



**ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES**

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

**FABRICATION, CHARACTERIZATION AND
SIMULATION OF FLAX-SISAL FIBER
REINFORCED EPOXY HYBRID COMPOSITE
FOR PROSTHETIC SOCKET**

**A Thesis Submitted to the Graduate School of Addis Ababa
University in Partial Fulfillment of the Requirement for the
Degree of Masters of Science in Mechanical Engineering
(Manufacturing Engineering)**

By: Luna Geo

Advisor: Dr. Desalegn Wogaso

**Addis Ababa, Ethiopia
July, 2021**

**Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies**

School of Mechanical and Industrial Engineering

**FABRICATION, CHARACTERIZATION AND
SIMULATION OF FLAX-SISAL FIBER
REINFORCED EPOXY HYBRID COMPOSITE
FOR PROSTHETIC SOCKET**

By: Luna Geo

Approved by Board of Examiners

Dr. Dessalegn Wogaso

Advisor


Signature

24-09-21
Date

Dr. Mestir Gizaw

Internal Examiner


Signature

30/09/21
Date

Gefasaw A-

External Examiner


Signature

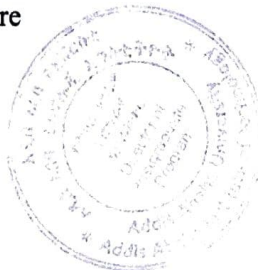
30/09/21
Date

Dr. Yilma Tadesse

Chairman of the School


Signature

Oct 10 / 2021
Date



DECLARATION

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by **Luna Geo**, entitled: *Fabrication, Characterization and Simulation of Flax-Sisal Fiber Reinforced Epoxy Hybrid Composite for Prosthetic Socket*, do hereby declare this thesis is my original work and that it has not been submitted partially or in full for a degree in any university/ institution, which complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

Name: Luna Geo

Place: Addis Ababa, Ethiopia

Signature:  _____

Date: 05/20/2021

Advisor's Signature:

Dr. Dessalegn Wogaso

Advisor



Signature

24-09-21

Date

ACKNOWLEDGMENT

In the journey of completing this thesis, I have been through lots of ups and downs. Have met different generous people, have struggled a lot and thrived through all the difficulties. And this all experience and life lessons were possible because of GOD. So, first and for most, I would love to thank the almighty GOD for his immeasurable blessings and lessons in my life.

I would like to express a deep sense of gratitude to my advisor Dr. Desalegn Wogaso for his support and understanding throughout the thesis.

I also owe a great thanks to Mr. Haileloul S. for his relentless advice, suggestion and support. Furthermore, my appreciation goes to Mr. Araya A., Mr. Getasew A. and Dr. Kassu J. for their support and advice.

My special and deepest gratitude and love, to my one and only Mrs. Afomiya Kassa for her unconditional love, support and understanding. I thank you so much and love you more for all those sleepless nights you spent supporting me. You have been my motivation throughout this and I know you will be my pillar throughout my life.

I feel deep sense of gratitude for my whole family; their love, encouragement, appreciation and endless support have made me stronger each day. Especially Mr. Yohannes M., for your special advises and encouragements that gave me the strength to complete this work. I would also like to thank my brother Mr. Samuel L. and his wife for their support.

Last but not least, I would like to acknowledge all my classmates, especially, Ms. Zodiac S. for always having my back and being there whenever I needed help. In addition, my deep sense of gratitude goes to Mr. Masresha.

Thank you all.

DEDICATED TO MY WIFE AND MAYA

ABSTRACT

Prosthetic limb socket is the major part of a prosthetic leg and arm. It provides comfortable connection, transfers the load, ensures stability between the residual limb and the device. This study aims to investigate tensile, flexural, compression, impact and water absorption properties of **Flax-Sisal Fiber Reinforced Epoxy Hybrid Composite**. The research also targets to explore its application for prosthetic socket. Hand-layup method was utilized to fabricate thirteen composite specimens having 30mm fiber length and fiber-matrix volume percentages of 40-60, 30-70, and 35-65 according to ASTM standards. Eight composite specimens were treated with 5% NaOH. Comparing the thirteen composites, the result showed the treated composite with F25%-S15%-E60% had superior mechanical and physical properties with tensile strength of 68.40MPa, flexural strength of 145.7MPa, compression strength of 45.64MPa, impact energy of 10.83J and water absorption percentage of 3.66%. In addition, using ANSYS 2020, Prosthetic socket was modeled and loading conditions were applied on composition F25%-S15%-E60% from this, maximum von missed stress of 2.214MPa and deformation of 0.0064mm was obtained. Based on the results and analysis, the selected Flax-Sisal-Epoxy hybrid composite has the potential to be further developed as an alternative material of prosthetic socket.

Keywords: Prosthetic Socket, Flax/Sisal/Epoxy, Tensile strength, Flexural Strength, Compression strength, Impact Strength, Water Absorption, ANSYS 2020.

TABLE OF CONTENTS

ACKNOWLEDGMENT.....	i
ABSTRACT.....	ii
TABLE OF CONTENTS.....	iii
LIST OF FIGURES	vi
LIST OF TABLES.....	x
LIST OF ABBREVIATIONS AND ACRONYMS	xi
CHAPTER ONE.....	1
INTRODUCTION	1
1.1 BACKGROUND	1
1.2 PROBLEM STATEMENT	2
1.3 OBJECTIVE	3
1.3.1 GENERAL OBJECTIVE.....	3
1.3.2 SPECIFIC OBJECTIVES	3
1.4 RESEARCH QUESTION.....	3
1.5 SCOPE OF THE STUDY	3
1.6 LIMITATIONS OF THE STUDY.....	4
1.7 ORGANIZATION OF THE THESIS.....	4
CHAPTER TWO	5
LITERATURE REVIEW	5
2.1 COMPOSITE MATERIALS	5
2.2 FIBERS	8
2.2.1 TYPES OF FIBERS.....	8
2.2.2 SISAL PLANT.....	10
2.2.2.1 EXTRACTION METHOD OF SISAL FIBER	10
2.2.3 FLAX PLANT	11
2.2.3.1 EXTRACTION METHOD OF FLAX FIBER	12
2.3 MANUFACTURING METHODS OF COMPOSITES	13
2.4 FACTORS INFLUENCING THE PERFORMANCE OF COMPOSITES	14
2.5 HYBRID COMPOSITES	16
2.6 PROSTHETICS LIMBS	16
2.7 PROSTHETIC SOCKET.....	17
2.7.1 MATERIALS USED FOR PROSTHETIC SOCKET.....	19
2.8 RELATED RESEARCHES.....	20

2.8.1 GAPS IDENTIFIED	30
CHAPTER THREE	31
MATERIALS, CONDITIONS AND METHODS	31
3.1 METHODOLOGY	31
3.2 MATERIALS USED	33
3.2.1 FIBER COLLECTION AND EXTRACTION	33
3.2.1.1 SISAL FIBER	34
3.2.1.2 FLAX FIBER	38
3.2.2 MATRIX MATERIAL	39
3.2.2.1 EPOXY RESIN	39
3.2.2.2 HARDNER	40
3.2.2.3 PREPARATION OF EPOXY AND HARDENER MIXTURE	40
3.2.3 ADDITIONAL MATERIALS	40
3.3 FIBER TREATMENT	41
3.3.1 TREATMENT OF BOTH FLAX FIBER AND SISAL FIBER	43
3.4 PREPARATION OF MOLD	46
3.5 FABRICATION OF THE HYBRID COMPOSITE	48
3.5.1 RULE OF MIXTURE / FIBER AND MATRIX MASS COMPOSITION CALCULATION FOR THE COMPOSITE	49
3.5.2 FABRICATION OF COMPOSITES SPECIMEN	54
3.6 SPECIMENS PREPARATION FOR TESTING	58
3.7 EXPERIMENTAL TESTING PROCEDURES AND CONDITIONS	59
CHAPTER FOUR	67
EXPERIMENTAL RESULTS AND DISCUSSIONS	67
4.1 RESULT	67
4.1.1 TENSILE TEST RESULT	67
4.1.2 COMPRESSION TEST RESULT	81
4.1.3 FLEXURAL TEST RESULT	89
4.1.4 IMPACT TEST RESULT	98
4.1.5 WATER ABSORPTION TEST RESULT	100
4.2 DISCUSSION	102
4.2.1 TENSILE TEST DISCUSSION	102
4.2.2 COMPRESSION TEST DISCUSSION	103
4.2.3 FLEXURAL TEST DISCUSSION	104
4.2.4 IMPACT TEST DISCUSSION	104

4.2.5 WATER ABSORPTION TEST DISCUSSION	105
4.3 COMPARISON OF RESULTS WITH LITERATURES	106
4.3.1 RESEARCHES ON FLAX AND SISAL AS A HYBRID.....	106
4.3.2 RESEARCHES ON MATERIALS FOR PROSTHETIC APPLICATIONS.....	107
4.4 SIMULATION OF PROSTHETIC SOCKET.....	108
4.4.1 FINITE ELEMENT MODELING AND ANALYSIS	108
4.4.1.1 DEFINING ENGINEERING DATA FOR THE MATERIAL	108
4.4.1.2 MODELING OF PROSTHETIC SOCKET IN ANSYS.	110
4.4.1.3 MESH GENERATION.....	110
4.4.1.4 APPLYING BOUNDARY CONDITIONS AND LOAD CONDITIONS ...	111
4.4.1.5 GENERATING SOLUTIONS.....	112
4.4.2 RESULT	113
4.4.3 DISCUSSION	114
4.4.4 COMPARING RESULT WITH LITERATURE	114
CHAPTER FIVE	115
CONCLUSION AND RECOMMENDATION.....	115
5.1 CONCLUSION.....	115
5.2 RECOMMENDATION	116
5.3 FUTURE WORK.....	116
REFERENCE.....	117
APPENDICES	124
APPENDIX A.....	124
APPENDIX B	138

LIST OF FIGURES

Figure 2.1 Classification of Composites [14]	5
Figure 2.2 Structural Reinforced Composites [22], [23]	6
Figure 2.3 Classification of Fibers [11][17]	8
Figure 2.4 Structure of flax fiber [43].....	11
Figure 2.5 Extraction process of fiber.....	12
Figure 2.6 Dressing of Flax fiber [45]	13
Figure 2.7 Prosthetic Socket Parts [59].....	18
Figure 2.8 Prosthetic socket classification for lower limb [60]	19
Figure 3.1 Methodology.....	32
Figure 3.2 Extraction of Sisal Fiber	35
Figure 3.3 Fiber Density Measuring Process	37
Figure 3.4 Epoxy Resin LY556	39
Figure 3.5 Hardner HY951	40
Figure 3.6 Releasing Wax.....	41
Figure 3.7 Process of Mixing of NaOH with Water	42
Figure 3.8 Treatment of Flax Fiber.....	44
Figure 3.9 Treatment of Sisal Fiber	46
Figure 3.10 Mold Design and Mold Cover Weight (320*300*4)	48
Figure 3.11 Preparation of Flax and Sisal Fiber	49
Figure 3.12 Fabrication Process of Composite	57
Figure 3.13 Circular Band Saw.....	58
Figure 3.14 Charpy Impact Testing Machine	59
Figure 3.15 Gunt Hamburg WP 310 Hydraulic material testing machine 50KN	60
Figure 3.16 Tensile Test Specimen.....	61
Figure 3.17 Tensile Strength Setup and Specimen at Fracture	61
Figure 3.18 Compression Specimens.....	62
Figure 3.19 Compression Test Process	62
Figure 3.20 Flexural Test Specimens.....	63
Figure 3.21 Flexural Test Setup.....	63
Figure 3.22 Deformation of Flexural Test Specimen	64
Figure 3.23 Impact Test Specimen	64
Figure 3.24 Impact Test Setup	65
Figure 3.25 Impact test Specimen after Test	65
Figure 3.26 Water Absorption Specimens	66
Figure 3.27 Specimens Socked in Water	66
Figure 4.1 Tensile Stress – Strain Curve for Composite 1 (Treated – F20%, S20% and E60%)	67
Figure 4. 2 Tensile Strength of Samples and its average (Treated – F20%, S20% and E60%)	68
Figure 4.3 Tensile Stress – Strain Curve for Composite 2 (Treated – F15%, S25% and E60%)	68
Figure 4.4 Tensile Strength for Samples and its average (Treated – F15%, S25% and E60%)	69

Figure 4. 5 Tensile Stress – Strain Curve for Composite 3 (treated – F25%, S5% and E60%)	69
Figure 4.6 Tensile Strength for All Samples and its average (treated – F25%, S15% and E60%)	69
Figure 4.7 Tensile Stress – Strain Curve for Composite 4 (Treated – F20%, S15% and E65%)	70
Figure 4.8 Tensile Strength for Samples and its average (Treated – F20%, S15% and E65%)	70
Figure 4.9 Tensile Stress – Strain Curve for Composite 5 (Treated – F15%, S20% and E65%)	71
Figure 4.10 Tensile Strength of All Samples and its average (Treated – F15%, S20% and E65%)	71
Figure 4.11 Tensile Stress – Strain Curve for Composite 6 (Treated – F10%, S20% and E70%)	72
Figure 4.12 Tensile Strength for All Samples and its average (Treated – F10%, S20% and E70%)	72
Figure 4.13 Tensile Stress – Strain Curve for Composite 7 (Treated – F10%, S20% and E70%)	73
Figure 4.14 Tensile Strength for All Samples and its average (Treated – F10%, S20% and E70%)	73
Figure 4.15 Tensile Stress – Strain Curve for Composite 8 (Treated – F15%, S15% and E70%)	74
Figure 4.16 Tensile Strength for All Samples and its average (Treated – F15%, S15% and E70%)	74
Figure 4.17 Tensile Stress – Strain Curve for Composite 9 (Untreated – F20%, S15% and Epoxy 65%)	75
Figure 4.18 Tensile Strength for All Samples and its average (Untreated – F20%, S15% and E65%)	75
Figure 4.19 Tensile Stress-Strain Curve for Composite 10 (Untreated–F15%, S25% and E60%)	76
Figure 4.20 Tensile Strength of All Samples and its average (Untreated–F15%, S25% and E60%)	76
Figure 4.21 Tensile Stress – Strain Curve for Composite 11 (Untreated–F20%, S20% and E60%)	77
Figure 4.22 Tensile Strength for All Samples and its average (Untreated–F20%, S20% and E60%)	77
Figure 4.23 Tensile Stress-Strain Curve for Composite 12 (Untreated–F25%, S15% and E60%)	78
Figure 4.24 Tensile Strength for All Samples and its average (Untreated–F25%, S15% and E60%)	78
Figure 4.25 Tensile Stress–Strain Curve for Composite 13 (Untreated–F10%, S20% and E70%)	79
Figure 4.26 Tensile Strength for All Samples and its average (Untreated–F10%, S20% and E70%)	79
Figure 4. 27 Tensile strength – Composite for all composites Flax/Sisal – Epoxy Composite	80

Figure 4.28 Tensile Modulus – Composite for all composites Flax/Sisal – Epoxy Composite	80
Figure 4.29 Compression Strength for All Samples and its average (Treated – F20%, S20% and E60%).....	81
Figure 4.30 Compression Strength for All Samples and its average (Treated–F15%, S25% and E60%))	82
Figure 4.31 Compression Strength for All Samples and its average (Treated–F25%, S15% and E60%)	82
Figure 4.32 Compression Strength for All Samples and its average (Treated–F20%, S15% and E65%)	83
Figure 4.33 Compression Strength for All Samples and its average (Treated–F15%, S20% and E65%)	83
Figure 4.34 Compression Strength for All Samples and its average (Treated – Flax 10%, Sisal 20% and Epoxy 70%)	84
Figure 4.35 Compression Strength for All Samples and its average (Treated–F10%, S20% and E70%)	84
Figure 4.36 Compression Strength for All Samples and its average (Treated–F15%, S15% and E70%)	85
Figure 4.37 Compression Strength for All Samples and its average (Untreated–F20%, S15% & E65%)	85
Figure 4.38 Compression Strength for All Samples and its average (Untreated–F15%, S25% & E60%)	86
Figure 4.39 Compression Strength for All Samples and its average (Untreated–F20%, S20% & E60%)	86
Figure 4.40 Compression Strength for All Samples and its average (Untreated–F25%, S15% & E60%)	87
Figure 4.41 Compression Strength for All Samples and its average (Untreated–F10%, S20% & E70%)	87
Figure 4.42 Compression strength – Composite for all composites Flax/Sisal – Epoxy Composite	88
Figure 4.43 Compressive modulus – Composite for all composites Flax/Sisal – Epoxy Composite	88
Figure 4.44 Computer Output	89
Figure 4.45 Flexural Strength & Applied Force (Treated – F20%, S20% and E60%).....	90
Figure 4.46 Flexural Strength & Applied Force (Treated – F15%, S25% and E60%).....	90
Figure 4.47 Flexural Strength & Applied Force (Treated – F25%, S15% and E60%).....	91
Figure 4.48 Flexural Strength & Applied Force (Treated – F20%, S15% and E65%).....	91
Figure 4.49 Flexural Strength & Applied Force (Treated – F15%, S20% and E65%).....	92
Figure 4.50 Flexural Strength & Applied Force (Treated – F10%, S20% and E70%).....	92
Figure 4.51 Flexural Strength & Applied Force (Treated –F10%, S20% and E70%).....	93
Figure 4.52 Flexural Strength & Applied Force (Treated – F15%, S15% and E70%).....	93
Figure 4.53 Flexural Strength & Applied Force (Untreated – F20%, S15% and E65%)	94
Figure 4.54 Flexural Strength & Applied Force (Untreated – F15%, S25% and E60%)	94
Figure 4.55 Flexural Strength & Applied Force (Untreated – F20%, S20% and E60%)	95
Figure 4.56 Flexural Strength & Applied Force (Untreated – F25%, S15% and E60%)	95

Figure 4.57 Compression Stress – Strain Curve for Sample One of Composite thirteen (Untreated – Flax 10%, Sisal 20% and Epoxy 70% composition)	96
Figure 4.58 Flexural Strength Vs Composite for all Flax/Sisal – Epoxy Composite	96
Figure 4.59 Maximum Testing Force Vs Composite for all Flax/Sisal – Epoxy Composite ..	97
Figure 4.60 Impact Energy Vs Composite.....	99
Figure 4.61 Steps in ANSYS Analysis	108
Figure 4.62 Material Engineering Data of Flax/Sisal/Epoxy.....	109
Figure 4.63 Overall geometry and 3D model of Prosthetic Socket	110
Figure 4.64 Meshing details and Meshed Prosthetic Model.....	110
Figure 4.65 Regions where pressure are applied [80].....	111
Figure 4.66 Applied Boundaries	112
Figure 4.67 Applied Loads and Boundary Conditions	112
Figure 4.68 Solution Tab	112
Figure 4.69 Result of the Equivalent Von Mises Stress	113
Figure 4.70 Result of Deformation	113
Figure A.1 Tensile Test Graphs	130
Figure A.2 Compression Test Graphs.....	137
Figure B.1 Flax and Sisal Fiber Ready for Testing of Elongation, Tenacity, Tensile.....	138
Figure B.2 Result of Property Test	138
Figure B. 3 Flax Fiber Dimension test setup	139
Figure B.4 Result	139

LIST OF TABLES

Table 2. 1 Advantage and Disadvantage of epoxy [29].....	7
Table 2. 2 Advantage and Disadvantage of Natural Fibers	9
Table 3. 1 Materials used to fabricate the composite.....	33
Table 3. 2 Property of Epoxy Resine LY556.....	39
Table 3. 3 Property of Hardner HY951	40
Table 3. 4 Fiber Matrix Composition Table 3. 5 Fiber – Fiber Composition	49
Table 3. 6 Composition of Thirteen Composites	50
Table 3. 7 Composite one Property and Mass required	51
Table 3. 8 Composite two Property and Mass required.....	51
Table 3. 9 Composite three Property and Mass required.....	52
Table 3. 10 Composite four Property and Mass required	52
Table 3. 11 Composite five Property and Mass required.....	52
Table 3. 12 Composite Six Property and Mass required	53
Table 3. 13 Composite Seven Property and Mass required	53
Table 3. 14 Composite Eight Property and Mass required	53
Table 3. 15 Mass of each Composite	54
Table 3. 16 Experimental Test Standards	59
Table 4. 1 Flexural Strength and Maximum Test Force	97
Table 4. 2 Impact Energy Result.....	98
Table 4. 3 Water Absorption Percentage of All Composites.....	100
Table 4. 4 Overall Results obtained from the experiment	102
Table 4. 5 Result obtained by C. M. Meenakshi and A. Krishnamoorthy[91]	106
Table 4. 6 Result obtained by G. Rajamurugan et. al. [71].....	106
Table 4. 7 Researches on Materials for Prosthetic Applications [12].....	107
Table 4. 8 Applied Pressures on the Prosthetic.....	111
Table 4. 9 Result obtained using ANSYS Software for Prosthetic Socket.....	114
Table B.1 Data of Flax Fiber Dimensions from Physical Test	140

LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	American Standard Test Methods
C1 – C13	Composite one – Composite Thirteen
E	Elastic Modulus
F	Flax Fiber
F	Force
FEM	Finite Element Method
Hrs.	Hours
KPa	Kilo Pascal
KN	Kilo Newton
MPa	Mega Pascal
NaOH	Sodium Hydroxide
Pa	Pascal
RHS	Rectangular Hollow Section
RTM	Resin Transfer Molding
S1C1	Sample One Composite One
S2C1	Sample Two Composite One
S3C1	Sample Three composite One
SF	Sisal Fiber
S	Sisal
UTM	Universal Testing Machine
VARTM	Vacuum Assisted Resin Transfer Molding
ρ_S	Density of Sisal
ρ_F	Density of Flax
ρ_E	Density of Epoxy
V	Volume

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Currently, composite materials are becoming highly common in different prosthetics and orthotics applications because of their properties such as; high specific to weight ratio, corrosion resistance, flexibility, lower cost and ease of fabrication [1], [2].

In developing countries, amputations are becoming very usual. Especially, for the lower limb [3]. In Ethiopia, amputation is often the only treatment for vascular diseases, gangrene, tumors and for chronic infections. Furthermore, traffic accidents, diabetes, war, industrial are the causes of amputation [4], [5]. Therefore, in order for these amputees to perform their day-to-day activity comfortably, prosthesis is used.

A prosthesis is a device that replaces the function or appearance of a lost limb or body part. They should be convenient to wear, easy to put on and take off, light weight, robust, mechanically comfortable, easy to maintain, and economical [5].

A prosthetic limb consists of three major components. These are: Socket, Extension and Foot/Hand [6]. Socket is the major part of a prosthetic limb that provides comfortable connection, transfer the load, ensure stability between the residual limb and the device [3] [7].

Most of the materials used in fabrication of prosthetic sockets are synthetic composite materials (carbon fiber and glass fiber) and thermoplastics (polyethylene and polypropene). These materials provide good mechanical and physical properties. In addition, they are resistant to many chemical solvents, bases and acids [1]. But they have some drawbacks; the synthetic composite materials create gases that are harmful during production, have higher weight and higher cost [8]. And the thermoplastic materials have lower ductility and higher shrinkage [9]. Due to these, various research has been conducted to replace the conventional materials with environmental friendly, flexible, sustainable, effective and lower cost materials.

Natural fibers have received more attention in order to be used in applications of prosthetic sockets [1]. These fibers have great extensive engineering application where strength to weight ratio, low cost and easy fabrication are required [10]. Natural fibers are the best synthetic fiber substitute because of their low cost, light weight, availability, environmentally friendly, biodegradability, and acceptable mechanical properties [11]. In using of natural fiber rather

than synthetic fiber (glass fiber), the weight and energy for production will be reduced by 10% and 80% respectively [12].

With all the specific and individual forces and stress involved with a prosthetic socket, the material required should have following properties, these are; lightweight, strong under tension, strong under compression, flexible, resist bending, resist fracture under impact, cost effective [2]. In order to obtain these different properties in one composite a hybrid of flax and sisal fibers was selected based on their higher tensile strength, higher specific strength, lower water absorption and availability in Ethiopia. Hybridization reduces the drawbacks associated with the individual fibers and results into better mechanical properties [11].

Therefore, this research studied the mechanical and physical properties of flax-sisal hybrid fiber reinforced epoxy composite with different fiber – matrix volume percentage. Based on the result obtained, the composite with superior properties was selected. By modeling the prosthetic socket on ANSYS 2020, the selected material was further analyzed to suggest as an alternative material for prosthetic socket.

1.2 PROBLEM STATEMENT

Amputees need a comfortable, affordable prosthetic limbs. In Ethiopia, the materials used for the prosthetic socket are polyethylene and polypropene. However, studies estimate that between 32% and 90.9% of the population that use these material devices have experienced skin problems on the affected stump or limb, such as excessive sweating, wounds and irritation [9]. According to a study conducted in Addis Ababa, Ethiopia, 80% of available devices were in need of repair and the components for repairing results in high import cost. [13]. Also these parts are designed for very different lifestyles [6]. In addition, the weight and cost of the materials used for prosthetic socket is higher compared to natural fiber composites. furthermore, the study of flax-sisal fiber natural hybrid composite is limited.

Therefore; the research started with hypothesis that, hybridized material of flax and sisal fiber reinforced epoxy composite will reduce the above-mentioned problems and become an alternative material for prosthetic socket application.

1.3 OBJECTIVE

1.3.1 GENERAL OBJECTIVE

The general objective of this thesis is to fabricate flax-sisal fiber reinforced epoxy hybrid composite specimens of various compositions to characterize their physical and mechanical properties then analyze effect of loads on simulated prosthetic limb socket in order to suggest the material for the application of prosthetic socket.

1.3.2 SPECIFIC OBJECTIVES

- To fabricate specimens of flax-sisal-epoxy hybrid composite with different fiber-matrix composition.
- To test and analyze physical and mechanical properties like tensile, compression, flexural, impact and water absorption of Flax-Sisal-Epoxy hybrid composites with different compositions.
- To simulate and analyze the suggested material for prosthetic limb socket model using ANSYS 2020 software
- To compare the suggested composite material with currently used material for prosthetic limb sockets.

1.4 RESEARCH QUESTION

- ✓ Which composition of flax-sisal fiber reinforced epoxy hybrid composite from tested compositions has superior mechanical and physical property for the application of prosthetic socket?

1.5 SCOPE OF THE STUDY

In this study, material with better mechanical and physical properties that can be applicable for prosthetic limb socket will be presented by fabricating flax-sisal-epoxy hybrid composite specimens with various. It involves hand-layup manufacturing, experimental characterization based on ASTM standards for Tensile, compression, flexural, impact and water absorption, and simulation using ANSYS for analyzing the effect of load on the suggested material.

For the selected application, the study is limited to only 3D modeling and analysis. There will not be manufacturing of physical prototype. The 3D model is based on **85KG** male with a height of **175cm**. The subject's pressure and loads were taken to analyze the material.

1.6 LIMITATIONS OF THE STUDY

In completion of this thesis work, there were many obstacles. First and for most experimental setups are very limited and it was difficult to find machines that are used for testing under one roof. Machines to measure single fiber density, diameter and other property was also very difficult to find.

In addition, literatures that studied hybrid natural composite of Sisal and Flax fiber were very limited.

1.7 ORGANIZATION OF THE THESIS

Chapter One: intends to introduce the overall background of the topic and the purpose in doing the research.

Chapter Two: addresses the detailed science behind natural hybrid composite and prosthetic limb sockets by reviewing different literatures.

Chapter Three: Explains the materials used, preparation methods, process and condition for setting up the needed specimens for test.

Chapter Four: presents different results obtained from the experimental tests and the results are discussed in detail. In addition, from the result obtained, a prosthetic limb socket is modeled on ANSYS and the results are discussed in detail.

Chapter Six: gives conclusion and recommendations on the research done. In addition, future work is proposed.

CHAPTER TWO LITERATURE REVIEW

2.1 COMPOSITE MATERIALS

Composites are materials that consists two or more constituent materials. These materials significantly have different chemical and physical properties. One constituent is called **reinforcement phase** and the other in which its embedded is called the **matrix phase** [14].

Reinforcement phase is the major load carrying member of composite while the matrix phase protects the reinforcement material from environmental damage, transfer loads between the two in addition it keeps the reinforcement in place [15].

The composite material has several advantages and disadvantages when compared with conventional materials. Some of the **advantages** are: Flexibility, high strength to weight ratio, non-corrosive, good stiffness, good dumping, low electric conductivity, lightweight, low cost. Some of the **Disadvantages** are: long development time, low ductility, temperature limit, susceptible to moisture attack [16], [17].

REINFORCEMENT MATERIAL: They are the main constituent of composites. Reinforcement materials provide strength, stiffness and support the structural load [18]. Because of this, the choice of reinforcement is very important to obtain needed finished product with desired properties.

There are different types of reinforcement materials, these are: Particle Reinforced Composite, Fiber Reinforced Composite, Whisker Reinforced Composite, Structural Reinforced Composite [14].

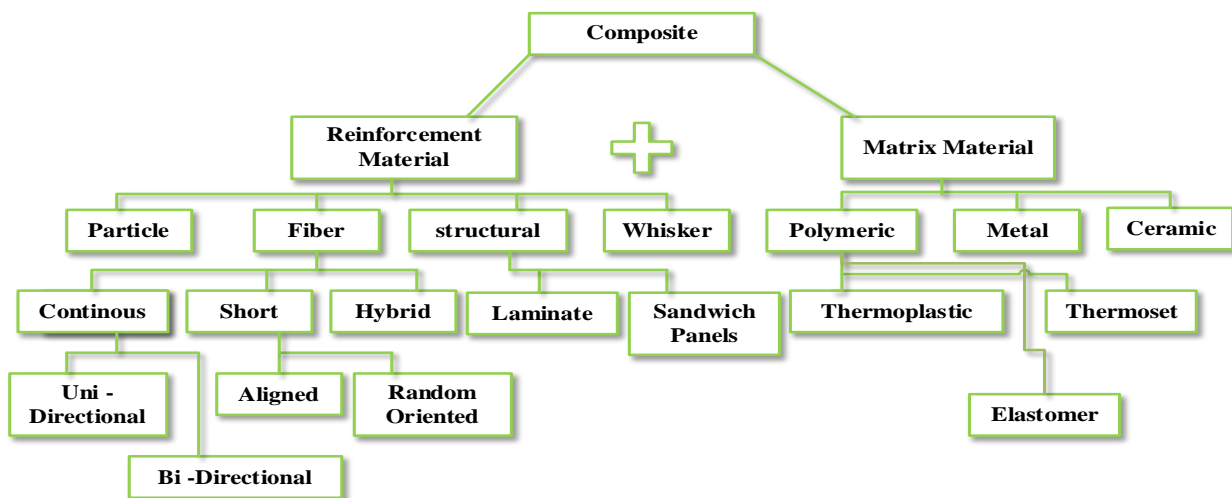


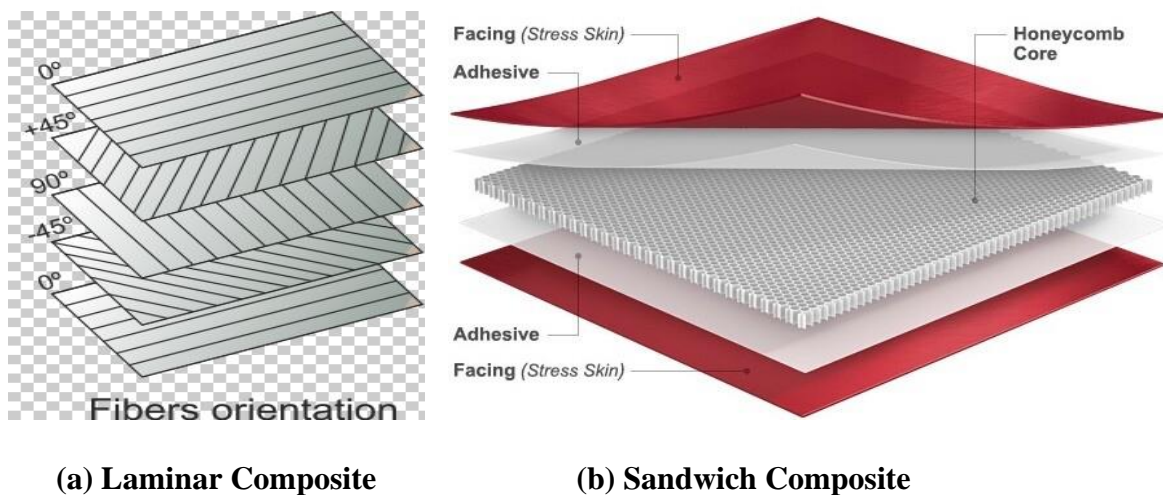
Figure 2. 1 Classification of Composites [14]

Particle Reinforced Composite: Consists of particles as a reinforcement that are dispersed in a matrix. These particles have no long dimension. They are polyhedral, ellipsoidal, spherical, or irregular in shape [19].

Whisker Reinforced Composite: Whiskers are short form of fiber where its microstructure is a single crystal[20]. They have shorter length compared to normal fibers. Their composite structure is strong and most successful application are manufactured using this reinforcement material[21].

Structural Reinforced Composite: consists of two types, laminar and sandwich type. **Laminar Composite** consists of two-dimensional sheets which are arranged in preferred orientation to achieve the highest strength desired. The sheets are stacked layer by layer.

The sandwich type is also layered composite which consists **face** and **core**. The face is formed by two strong outer sheets and the core is layer of dense material. The core can be honeycomb or a foam. Thickness of the core can be manipulated as needed [14].



(a) Laminar Composite

(b) Sandwich Composite

Figure 2. 2 Structural Reinforced Composites [22], [23]

Fiber Reinforced Composite: are composites composed of fibers that are embedded in matrix material. Fibers can be either continuous/long/ fibers or Short/Chopped Fibers/.

Orientation, fiber loading, distribution of fibers has a significant effect on the strength and other properties of the fiber reinforced composite material. Also using the short fiber and random orientation, loads from different directions can be resisted [24].

Compared to other reinforcement materials; The fiber reinforced composites are widely used materials because of their versatile orientation and length [18].

MATRIX MATERIAL: binds the reinforcement constituent together. The matrix protects the reinforcement from structural damage and chemical attacks. It provides the shape and form, provides toughness, stabilizes the composite against buckling, distributes stress [15], [25].

There are three types of matrix; Ceramic Matrix Composite, Metal Matrix Composite and Polymer Matrix Composite [26].

