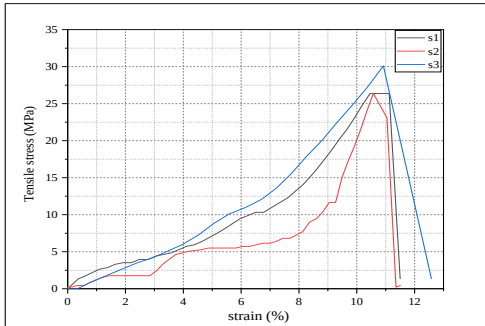
- Porras, A., Maranon, A., & Ashcroft, I. A. (2016). Composites : Part A Thermo-mechanical characterization of Manicaria Saccifera natural fabric reinforced poly-lactic acid composite lamina. *COMPOSITES PART A*, 81, 105–110. <https://doi.org/10.1016/j.compositesa.2015.11.008>
- Pothan, L. A., George, J., & Thomas, S. (2012). *Effect of fiber surface treatments on the fiber – matrix interaction in banana fiber reinforced polyester composites*. October 2014, 37–41. <https://doi.org/10.1163/156855402760194692>
- Prabhu, L., Krishnaraj, V., Sathish, S., Gokulkumar, S., Karthi, N., Rajeshkumar, L., Balaji, D., Vigneshkumar, N., Elango, K. S., Karpagam, J., Vijayalakshmi, V. J., Gowarthan, E. R., & Jayakumar, H. (2021). Experimental investigation on mechanical properties of flax/banana/ industrial waste tea leaf fiber reinforced hybrid polymer composites. *Materials Today: Proceedings*, 45(xxxx), 8136–8143. <https://doi.org/10.1016/j.matpr.2021.02.111>
- Rahman, M. Z., Jayaraman, K., & Mace, B. R. (2018). Impact energy absorption of flax fiber-reinforced polypropylene composites. *Polymer Composites*, 39(11), 4165–4175.
- Ramakrishnan, T., Gift, M., Chitradevi, S., Jegan, R., Jose, H., Subha, P., Nagaraja, H. N., Sharma, R., Selvakumar, P., & Hailegiorgis, S. M. (2022). Study of numerous resins used in polymer matrix composite materials. *Advances in Materials Science and Engineering*, 2022.
- Ramesh, M., Palanikumar, K., & Reddy, K. H. (2017). Plant fibre based bio-composites: Sustainable and renewable green materials. *Renewable and Sustainable Energy Reviews*, 79, 558–584.
- Rana, S. S., Gupta, M. K., & Srivastava, R. K. (2017). Effect of variation in frequencies on dynamic mechanical properties of short sisal fibre reinforced epoxy composite. *Materials Today: Proceedings*, 4(2), 3387–3396. <https://doi.org/10.1016/j.matpr.2017.02.227>
- Ratim, S., Bonnia, N. N., & Surip, N. S. (2012). The effect of woven and non-woven fiber structure on mechanical properties polyester composite reinforced kenaf. *AIP Conference Proceedings*, 1455(March 2014), 131–135. <https://doi.org/10.1063/1.4732481>
- Rwawiire, S., Tomkova, B., Militky, J., Jabbar, A., & Kale, B. M. (2015). Development of a biocomposite based on green epoxy polymer and natural cellulose fabric (bark cloth) for automotive instrument panel applications. *Composites Part B: Engineering*, 81, 149–157. <https://doi.org/10.1016/j.compositesb.2015.06.021>
- Sampathkumar, D., Punyamurth, R., Venkateshappa, S. C., & Bennehalli, B. (2012). Effect of