Ceramic Matrix Composite: these composites are composed of a ceramic matrix and fibers as the dispersed phase [26].

Metal Matrix Composite: they are composites composed of metallic matrix and fibers as the dispersed phase. Magnesium, Aluminum, iron, copper is used as the metallic matrix [26].

Polymer Matrix Composite: Polymers are large molecules made up of long chains of smaller molecules called monomers. This type of composite has three types of polymers used as a matrix. These are; **Thermoplastics, Thermosetting** and **elastomer** polymers. Matrix in case of polymer is called resin [26].

Epoxy: Epoxy resins have been well known and feasible thermosetting polymer used with curing cross-link agent known as hardener [27]. Epoxy has high effective strength, resistance to moisture, resistance to chemical attack, great electrical insulation, good adhesive properties, stiffness but do not have good UV resistance [28].

The resin's structure can be tweaked to produce a variety of products with differing levels of performance. Epoxies are mainly used to fabricate high-performance composites with superior mechanical properties. They are preferred first among the polyester resin and vinyl ester resin [28].

A good resin should have the following characteristics[21]:

- Good impregnation – allowing fibers to bind with resin
- Controlled moisture content – environmental factor should not affect it
- Non-toxic
- High availability

Table 2. 1 Advantage and Disadvantage of epoxy [29]

Advantage	Disadvantage
High mechanical and thermal properties	Expensive
High water resistance	Critical mixing
Long working time	Corrosive handling
Low cure shrinkage	Low UV resistance

2.2 FIBERS

2.2.1 TYPES OF FIBERS

Depending on source of the fiber there are two types of fibers. These are

- Natural Fiber
- Synthetic Fiber

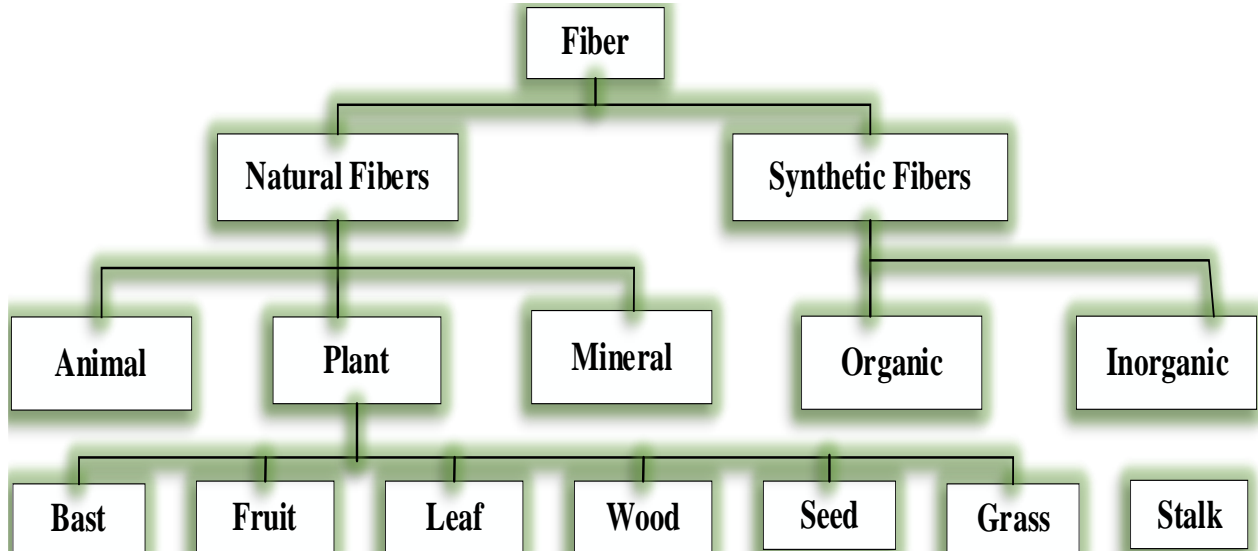


Figure 2. 3 Classification of Fibers [11][17]

SYNTHETIC FIBERS: They are long lasting fibers that are manmade which are derived from chemical resources. Petroleum byproducts are the major source of synthetic fibers. Most commonly used synthetic fibers are; Glass fibers, Carbon fibers and Kevlar fibers [10].

NATURAL FIBERS: They are naturally occurring fibers that can be sourced from plants, animals and minerals. These types of fibers exhibit superior mechanical properties such as stiffness, flexibility and modulus compared to synthetic fibers [30].

Nowadays, natural fibers are serving better material in terms of high strength to weight ratio, biodegradability and corrosion resistance when compared to other conventional materials. Composites reinforced with these materials are replacing metals due to the properties mentioned above. However, their lack of resistance to moisture, lower melting point has limited their use[31].

Table 2. 2 Advantage and Disadvantage of Natural Fibers

ADVANTAGES AND DISADVANTAGES OF NATURAL FIBERS	
ADVANTAGE	DISADVANTAGE
No health risks	The quality is dependent on different factors
Biodegradable	Lower melting temperature
Low density	Poor water resistant
Recyclable	Poor fire resistance
Low energy requirement during production	Lower durability
Low cost	
Easily available	
Light weight	
High specific strength and modulus	
Stiffness	
Flexible	
Non-abrasive	
Easy handling	
acoustic insulation	

Depending on their source, natural fibers are classified as; Animal fibers, Mineral fibers and Plant fibers. The natural fiber composites are innovative composite materials made up of a polymer matrix and high-strength natural fiber reinforcement [32].

Plant Fibers: Plant natural fibers are naturally occurring fibers consisting of cellulose, hemicellulose, lignin, pectin and wax [27].

They are abundantly available and that is the main reason for choosing this type of fibers over the other. Plant fibers can vary in properties and quality depending different factors such as; source, age, environment, processing methods, growing conditions, geographical and climatic variations. At the stage of growth: the quality and property depend on the species, location and climate of the environment. At the stage of harvesting: the quality can be affected by age, cell wall thickness. Even the extraction process can have big impact on the quality and property of the fiber. Therefore, it is very essential to study the fibers before proceeding to processing and selection [33].

These fibers have many advantages such as; renewability, recyclable, biodegradable, environmentally friendly, low cost. Some of the disadvantages are; hydrophilic, poor

wettability, poor fiber-matrix interface bonding, easy damage during fabrication, degrades when processed at temperatures excess of 200⁰C. these reasons reduce the strength of plant fiber reinforced composites [34], [35].

Natural plant fibers are divided into six depending on the part of the plant from which they are extracted. These are: bast fibers, leaf plant fibers, seed plant fibers, fruit plant fibers, wood plant fibers, stalk plant fibers and grass plant fibers [21].

Bast fiber: these types of fibers are collected from the skin or bast. They have higher tensile strength when compared with other plant fibers. Some of them are flax, Ramie, Jute, Hemp [21].

2.2.2 SISAL PLANT

Sisal is a plant known as *Agave Sisalana* which belongs to family of *Asparagaceae*. This plant mostly grows in the western hemisphere, Africa and Asia. The plant contains fleshy leaves usually long and narrow. These leaves are 1-2m long, 10-15cm wide and about 6mm thick at the center. In average, 200-250 leaves are produced by a sisal plant. One leaf consists 1000-12700 fiber bundles. Sisal fiber is one of the widely used natural fibers and is obtained from the leaves. The fibers are embedded longitudinally in the leaves and are most abundant near the leaf surfaces. Sisal fibers are about 1.0–1.5 m in length having a diameter of 100–300 μm [36].

Fiber contains 60% cellulose and some percentage of lignin. The high content of cellulose makes sisal fiber one of the superior natural fibers [37]. Sisal fiber has high tenacity and tensile intensity, abrasion resistance, salt water resistance, acid and alkali resistance and it is hydrophilic in nature [38].

2.2.2.1 EXTRACTION METHOD OF SISAL FIBER

These plants produce sword-shaped leaves which start out toothed, and gradually lose the teeth with maturity. Each leaf contains a number of long, straight fibers. There are three methods of extracting fiber from sisal plant. These are: Chemical extraction, mechanical extraction and retting extraction[39].

The Chemical extraction method involves an alkali, acids and enzymes. The retting method uses water and warm temperature to extract the fiber by microbial process. The mechanical or decortication process involves crushing, beating, and brushing of the plant with blunt knives

so the fibers remain. Even though it is time taking process, the mechanical extraction process is widely used because of simplicity and fewer setup.

2.2.3 FLAX PLANT

Flax is an annual herbaceous plant known as *L. Usitaissimum* which belongs to Linaceae family. It takes around hundred days to mature fully. The plant is cultivated for two distinct usages, one is for oilseed and the other is for flax fiber. The oilseed flax has a high oil content, have many secondary branches which increases seed yield and short stem and the flax used for fibers is long with a height of 80-150cm, slender, less branches and it contains 25% seed and 75% stem & leaves. From theses 75% stem, 25% is fiber [36], [40].

The stem of flax has a composite material structure. It has three layers; Bark, bundle and xylem. The bark serves as a protective cover it only allows water and other nutrients [20].

Flax fiber has a multilayer structure; primary wall on a secondary wall reinforced by cellulose. It has polygonal cross section with a central lumen. 10-40 elementary fibers held together by pectin and hemicellulose form technical fibers. The mean diameter of flax fiber is 15-20 μm [20], [41].

The fiber shows better specific tensile properties. In addition, it has low density, high strength and stiffness. It is believed to be one of the strongest natural fiber candidates to replacing synthetic fibers [41], [42].

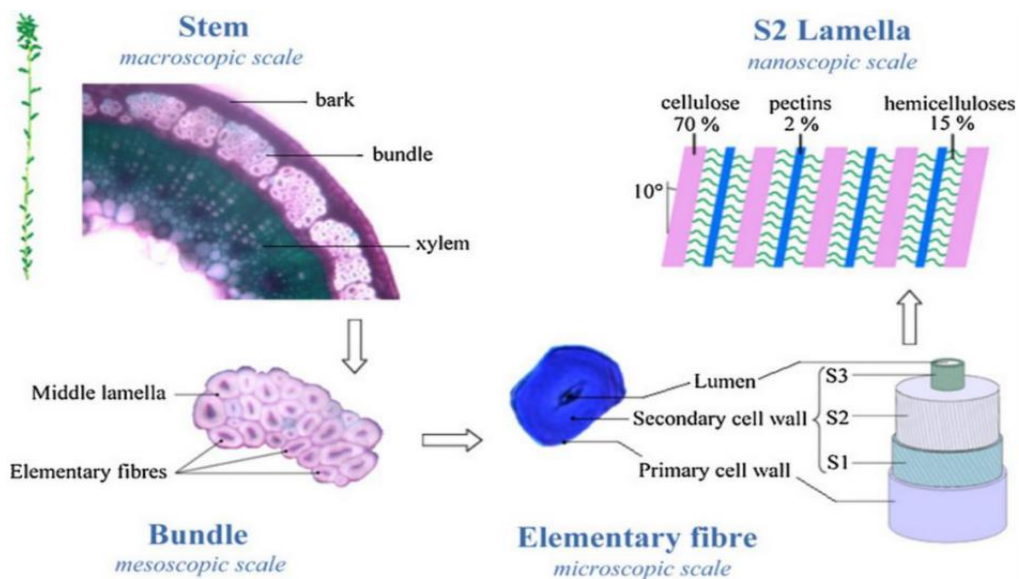


Figure 2. 4 Structure of flax fiber [43]

2.2.3.1 EXTRACTION METHOD OF FLAX FIBER

Flax fiber is extracted from the bast of flax plant. For high quality of fiber, the plant must be harvested before full maturation.

The following are the extraction processes executed to obtain good quality flax fiber.

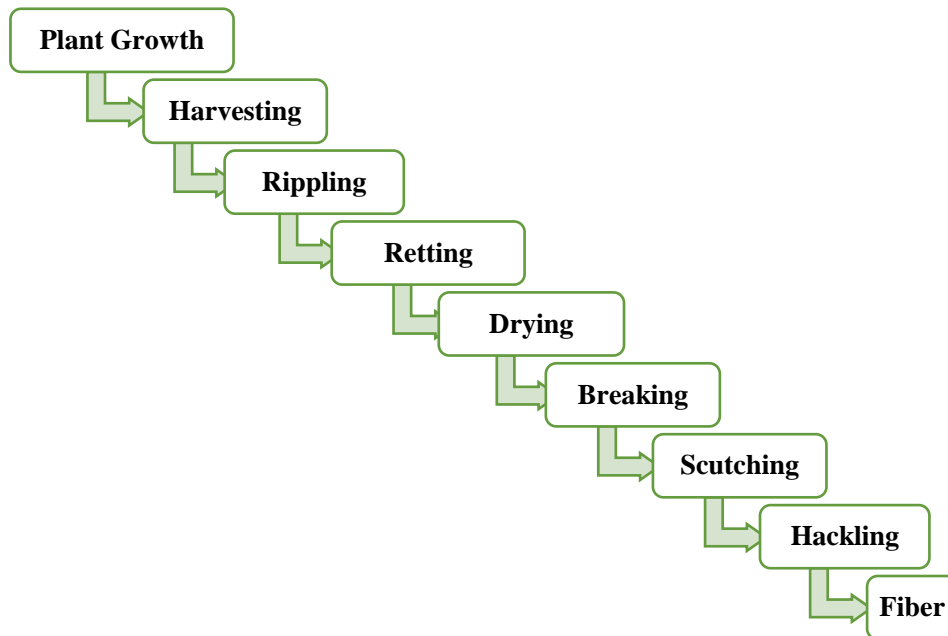


Figure 2. 5 Extraction process of fiber

Rippling: is removal of the seed by drawing the bundle through dense comb like structure [44].

Retting: This is microbial process where separation of cellulosic fibers from non-fiber tissues occurs. Here the bast fiber and core tissue separates because of enzymatic action. In addition, pectin degradation occurs [44].

There are two methods used to ret flax plant. These are; **Water Retting** and **Dew Retting** [44].

Water retting is done by submerging bundles in water. And Dew retting is done by spreading evenly out the fiber plant out in moist meadows or grassy field.

For water Retting it can be done in a pond, stream/river, or tank. It has 2-3weeks long process [44].

After retting it is necessary to **dry** the flax and then remove the remaining straw to extract pure fiber. To do that a process called **dressing** is used. Dressing consists; **Breaking, Scutching** and **Hackling**.

Breaking: it is breaking up the remaining straw into shorter segments. Here a beater which is a blunt wooden blade like structure with upper and lower jaw that mesh together is used. The bundles are beaten between the jaws till it is softer [44].

Scutching: here, the straw is scraped away from the fiber. A wooden scutching knife is used. In this process some the fibers will also be scutched away and that is unavoidable [44].

Hackling: In this process, the fiber bundle is pulled through various different sized comb like structures made from longer and sharper nails [44].

After these processes fine and a good quality fiber can be obtained. The research has followed each step to extract the flax fiber from the plant.



(a) Breaking Flax Fiber

(b) Scutching Flax Fiber



(c) Hackling Flax Fiber

Figure 2.6 Dressing of Flax fiber [45]

2.3 MANUFACTURING METHODS OF COMPOSITES

There are numerous numbers of manufacturing techniques in production of composite materials. There are; hand lay-up on open mold, Hand layup assisted by vacuum bagging, resin infusion, spray-up, RTM and VARTM, RTM light, hot press molding, cold/warm press

molding, filament winding, pultrusion and autoclave. Selection of a method depends on the materials, design and application [46], [47].

Hand lay-up on open mold: this type of manufacturing is the simplest and most widely used method. It required higher labor force but low cost and it is an effective process [47]. Open mold creates only one side of a product. Lay-up is performed in the following steps: brushing or spraying of releasing agent is applied after this a thin coat of resin and layer of reinforcement are placed on it. After that, rollers and brushes are applied to fully impregnate the reinforcement. The layers are added until desired thickness is achieved. When complete the product is laid to cure properly. After cure, the product is detached from its mold [46].

2.4 FACTORS INFLUENCING THE PERFORMANCE OF COMPOSITES

Selection of fibers and their orientations, selection of matrix and selection of manufacturing methods can be done to tailor composite for a needed application [34]. Under selection and orientation of fibers; fiber type, harvesting time, extraction method, treatment, aspect ratio, orientation should be considered to attain the best result. Under matrix selection; matrix type, interfacial strength should be considered.

There are different factors that influence the performance of composite material. Some of them are; Fiber selection, matrix selection, fiber loading, treatment of fibers, fiber orientation, manufacturing method, environmental conditions.

Fiber Orientation: this creates direction dependent specific properties for the composite [14], [48].

Fiber Volume fraction / Fiber loading: this is the ratio of fiber to matrix. This specifically depends on the material used and orientation. The mechanical property increases dependently [14].

Fiber/Matrix Interface: this is the bond strength between the two constituents of composite. Load is transferred between the matrix and fibers, to withstand and transfer the load the interface bonding should be good. It is crucial to decide the performance and properties of composite.

Good interfacial bonding can be achieved by dispersing the fibers into the matrix thoroughly, this reduces voids by ensuing the fibers are fully surrounded by the matrix material. If there is

poor adhesion between the fiber and the matrix, weak dispersion of force develops, resulting in poor mechanical properties of the composite.

For Plant fiber composite, this interfacial bonding is weak because of hydrophilic nature of the fibers and this limits the mechanical ability and moisture resistance [14].

Fiber Treatment: proper fiber treatments increase the interface adhesion between the fiber and matrix, and decrease water absorption [49]. Most treatments increase the surface roughness which leads to better interlocking between the constituents. Treatments also reduce the hydrophilic behavior of fibers especially plant fibers. This in turn enhances the mechanical strength and dimensional stability [27].

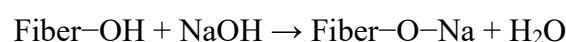
Natural fibers have lots of advantages, they also have few drawbacks and high moisture absorption (hydrophilic) behavior is the major problem associated with natural fibers. Therefore, the external surface fiber cell wall is treated to eliminate pectin, lignin, waxy substances, and natural oils. This reveals the fibrils, and provides a rough surface topography [50].

Different Physical, biological and treatments can be done on fibers. Such treatments include; Corona, plasma, silane, acetylation, enzyme and alkaline. These treatments alter the properties of natural fibers significantly [51].

Alkaline treatment: Alkaline treatment also known as mercerization is one of the most used and simple chemical treatments. The mercerization process removes certain amount of wax, lignin, hemicelluloses and depolymerizes the cell wall and exposes the short length crystallites, this results in change of the structure, morphology, dimension and consequently mechanical performance [51].

mercerization increases number of reactive sites and allows better fiber wetting [52]. It reduces the fiber diameter which in turn increases the effective contact area with the matrix. This leads to better adhesion between the matrix and fiber. In addition, Alkali treatment reduces the fatigue properties due to better fiber packing density [53].

Sodium hydroxide (NaOH) is the chemical used in alkaline treatment. This method removes the hydrogen bonding in the network structure of the fiber's cellulose. The following is the chemical reaction of fiber hydroxyl with sodium hydroxide [51].



2.5 HYBRID COMPOSITES

Composite with two and more reinforcement phase or with two or more matrix phase is called hybrid composite. Hybridization helps to tailor the properties of composites to get the best properties required.

It is used when a material is required to attain combination of properties (tensile modulus, compressive strength and impact strength) that can be obtained from different reinforcement or matrix materials [54]. Hybridization provides combination of properties that cannot be realized by an individual composite component [55].

Considering the reinforcement as fiber, hybrid composites reinforcement can be a combination of Synthetic– Synthetic, Natural – Synthetic and Natural - Natural fiber [49].

The hybrid constituents of composites can be arranged in the following ways [56]:

1. **Inter ply hybrids:** in which two or more plies are arranged in a way that they do not interfere with hybrids that have the same reinforcements.
2. **Intra ply hybrids,** in which two or more fibers are mixed in the same ply.
3. **Intermingled hybrids** where the constituent fibers are mixed randomly as possible so that no concentrations of either type are present in the material.
4. **Selective hybrids** where placements in which reinforcements are placed wherever additional strength is required, over the base reinforcing laminate layer
5. **Super hybrid** composites which contain metal foils or metal composite plies stacked in a specified orientation.

In this research, natural – natural hybrid and intermingled hybrid arrangement was used to fabricate the composite.

2.6 PROSTHETICS LIMBS

War, natural disasters, chronic diseases, vascular diseases, cancer, infections are all contributing factors that lead to amputation and demand for prosthesis. Prosthesis is an artificial missing body part structure that replaces amputated or missing body part. The function of the prosthesis is helping the patient return to state of life prior to amputation.

The first prosthetic in the world dates back to the 15th century BC in the ancient Egypt. It is a big toe prosthetic made of cartonnage a material made of layers of papyrus covered in plaster and it is strapped onto the foot in a fashion similar to an Egyptian sandal [57].

Prosthesis should be comfortable to wear, easy to put on and off, durable, light weight, functioning well and require reasonable maintenance [1]

Generally, based on level of amputation prosthesis can be classified as;

- **Below the knee (Transtibial):** this is a prosthetic that is attached to an intact upper leg.
- **Above the knee (Transfemoral):** this is a prosthesis attached starting from above the knee. Therefore, it includes prosthetic knee.
- **Below the elbow (Transradial):** prosthetic that replaces the forearm.
- **Above the elbow (Transhumeral):** this is a prosthetic of lower and upper arm that also includes the prosthetic elbow.

The prosthetic legs basically contain; **Socket, Knee Joint, Pylon, Knee, Foot-ankle assembly** and **Suspension system** [1].

Socket: It is the most important part where contact between the stumps and the prosthesis occur. Transmits the force and protects the stumps. It provides support and relief [1].

Prosthetic sockets must have durability, sufficient strength to withstand maximum expected stresses, perfect close fitting with the stump, safe, stability, minimum weight and low cost. It should be manufactured according to degree of mobility required and the shape of the patient [9].

There are two types of sockets, these are; rigid and soft concave sockets. **Rigid sockets** distribute the loads generated during gait cycle on the residual limb. **soft sockets /liners/** are soft material that cover the residual limb. They provide comfort, freedom of movement and transfer of loads, and diffuses uniform pressure over the entire surface of the stump [9].

2.7 PROSTHETIC SOCKET

The prosthetic socket is the main part of the prosthesis as it represents the critical interface between prosthesis and the residual limb. Its main function is to hold and protect the residual limb. To ensure that the correct fitting, sockets are fabricated from mold of person's residual limb [58].

The prosthesis socket is divided into three portions. The top portion is called **seating face**, the central portion is the **controlling socket** area with the function to ensure correct movement and restrain it in the P-A direction, which is important during the gait. The last portion is the **distal**

socket end which, should transfer few percentages of an individual's weight to avoid inappropriate load transfer and subsequent damage to soft tissues [59].

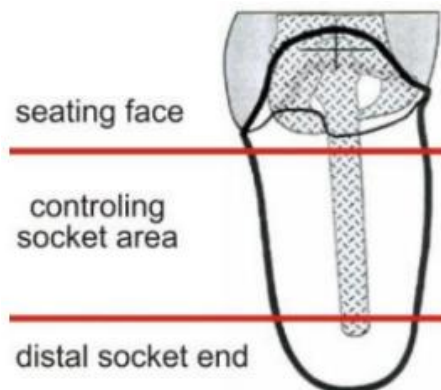


Figure 2. 7 Prosthetic Socket Parts [59]

A socket must ensure proper transfer of load, stability, efficient fitting and provide efficient control during movement [60].

Improper prosthetic socket can causes skin problems such as; raise in temperature, pressure ulcers, hyperhidrosis, irritations, friction blisters, unpleasant odor, infection and bacterial invasion to residual limb [58].

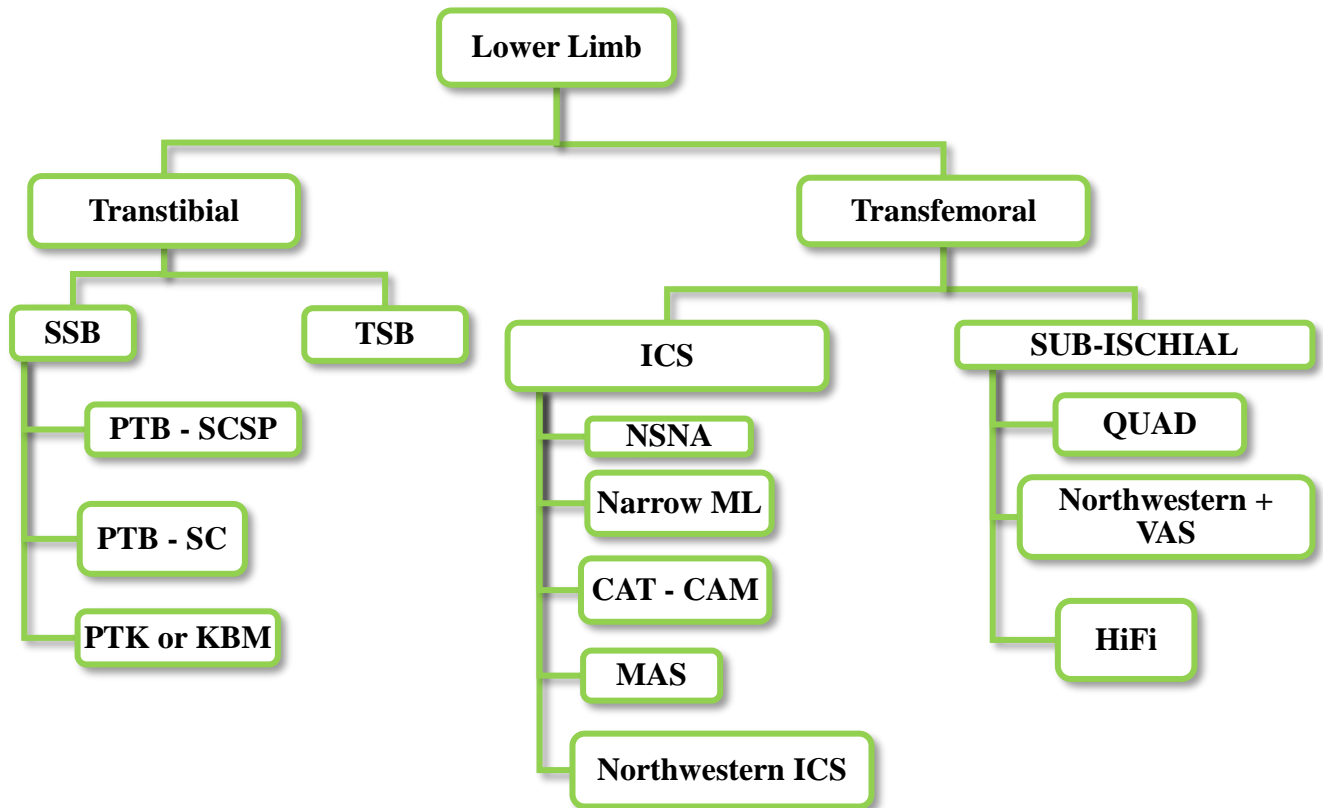


Figure 2. 8 Prosthetic socket classification for lower limb [60]

N.B. SSB = Specific Surface Bearing, TSB = Total Surface Bearing, ICS = Ischial Containment Sockets, PTB = Patellar Tendon Bearing, SC = Supra Condylar; SCSP = Supra Condylar Supra Patellar, PTK = Patellar Tendon Kegel, KBM = Kondylen Bein Muenster, NSNA = Normal Shape Normal Alignment, Narrow ML = Narrow Medio Lateral, CAT-CAM = Contoured Adducted Trochanteric - Controlled Alignment Method, MAS = Marlo Anatomical Socket, QUAD = Quadrilateral, VAS = Vacuum Assisted Socket

2.7.1 MATERIALS USED FOR PROSTHETIC SOCKET

In order to make prosthetic socket functional, material selection plays major role. Before the introduction of composites and thermoplastics prosthetic sockets were fabricated from materials such as, wood, leather, metal and latex [1].

High-tensile-strength materials increase device suspension and adjustability by decreasing sliding during the gait cycle. However, it's also crucial to look at the materials' adhesion and deformation qualities [9].

Rigid prosthetic sockets are usually made from thermoplastic or thermostable polymers. Most commonly used materials are; Polypropylene and Polyethylene. Most prosthetic sockets are made from polypropylene. This material is resistant to many chemical solvents, bases and acids [1], [9], [61].

Nowadays, natural fibers are more used in sockets for prostheses, as they increase mechanical properties such as strength, hardness, stiffness and dimensional stability of polymeric compounds. In addition, use of natural fiber-based composites as socket reduces the manufacturing cost and provides eco-friendly replacements to plastic based sockets [1].

2.8 RELATED RESEARCHES

In recent years the method of using natural composite materials has increased significantly. There are different researches conducted on different natural hybrid fibers, their composition and application on prosthetic limbs.

RELATED TO SISAL FIBER COMPOSITE

M. Boopalan et. al, investigated and compared properties of raw and treated composite of jute-sisal fiber reinforced epoxy composite. 20% NaOH for 2h was used to treat the fibers before introducing them into epoxy matrix. The obtained result showed that the treated composite exhibited higher tensile and flexural strength than that of the raw [15].

M. Ramesh et. al, evaluated and compared the mechanical properties hybrid glass-sisal fiber and hybrid glass– jute fiber reinforced epoxy composite. Tensile, flexural tests and SEM examination was carried out. The result showed the integration of sisal with GF gives superior properties than that of jute in tensile properties but the jute and GF combination gives better flexural property [62].

R. Rana et. al, studied, sisal and glass fiber were reinforced into the epoxy matrix. Sisal fiber was chemically treated by acetylene to increase the interfacial bonding between fiber-matrix. Two fixed layer of glass fiber with different weight percentage of sisal fiber (0%, 2%, 4%, and 6%) was reinforced with epoxy matrix composite. As a result, there was 4% increase in tensile and flexural strength as sisal fiber composition decreased [63].

A. Betelie et. al. Deals with the investigation of fracture toughness behavior of sisal reinforced epoxy composite using fracture toughness testing method by including stress intensity factor K. Chopped sisal fibers was used as reinforcement. The samples have been fabricated by using

the epoxy resin (AY-105) as a matrix and the hardener (HY-951) and sisal fiber with the 15%, 25%, 30%, 35% and 40% fiber weight fraction with random orientation and Hand lay-up fabrication technique was used. The result showed the 30% sisal composition had superior fracture with KIC of 5.54MPa and critical strain energy release rate (GIC) of 13.72 MPa·mm. from this it was concluded, using chopped sisal fibers as reinforcement in epoxy could successfully develop a composite material with high strength and rigidity for light weight material [64].

From the literatures it can be observed that, treated and chopped sisal fiber gives better mechanical properties.

RELATED TO FLAX FIBER COMPOSITE

B. Muralidhar, investigated the thermal, mechanical and thermomechanical properties of flax hybrid reinforced epoxy composites. Hand lay-up method was used to fabricate the composite. The characters studied were; Thermogravimetric analysis (TGA), Dynamic mechanical analysis (DMA), Tensile, compression and scanning electron microscope. The TGA test indicated a decrease in thermal stability of the matrix. The DMA showed a shift in the glass transition with the addition of flax hybrid. The tensile strength and stiffness are a product of the fiber/matrix synergy, whereas the compressive strength and stiffness are contributed by the reinforcing matrix. The failure mechanism was analyzed, by SEM. It was concluded that hybrid composite offers better performance [65].

H. Assaedi et. al, presented the mechanical and thermal properties of geopolymer based composites reinforced with flax fiber. The composite was reinforced with 2.4,3 and 4.1% woven flax fiber in different layers. The fabrication method used in this study was hand lay-up. The flexural strength, compressive, hardness and fracture toughness, Fourier transform infrared spectroscopy, scanning electron microscopy and thermogravimetric analysis tests were carried out. The mechanical properties showed superior performance when the flax fiber content was increased. From the thermal test it was shown that, the flax fiber significantly degrades at 300°C [66].

M. Ghasemzadeh-Barvarz et. al, investigated aging and mechanical properties of flax - glass fibers reinforced polypropylene hybrid composites. The adding of glass fiber improved the tensile strength and impact resistance has very low effect on train at yield and elongation at break. From the tests, it showed that glass fibers enhance water resistance of polypropylene/flax composites. Thermal aging at 85°C shows, composites are thermally resistant. According to

accelerated UV aging tests, the presence of glass fiber accelerates the degradation of the polypropylene matrix, but flax fiber protects the composites [67].

From the literatures, it can clearly be observed that flax fibers composites have good thermal resistivity. And in hybrid conditions, increasing the flax content increases the mechanical properties of the material.

RELATED TO FLAX – SISAL HYBRID COMPOSITE

Ganesh R Kalagi et. al, in this research, damping properties of Flax - Sisal fiber reinforced hybrid epoxy composite was studied. 300 x 300 x 5mm plate was used to test the damping effect of the composite. The three composites had composition of 20% Sisal 5% Flax 75% epoxy, 20% Sisal 10% Flax 70% epoxy, 20% sisal 15% Flax 65% Epoxy. The Fast Fourier Technique was used to obtain frequency, damping and mode shape. And it was concluded that 20% Sisal 15% Flax 65% Epoxy were eligible to replace glass fiber for industrial application such as wind turbine blade [68].

Ganesh R Kalagi et. al, tested the mechanical behavior of SiC Nano powder/flax/sisal fiber reinforced epoxy-based hybrid composites. Tests such as; Flexural strength, tensile strength, hardness, and impact strength of the composites was carried out. It has been observed that impact strength was improved with the increase in the weight fraction of natural fibers to some extent. From tested compositions 17% Flax, 17%Sisal 6%SiC was better composite. Maintaining its low density, 6% SiC in epoxy improved the impact strength up to 137.66KJ/m², tensile up to 28N/mm² and flexural up to 63N/mm² [69].

Santosh Madeva Naik et. al, Studied hybrid composite of flax and sisal with epoxy matrix. The various compositions used are; 20% Sisal 5% Flax, 75%. The Other Composition is 20% Sisal 10% Flax, 70% Epoxy and In Another Composition 20% Sisal,15% Flax, 65% Epoxy. Used hand layup to fabricate the composite. Tensile, compression and flexural was tested. it was concluded that, tensile strength, compression strength and flexural strength is high for the combination 20% sisal+15% flax+65% epoxy resin and low for 20% sisal+5% flax+75% epoxy resin. It was observed, when the percentage of sisal and flax is more, the tensile strength, compression strength and flexural strength increases [70].

G Rajamurugan et. al, investigated mechanical, twist drilling performance and microstructural analysis in aluminum foil reinforced sisal-flax epoxy composite. Six composites were fabricated using hand layup with two different orientations. tensile, flexural,

impact, and hardness investigation were tested. The obtained results showed that SF6 – 9.19% flax 0.82% Al. foil Sisal 6.64% and Epoxy 83.33% composite holds the excellent mechanical properties like tensile strength (31 MPa), flexural strength (76 MPa), impact strength (1.5 J), and hardness value (23 VHN) compared to other combinations [71].

From literatures related to flax-sisal composites, it is observed that, flax-sisal composite is eligible to replace glass fiber materials for industrial applications. With the volume percentage increase of these fibers the impact strength can be enhanced especially, the increase of the flax constituent in the hybrid results in the increase of the tensile, compression and flexural strength.

RELATED TO CHEMICAL TREATMENTS

C. M. Meenakshi et. al, this study analyzed the effect of surface treatment of flax, sisal and glass fiber reinforced composites on mechanical, thermal, and water absorption. After testing the specimens fabricated, The Tensile strength of glass - flax fiber reinforced hybrid increased by 58%, the flexural 36% and impact by 51%. after surface alkaline treatment using 5% NaOH. Using SEM, the interfacial bonding properties were analyzed. The study concluded that, surface treatment improves the performance of natural fiber in hybrid fiber-reinforced composites, particularly flax fiber [72].

D. Cavalcanti et. al, focuses on the effect of hybridization and chemical treatments on the mechanical properties of Jute, sisal and curauá fibers with epoxy matrix composite. The products were fabricated by hand lay-up technique. The volume fraction used was 30-70 fiber-epoxy. Tensile, flexural and impact tests were carried out according to ASTM. The result showed significant improvement of the mechanical properties by addition of the natural fibers to pure jute-based composites. Alkaline treatment was implemented on the fiber and the result showed increased mechanical property for the sisal reinforced hybrid composites but it had a negative impact for the jute + curauá hybrid composites. But the mixed alkalization + silanization treatment had a positive effect on the jute + curauá flexural properties, while decreased the flexural properties for the jute + sisal composite [49].

From the literatures it can be concluded that, 5% Alkaline treatment of flax-sisal hybrid fibers, the mechanical properties significantly increase, particularly flax fiber.

RELATED TO PROSTHETIC AMPUTATION IN ETHIOPIA

Berhe Gebreslassie1 et. al, the research focused on patterns and causes of amputations in patients presented to Ayder Referral Hospital, Mekelle, Ethiopia. 87 patients who had

amputation in three years were reviewed retrospectively. From these 87, 78.2% were males. Their age was from 3 to 95 years, and the mean age was 40.6 years. The most common indications were trauma (37.7%), tumor (24.1%), and peripheral arterial disease (20.7%). major lower limb amputation (58.6%) was the most. This includes above knee amputation (35.6%) and below knee amputation (23%). The second largest was digital amputation (17.2%). There was 11.4% major upper limb amputation of which there was one patient who had re-amputation [73].

From the literature it can be observed that amputation is a great concern in Ethiopia but, there are very limited researches.

RELATED TO PROSTHETICS

Harsimran Jeet Singh Sidhu et. al, the goal of this research was to fabricate a prosthetic leg which can fill the gap between the imported and conventional leg. The leg was designed to be lighter in weight and cheaper. This was accomplished by assessing the shortcomings of the traditional leg and proposing improvements that result in a lighter leg. Following that, using the features of several polymer matrix composites materials, the optimum material for lowering weight was discovered to be E-Glass Epoxy. The socket for the prosthetic leg was developed in SOLIDWORKS utilizing the material properties of this composite, and stress analysis was performed using simulation studies [74].

S. M. Abbas, this study used nine types of laminated composites (perlon, n-glass, glass fiber and carbon) to investigate the tensile and fatigue properties of partial foot prosthetic socket which was fabricated by vacuum pressure system with 80:20 composition. The results showed that the mechanical properties were improved by increasing the two layers of carbon fiber, glass fiber and n-glass layers instead of zero layer with six layers of perlon lead to the increased in yield strength, ultimate tensile strength and modules of elasticity with (71% ,76% and 58%) respectively for carbon fiber, (20%, 19% and 40%) for fiber glass and (22%, 5.5% and 29%) for n-glass. Results showed that (3perlon+2carbon fiber+3perlon) gives the best value of mechanical properties and has higher Endurance limit stresses [75].

Andrew Campbell et. al, investigated the feasibility of using a renewable plant oil-based polycarbonate-polyurethane copolymer resin and plant fiber composite, instead of conventional materials to improve safety and accessibility of prosthetic limb manufacturing. Socket of both conventional composite materials and plant fiber composites were constructed and tested. As a result, combinations of plant resin and either banana or ramie fibers gave high

tensile strengths. Socket made from conventional material and ramie-plant resin composite socket failed at a similar loading. They concluded that, the plant resin and ramie fiber composite socket have the potential to replace the standard layup. Such composite materials reduce environmental impact [8].

Mohsin Al-Shammari et. al, investigated the influence of volume fraction and lay-up of layers on tensile, flexural strength and fatigue for composite material was investigated. Woven carbon fibers, knitting perlon with acrylic resin as a matrix with different volume fraction were used. The first proposed laminate has eight layers with lay-up (3-perlon + 2-carbon fiber + 3-perlon) and the other have ten layers with different lay-up (2-perlon + 1-carbon fibers + 1-perlon + 2-carbon fiber + 1-perlon + 1-carbon fibers + 2-perlon). The second composite gave an excellent result in tensile, flexural and fatigue tests. The ultimate tensile strength and Young's modulus increased by approximately factor 3.77 and 2.61 respectively with increasing fiber volume fraction into 40.63% and by approximately factor 1.96 and 1.36 respectively for 26.2% fiber volume fraction of first proposed composite if they compared with matrix material and the endurance limit of the second composite material was about twice the endurance limit for the first where it was a positive indication [76].

D. Chandramohan & A. John Presin Kumar, this paper reviewed literatures on composites that focus on mechanical properties of fiber reinforced composites for prostheses. In the present scenario sustainable alternatives to conventional materials, specifically glass fibers are to be used within the lamination of prosthetic sockets. Natural fibers are known and compared to artificial fibers to see their viability through the subsequent measures: mechanical properties, environmental effects and health hazards. It was concluded that the combining of natural fibers with polymer matrices results in an improvement of mechanical properties[77] .

By using renewable plant fiber composite material with low environmental impact can be manufactured. It can also be absorbed, there is limited literature studies on prosthetics with natural fiber composites.

RELATED TO PROSTHETIC SOCKETS

Mohsin Abdullah Al-Shammari et. al, the study is composed of experimental and theoretical sections. For the experimental part: the interface pressure between stump and socket was measured using F-Socket. and for the theoretical part; the result was calculated analytically. The combined result of the two with the geometry was fed into ANSYS for numerical simulation to obtain the equivalent Von-Mises stresses and safety factors. Composite materials

were suggested and for this material the results showed that the maximum equivalent Von-Mises stress is equal to 15.42 MPa [78].

Nazik Abdulwahid Jebur et. al, here, composite material with 3pyrilon,3carbon,3pyrilon was fabricated. The patient case study was 23-year-old, 85kg man with amputation below the knee of his right limb. The ground reaction force test and F-Socket test was done to measure the interface pressure between the stump and socket. In addition, mechanical tensile test was employed on specimens fabricated from same material as the socket to find modules of elasticity (1.109 GPa), yield stress (34 MPa), and ultimate stress (38 MPa). The simulation of prosthetic socket was performed using ANSYS to find equivalent Von-Mises stress (18.5 e7 Pa) and maximum deflection (0.00604 mm) [79].

Fahad M. Kadhim et. al, in this work, three types of composite materials were proposed as an alternative to polypropylene which is material used for prosthetic socket. Tensile test, fatigue test and pressure measurement between stump and socket was executed. The result shows that the yield stress, ultimate stress and the modules of elasticity is increased in 22%, 15% and 21% respectively for the first group of suggestion material relative to the variable material (polypropylene), While the yield stress, ultimate stress and the modules of elasticity is increased, 56%, 52% and 22.5% respectively for the second group relative to the polypropylene, and 72%, 71% and 36% respectively for third group. The best is from the third suggested group which is two layers of bamboo, one layer of carbon fiber, two layers of bamboo, one carbon fiber, two layers of bamboo with lamina due to its high mechanical properties [80].

Kahtan Al-Khazraji et. al, Using the vacuum molding technique, five laminated composite materials were used to manufacture trans-tibial prosthetic sockets in this study. Perlon layers, fiber glass layers, carbon fiber layers, hybrid (carbon and glass) fiber layers, and hybrid (carbon and glass) fiber layers with micro-Silica particles reinforce the matrix, which is made up of 50 wt. % Epoxy and 50 wt. % PMMA. tensile, shear stress, fracture toughness and bending tests was done. Failure index, factor of safety and fatigue ration were dealt with calculation. By observing the contours distribution of fatigue life, safety factor, equivalent Von Mises stress, total deformation, and maximum shear stress, ANSYS was used to analyze and evaluate alternating bending fatigue characteristics. The ultimate tensile strength of (Blend with Glass reinforcement) was found to be the highest. The highest maximum shear stress, fracture toughness, fatigue limit, strain energy limit and safety factor are obtained in Blend with Glass

composite with 59.42 MPa, 8.45 MPa.m^{1/2}, 62 MPa, 96.66 Joul/mm³ and 9.3, respectively. Reinforcement with perlon gave the lowest values in all measured properties. Therefore, (Blend with Glass reinforcement) was selected as the best candidate for prosthetic socket [81].

Muhsin J. Jweeg et. al, this study used perlon and carbon fibers as reinforcement and Acrylic as a matrix. The mechanical properties were studied using tensile, bending tests and fatigue test. F-socket apparatus was used to measure the interface pressure between the residual limb and socket. ANSYS was used to calculate the deformation, maximum principal stress, and safety factors. The results showed that laminations laid-up from eight layers of perlon plus four layers of carbon gave optimum mechanical properties. A total contact socket with a high Young's Modulus will provide the best level of patient comfort. With increasing stump length, the maximum principal stress and total deformation increased: A long socket's maximum principal stress increased by 0.3% over a medium socket's, although the medium socket's overall deformation was lower than the long socket's [82].

Agustinus Purna Irawan et. al, researched on the tensile and impact strength of bamboo fiber reinforced epoxy composite for above knee prosthetic socket. Here, the laminated composite was made with woven bamboo fiber. The fiber volume fraction was 10,20,30,40 and 50%. Then, tensile test, impact test and compressive test of socket prosthesis was carried out. Prototype was made and tested. The results were: tensile 78.09MPa, modulus of elasticity of 8.96GPa, impact strength of 57.93KJ/m² and compressive strength of 87.1KN. It was concluded that BRECO have the potential to further development as above knee prosthetic socket material [83].

Agustinus Purna Irawan et. al, Rattan fiber reinforced epoxy composite was developed for lower limb prosthetic socket. Three tests were executed. These were; the compressive, gait analysis by using Six Minute Walk Test Method (6MWT), and psychophysical analysis by measuring the pulse rate of the respondents before and after gait analysis. The test results showed that maximum compressive load of socket: (5.54 ± 0.3) kN. Such as besides, gait analysis results showed that walking speed: (0.6 ± 0.01) m/s, cadence: (86.3 ± 0.33) steps/min, step width: (20.8 ± 0.84) cm, stride length: (84.4 ± 1.14) cm, stride total: (259 ± 1.00) cycles, and walking length total: (218.6 ± 3.41) m. Furthermore, the result of measurement of pulse rate before test: (84.6 ± 0.83) pulse/min and after test: (88.9 ± 0.92) pulse/min. Therefore, it was concluded that, RFREC materials can be used to develop prosthesis socket with good level in safety and comfort [84].

A.P. Irawana, et. al, investigated properties of socket prosthesis made from chopped ramie fiber reinforced epoxy composite (RE). Filament winding method was used to fabricate socket prosthesis. Tensile and Flexural tests were applied. Separate tests were performed on each socket prosthesis made of ramie polyester composites (RP) and FGP as a comparison. When compared to RP and FGP composite materials, the results showed that socket prostheses made of RE have the highest tensile and flexural strengths. RE composite materials have tensile strength of 86 ± 6.07 MPa and Young's Modulus of 9.56 GPa. The flexural strength of RE composite materials is 103 ± 15.62 MPa. RE composite material can be replacement to glass fiber [85].

M H Nurhanisahl et. al, this study developed a prosthetic socket made from kenaf-glass fiber composite as a possible replacement for a prosthetic socket made of fiberglass polyester composite. Woven kenaf, glass silk knitted fabric, and nylon knitted fabric are all used in the laminate. The volumetric and mechanical properties of kenaf fabric layering sequence were investigated. The flexural and impact strength of 2 layers of kenaf fiber-based laminates are 7.11 MPa and 16.7 kJ/m² respectively which is higher than the single layer kenaf fabric-based composites. From the results woven kenaf can be a replacement to glass fiber reinforced epoxy composite[61].

Dominic Monette1et. al, this research used impact testing on flat and socket shaped composite. Accelerometers, load cells, and a dynamometer were used to quantify sample vibration dissipation. Composite sockets made entirely of flax fibers were lighter and more effective at dampening vibrations than sockets made entirely of carbon fiber, lowering vibration amplification by roughly four times. The mechanical qualities of the composite, such as vibration damping, might be improved by increasing fiber volume fraction when using the traditional socket manufacturing method, and flax fiber benefits could be studied further. The research finally concluded that flax fiber has better vibration damping than carbon fiber and fiberglass. For prosthetic leg assembly, flax or flax hybrid sockets were the most efficient at damping vibrations [86].

J. K. Odusote and A. T. Oyewo, investigated mechanical properties of pineapple leaf fiber reinforced thermoset composite as possible alternatives to the above-knee glass fiber reinforced prosthetic socket. Treated continuous pineapple leaf fibers were used, and then added to epoxy and polyester at fiber loadings of 0, 20, 30, 40 and 50% to produce fiber reinforced composites using the hand lay-up method. Results from the investigation showed that PLEC, particularly at 40% fiber loading, had superior mechanical properties than GFPC and PLPC. The tensile,

flexural and impact strengths of PLEC are 76.47 ± 3.85 MPa, 81.27 ± 1.77 MPa and 59.03 ± 0.99 k/Jm², respectively. Thus, it was concluded PLEC has the potential to be replacement for glass fiber in above-knee prosthetic sockets [87].

Jamiu K. Odusote et. al, worked on banana pseudo fiber epoxy composite. The tensile, flexural, and hardness properties of the composite was investigated. Samples were treated with 5 % NaOH and 2 % asetic acid solution and are continuous fibers. Hand-lay-up method with the fiber ratio of 0, 20, 30, 40 and 50 % was fabricated. The results of 30 % glass fiber polyester composite (GFPC) were compared with those of banana pseudo stem epoxy composite (BPEC). The tensile, hardness and impact tests of BPEC at 40 % fiber content were 64.23 ± 4.11 MPa, 63.31 ± 0.03 MPa, 55.23 ± 0.20 BHR, respectively. These were slightly lower than those of the glass fiber composite, which are respectively 65.72 ± 3.30 MPa, 66.10 ± 1.88 MPa, and 61.05 ± 1.77 BHR. Finally, it was concluded that BPEC can further be developed to be used as a potential replacement for glass fiber composite in prosthetic socket [88].

Prasanna Kumar Lenka and Amit Roy Choudhury, developed a realistic three-dimensional finite element model of prosthetic socket to find the stress distribution pattern under relevant loading condition during normal walking. ANSYS was used to conduct the analyses. The analysis assumed that all structural materials were linearly elastic, homogenous, and isotropic. Sockets were made of various materials, whereas the socket adopter was made entirely of polypropylene. The analysis was performed on sockets with thicknesses of 2mm, 3mm, 4mm, 5mm, and 6mm in different materials. The bottom of socket was fixed and vertical loads in relation to stance phase of gait cycle were applied under static condition at the patella tendon brim. The 3 mm laminated composite sockets were found to be optimum in terms of strength, weight and factor of safety [89].

The literatures related to prosthetic socket shows that, natural fiber composites for the application of prosthetic socket are capable of replacing conventional materials such as; polyethylene, polypropylene and glass fiber. In addition, multiple literatures have used ANSYS software to analyze the materials equivalent von-misses stress, safety factor and deformation.

2.8.1 GAPS IDENTIFIED

From the above literatures and others, even though, they have some drawbacks such as; high moisture absorption, quality variation depending on harvest season and growing site; it is understandable that natural fiber composites are becoming the most favorable materials. The use of prosthetic is essential especially in the developing countries.

- For both Natural fibers and prosthetics, significant number of studies has been conducted. However, inadequate study on hybridization of natural fibers especially, flax and sisal hybrid were observed.
- Insignificant number of researches on hybridized natural fiber composite in Ethiopia.
- The application of these hybridized composite materials for the use of prosthetic socket is limited.
- Former studies related to flax – sisal hybrid composite presented their work with few numbers of fiber-fiber and fiber-matrix ratio.
- Concerning flax-sisal hybrid fiber, most researches presented long fiber with weave arrangement. There are few studies with chopped fibers with random arrangement.
- In most researches, water absorption is not taken into account, even though it has an impact on the overall performance of the prosthetic socket.

CHAPTER THREE

MATERIALS, CONDITIONS AND METHODS

3.1 METHODOLOGY

In approaching the problem, different methods of analysis and data collections were followed.

Reviewing Literature: this was done by collecting and studying different articles, journals, books concerning composites, natural fibers, hybrid fibers, prosthetics, prosthetic limb sockets in order to have better understanding of the problem and solution and ways to achieving the objective of the research.

Setting Criteria for selecting plants: natural fiber properties are affected by the age/maturity/ of the plant. Therefore, the selected flax and sisal plant were collected accordingly.

Designing fiber matrix composition: based on different literatures different fiber-matrix composition were selected. In addition, the fiber-fiber loading was also selected.

Selection of treatment: NaOH were used for treatment to improve the adhesion between the fibers and matrix, bleaching and cleaning the surface of natural fibers.

Selection of fabrication method: there are different methods to fabricate composite materials. Hand layup, compression molding, resin transfer, vacuum bagging assisted hand lay-up technique. In this study Hand layup followed by compression as a curing method was used because of its simplicity.

Fabrication of natural hybrid composite: in this phase the epoxy, hardener, alkali agent, mold, releasing agent, were prepared and thirteen composite specimens were fabricated with different compositions. Eight composites were treated with NaOH and the remaining were untreated.

Experimental test setup and Experimentation: thirteen composite specimens fabricated were machined according to the ASTM specimen standards and these specimen samples were tested for Tensile, Flexural, compression, impact and water absorption.

Modeling, simulation and analysis of prosthetic limb socket: after obtaining the result, the composition with superior properties among the thirteen was selected.

Prosthetic socket was modeled using **ANSYS 2020 DesignModeler** and further analyzed using ANSYS 2020 software for analysis. On the ANSYS software, the results obtained from the

test, prosthetic socket loads obtained from literature were inserted and analyzed to obtain deformation and von misses stress.

Finally, the result was compared with other materials used for prosthetic sockets.

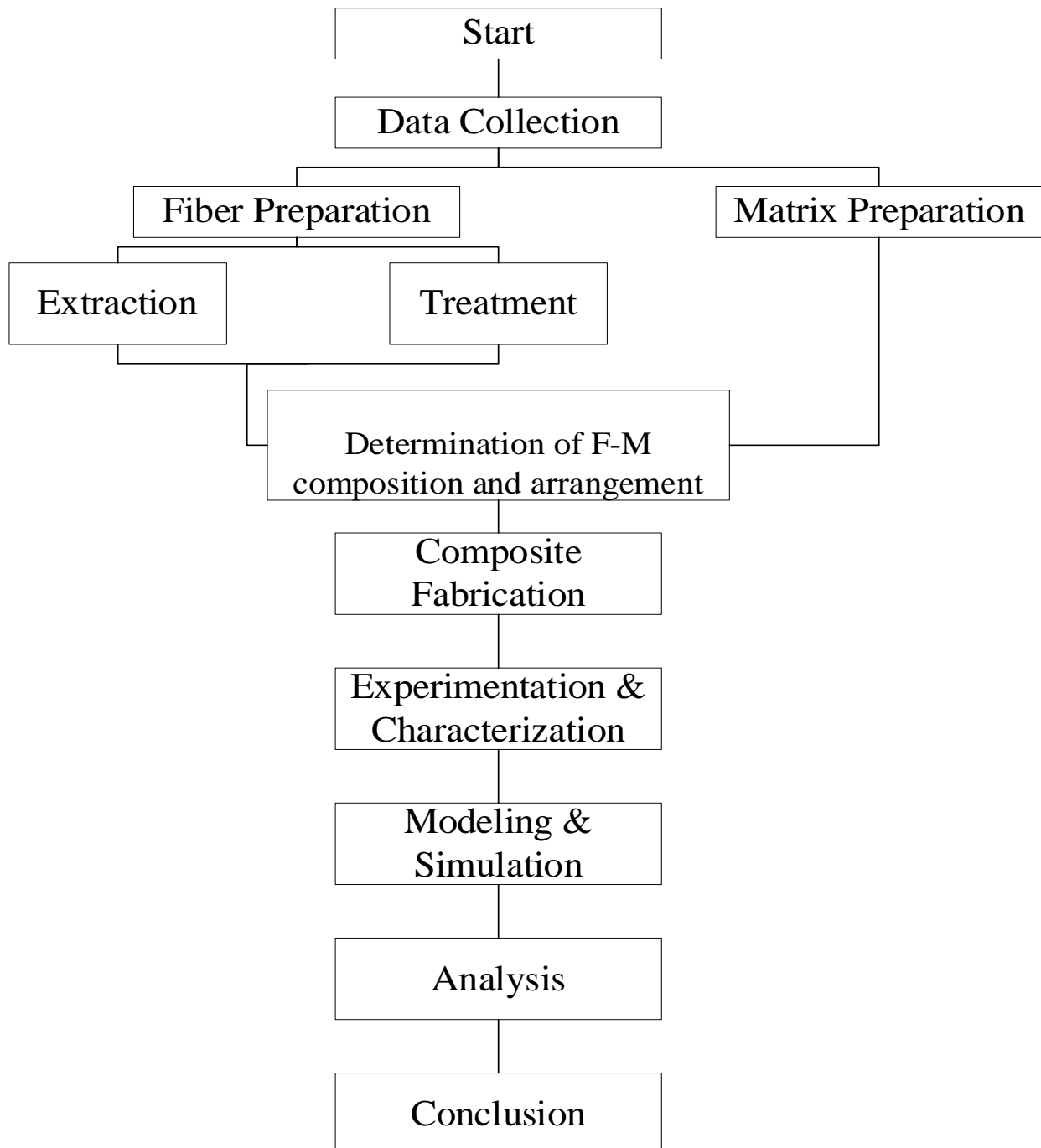


Figure 3. 1 Methodology

3.2 MATERIALS USED

To understand mechanical and physical properties of composites, it is essential to execute different mechanical, thermal and physical testing. The result obtained from these tests can be used in designing and fabrication of different mechanical structures.

In this study, two types of fiber were selected as reinforcement and an epoxy polymer as the matrix to fabricate composite that can be used to manufacture prosthetic socket. This composite material is investigated to replace the conventional material that is used to fabricate prosthetic socket.

To fabricate and investigate the composite, different fiber – matrix compositions, different materials and equipment were used.

Here, thirteen fabricated composite specimens were investigated. These composites consist two different fiber reinforcements and one polymer matrix. From the thirteen composites eight are treated with NaOH and the rest are untreated.

The two reinforcing fibers studied are; Flax and Sisal. The polymer matrix used in this thesis is Epoxy resin.

List of materials used in this research are:

Table 3. 1 Materials used to fabricate the composite

NO.	MATERIALS
1	Sisal Fiber
2	Flax Fiber
3	Epoxy Resin
4	Hardener
5	NaOH
6	Mold (320*300*4)
7	Roller
8	Releasing agent
9	Plastic sheet
10	Brush
11	Band Saw

3.2.1 FIBER COLLECTION AND EXTRACTION

Different researchers have used different natural fibers and matrix materials to fabricate prosthetic socket. the compositions and other process might differ from one researcher to another researcher. In the process of selection; strength to weight ratio, availability, mechanical

strength as single fiber and as hybrid, ease of manufacturing and physical properties have been considered.

This research was performed in Ethiopia and considers the conditions of the area. Even though, the combination of selected fibers (Flax and Sisal) hasn't been studied in Ethiopia, the fibers selected have preferred properties and the availability of the fibers is abundant

In the case of Ethiopia, mostly the Sisal and flax fiber are not used for modern application. Instead, they are used to make ropes. Sisal Plants are used as a fence for their compound and Flax plant are used as a means of collecting flax seed.

The selected fibers, have better mechanical properties than other natural fibers [32]. These fibers have low density and favorable mechanical properties [15].

3.2.1.1 SISAL FIBER

The Sisal plant leaves were collected from Meki, Ethiopia. Meki, a town in east-central Ethiopia. located 134km to the South East of Addis Ababa on the main asphalt road to Ziway town. Mature sisal plant leaves with higher length were collected by cutting the plant at the base. The fibers were extracted from the leaves manually using blunt knife. the leaves are cut in smaller longitudinal strips order to ease the process. Then the single strip of the plant is placed on flat wood and get crushed between the blunt knife and wood simultaneously the plant is pulled gently in the longitudinal direction. This process removes the moisture and fleshy pulp from the fiber.

After extraction of the fiber, the fiber is washed using clean water in order to remove unwanted particles on the fiber. Then the cleaned fiber is put on open air, under the sun to dry the fiber. After drying the fiber becomes ready for usage.

After obtaining manufacturing ready sisal fiber the properties were studied because fibers from this area haven't been investigated. So, the properties have been investigated in order identify and use the fiber for further processing.



(a) Sisal Plant



(b) Collected Sisal Leaf



(c) Extracting Sisal Fiber



(d) Extracted Sisal Fiber

Figure 3. 2 Extraction of Sisal Fiber

Density: The density of sisal fiber was found using pycnometer. Pycnometer is an equipment that uses liquid with well-known density such as; water to identify density.

In this thesis, water was used to calculate the density of fibers. Before measuring the density, the pycnometer should be calibrated to find the exact volume of the instrument. Taking the volume on the instrument gives wrong calculation, that is the reason needed for calibration.

To do that,

1. Measure the mass of pycnometer
2. Measure Mass of pycnometer with water filled in it.
3. Subtract mass of pycnometer + Water with Mass of Pycnometer to find mass of water
4. To find the volume use the formula $V = \text{Mass}/\text{Density}$
5. The Volume obtained is the exact volume of pycnometer

Mass of Pycnometer = **16.7g**

Mass of Pycnometer + Water = **44.4g**

Mass of Water = $44.4\text{g} - 16.7\text{g}$

$=$ **27.7g**

Volume of water = $\frac{\text{Mass of Water}}{\text{Density of Water}}$

Density of water at $21^{\circ}\text{C} =$ **0.99802g/ml**

$= \frac{27.7\text{g}}{0.99802\text{g/ml}} =$ **27.755ml**

The above value should be used instead of 25ml which is labeled on the pycnometer.

After calibration, the next step is to calculate the density of the fiber; Sisal Fiber.

To calculate the density of fiber

1. Measure Mass of Pycnometer + Sisal Fiber
2. Calculate mass of Sisal by Subtract mass of pycnometer + Sisal Fiber with Mass of Pycnometer which was found under calibration.
3. Measure Mass of Pycnometer + Sisal Fiber + Water
4. Subtract Mass of Pycnometer + Sisal Fiber + Water with Mass of Pycnometer + Sisal Fiber
5. Calculate volume of water
6. Calculate Volume of sisal by subtracting Volume of water from Volume of Pycnometer
7. Calculate density of sisal by dividing mass of Sisal with Volume of sisal

Mass of Pycnometer + Sisal Fiber = **17.2g**

Mass of Sisal fiber = 17.2g – 16.7g = **0.5g**

Mass of Pycnometer + Sisal Fiber + Water = **44.5g**

Mass of Water = 44.5g + 17.2g = **27.3g**

$$\text{Volume of Water} = \frac{\text{Mass of Water}}{\text{Density of Water}} \dots\dots\dots \text{eqn. 1}$$

$$= \frac{27.3\text{g}}{0.99802\text{g/ml}} = \mathbf{27.35\text{ml}}$$

Volume of Sisal = 27.755ml – 27.35ml

$$= \mathbf{0.405\text{ml}}$$

$$\text{Density of Sisal} = \frac{\text{Mass of Sisal}}{\text{Volume of Sisal}} \dots\dots\dots \text{eqn. 2}$$

$$= \frac{0.5\text{g}}{0.405\text{ml}} = \mathbf{1.234 \text{ g/ml}}$$



(a) Mass of Pycnometer

**(b) Flax fiber + Water
in Pycnometer**

**(c) Sisal Fiber + Water
in Pycnometer**

Figure 3. 3 Fiber Density Measuring Process

The Sisal single fiber has an elongation of 1.74%, Maximum force is 9.41N, Tenacity of 33.46cN/tex,

3.2.1.2 FLAX FIBER

The Flax plant was obtained from Holeta Agricultural Research Center located in Holeta Town, Ethiopia. The fiber plant was harvested on time of maturity. The flax seed was removed using rippling process. The stem with longer length and quality was collected from the field and was dipped into a tank filled with water to start the retting process. This process separates the cellulose fibers from non-fiber tissues. The stem was let there for 2 weeks. After 2 weeks it was removed from the tank and left the flax on the field under the sun to dry.

After the flax dry, the breaking process was executed by beating the flax with blunt wooden plate. Then the scutching process continued. After scutching of the flax, hackling was done by using brush like structure where the handle is wood and the comb is metal. Here the scotched fiber is pulled though the brush in order to obtain sooth and ready flax fiber.

Like the sisal fiber, after obtaining manufacturing ready flax fiber, the properties were investigated in order to know and use the fiber for further processing.

Density: Same procedure is used to measure the density of Flax fiber.

$$\text{Mass of Pycnometer + Flax Fiber} = \underline{\underline{17.4g}}$$

$$\text{Mass of Flax fiber} = 17.4g - 16.7g = \underline{\underline{0.7g}}$$

$$\text{Mass of Pycnometer + Flax Fiber + Water} = \underline{\underline{44.6g}}$$

$$\text{Mass of Water} = 44.6.g - 17.4g = \underline{\underline{27.2g}}$$

$$\begin{aligned} \text{Volume of Water} &= \frac{\text{Mass of Water}}{\text{Density of Water}} \\ &= \frac{27.2g}{0.99802g/ml} = \underline{\underline{27.25ml}} \end{aligned}$$

$$\begin{aligned} \text{Volume of Flax} &= 27.755ml - 27.25ml \\ &= \underline{\underline{0.505ml}} \end{aligned}$$

$$\begin{aligned} \text{Density of Flax} &= \frac{\text{Mass of Flax}}{\text{Volume of Flax}} \dots\dots\dots \text{eqn. 3} \\ &= \frac{0.7g}{0.505ml} = \underline{\underline{1.386 g/ml}} \end{aligned}$$

The Flax single fiber has an elongation of 0.7%, Maximum force is 7.29N, Tenacity of 4.94cN/tex.

3.2.2 MATRIX MATERIAL

3.2.2.1 EPOXY RESIN

Matrix determines the working conditions of the composite. Among many thermoset polymer matrix, Epoxy resins are the most commonly used. This is because; they have excellent adhesion, good performance at elevated temperature, better mechanical and electrical properties, low shrinkage, great working time, good chemical resistance, good corrosion resistance, cost efficiency, low viscosity, long pot life at room temperature and ease of fabrication. In this thesis, epoxy resin which is **LY556** imported from India was used.

It has the following property;

Table 3. 2 Property of Epoxy Resine LY556

Specification	Epoxy Resin LY556
Model	Herebna
Color	Clear
Viscosity @25 ⁰ C	10,000 – 12000 Mpa S
Density @ 25 ⁰ C	1.10-1.2g/cm ³
Flash Point	>200 ⁰ C
Curing Time	10-20min
Shelf Time	2 years

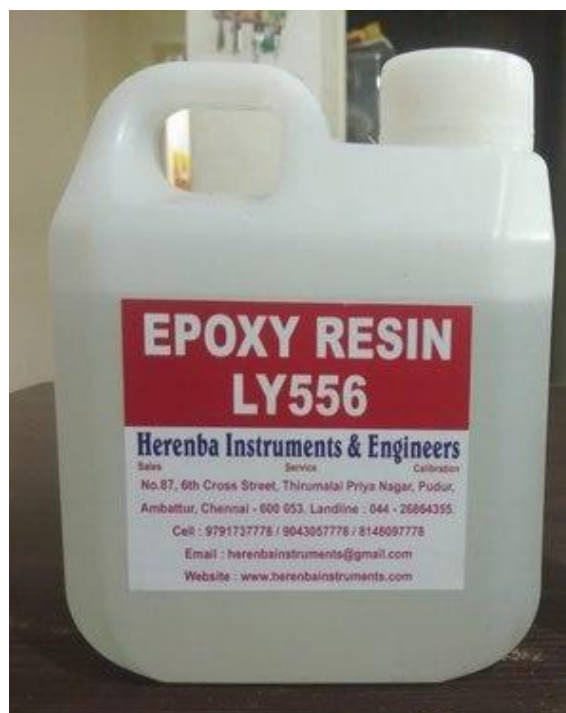


Figure 3. 4 Epoxy Resin LY556

3.2.2.2 HARDNER

In order to put the epoxy to use an adding of catalyst is needed. The catalyst cures the epoxy by initiating chemical reaction and changes it from liquid to solid. To obtain better mechanical properties appropriate amount of hardner should be used. The hardner catalyst used here is, HY951 that is purchased and imported from India.

Table 3. 3 Property of Hardner HY951

Specification	Hardner HY951
Model	Herebna
Color	Clear
Viscosity @25 ⁰ C	10 – 20 Mpa S
Density @ 25 ⁰ C	0.98g/cm ³
Flash Point	>110 ⁰ C
Curing Time	10-20min



Figure 3. 5 Hardner HY951

3.2.2.3 PREPARATION OF EPOXY AND HARDENER MIXTURE

Proper amount of mixture must be executed to obtain better mechanical, thermal and physical properties of composite. To prepare the composite, an epoxy LY556 and Hardener HY951 is mixed. The two elements were mixed with epoxy-hardener weight ratio of 10:1. After properly adjusting the mixture composition, they were poured into Bowl and stirred thoroughly to fully mix them and avoid air bubbles.