- chemical treatment on water absorption of areca fiber. *Journal of Applied Sciences Research*, 8(11), 5298–5305.
- Santhanam, V., Dhanaraj, R., Chandrasekaran, M., Venkateshwaran, N., & Baskar, S. (2020). Experimental investigation on the mechanical properties of woven hybrid fiber reinforced epoxy composite. *Materials Today: Proceedings*, 37(Part 2), 1850–1853. <https://doi.org/10.1016/j.matpr.2020.07.444>
- Sapuan, S. M., & Maleque, M. A. (2005). Design and fabrication of natural woven fabric reinforced epoxy composite for household telephone stand. *Materials and Design*, 26(1), 65–71. <https://doi.org/10.1016/j.matdes.2004.03.015>
- Sathees Kumar, S., Sridhar Babu, B., Chankravarthy, C. N., & Prabhakar, N. (2021). Review on natural fiber polymer composites. *Materials Today: Proceedings*, 46(xxxx), 777–782. <https://doi.org/10.1016/j.matpr.2020.12.599>
- Sharma, A. K., Bhandari, R., Aherwar, A., Rimašauskienė, R., & Pinca-Bretotean, C. (2020). A study of advancement in application opportunities of aluminum metal matrix composites. *Materials Today: Proceedings*, 26, 2419–2424.
- Singh, C. P., Patel, R. V., Hasan, M. F., Yadav, A., Kumar, V., & Kumar, A. (2020). Fabrication and evaluation of physical and mechanical properties of jute and coconut coir reinforced polymer matrix composite. *Materials Today: Proceedings*, 38(September), 2572–2577. <https://doi.org/10.1016/j.matpr.2020.07.684>
- Subagyo, A., & Chafidz, A. (2020). Banana Pseudo-Stem Fiber: Preparation, Characteristics, and Applications. *Banana Nutrition - Function and Processing Kinetics*. <https://doi.org/10.5772/intechopen.82204>
- Sukanto, H., Raharjo, W. W., Ariawan, D., Triyono, J., & Kaavesina, M. (2021). Epoxy resins thermosetting for mechanical engineering. *Open Engineering*, 11(1), 797–814. <https://doi.org/10.1515/eng-2021-0078>
- Tang, X., Whitcomb, J. D., Li, Y., & Sue, H. J. (2005). Micromechanics modeling of moisture diffusion in woven composites. *Composites Science and Technology*, 65(6), 817–826. <https://doi.org/10.1016/j.compscitech.2004.01.015>
- Thyavihalli Girijappa, Y. G., Mavinkere Rangappa, S., Parameswaranpillai, J., & Siengchin, S. (2019a). Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review. *Frontiers in Materials*, 6(September), 1–

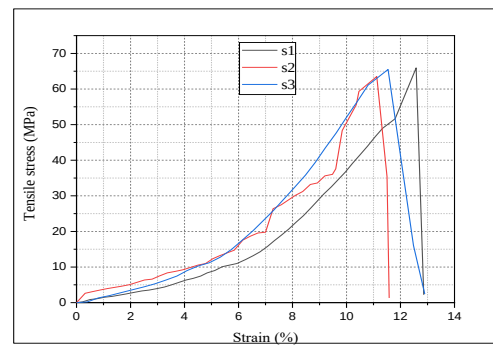
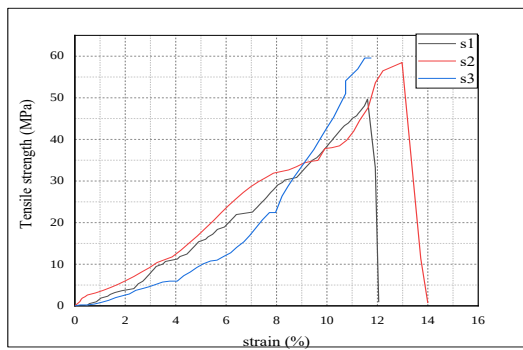
14. <https://doi.org/10.3389/fmats.2019.00226>
- Thyaviahalli Girijappa, Y. G., Mavinkere Rangappa, S., Parameswaranpillai, J., & Siengchin, S. (2019b). Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review. *Frontiers in Materials*, 6(September). <https://doi.org/10.3389/fmats.2019.00226>
- Tzounis, L., Debnath, S., Rooj, S., Fischer, D., Mäder, E., Das, A., Stamm, M., & Heinrich, G. (2014). High performance natural rubber composites with a hierarchical reinforcement structure of carbon nanotube modified natural fibers. *Materials and Design*, 58, 1–11. <https://doi.org/10.1016/j.matdes.2014.01.071>
- Venkateshwaran, N., ElayaPerumal, A., Alavudeen, A., & Thiruchitrambalam, M. (2011). Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites. *Materials and Design*, 32(7), 4017–4021. <https://doi.org/10.1016/j.matdes.2011.03.002>
- Wang, Y., Wang, Z., & Zhu, L. (2022). A Short Review of Recent Progress in Improving the Fracture Toughness of FRP Composites Using Short Fibers. *Sustainability (Switzerland)*, 14(10). <https://doi.org/10.3390/su14106215>
- Wongsriraksa, P., Togashi, K., Nakai, A., & Hamada, H. (2013). *Continuous Natural Fiber Reinforced Thermoplastic Composites by Fiber Surface Modification*. 2013.
- Zafra Mejía, C. A., Mendoza Castañeda, F. A., & Montoya Varela, P. A. (2012). The influence of alkali treatment on banana fibre's mechanical properties. *Ingenieria e Investigacion*, 32(1), 83–87.
- Zakikhani, P., Zahari, R., Sultan, M. T. H., & Majid, D. L. (2014). Bamboo Fibre Extraction and Its Reinforced Polymer Composite Material. *International Journal of Chemical, Biomolecular, Metallurgical, Materials Science and Engineering*, 8(4), 271–274.
- Zhengcai, M., Chengyao, H., Jichuan, H., & Dong, Y. (2017). Ramie Short Fiber Interlayer Toughened Carbon Fiber/Epoxy Composite. *Journal of Composite Materials*, 34(6), 1237–1244.