3.2.3 ADDITIONAL MATERIALS

Roller: is a cylindrical shaped metal used to distribute the epoxy resin throughout the composite. In addition, they are used to remove air gaps created and squeeze out excess resin while fabrication. Roller gives homogenous fiber wetting.

Releasing agent /wax/: this agent is used to release the composite from the mold after fabrication. It prevents the epoxy from sticking to the mold. There are different types of releasing agents. In this work the wax type was used for better surface finish. The wax type is preferred because of; their ease of use, availability and lower price. Brand of **Miracle Gloss – Maximum Mold Release Wax 82.0** was used.



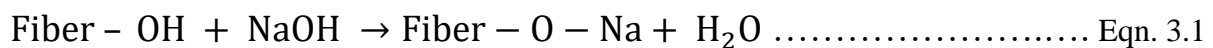
Figure 3. 6 Releasing Wax

Plastic sheet: these sheets are used to prevent the composite from dirt on the mold and the surrounding environment. In addition, it eases the removal of completed composite product.

Brush: used to spread the epoxy resin throughout the composite bed.

3.3 FIBER TREATMENT

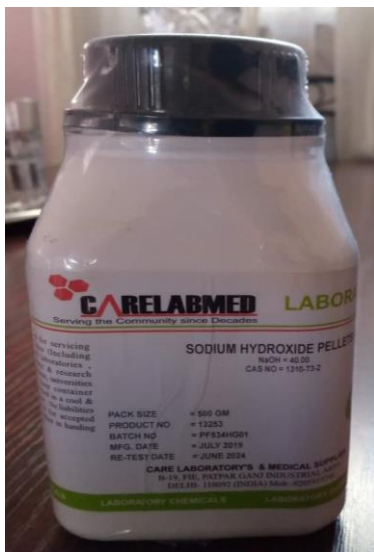
There are different kinds of treatments used to modify properties of fibers. In this thesis work the treatment named Mercerization or Alkaline treatment was used. This treatment uses Sodium Hydroxide (NaOH) to treat fibers by removing the hydrogen bonding in the network structure. In addition, it removes certain amount of wax and lignin. This treatment is the simplest chemical treatment method. The following reaction takes place under mercerization.



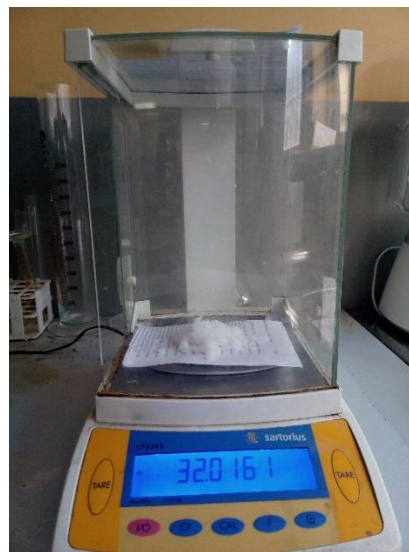
The chemical was available in form of pellets, flakes and granules. For the treatment of both Sisal and Flax fiber, pellet form was purchased from local chemical suppliers. The brand name of the NaOH chemical product was; **CARELABMED**, Sodium Hydroxide pellets containing **500g** with product number **13253**.

Considering [72] [90], 5% NaOH concentration was used for both Sisal and Flax fiber. The treatment was performed at Addis Ababa Institute of Technology, School of Chemical Engineering, Addis Ababa, Ethiopia.

To prepare the alkaline solution, NaOH pellet was mixed with water using electric stirrer. To mix the two appropriately different calculations was executed depending on the NaOH percentage concentration needed. So, the proper mass was measured using scale and proper measured liter of water was poured into plastic tub.



(a) NaOH Pallet Product



(b) Measuring of NaOH needed



(c) Mixing the NaOH with water using Electric Stirrer

Figure 3. 7 Process of Mixing of NaOH with Water

3.3.1 TREATMENT OF BOTH FLAX FIBER AND SISAL FIBER

To treat **flax fiber**, First the flax fiber was washed many times using tap and distilled water to remove dust particles from the surface of fiber. Then proper amount of NaOH and water are mixed in a plastic tub. Here, considering [90] 5% NaOH was used. According to the research 5% NaOH treatment for 30min increased the tensile strength by 21.9% and Flexural strength by 16.1%. Considering the percentage, 288g of NaOH and 12L of water was mixed thoroughly using electric stirrer at 198rpm.

After mixing, the washed flax fiber was immersed in a bath of NaOH solution and was soaked for 30min. Then the fiber was taken out to be washed and cleaned with distilled water until the chemical is removed and neutral PH level is obtained. The next process was dispersing the cleaned fibers on to trays and put the tray with the fiber into an oven for 48hrs. the oven was set at 45⁰C. Lastly, the treated and dried fiber was taken out for fabrication on the hybrid composite intended.

For Sisal Fiber treatment, same procedure was executed as the flax fiber. The only difference is that the sisal plant was soaked in the NaOH solution for 24hrs.



(a) Washed Flax Fiber



(b) Mixing of NaOH with Water



(c) Soaked Flax Fiber in NaOH



(d) Removal of Flax Fiber from NaOH Solution



(e) Washing After Soak



(f) Dried Flax Fiber in Oven

Figure 3. 8 Treatment of Flax Fiber



(a) Untreated Sisal Fiber



(b) Washing Before Treatment



(c) Washed Sisal Fiber



(d) Mixing NaOH with Water



(e) Socking of Sisal Fiber



(f) Socked Sisal Fiber



(g) Sisal Fiber after treatment



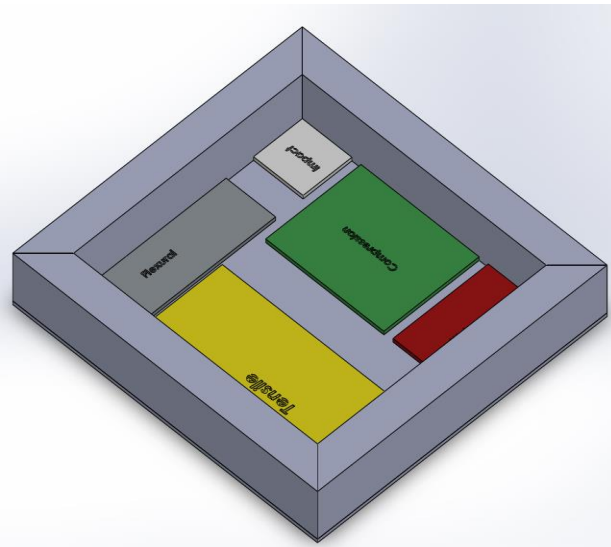
(h) Sisal Fiber in Oven

Figure 3. 9 Treatment of Sisal Fiber

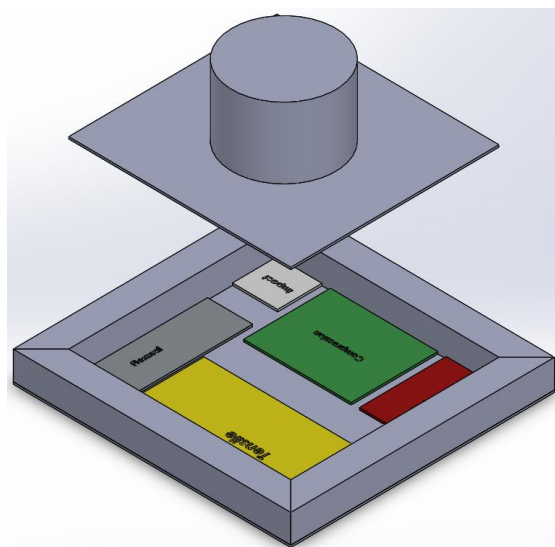
3.4 PREPARATION OF MOLD

The mold was designed depending on the dimension and number of test specimen and number of tests. From that, the mold was designed to have a dimension of 320 x 300 x 4mm. The material used to fabricate the mold was steel. The mold consists base plate and upper plate.

The base plate was made from flat sheet metal and four RHS steel welded as frame on it. The inside of the base plate has exact area as the mold needed. The upper plate had a sheet metal and a cylindrical block with four wings attached to it. The four wings and cylinder is used to distribute the load applied by the compressor at the time of curing. The cylinder has a weight of 8.5Kg. to ease the release of completed composite additional portable sheet metal with **320 x 300 x 4mm** was fabricated. The upper plate also helps as a cover for the composite.



(a) Mold Base Design



(b) Assembly design of Mold



(c) Fabricated Mold Base



(d) Fabricated Mold Cover



(e) Mold Cover Mass Measurement



(f) Mass of Mold Cover (8.5Kg)

Figure 3. 10 Mold Design and Mold Cover Weight (320*300*4)

3.5 FABRICATION OF THE HYBRID COMPOSITE

The hybrid composite is composed of Sisal and flax as reinforcement and epoxy as the matrix. Both the reinforcing fibers are chopped with length of 30mm and the matrix epoxy (LY556) is mixed thoroughly with hardener (HY951).

The fabrication of the hybrid composite includes calculation of mass needed for each reinforcement and matrix under thirteen compositions. Hand-layup method is used to manufacture all the composites. Each composite constituent is mixed according to their composition and mass.

PREPARATION OF FLAX AND SISAL FIBER: For fabrication of thirteen hybrid composites both treated and untreated natural fibers that are prepared ready for further processing are chopped into 30mm fiber length. This length of fiber is used for all the thirteen composites. According to the composition of the fabricated composite to be, the two fibers were measured and mixed together using hand and stirrer. The stirring will help the two fibers disperse uniformly into each other.



(a) Stirring of fiber mix

(b) Mixed Flax and Sisal Fiber

Figure 3. 11 Preparation of Flax and Sisal Fiber

3.5.1 RULE OF MIXTURE / FIBER AND MATRIX MASS COMPOSITION CALCULATION FOR THE COMPOSITE

Table 3. 4 Fiber Matrix Composition

Fiber Volume %	Matrix Volume %
40	60
35	65
30	70

Table 3. 5 Fiber – Fiber Composition

Flax Volume %	Sisal Volume %
20	20
15	25
25	15
20	15
15	20
10	20
20	10
15	15

Table 3. 6 Composition of Thirteen Composites

Composites	Fiber – Matrix %		Flax – Sisal %		
1	40	60	20	20	
2	40	60	15	25	
3	40	60	25	15	
4	35	65	20	15	
5	35	65	15	20	
6	30	70	10	20	
7	30	70	20	10	
8	30	70	15	15	
9	35	65	20	15	UNTREATED
10	40	60	15	25	UNTREATED
11	40	60	20	20	UNTREATED
12	40	60	25	15	UNTREATED
13	30	70	10	20	UNTREATED

The values obtained from measuring the densities and previous calculations, the known results are;

Density of Sisal (ρ_S) = **1.234 g/cm³**

Density of Flax (ρ_F) = **1.386 g/cm³**

Density of Epoxy (ρ_E) = **1.15 g/cm³**

Volume of Composite (V_C) = 320mm x 300mm x 3mm

= **288,000mm³** = **288.00 cm³**

$\rho_C = (\rho_F * \rho_F) + (\rho_S * \rho_S) + (\rho_E * \rho_E)$ eqn. 3.2

$V_{fiber} = V_C * v_{fiber}$ eqn. 3.3

$V_{M/E} = V_C * v_{M/E}$ eqn. 3.4

$M_C = V_C * \rho_C$ eqn. 3.5

The Fibers have their own volume fraction out of given percentage composition.

So, $V_F = V_{fiber} * v_F$eqn. 3.6

$$V_S = V_{fiber} * v_S \dots \dots \dots \text{eqn. 3.7}$$

$$M_F = \rho_F * V_F \dots \dots \dots \text{eqn. 3.8}$$

$$M_S = \rho_S * V_S \dots \dots \dots \text{eqn. 3.9}$$

$$M_E = \rho_E * V_{M/E} \dots \dots \dots \text{eqn. 3.10}$$

- ρ_C = Density of Composite V_F = Volume of Flax v_S = Volume Fraction of Sisal
 ρ_F = Density of Flax V_S = Volume of Sisal M_F = Mass of Flax
 ρ_S = Density of Sisal $V_{M/E}$ = Volume of Matrix/Epoxy/ M_S = Mass of Sisal
 ρ_E = Density of Epoxy v_{fiber} = Volume fraction of Fiber M_E = Mass of Epoxy
 V_C = Volume of Composite $v_{M/E}$ = Volume fraction of Matrix M_C = Mass of Composite
 V_{fiber} = Volume of Fiber v_F = Volume Fraction of Flax

COMPOSITE ONE:

Table 3. 7 Composite one Property and Mass required

Density 1= 1.214 g/cm. qu.	Volume fiber = 115.2 cm. qu.	Volume matrix= 172.8cm qu.
Mass of C1= 349.632 gram		
The volume has its own volume fraction out of 40 (0.2 - 0.2)		
convert to 100%		
1	0.5	
2	0.5	
		therefore;
	0.5 of vf	flax= 57.6 cm. qu.
	0.5 of vf	Sisal= 57.6 cm. qu.
Mass Flax = 79.8336 gram		Mass Epoxy = 198.72 gram
Mass Sisal = 71.0784 gram		

COMPOSITE TWO:

Table 3. 8 Composite two Property and Mass required

Density 2= 1.2064 g/cm. qu.	Volume fiber = 115.2 cm. qu.	Volume matrix= 172.8 cm qu.
Mass of C2= 347.4432gram		
The volume has its own volume fraction out of 40 (0.15 - 0.25)		
convert to 100%		
1	0.375	
2	0.625	
		therefore;
	0.375 of vf	flax= 43.2 cm. qu.
	0.625 of vf	Sisal= 72 cm. qu.
Mass Flax = 59.8752 gram		Mass Epoxy = 198.72 gram
Mass Sisal = 88.848 gram		

COMPOSITE THREE

Table 3. 9 Composite three Property and Mass required

Density 3= 1.2216 g/cm. qu.		Volume fiber = 115.2 cm. qu.		Volume matrix= 172.8 cm qu.	
Mass of C3= 351.8208 gram					
The volume has its own volume fraction out of 40 (0.25 - 0.15)					
convert to 100%					
1	0.625				
2	0.375				
			therefore;		
	0.625 of vf	flax= 72 cm. qu.			
	0.375 of vf	Sisal= 43.2 cm. qu.			
Mass Flax = 99.792 gram				Mass Epoxy = 198.7 gram	
Mass Sisal = 53.3088 gram					

COMPOSITE FOUR

Table 3. 10 Composite four Property and Mass required

Density 4= 1.2098/cm. qu.		Volume fiber = 100.8 cm. qu.		Volume matrix= 187.2 cm qu.	
Mass of C4= 348.4224 gram					
The volume has its own volume fraction out of 35 (0.2 - 0.15)					
convert to 100%					
1	0.571428571				
2	0.428571429				
			therefore;		
	0.2 of vf	flax= 57.6 cm. qu.			
	0.15 of vf	Sisal= 43.2 cm. qu.			
Mass Flax = 79.8336 gram				Mass Epoxy = 215.3 gram	
Mass Sisal = 53.3088 gram					

COMPOSITE FIVE

Table 3. 11 Composite five Property and Mass required

Density 5= 1.2022g/cm. qu.		Volume fiber = 100.8 cm. qu.		Volume matrix= 187.2 cm qu.	
Mass of C5= 346.2336 gram					
The volume has its own volume fraction out of 35 (0.15 - 0.2)					
convert to 100%					
1	0.428571429				
2	0.571428571				
			therefore;		
	0.15 of vf	flax= 43.2 cm. qu.			
	0.2 of vf	Sisal= 57.6 cm. qu.			
Mass Flax = 59.8752 gram				Mass Epoxy = 215.3 gram	
Mass Sisal = 71.0784 gram					

COMPOSITE SIX

Table 3. 12 Composite Six Property and Mass required

Density 6= 1.1904 g/cm. qu.		Volume fiber = 86.4 cm. qu.		Volume matrix= 201.6 cm qu.	
Mass of C6= 342.8352 gram					
The volume has its own volume fraction out of 30 (0.1 - 0.2)					
convert to 100%					
1	0.333333333				
2	0.666666667				
			therefore;		
	0.1 of vf	flax= 28.8 cm. qu.			
	0.2 of vf	Sisal= 57.6 cm. qu.			
Mass Flax = 39.9168 gram				Mass Epoxy = 231.84 gram	
Mass Sisal = 71.0784 gram					

COMPOSITE SEVEN

Table 3. 13 Composite Seven Property and Mass required

Density 7= 1.2056 g/cm. qu.		Volume fiber = 86.4 cm. qu.		Volume matrix= 201.6 cm qu.	
Mass of C7= 347.2128 gram					
The volume has its own volume fraction out of 30 (0.2 - 0.1)					
convert to 100%					
1	0.666666667				
2	0.333333333				
			therefore;		
	0.2 of vf	flax= 57.6 cm. qu.			
	0.1 of vf	Sisal= 28.8 cm. qu.			
Mass Flax = 79.8336 gram				Mass Epoxy = 231.84 gram	
Mass Sisal = 35.5392 gram					

COMPOSITE EIGHT

Table 3. 14 Composite Eight Property and Mass required

Density 8= 1.198 g/cm. qu.		Volume fiber = 86.4 cm. qu.		Volume matrix= 201.6 cm qu.	
Mass of C8= 345.024 gram					
The volume has its own volume fraction out of 30 (0.15 - 0.15)					
convert to 100%					
1	0.5				
2	0.5				
			therefore;		
	0.5 of vf	flax= 43.2 cm. qu.			
	0.5 of vf	Sisal= 43.2 cm. qu.			
Mass Flax = 59.8752 gram				Mass Epoxy = 231.84 gram	
Mass Sisal = 53.3088 gram					

Composite **9, 10, 11, 12** and **13** have the same composition as composite **4, 2, 1, 3** and **6** respectively. Therefore, the needed mass and density are the same.

Total mass needed for thirteen composites are listed as follows;

Table 3. 15 Mass of each Composite

COMPOSITE NO.	MASS OF FLAX	MASS OF SISAL	MASS OF EPOXY
1	79.8336	71.0784	198.72
2	59.8752	88.848	198.72
3	99.792	53.3088	198.72
4	79.8336	53.3088	215.3
5	59.8752	71.0784	215.3
6	39.9168	71.0784	231.84
7	79.8336	35.5392	231.84
8	59.8752	53.3088	231.84
9	79.8336	53.3088	215.3
10	59.8752	88.848	198.72
11	79.8336	71.0784	198.72
12	99.792	53.3088	198.72
13	39.9168	71.0784	231.84
TOTAL	918.0864g	835.1712g	2765.58g

3.5.2 FABRICATION OF COMPOSITES SPECIMEN

The fabrication process involves the Hand lay-up method. This method is the simplest method available to fabricate composite materials. The process requires minimum number of materials as compared with the other methods.

Before starting of fabrication; mold, roller, brush, plastic sheet, releasing agent, glove, chopped fibers, epoxy-hardener mixture should be prepared.

The first process of fabrication was cleaning of the mold. The mold was cleaned and metal sheet is put inside the mold for ease of extracting the composite after fabrication. On a clean table, two plastic sheets that can cover open part of the mold were placed. One plastic sheet is to be placed at the bottom of the cavity and the other on the top. After preparing the plastic sheet releasing agent was applied on it. Then the plastic that is being placed at the bottom was correctly positioned on the needed mold space.

After this, mixture of Epoxy – Hardener and proper weight composition of fiber was prepared. As mentioned earlier in this section, the Epoxy – Hardener was mixed 1:10 ratio. The epoxy

has its own weight according to each composite. Therefore; to obtain needed weight the epoxy was measured with a scale accordingly and using the 1:10 ratio the hardener was also measured and mixed gently and thoroughly using stirrer. Here, the air bubbles were avoided as much as possible. In addition, the Flax and Sisal fiber also has their own weight according to the thirteen compositions. Therefore, in order to prepare the fibers for fabrication each fiber needed weight was measured using scale. After measuring, the fibers were mixed using hand and stirrer to homogenously spread their content into each other.

Then, some mixture of Epoxy – Hardener was poured onto the prepared plastic sheet and uniformly spread throughout the mold using brush. Some of the prepared and mixed fibers then are added onto the matrix. This process was followed by application of small pressure using roller. The roller impregnates fibers uniformly.

Applying epoxy mixture, adding mixed fiber and applying roller was repeated accordingly until the fiber mixture was finished. Then at the top of the last application of fiber mixture, last layer of epoxy – hardener mixture was poured. Then again, the application of roller was performed. After completing this process, the second plastic sheet which was waxed previously was applied on the top of the composite. The plastic sheets also help to get good surface finish of final product.

For uniform wetting, clean roller was applied on the plastic sheet, the roller also helped release excess epoxy resin.

For the final process, after applying roller on the top of the composite, the lid or upper part of the mold was covered. This covered the composite completely.

Then, for the process of compression and curing, it was placed under hydraulic press machine to apply uniform load of 50Ton (5MPa) that helped release of excess epoxy, maintaining of constant thickness. The composite is held under the load for 24hr at room temperature and after 24hr the mold was opened and the fabricated composite material was extracted carefully.

Similar procedure was executed for all thirteen composites. All of them were manufactured and cured at room temperature.



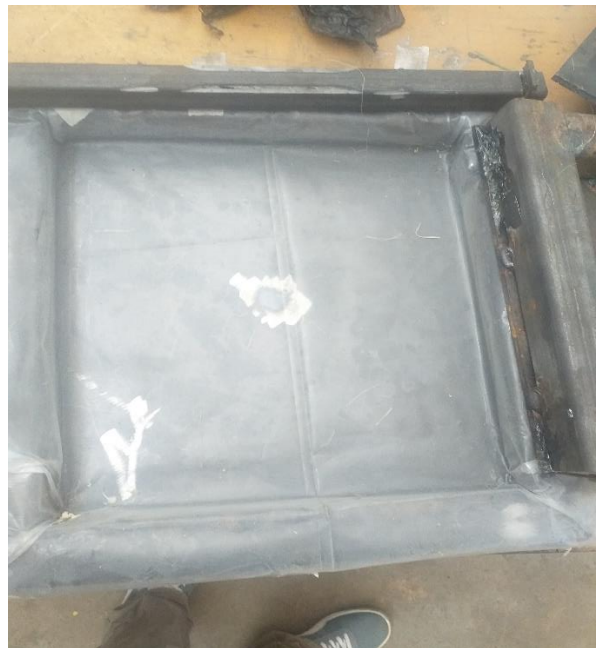
(a) Mixing Epoxy and Hardener



(b) Preparation of Fibers



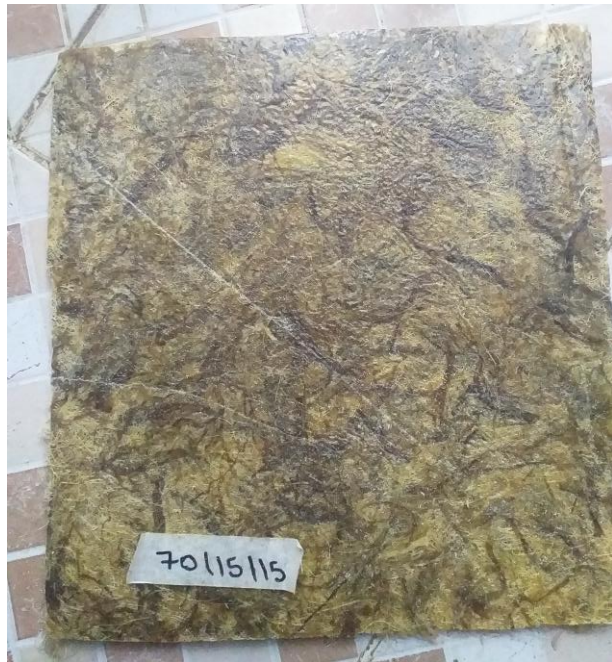
(c) Applying Wax on Plastic Sheet



(d) Placing Sheet on Mold Base



(e) Placing fibers and mixed matrix on mold (f) Applying cover on Mold Base



(g) Compression & Curing

(h) Final Product

Figure 3. 12 Fabrication Process of Composite

3.6 SPECIMENS PREPARATION FOR TESTING

The specimen prepared in this thesis was according to American Society for Testing Materials specification. The specimens were prepared for Tensile, Compression, Flexural, Impact and Water Absorption. Circular Band saw machine was used to cut fabricated composites according to ASTM standards. The Machine has cutting speed of 500 – 1000 m/min with blade length of 2560mm and maximum working height of 230mm.



Figure 3. 13 Circular Band Saw

Tensile Test Specimen: The tensile test standard used is ASTM D3039. This standard has a rectangular shape with dimension of 250mm x 25mm x 3mm.

Compression Test Specimen: The compression test standard used is ASTM D3410. This standard has a rectangular shape with dimension of 80mm x 20mm x 3mm

Flexural Test Specimen: The flexural test standard used is ASTM D790. This standard has a rectangular shape with dimension of 125mm x 13mm x 3mm

Impact Test Specimen: The impact test standard used is ASTM D256. This standard has a rectangular shape with dimension of 64mm x 13mm x 3mm

Water absorption Test Specimen: The water absorption test standard used is ASTM D570. This standard has a rectangular shape with dimension of 76mm x 25mm x 3mm

Table 3. 16 Experimental Test Standards

TEST	STANDARD	SPECIMEN DIMENSION (mm)
TENSILE TEST	ASTM D3039	250 x 25 x 3
COMPRESSION TEST	ASTM D3410	80 x 20 x 3
FLEXURAL TEST	ASTM D790	125 x 13 x 3
IMPACT TEST	ASTM D256	64 x 13 x 3
WATER ABSORPTION TEST	ASTM D570	76 x 25 x 3

3.7 EXPERIMENTAL TESTING PROCEDURES AND CONDITIONS

After cutting fabricated hybrid composite materials into standard specimen sizes, they were tested using five different testing procedures. The four experiments (Tensile, Compression, Flexural and Impact) were conducted at Bishoftu Defense Engineering College, Ethiopia. **Gunt Hamburg WP 310 Hydraulic material testing machine** having maximum 50KN capacity was used for Tensile, Compression and Flexural testing. The impact testing was conducted using **Charpy impact tester**. From each machine results were generated that can be evaluated and analyzed further.

For the five experimental tests, at least **five** specimen samples were tested for all the thirteen composite compositions. Therefore, a minimum of **325** specimen samples were tested to show repeatability and minimize errors as much as possible. All was executed under **room temperature**.



Figure 3. 14 Charpy Impact Testing Machine



Figure 3. 15 Gunt Hamburg WP 310 Hydraulic material testing machine 50KN

TENSILE TESTING: The tensile test was conducted at room temperature with speed of 6mm/min along the longitudinal direction of the composite. Specimen sample were placed vertically into the jaws of testing machine. The upper jaw was movable and the lower jaw was fixed. The machine displays results on a computer and stops at time of fracture.



Figure 3. 16 Tensile Test Specimen

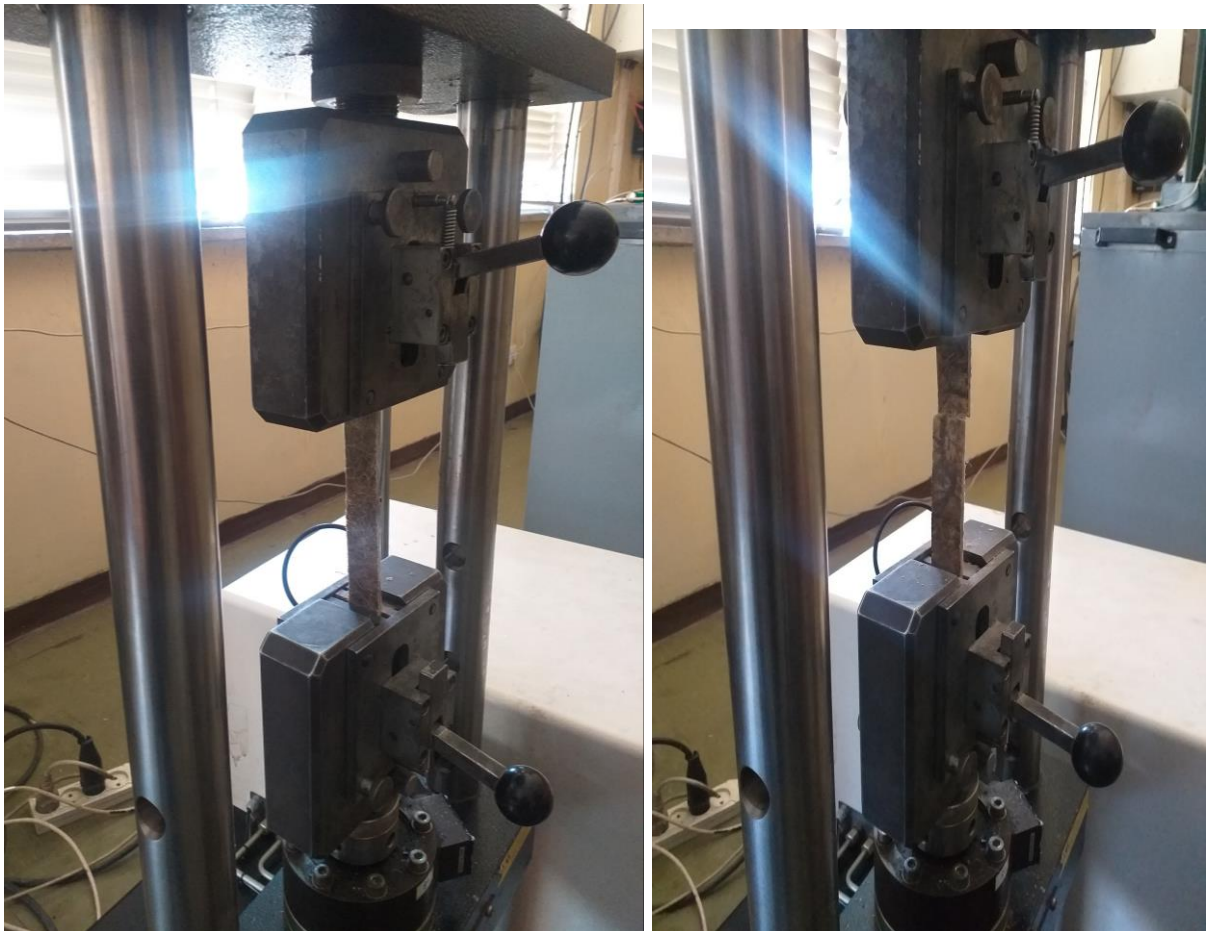
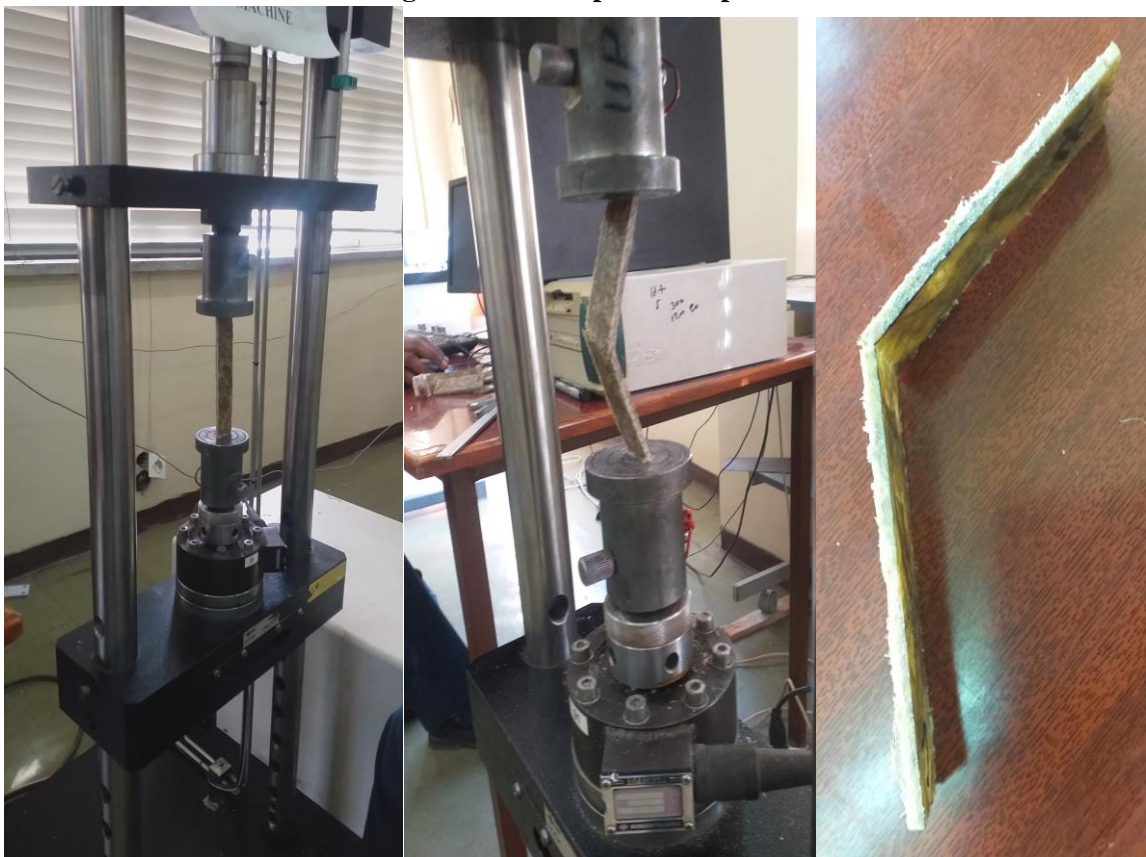


Figure 3. 17 Tensile Strength Setup and Specimen at Fracture

COMPRESSION TESTING: to test the compression strength, the specimens were subjected to axial compression load until fracture using UTM. Samples were placed between upper and lower compression anvils.



Figure 3. 18 Compression Specimens



(a) Setup

(b) Specimen at Deformation

Figure 3. 19 Compression Test Process

FLEXURAL TESTING: In this test, three-point bending mode was used to find the flexural strength. The specimen was placed on to 125mm span on two-point support bed. After that, the one-point upper jaw with load was applied at the middle span of the specimen. The experiment was conducted under room temperature with a speed of 6mm/min. Minimum of five samples from each composite was tested.



Figure 3. 20 Flexural Test Specimens

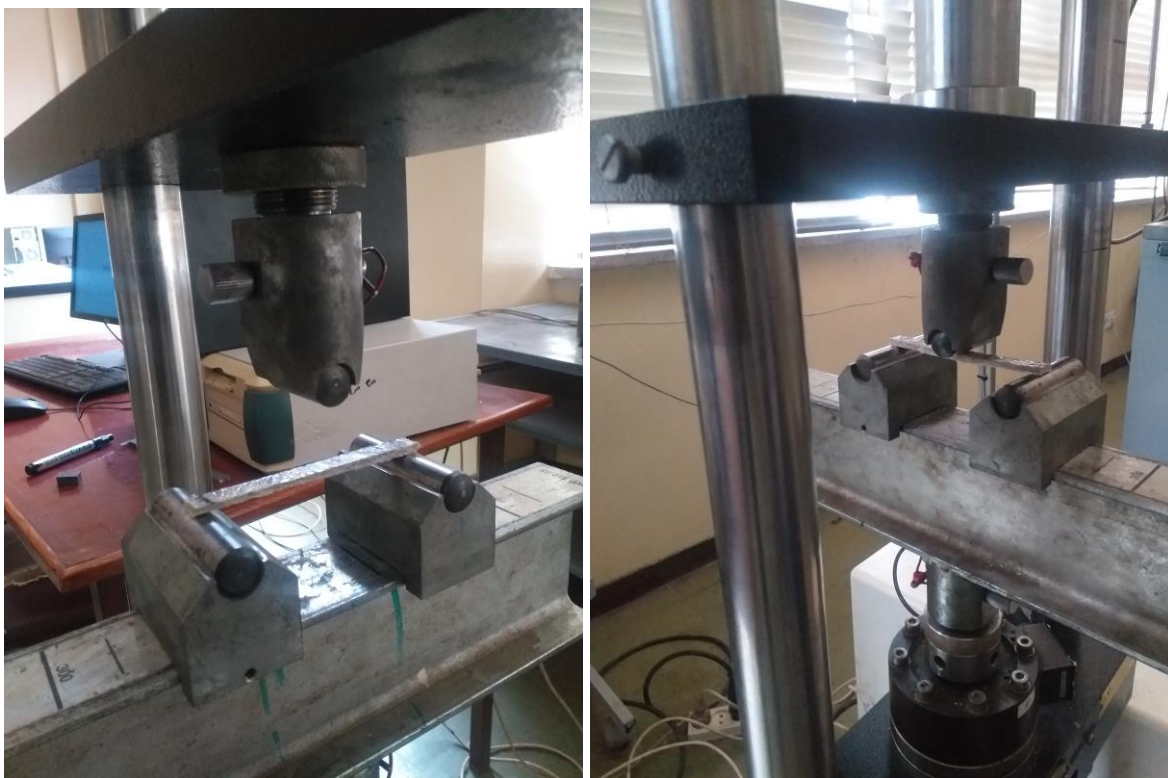


Figure 3. 21 Flexural Test Setup

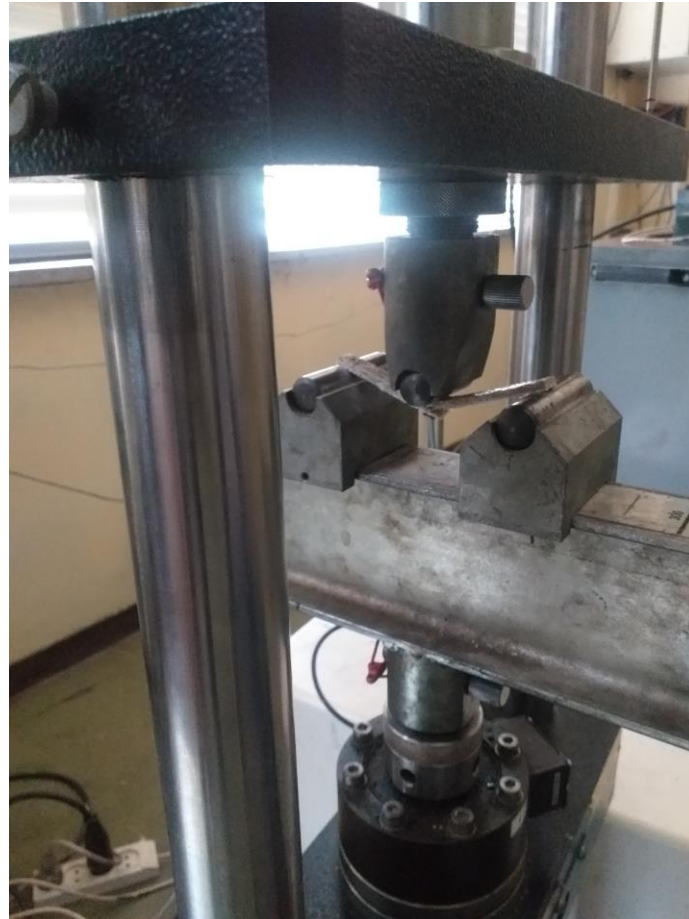


Figure 3. 22 Deformation of Flexural Test Specimen

IMPACT TESTING: to determine fracture toughness, the specimen was clamped into the bed of the tester and it is hit by a pendulum which was dropped from an angle of 45 degree to impact the specimen and fracture it. Charpy impact was employed to test the impact strength of all thirteen composites. The amount of energy absorbed by the specimen (the impact strength of the specimen) during the breaking was observed from the dial indicator attached to the pendulum rod. It directly shows the impact strength.



Figure 3. 23 Impact Test Specimen



Figure 3. 24 Impact Test Setup



Figure 3. 25 Impact test Specimen after Test

WATER ABSORPTION TESTING: For the water absorption test, all the specimens were immersed in water for 24 hours at room temperature. Before soaking all specimen were weighted using electronic balance machine and each sample results were registered. Then after 24hrs of soaking the specimens were removed and cleaned to remove excess water on the surface. Then finally the specimens were weighted once again. After this process the percentage increase in mass was calculated using the following formula.

$$\text{water absorption \%} = \frac{(\text{Final Weight}-\text{Initial Weight})}{\text{Initial Weight}} \times 100 \dots\dots\dots\text{eq. 6}$$

Where; Final Weight is the weight measured after 24hrs soaking

Initial weight is the weight measured before soaking



Figure 3. 26 Water Absorption Specimens



Figure 3. 27 Specimens Socked in Water

CHAPTER FOUR EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 RESULT

As mentioned in the previous section, there were thirteen composite specimens that were tested according to ASTM standards. The test results express properties of the Flax-Sisal fiber reinforced Epoxy hybrid composites manufactured. All fabricated composites have hybrid reinforcement that were chopped into 30mm length. Eight composites were treated with NaOH and have different fiber loading. Five composite specimens were untreated.

From each composition, a minimum of five specimen samples were prepared and tested. From those five specimen samples three were selected for further analysis.

Each composite was tested and the result have been discussed below.

4.1.1 TENSILE TEST RESULT

COMPOSITE ONE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

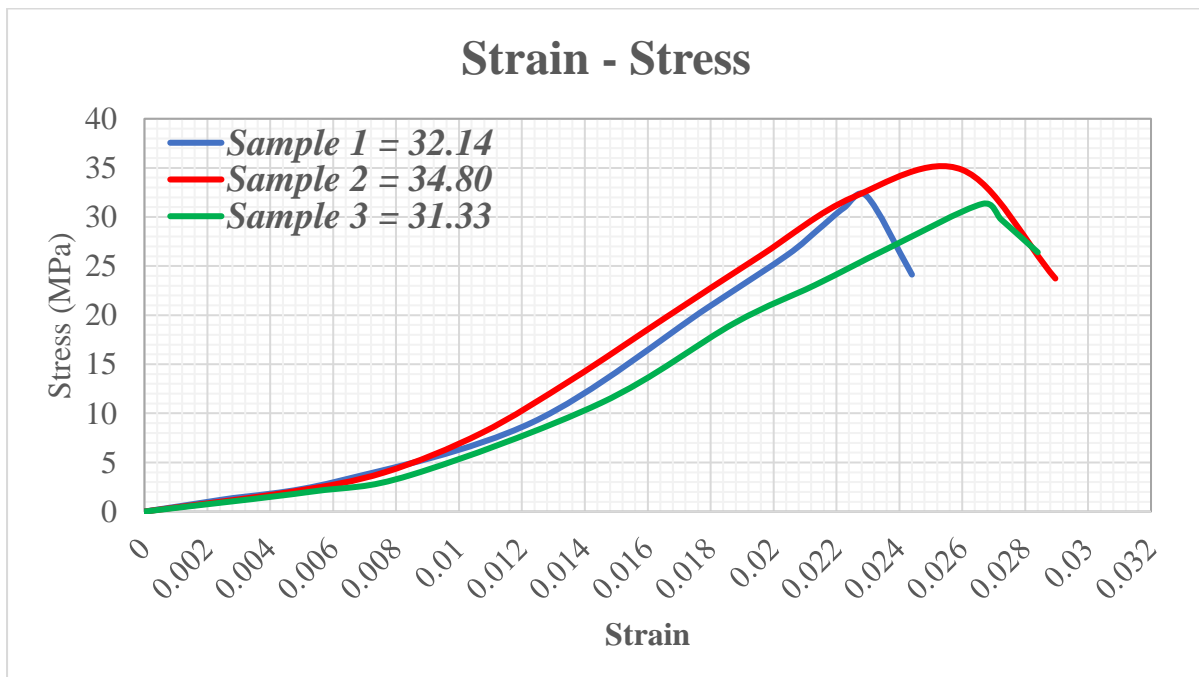


Figure 4. 1 Tensile Stress – Strain Curve for Composite 1 (Treated – F20%, S20% and E60%)

From the samples the following maximum Tensile stress and their average was plotted on bar graph.

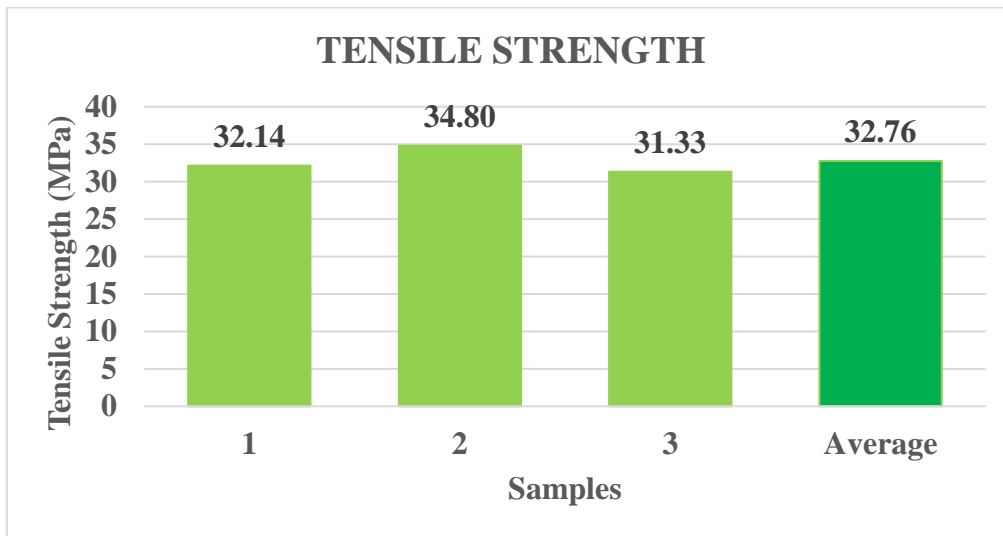


Figure 4. 2 Tensile Strength of Samples and its average (Treated – F20%, S20% and E60%)
COMPOSITE TWO: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

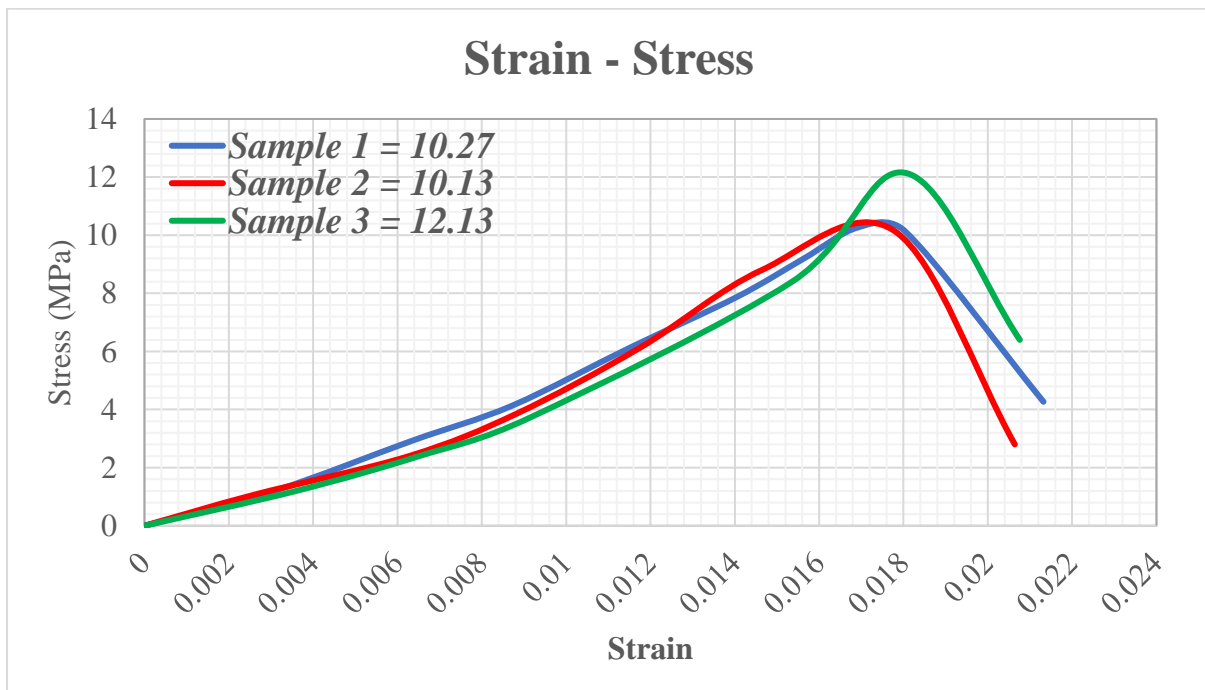


Figure 4. 3 Tensile Stress – Strain Curve for Composite 2 (Treated – F15%, S25% and E60%)

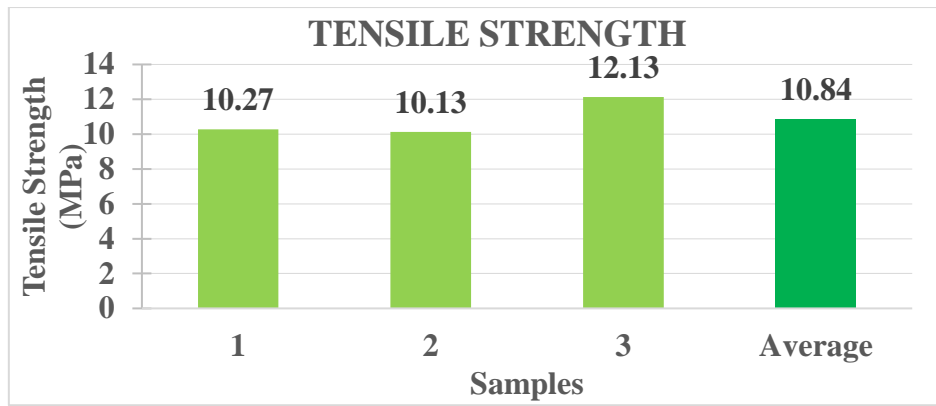


Figure 4. 4 Tensile Strength for Samples and its average (Treated – F15%, S25% and E60%)

COMPOSITE THREE: Is treated composite having chopped reinforced hybrid fibers with composition of 25% Flax 15% Sisal and 60% Epoxy. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

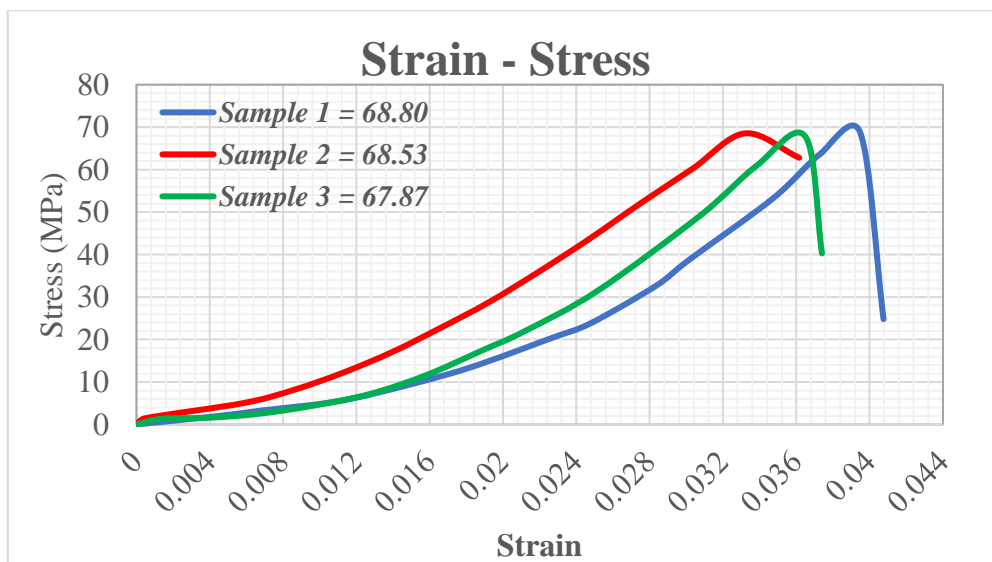


Figure 4. 5 Tensile Stress – Strain Curve for Composite 3 (treated – F25%, S5% and E60%)

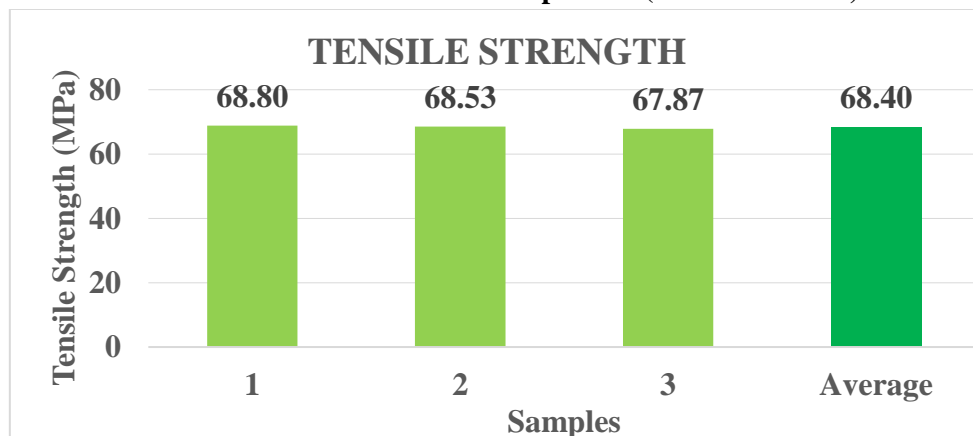


Figure 4. 6 Tensile Strength for All Samples and its average (treated – F25%, S15% and E60%)

COMPOSITE FOUR: Is a treated composite having chopped reinforced hybrid fibers with composition of 20% Flax 15% Sisal and 65% Epoxy. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

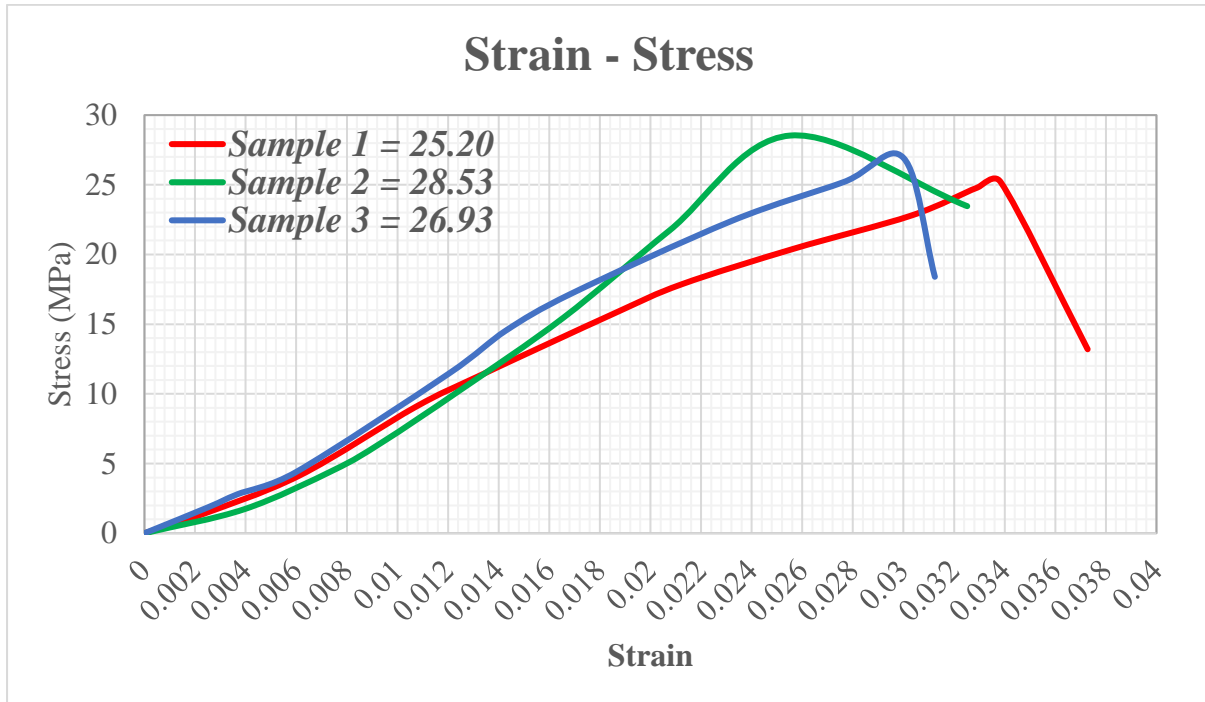


Figure 4. 7 Tensile Stress – Strain Curve for Composite 4 (Treated – F20%, S15% and E65%)

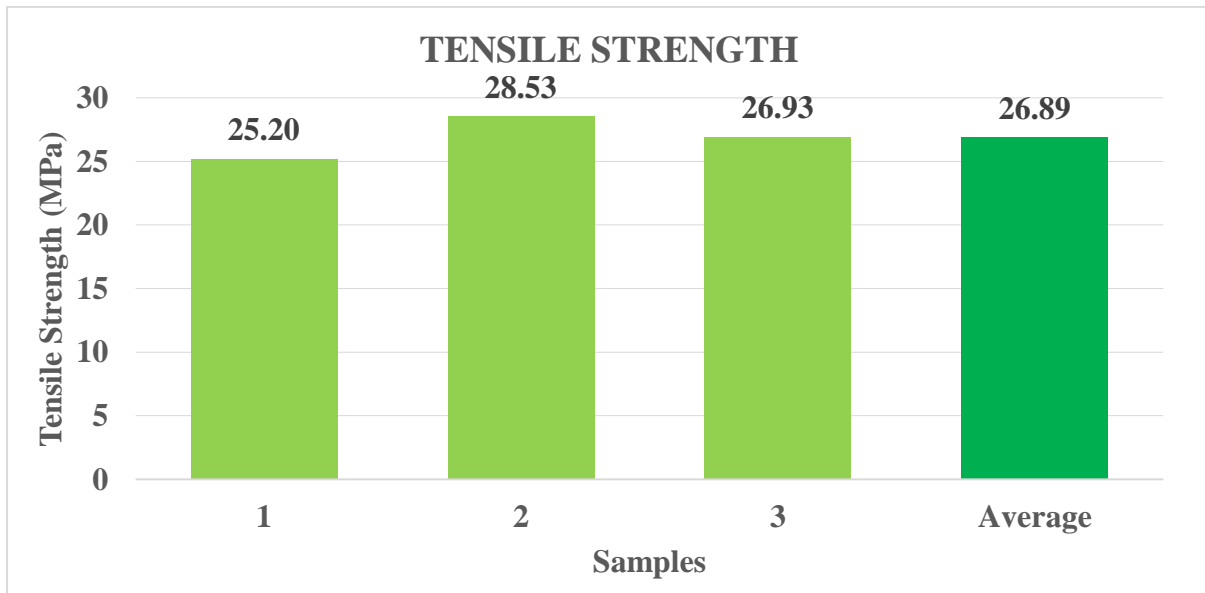


Figure 4. 8 Tensile Strength for Samples and its average (Treated – F20%, S15% and E65%)

COMPOSITE FIVE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 20% Sisal and 65% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

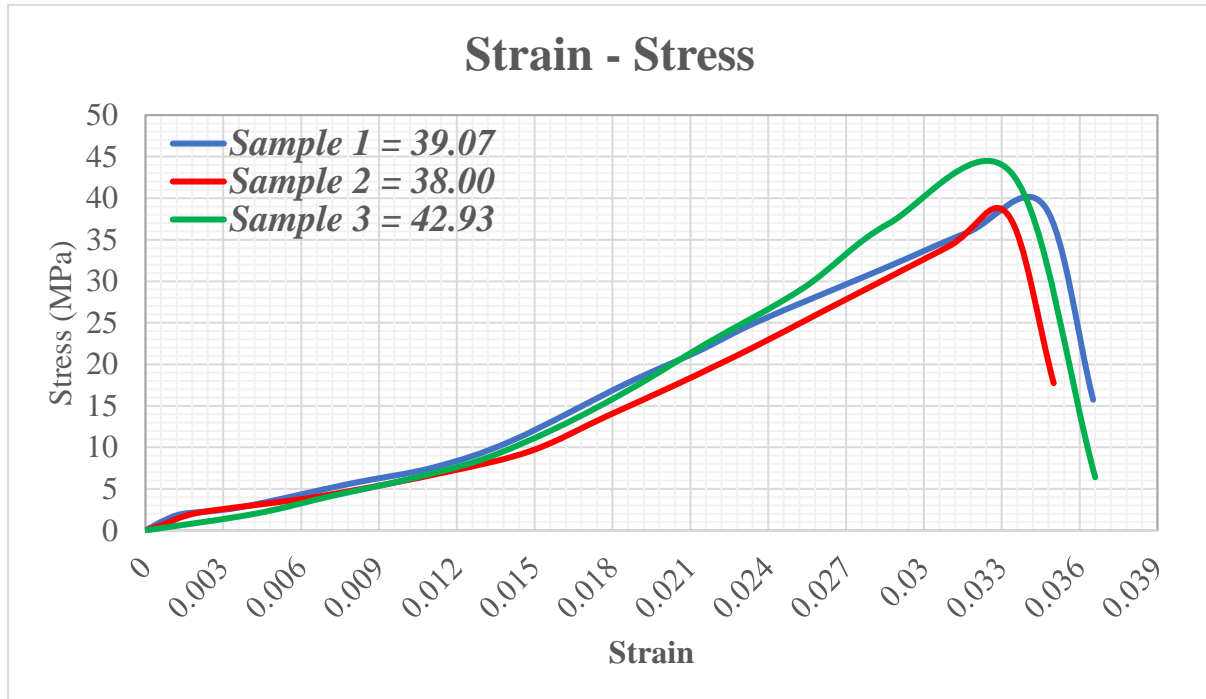


Figure 4. 9 Tensile Stress – Strain Curve for Composite 5 (Treated – F15%, S20% and E65%)

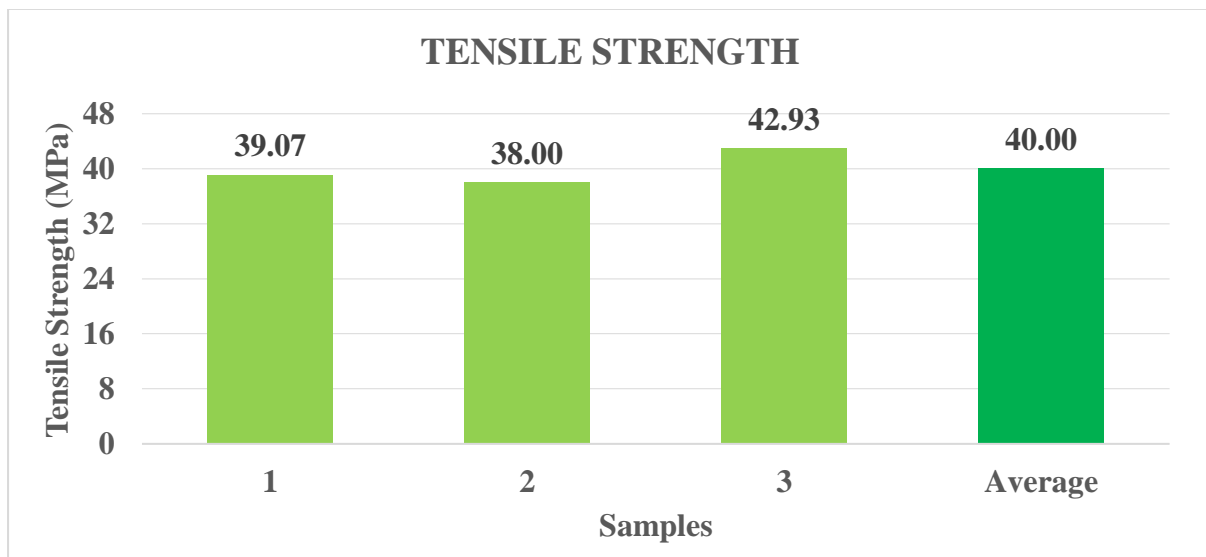


Figure 4. 10 Tensile Strength of All Samples and its average (Treated – F15%, S20% and E65%)

COMPOSITE SIX: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

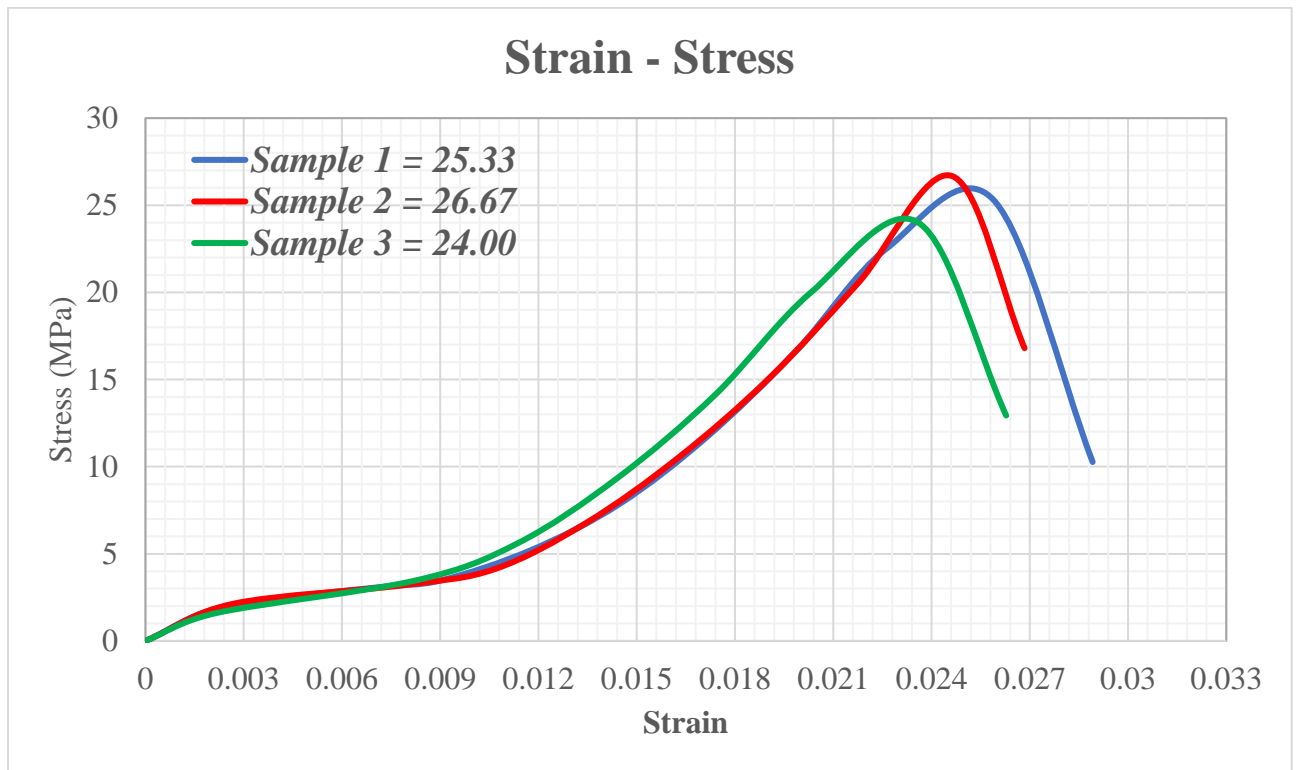


Figure 4. 11 Tensile Stress – Strain Curve for Composite 6 (Treated – F10%, S20% and E70%)

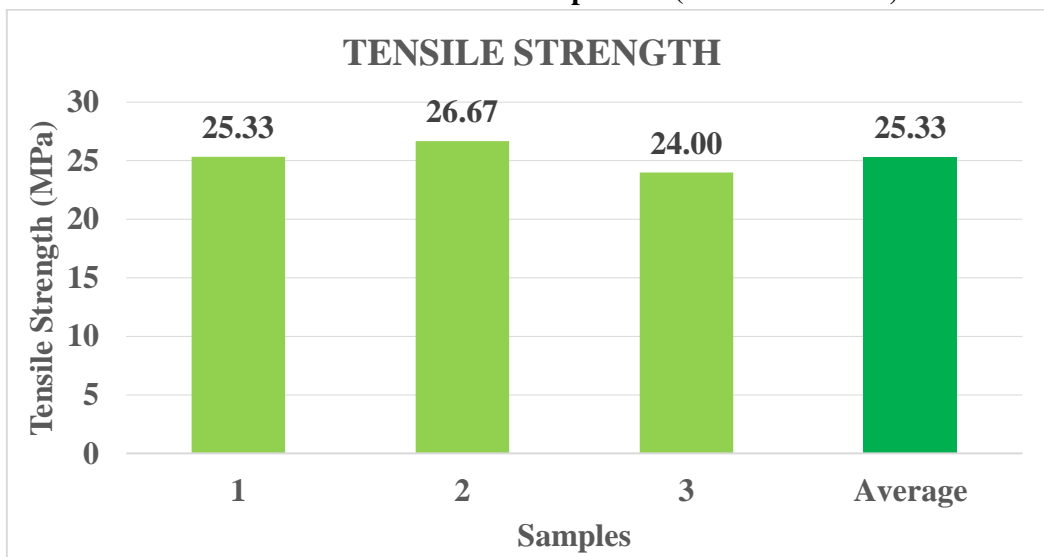


Figure 4. 12 Tensile Strength for All Samples and its average (Treated – F10%, S20% and E70%)