Appendix A

Tensile test

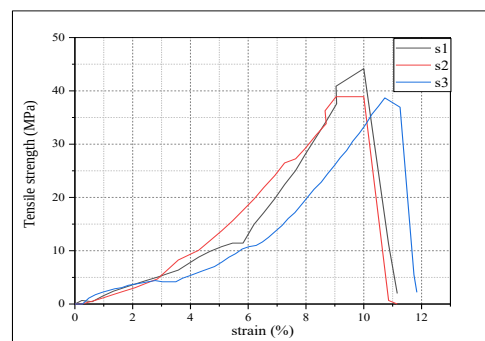
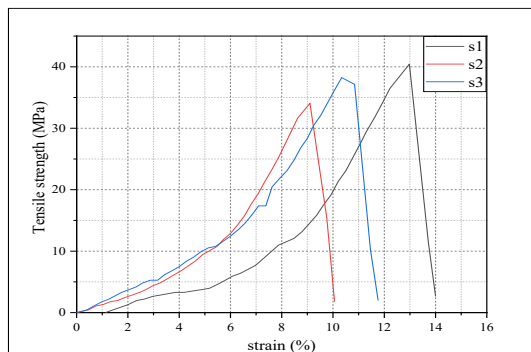


UTSB composite



UTWB composite

TWB composite

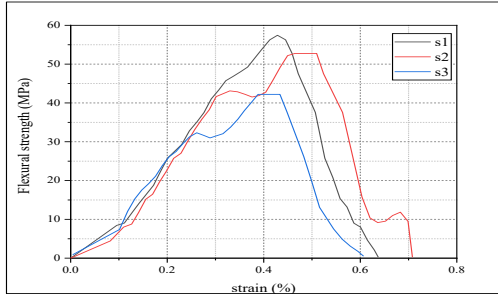


UTWSB composite