COMPOSITE SEVEN: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 10% Sisal and 70% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

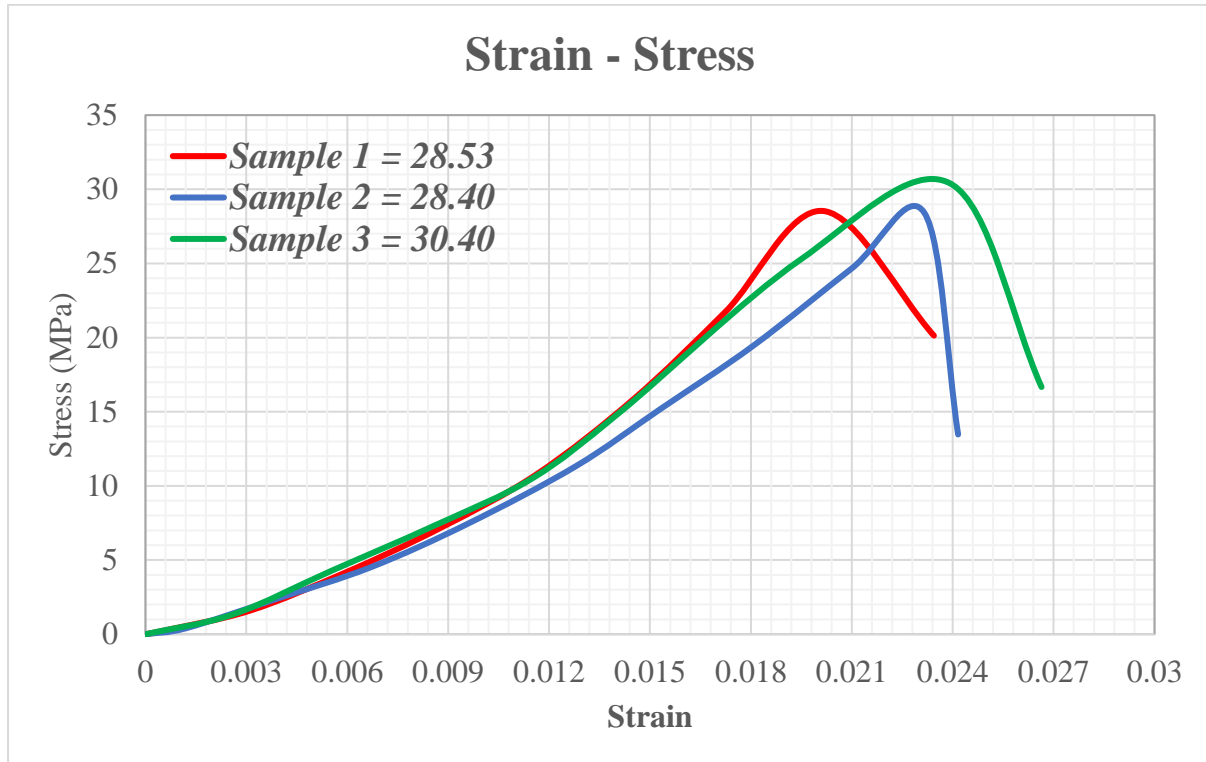


Figure 4. 13 Tensile Stress – Strain Curve for Composite 7 (Treated – F10%, S20% and E70%)

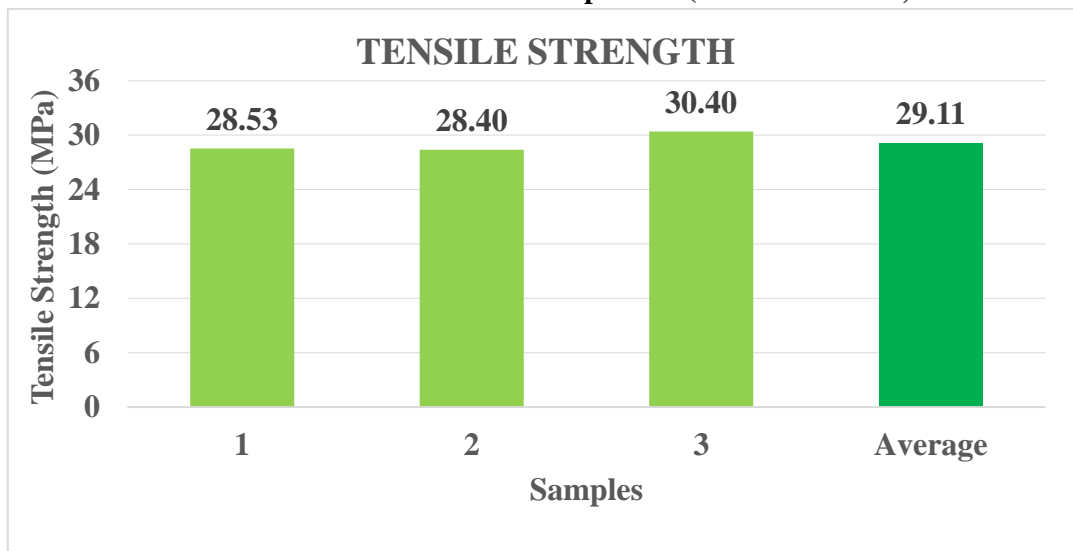


Figure 4. 14 Tensile Strength for All Samples and its average (Treated – F10%, S20% and E70%)

COMPOSITE EIGHT: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 15% Sisal and 70% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

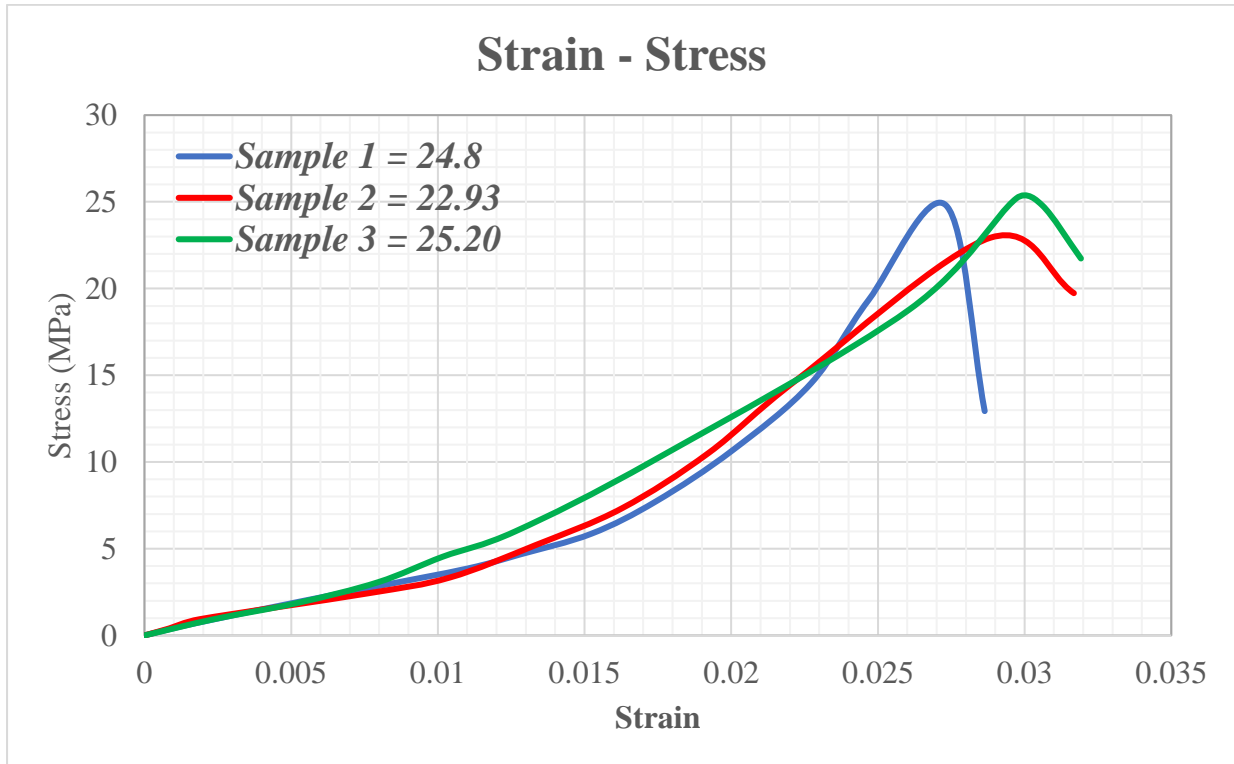


Figure 4. 15 Tensile Stress – Strain Curve for Composite 8 (Treated – F15%, S15% and E70%)

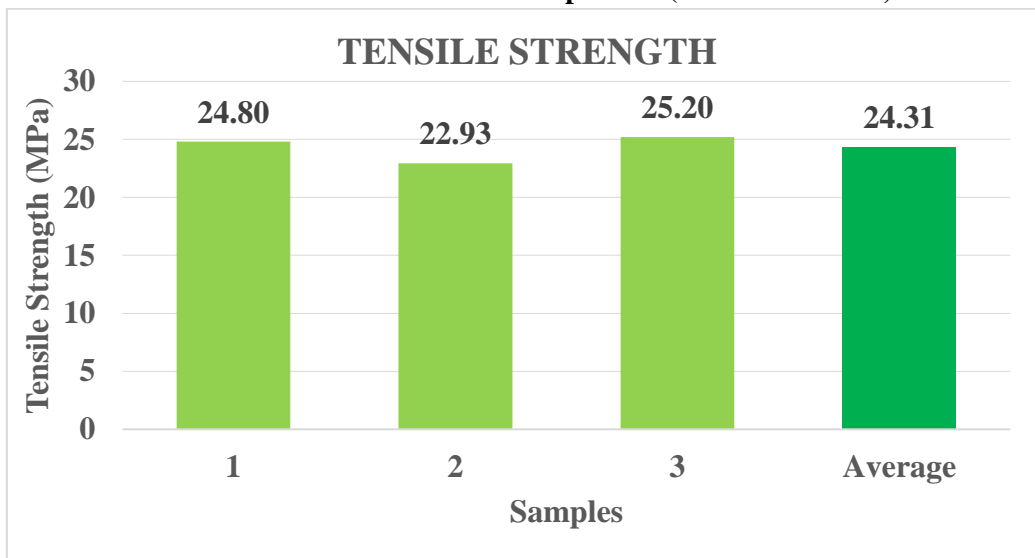


Figure 4. 16 Tensile Strength for All Samples and its average (Treated – F15%, S15% and E70%)

COMPOSITE NINE: Is an **untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 15% Sisal and 65% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

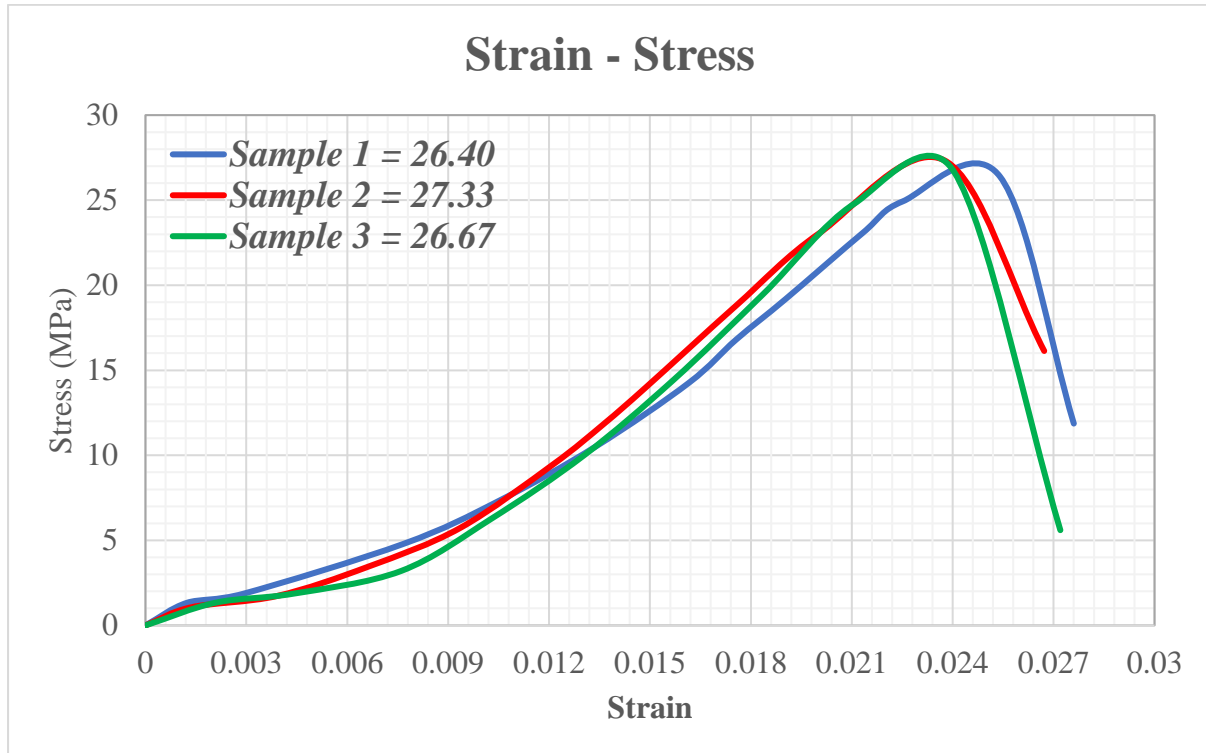


Figure 4. 17 Tensile Stress – Strain Curve for Composite 9 (Untreated – F20%, S15% and Epoxy 65%)

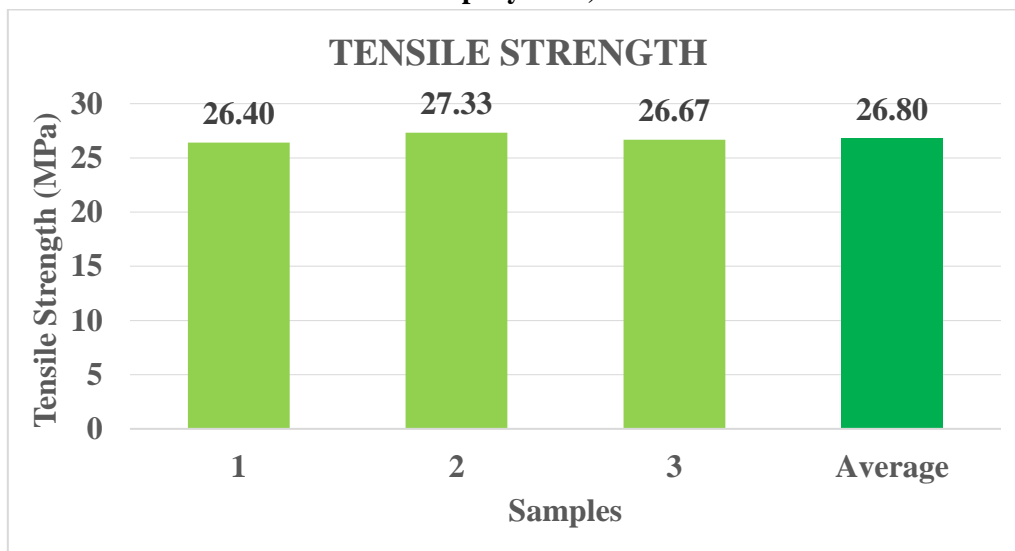


Figure 4. 18 Tensile Strength for All Samples and its average (Untreated – F20%, S15% and E65%)

COMPOSITE TEN: Is an **untreated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

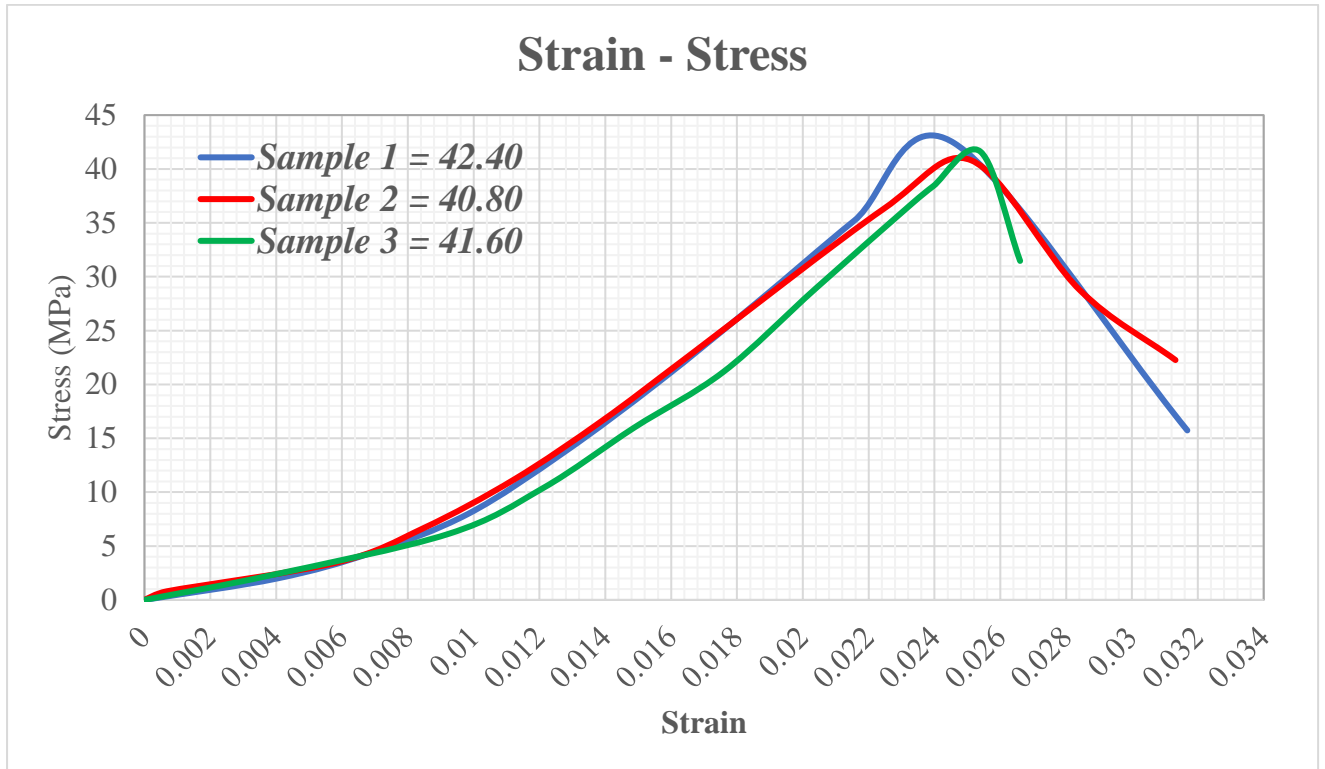


Figure 4. 19 Tensile Stress-Strain Curve for Composite 10 (Untreated-F15%, S25% and E60%)

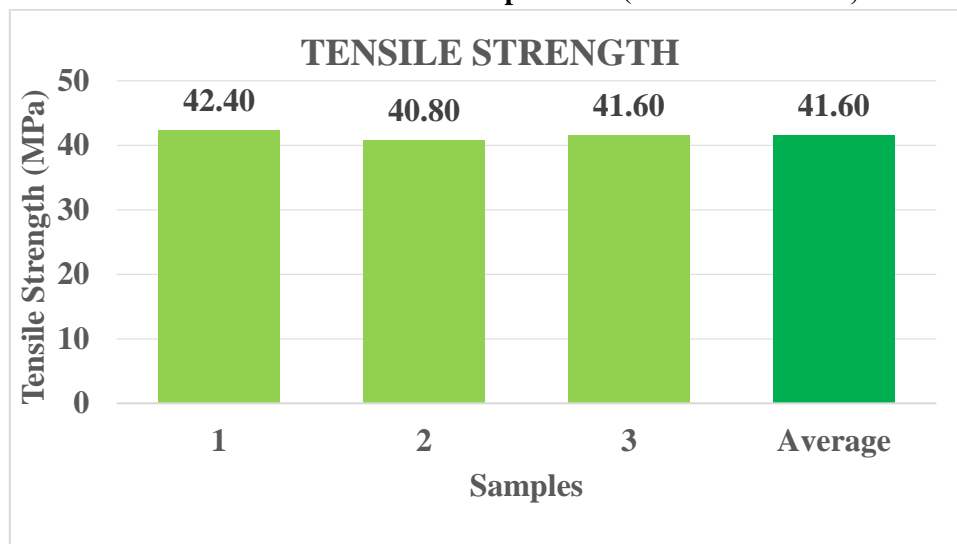


Figure 4. 20 Tensile Strength of All Samples and its average (Untreated-F15%, S25% and E60%)

COMPOSITE ELEVEN: Is as **Untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

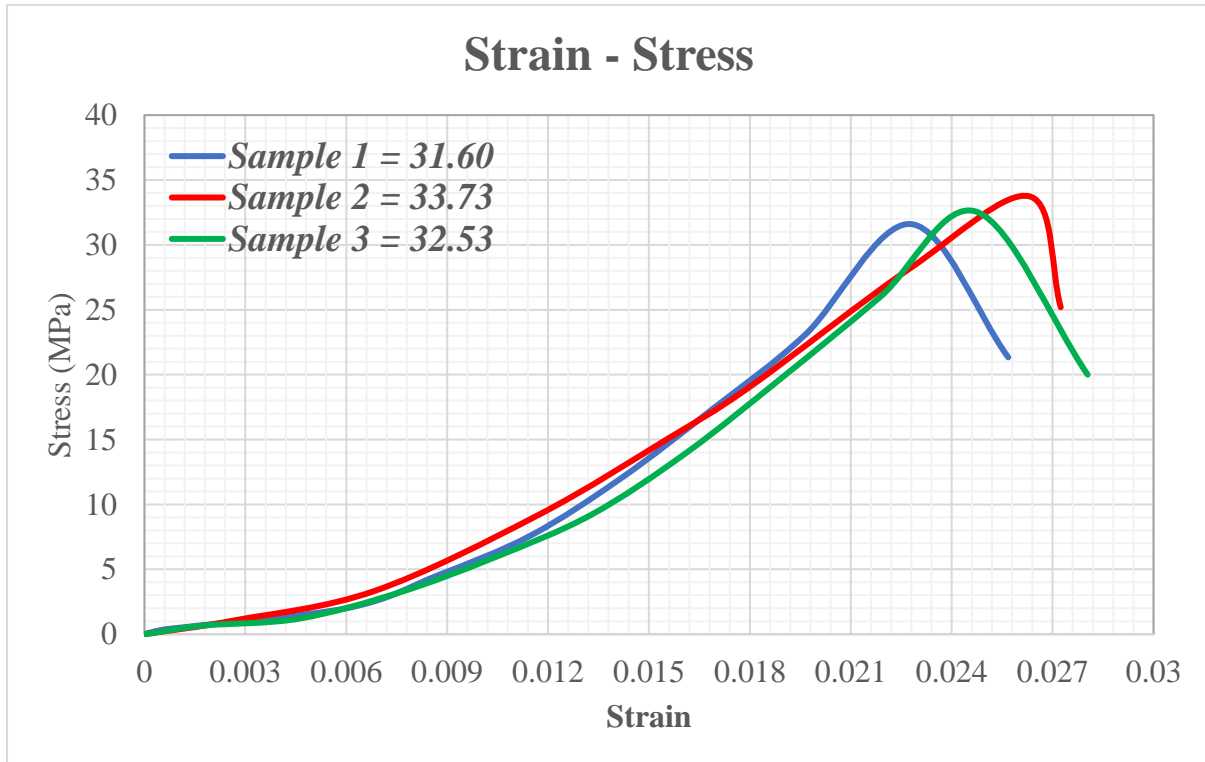


Figure 4. 21 Tensile Stress – Strain Curve for Composite 11 (Untreated–F20%, S20% and E60%)

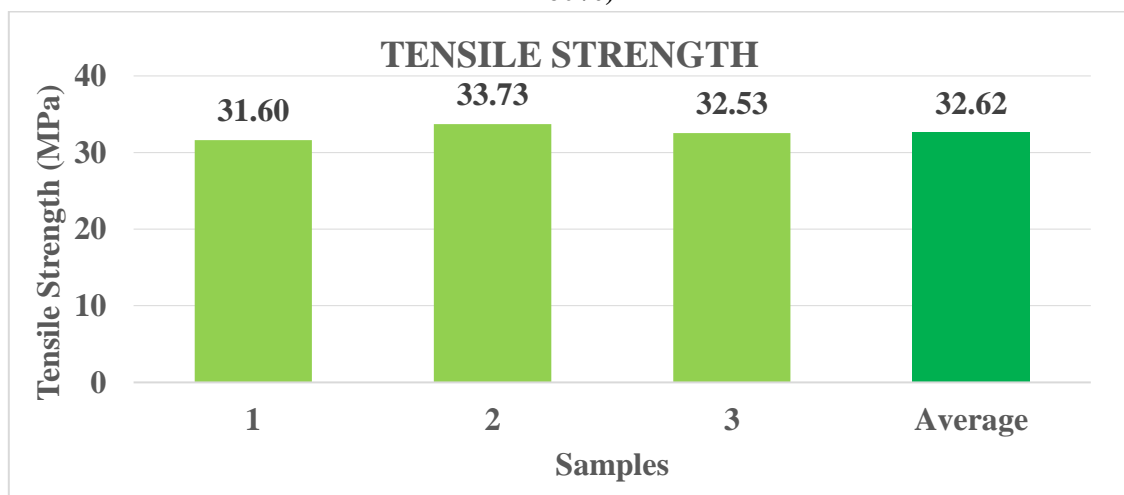


Figure 4. 22 Tensile Strength for All Samples and its average (Untreated–F20%, S20% and E60%)

COMPOSITE TWELVE: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **25% Flax 15% Sisal and 60% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

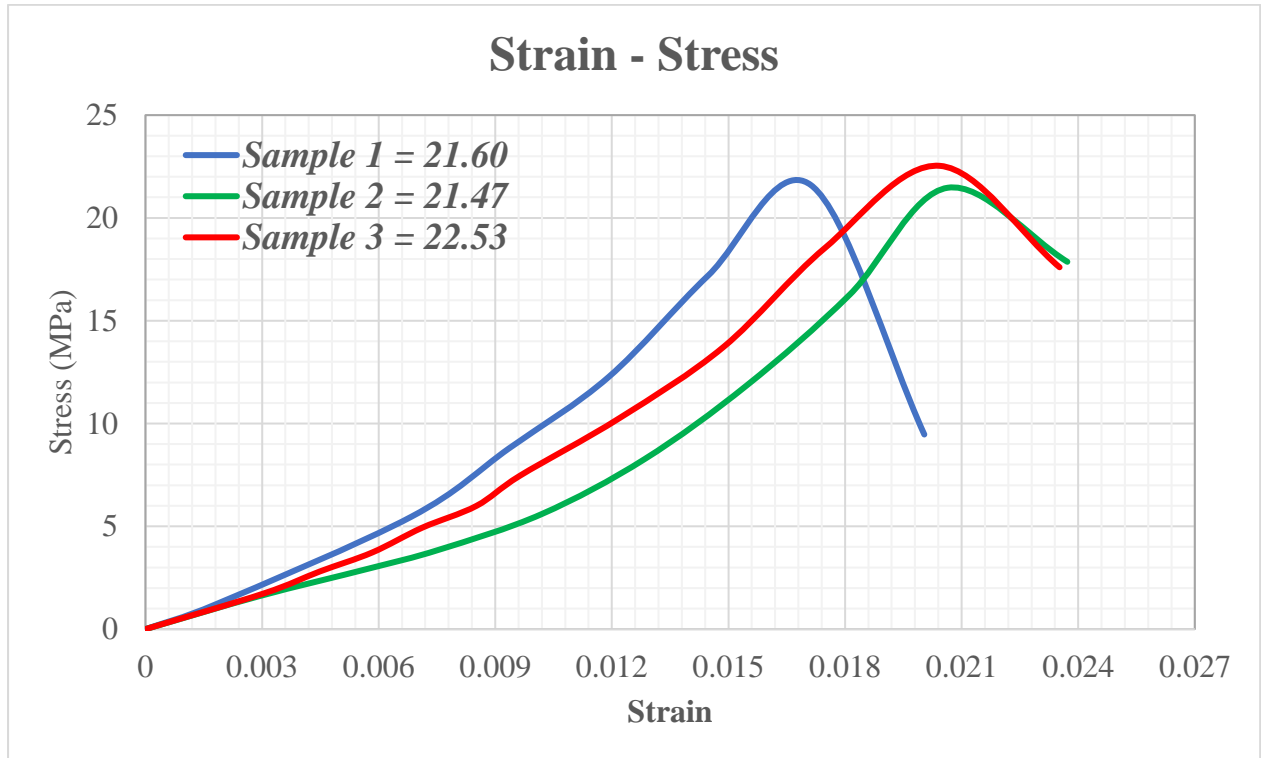


Figure 4. 23 Tensile Stress-Strain Curve for Composite 12 (Untreated–F25%, S15% and E60%)

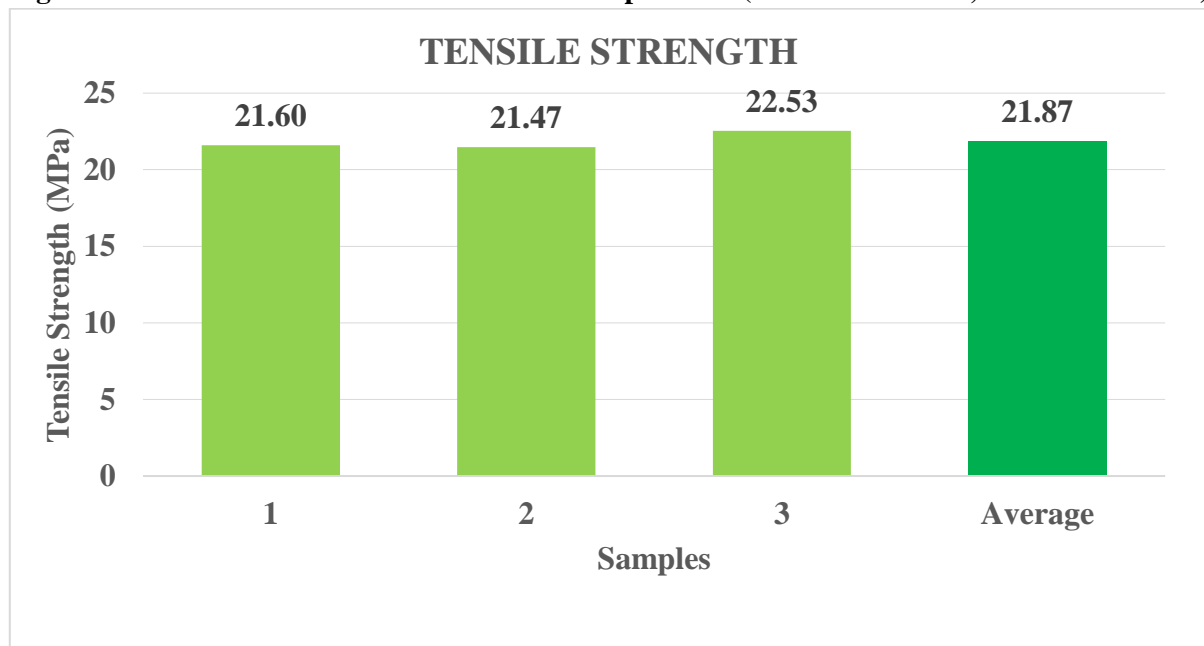


Figure 4. 24 Tensile Strength for All Samples and its average (Untreated–F25%, S15% and E60%)

COMPOSITE THIRTEEN: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. For this composite three specimens were tested according to ASTM D3039.

The result of the test is as follows.