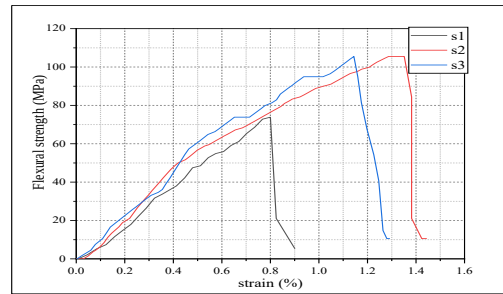
TWSB composite

Appendix B

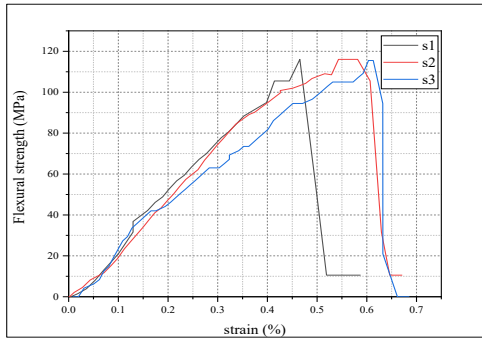
Flexural test



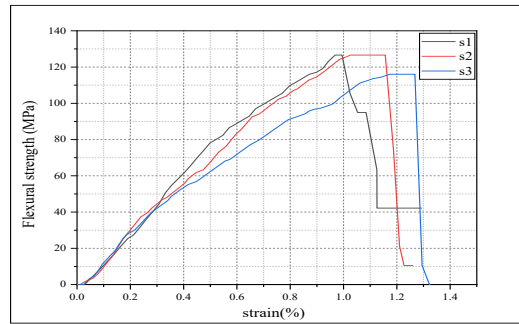
UTBS composite



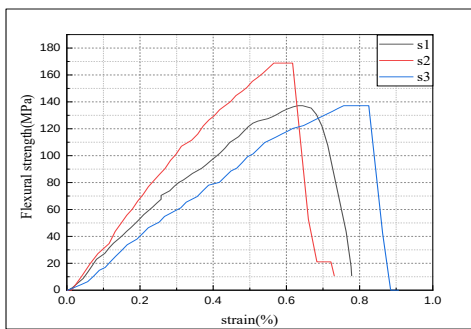
TSB composite