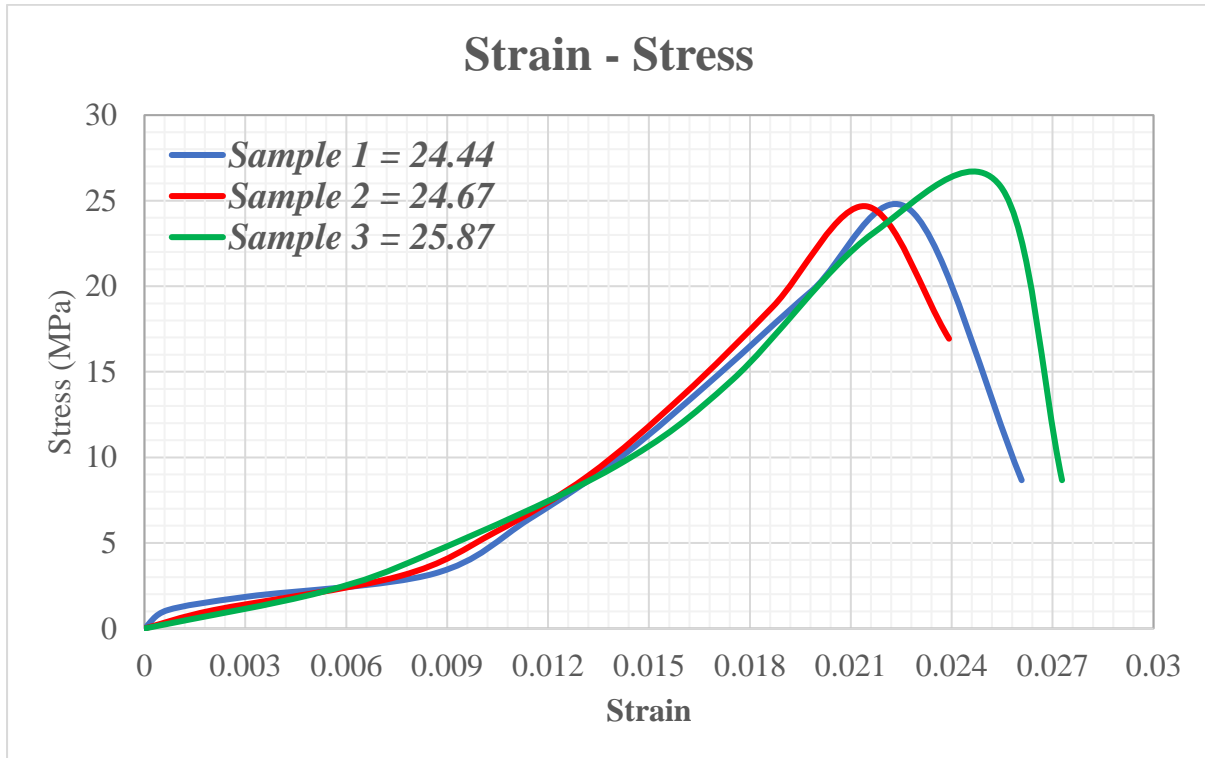


Figure 4. 25 Tensile Stress–Strain Curve for Composite 13 (Untreated–F10%, S20% and E70%)

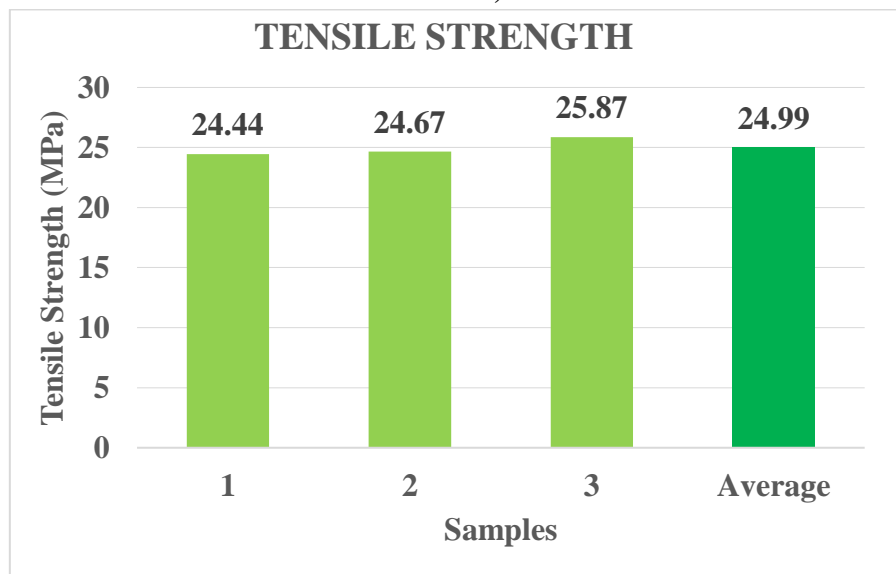


Figure 4. 26 Tensile Strength for All Samples and its average (Untreated–F10%, S20% and E70%)

Overall, the Tensile strength and Tensile Modulus obtained for the composites are shown in figure 4.27 and Figure 4.28 respectively.

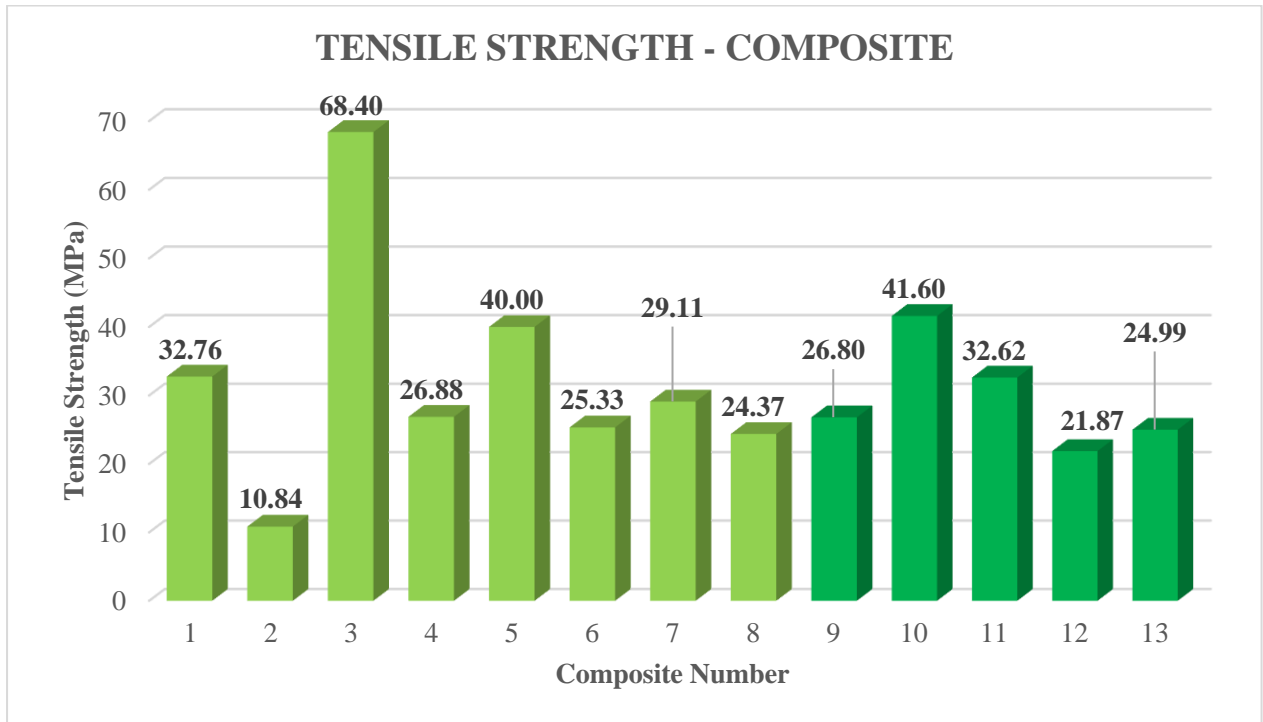


Figure 4. 27 Tensile strength – Composite for all composites Flax/Sisal – Epoxy Composite

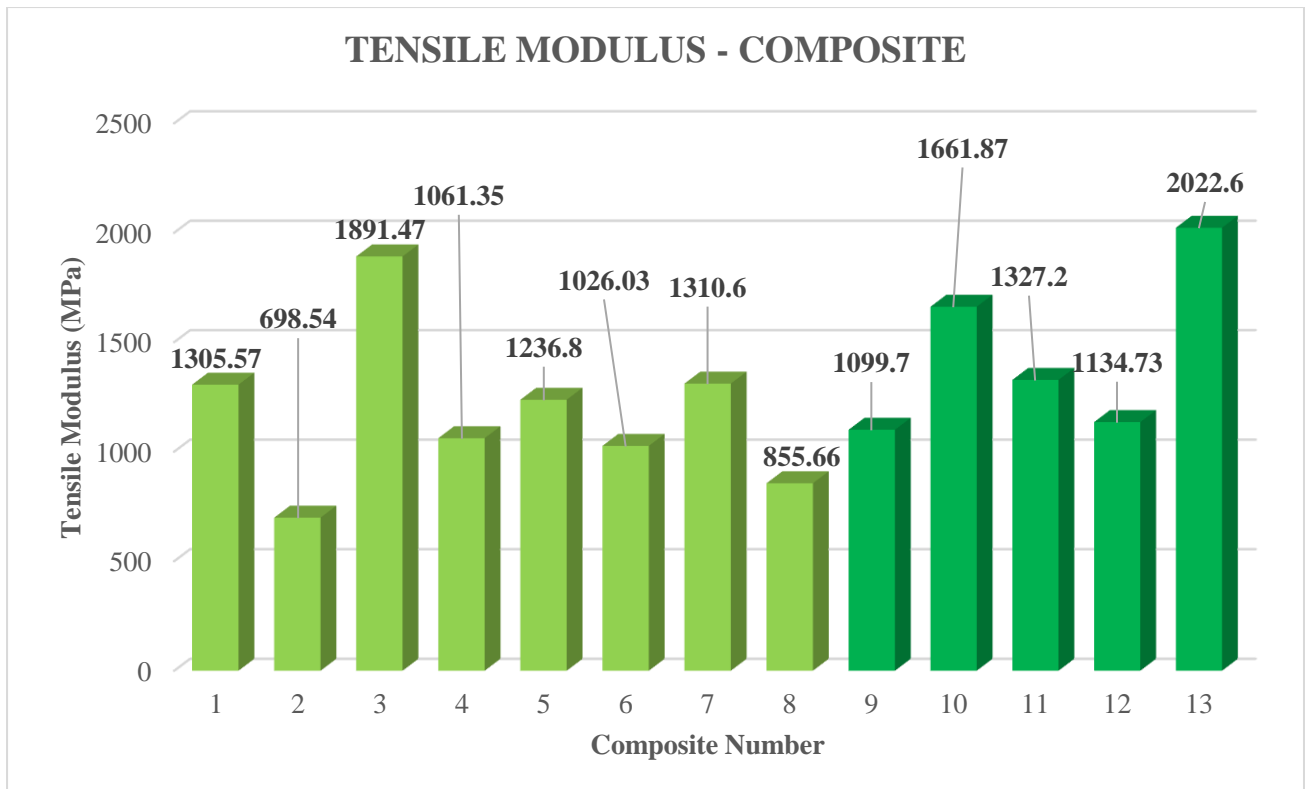


Figure 4. 28 Tensile Modulus – Composite for all composites Flax/Sisal – Epoxy Composite

4.1.2 COMPRESSION TEST RESULT

Under compression test minimum of **sixty-five** specimen samples were tested. Three specimen samples from each composite compositions were selected and presented in this study. The specimens were prepared according to ASTM specification. The average result from the tested specimen were taken to characterize each composite group that are studied in this thesis.

The graph obtained from testing all the thirteen specimen samples are presented on the Appendix section of this thesis. All the maximum values and their average are presented below using bar chart for each composite specimen.

COMPOSITE ONE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. ASTM D3410

The result of the test is as follows.

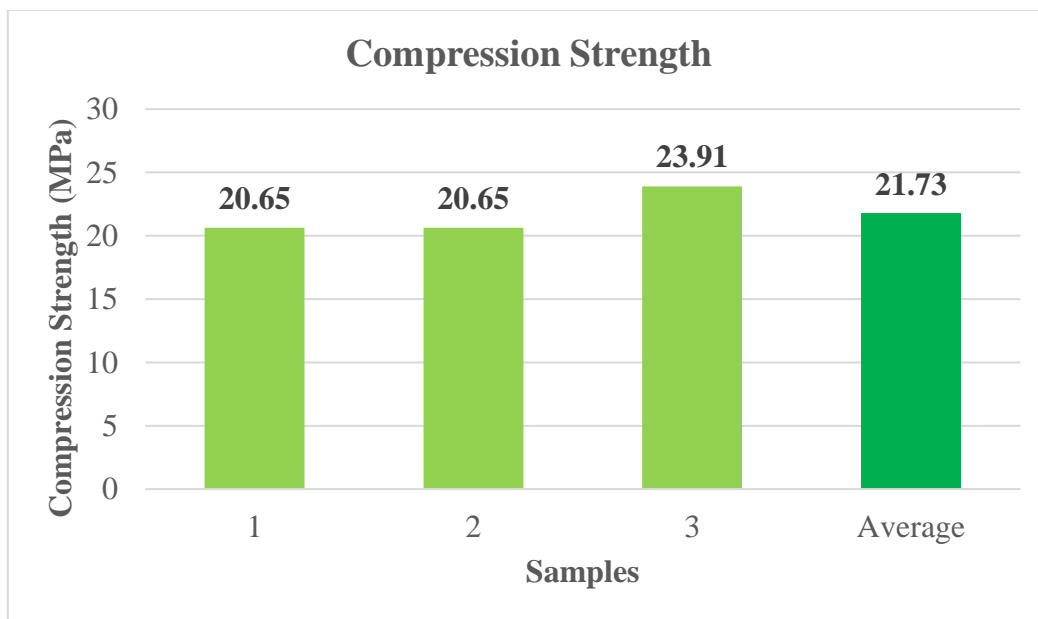


Figure 4. 29 Compression Strength for All Samples and its average (Treated – F20%, S20% and E60%)

COMPOSITE TWO: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. ASTM D3410.

The result of the test is as follows.

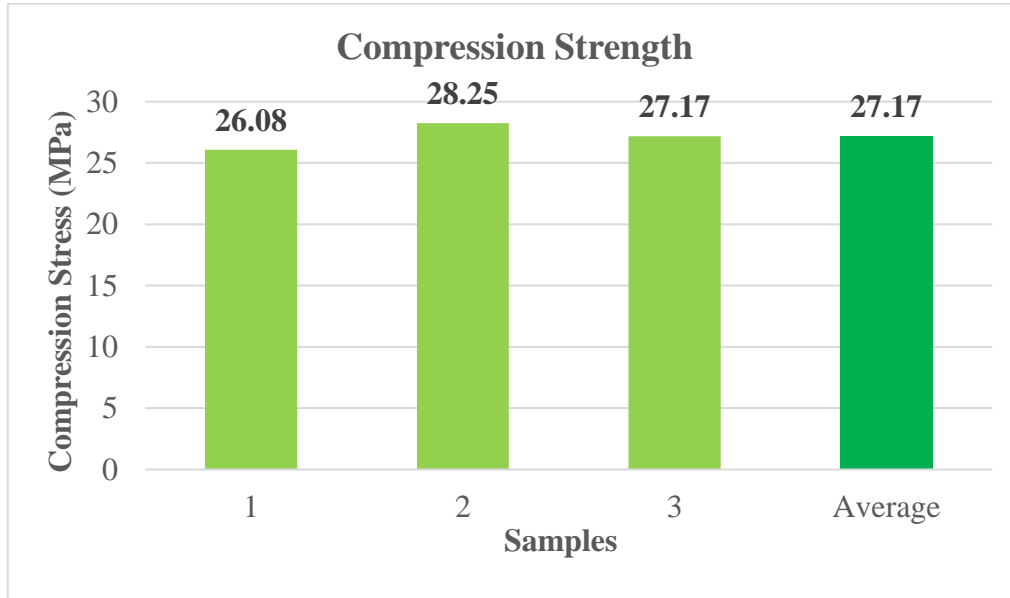


Figure 4. 30 Compression Strength for All Samples and its average (Treated–F15%, S25% and E60%)

COMPOSITE THREE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **25% Flax 15% Sisal and 60% Epoxy**. ASTM D3410.

The result of the test is as follows.

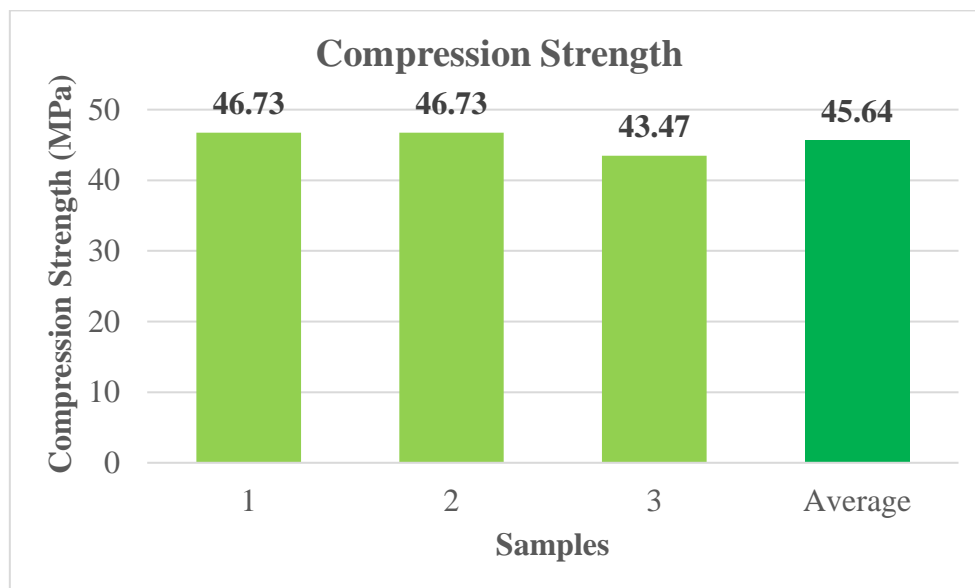


Figure 4. 31 Compression Strength for All Samples and its average (Treated–F25%, S15% and E60%)

COMPOSITE FOUR: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 15% Sisal and 65% Epoxy**. ASTM D3410.

The result of the test is as follows.

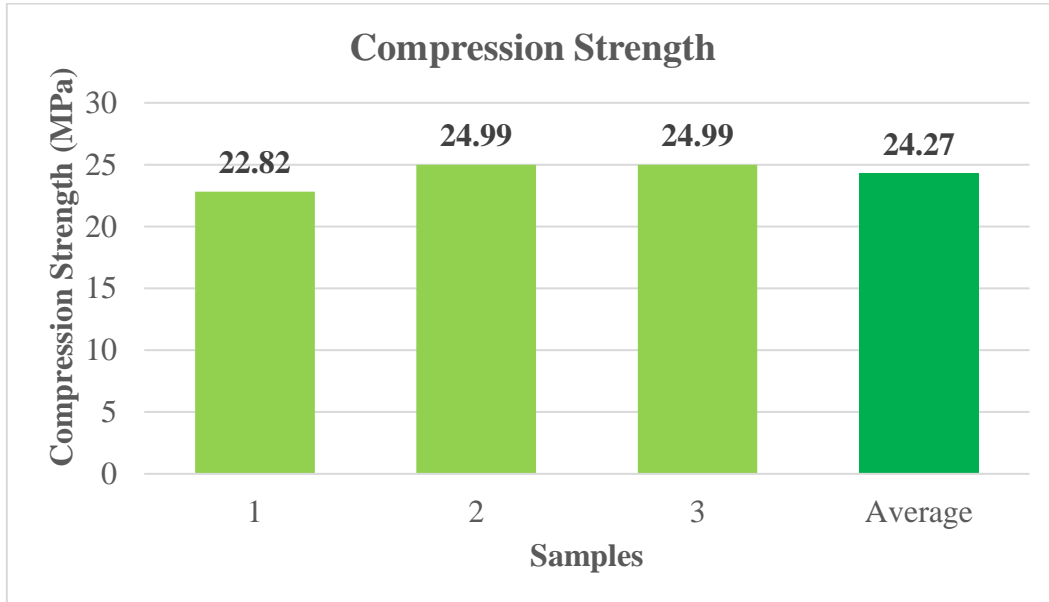


Figure 4. 32 Compression Strength for All Samples and its average (Treated–F20%, S15% and E65%)

COMPOSITE FIVE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 20% Sisal and 65% Epoxy**. ASTM D3410.

The result of the test is as follows.

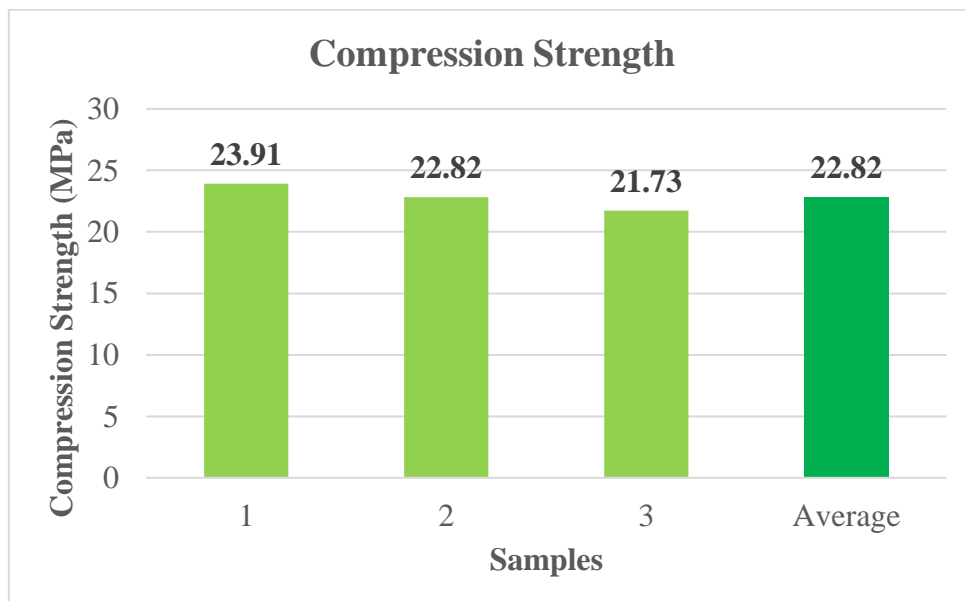


Figure 4. 33 Compression Strength for All Samples and its average (Treated–F15%, S20% and E65%)

COMPOSITE SIX: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. ASTM D3410.

The result of the test is as follows.

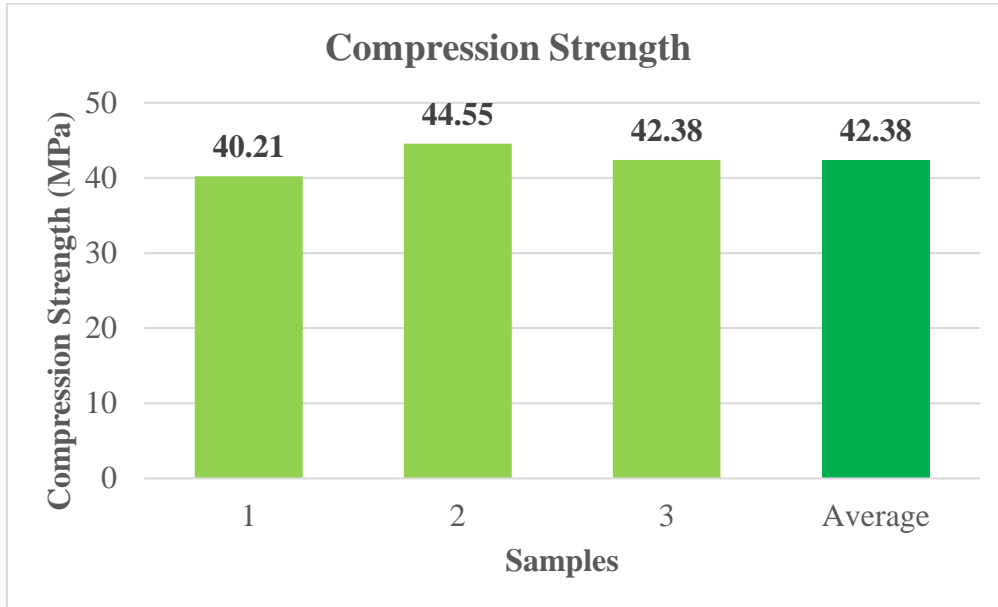


Figure 4. 34 Compression Strength for All Samples and its average (Treated – Flax 10%, Sisal 20% and Epoxy 70%)

COMPOSITE SEVEN: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 10% Sisal and 70% Epoxy**. ASTM D3410.

The result of the test is as follows.

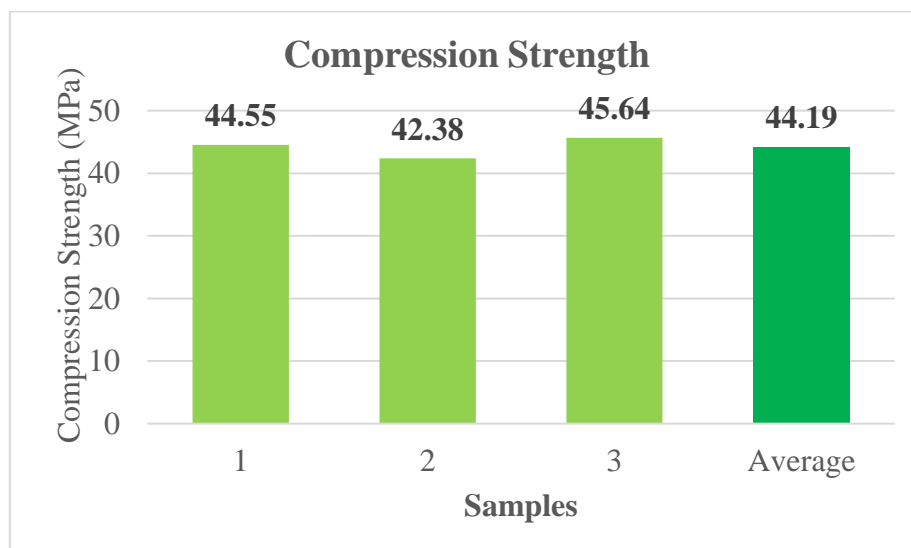


Figure 4. 35 Compression Strength for All Samples and its average (Treated–F10%, S20% and E70%)

COMPOSITE EIGHT: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 15% Sisal and 70% Epoxy**. ASTM D3410.

The result of the test is as follows.

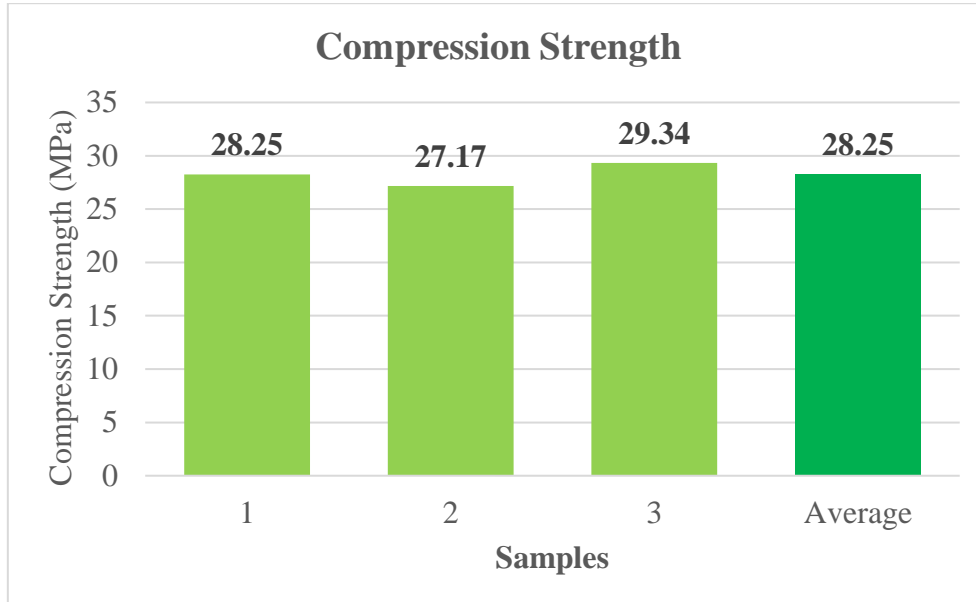


Figure 4. 36 Compression Strength for All Samples and its average (Treated–F15%, S15% and E70%)

COMPOSITE NINE: Is an **untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 15% Sisal and 65% Epoxy**. ASTM D3410.

The result of the test is as follows.

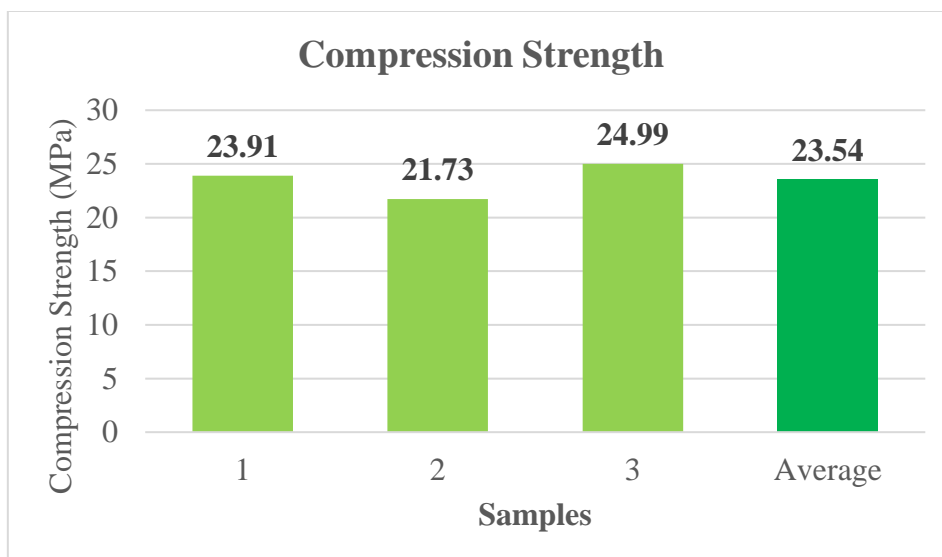


Figure 4. 37 Compression Strength for All Samples and its average (Untreated–F20%, S15% & E65%)

COMPOSITE TEN: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. ASTM D3410.

The result of the test is as follows.

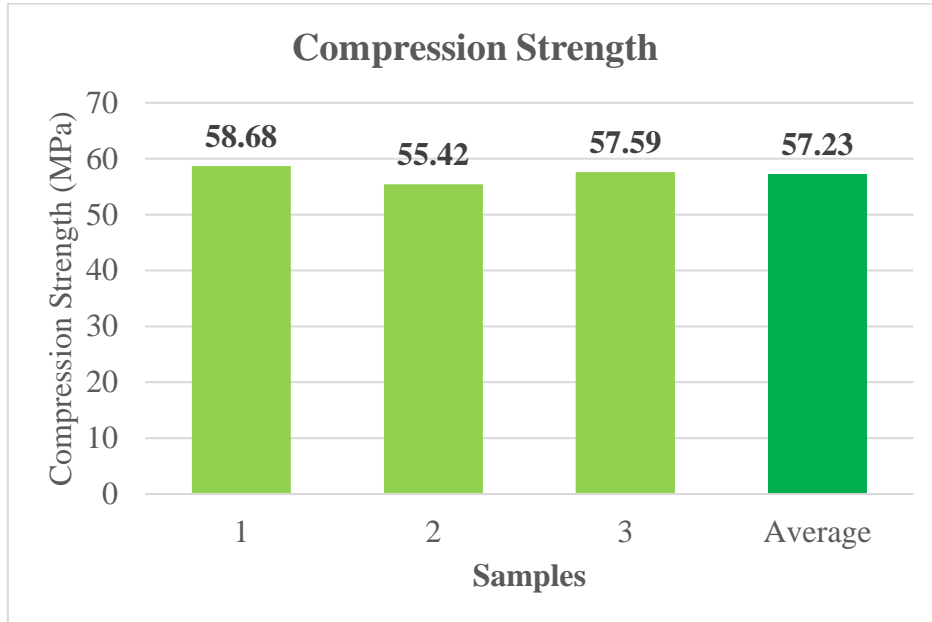


Figure 4. 38 Compression Strength for All Samples and its average (Untreated–F15%, S25% & E60%)

COMPOSITE ELEVEN: Is as **Untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. ASTM D3410.

The result of the test is as follows.

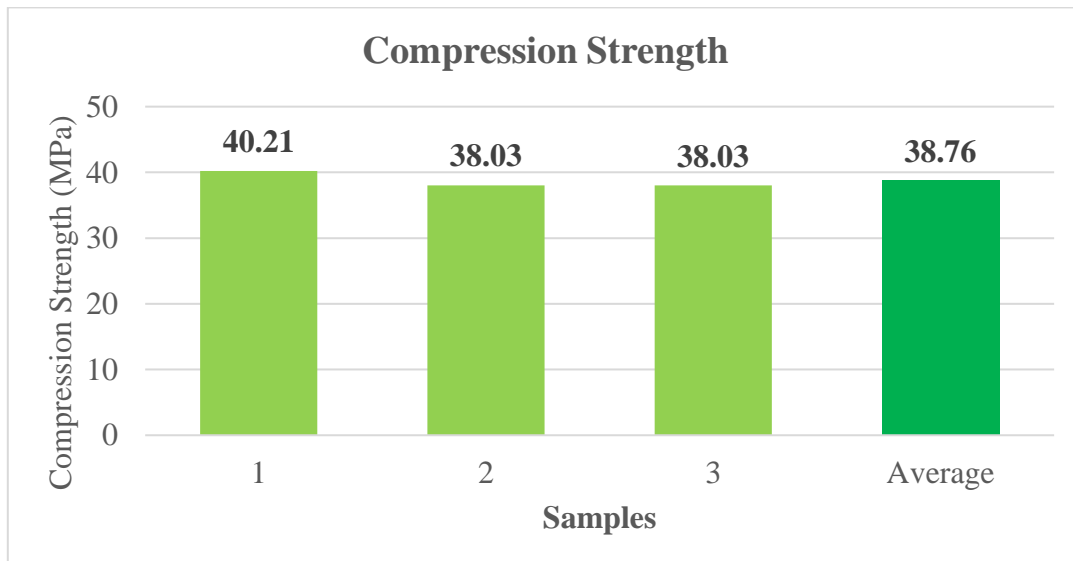


Figure 4. 39 Compression Strength for All Samples and its average (Untreated–F20%, S20% & E60%)

COMPOSITE TWELVE: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **25% Flax 15% Sisal and 60% Epoxy**. ASTM D3410.

The result of the test is as follows.

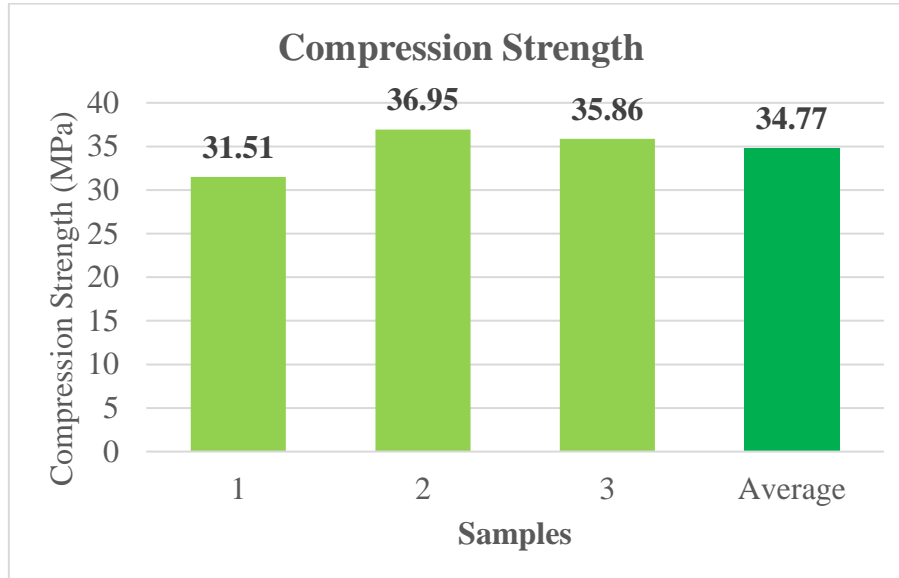


Figure 4. 40 Compression Strength for All Samples and its average (Untreated–F25%, S15% & E60%)

COMPOSITE THIRTEEN: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. ASTM D3410.