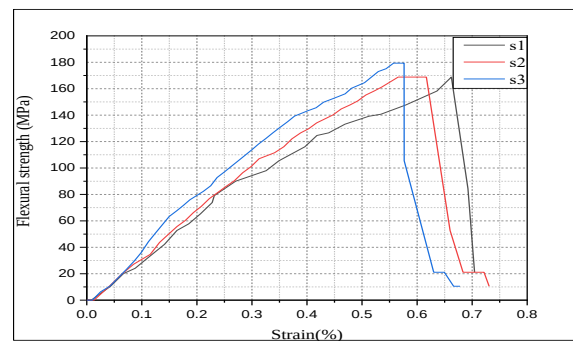
UTWB composite



TWB composite



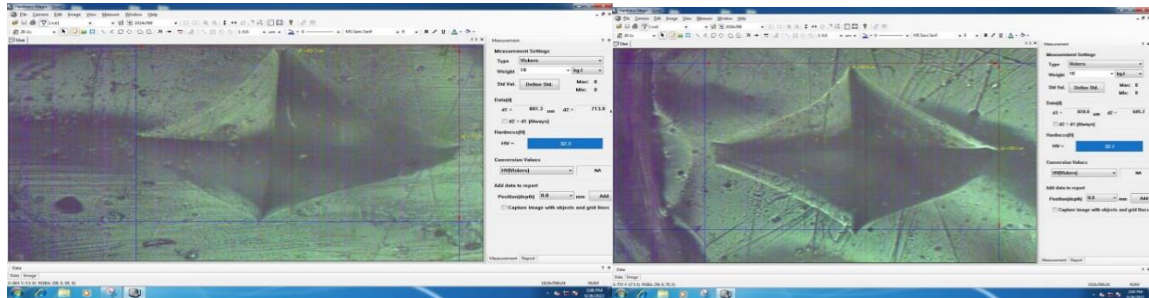
UTWSB composite



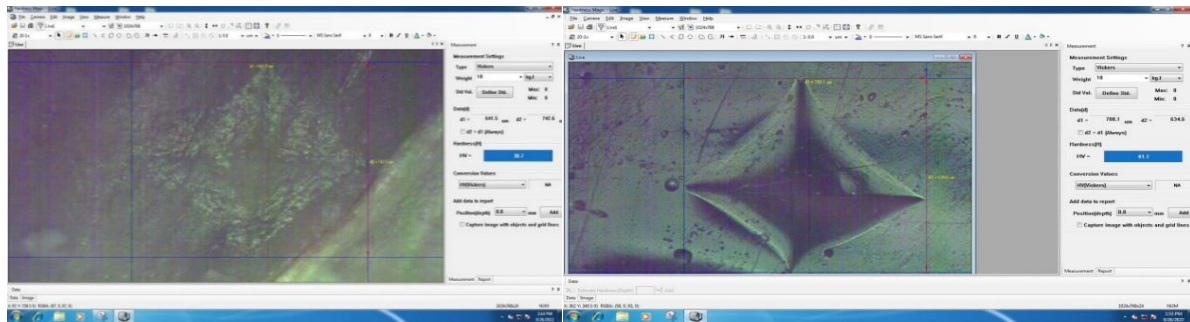
TWSWB composite

Appendix C

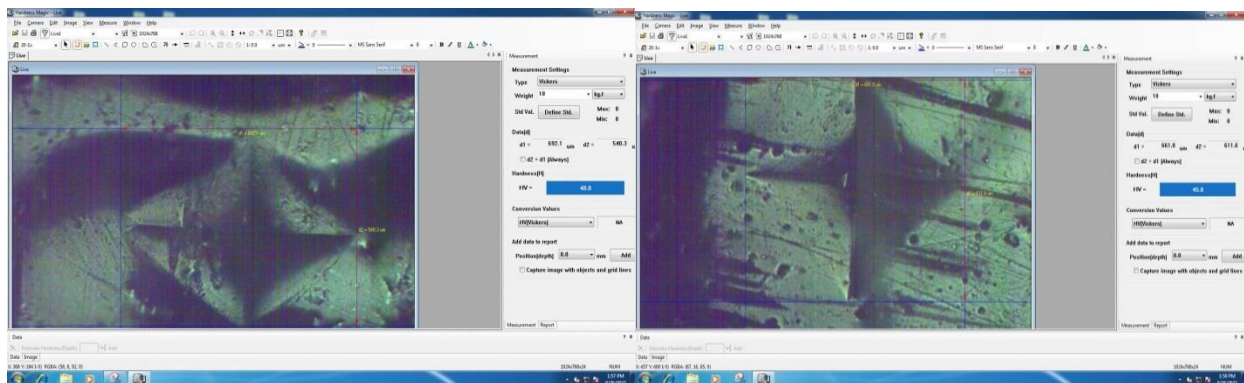
Hardness test



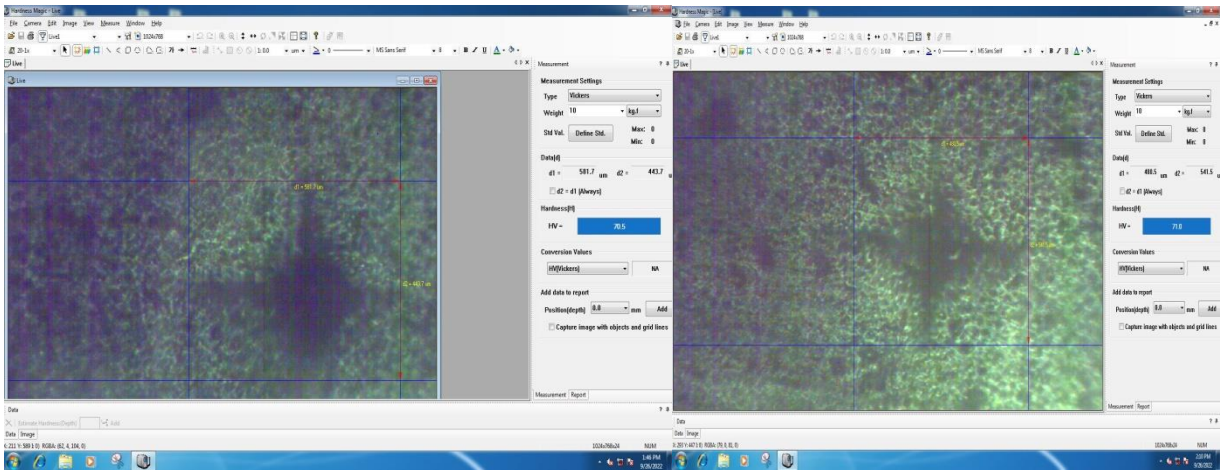
UTSB composite



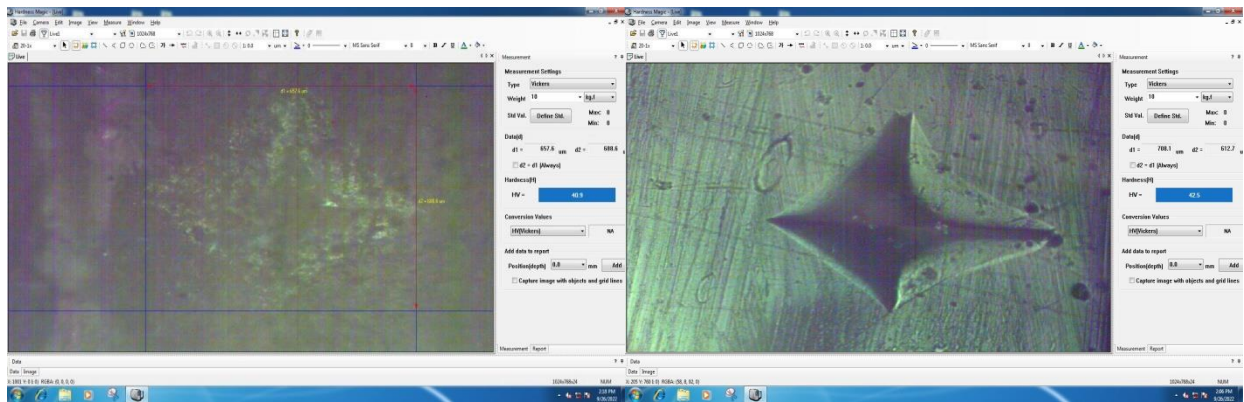
TSB composite



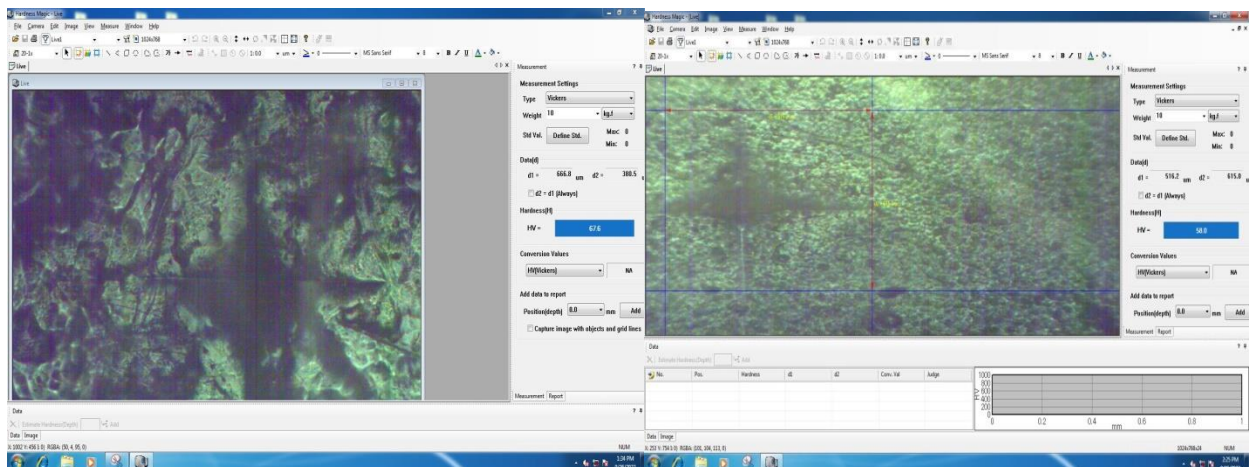
UTWB composite



TWB composite



UTWSWB composite



TWSWB composite