The result of the test is as follows.

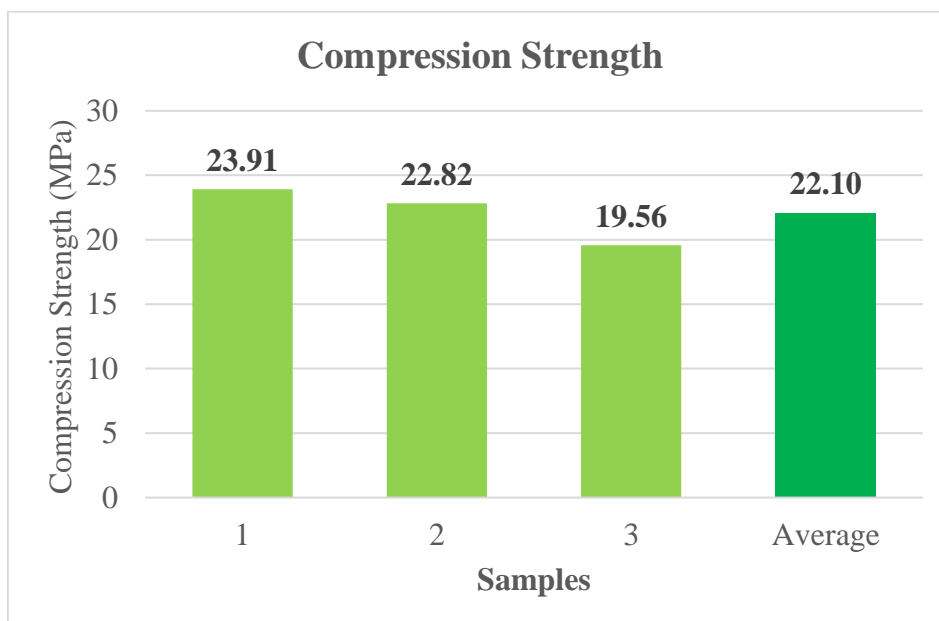


Figure 4. 41 Compression Strength for All Samples and its average (Untreated–F10%, S20% & E70%)

Overall, the Compression Strength and Compressive Modulus obtained for the composites are shown in Figure 4.42 and Figure 4.43 respectively.

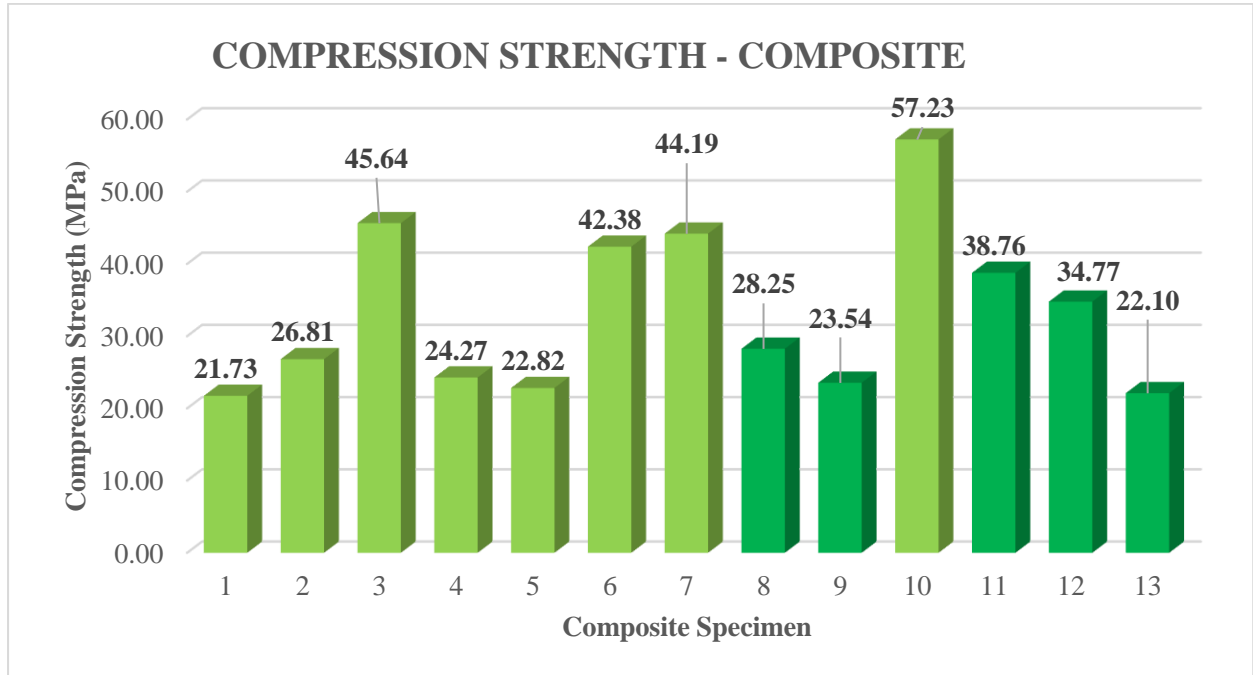


Figure 4. 42 Compression strength – Composite for all composites Flax/Sisal – Epoxy Composite

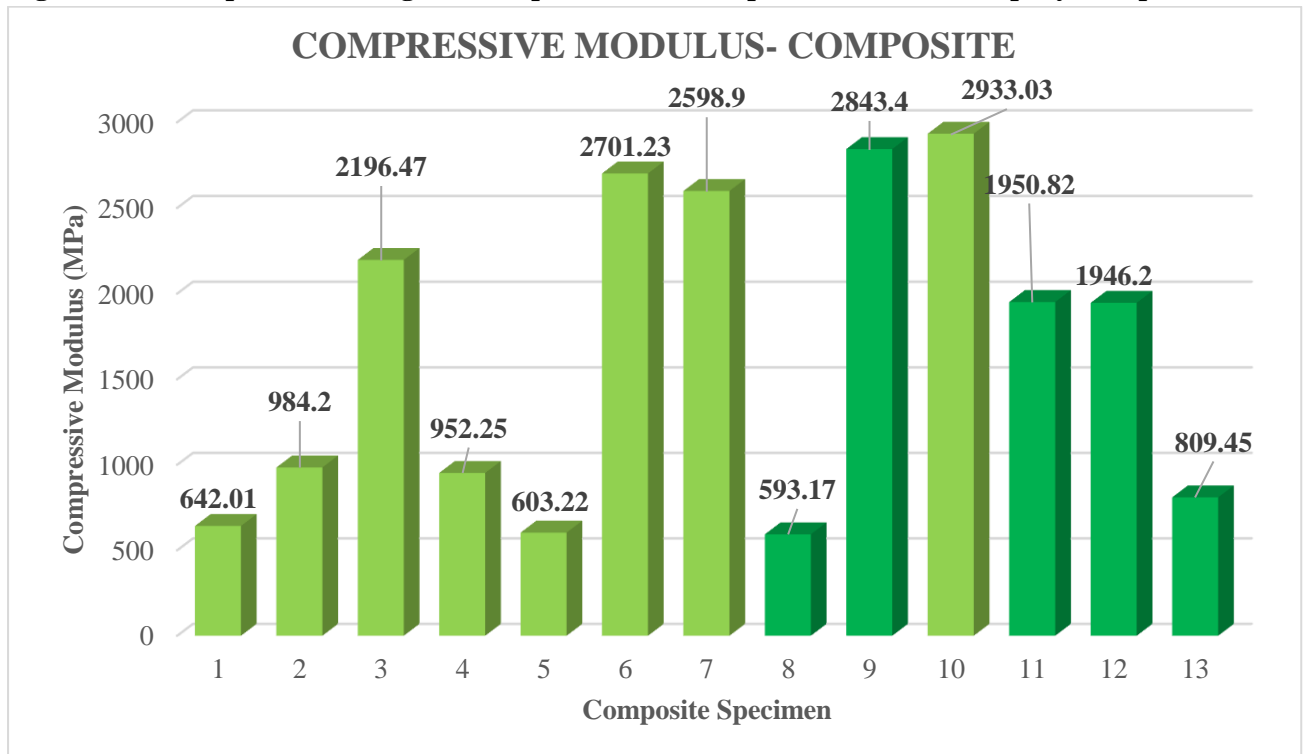


Figure 4. 43 Compressive modulus – Composite for all composites Flax/Sisal – Epoxy Composite

COMPOSITE ONE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. ASTM D790

The result of the test is as follows.

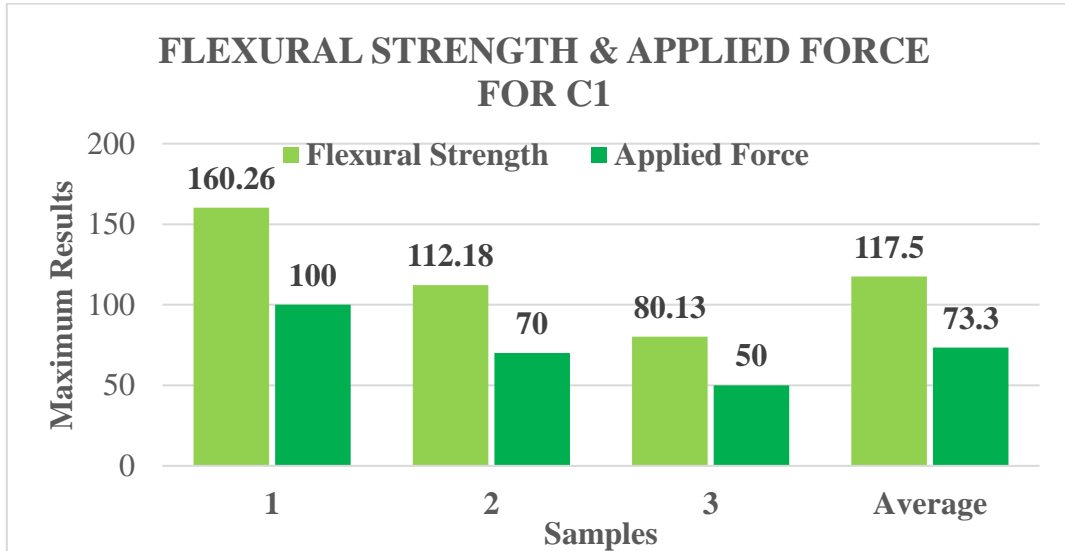


Figure 4. 45 Flexural Strength & Applied Force (Treated – F20%, S20% and E60%)

COMPOSITE TWO: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. ASTM D790

The result of the test is as follows.

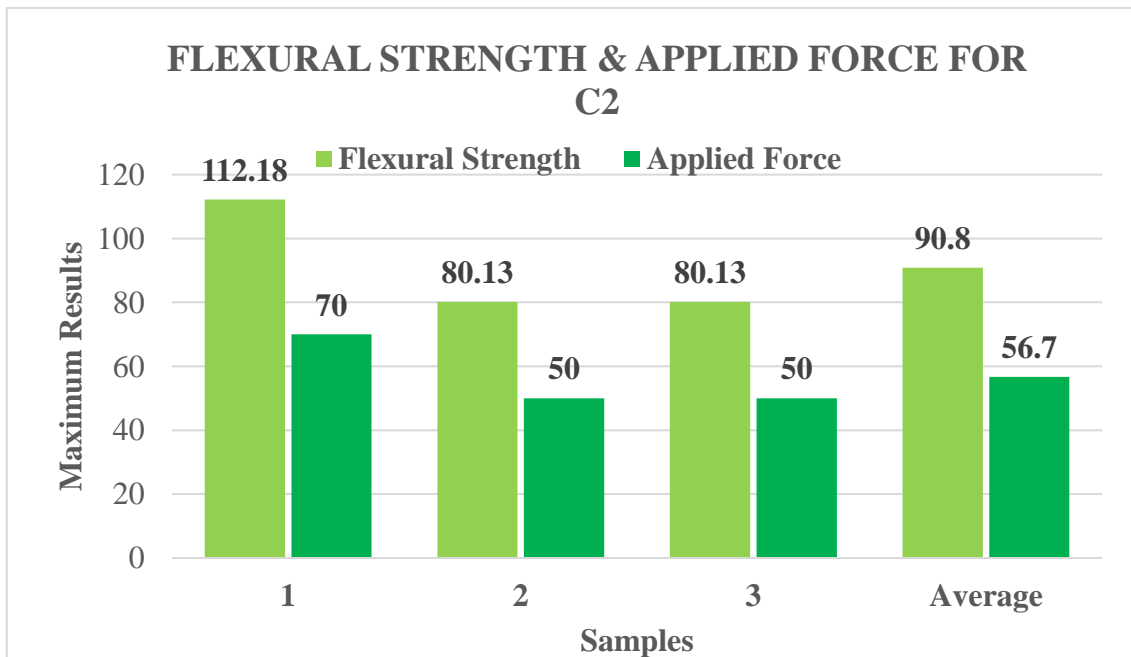


Figure 4. 46 Flexural Strength & Applied Force (Treated – F15%, S25% and E60%)

COMPOSITE THREE: Is a treated composite having chopped reinforced hybrid fibers with composition of 25% Flax 15% Sisal and 60% Epoxy. ASTM D790.

The result of the test is as follows.

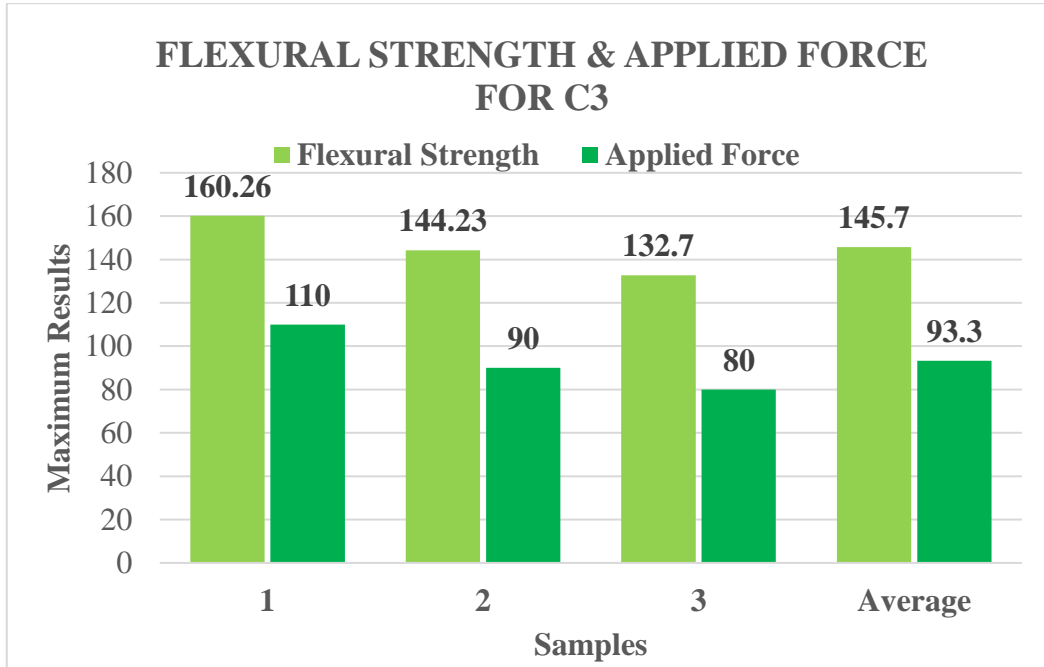


Figure 4. 47 Flexural Strength & Applied Force (Treated – F25%, S15% and E60%)

COMPOSITE FOUR: Is a treated composite having chopped reinforced hybrid fibers with composition of 20% Flax 15% Sisal and 65% Epoxy. ASTM D790.

The result of the test is as follows.

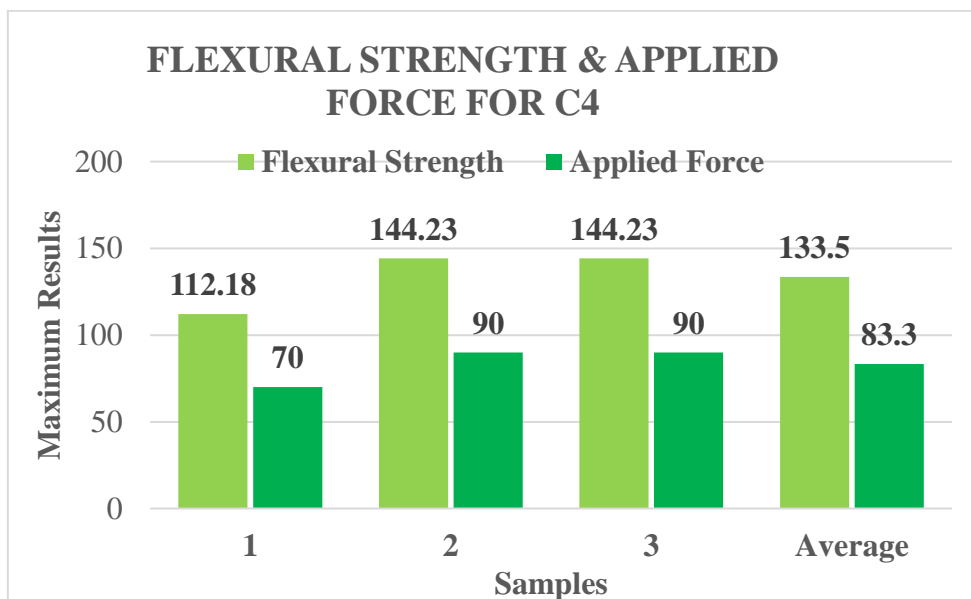


Figure 4. 48 Flexural Strength & Applied Force (Treated – F20%, S15% and E65%)

COMPOSITE FIVE: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 20% Sisal and 65% Epoxy**. ASTM D790.

The result of the test is as follows.

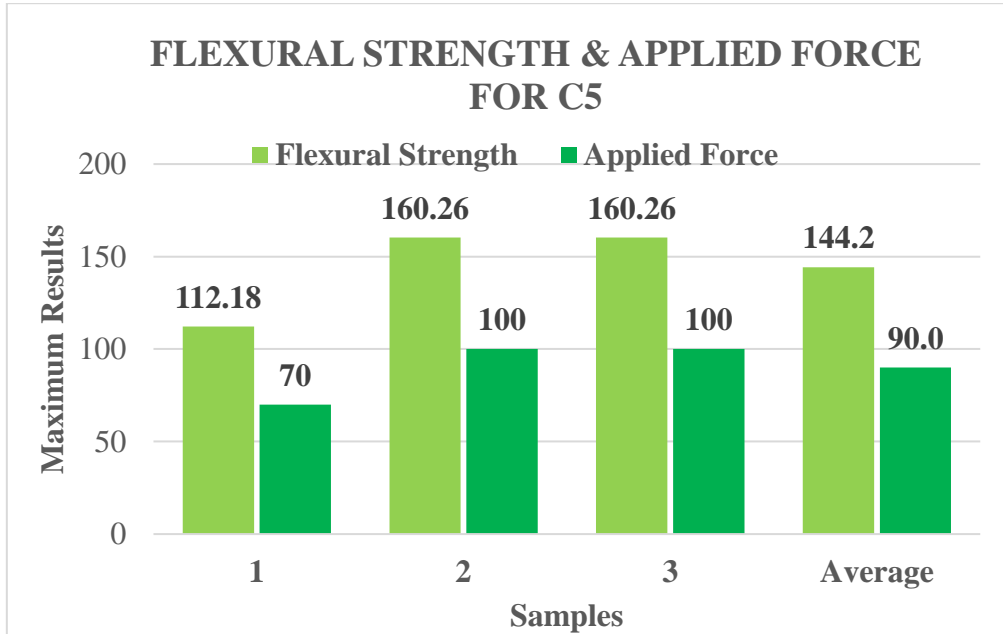


Figure 4. 49 Flexural Strength & Applied Force (Treated – F15%, S20% and E65%)

COMPOSITE SIX: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. ASTM D790.

The result of the test is as follows.

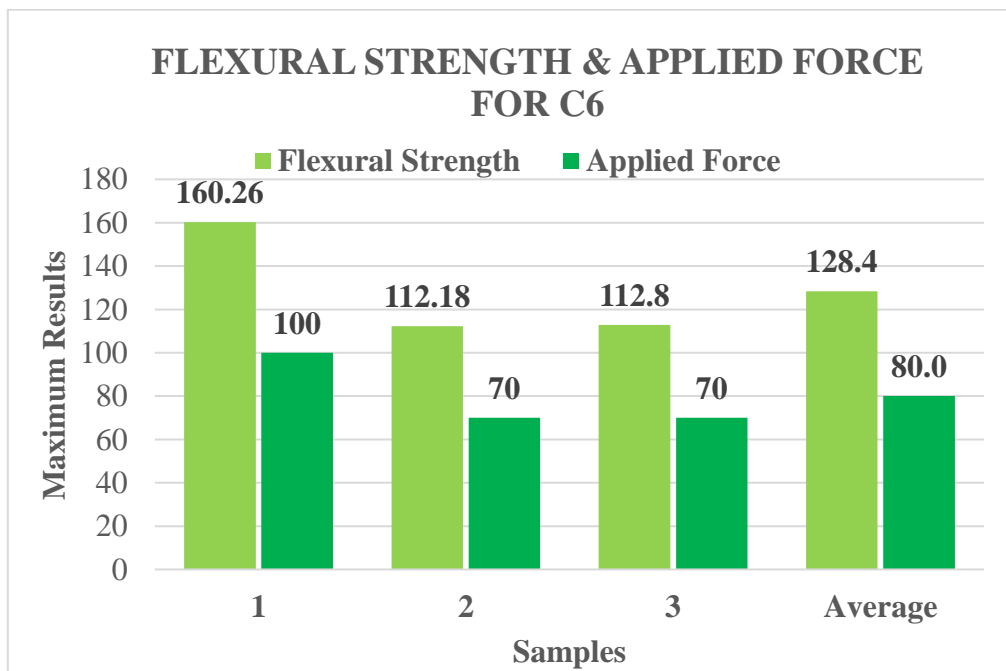


Figure 4. 50 Flexural Strength & Applied Force (Treated – F10%, S20% and E70%)

COMPOSITE SEVEN: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 10% Sisal and 70% Epoxy**. ASTM D790.

The result of the test is as follows.

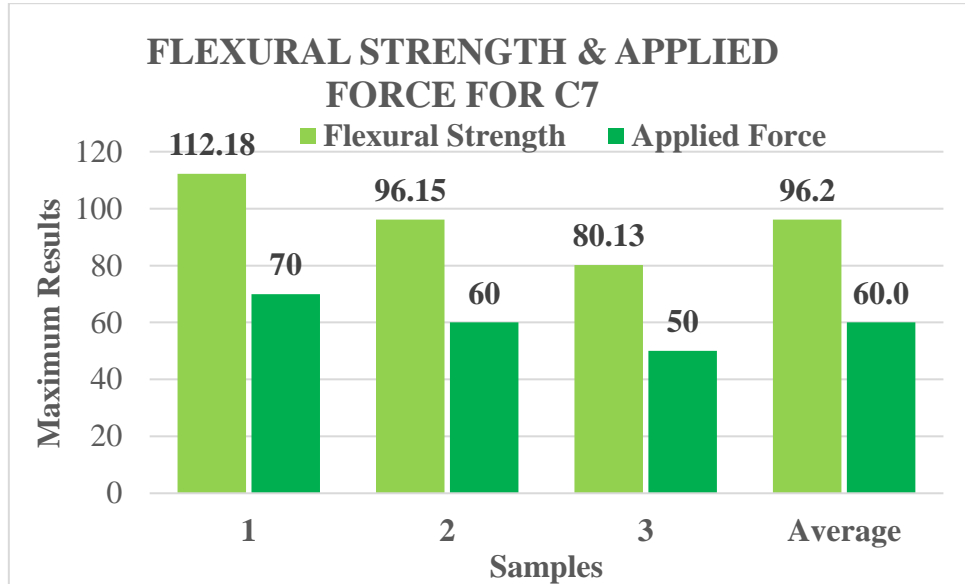


Figure 4. 51 Flexural Strength & Applied Force (Treated –F10%, S20% and E70%)

COMPOSITE EIGHT: Is a **treated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 15% Sisal and 70% Epoxy**. ASTM D790.

The result of the test is as follows.

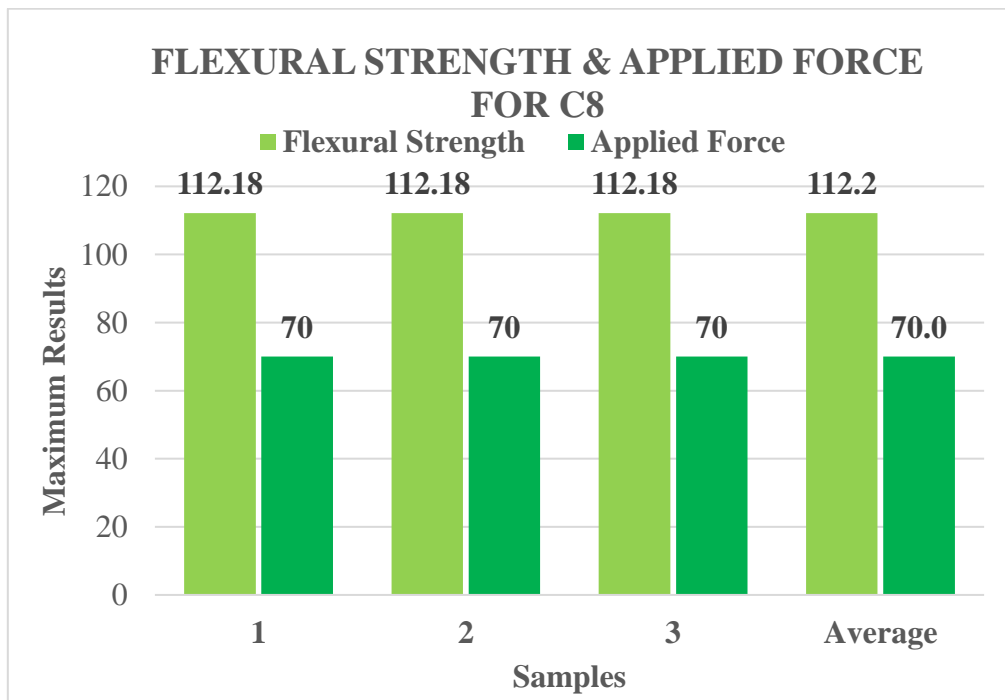


Figure 4. 52 Flexural Strength & Applied Force (Treated – F15%, S15% and E70%)

COMPOSITE NINE: Is an **untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 15% Sisal and 65% Epoxy**. ASTM D790.

The result of the test is as follows.

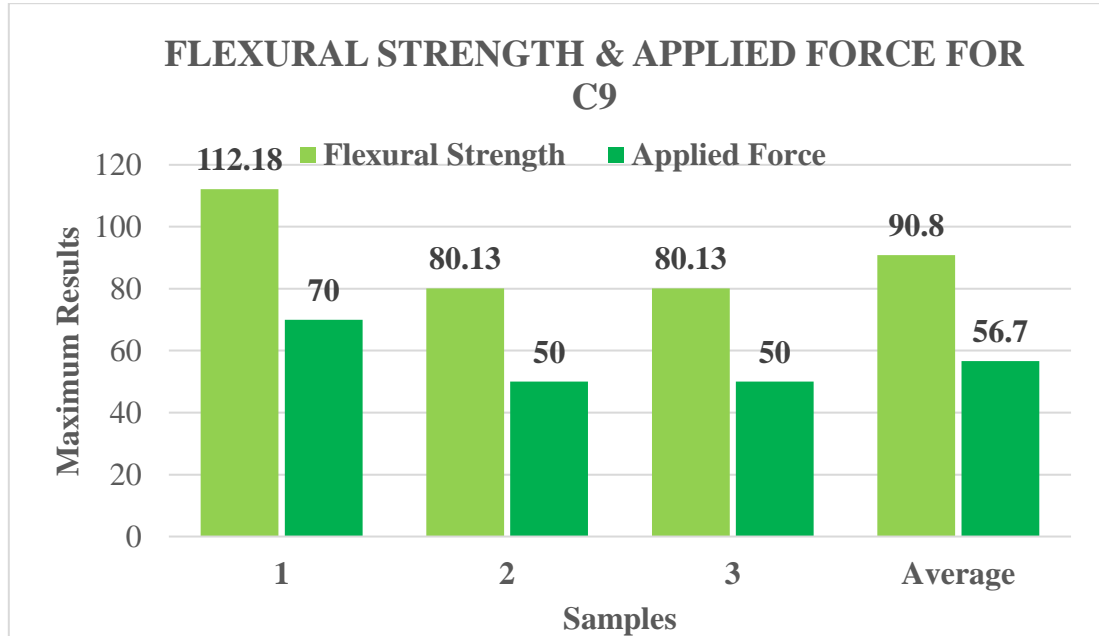


Figure 4. 53 Flexural Strength & Applied Force (Untreated – F20%, S15% and E65%)

COMPOSITE TEN: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **15% Flax 25% Sisal and 60% Epoxy**. ASTM D790.

The result of the test is as follows.

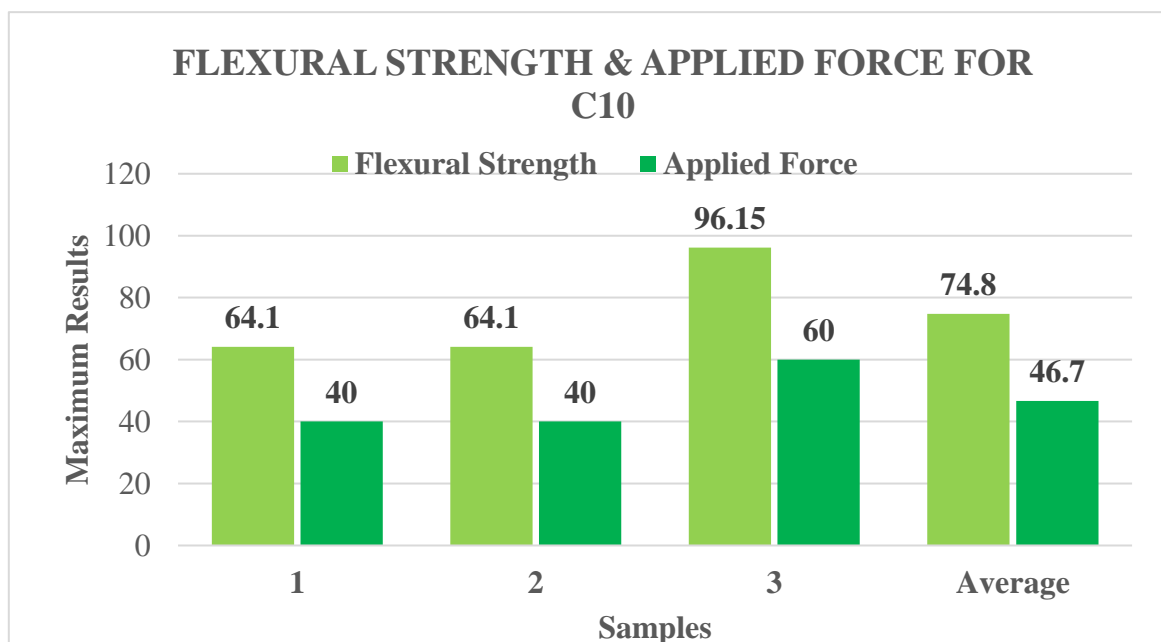


Figure 4. 54 Flexural Strength & Applied Force (Untreated – F15%, S25% and E60%)

COMPOSITE ELEVEN: Is as **Untreated** composite having chopped reinforced hybrid fibers with composition of **20% Flax 20% Sisal and 60% Epoxy**. ASTM D790.

The result of the test is as follows.

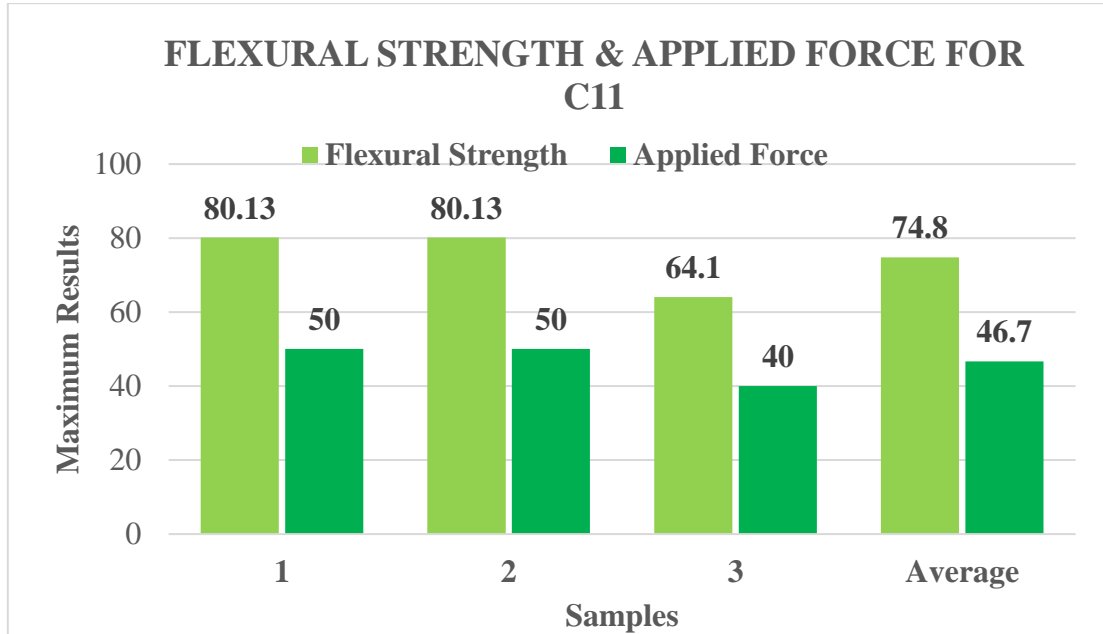


Figure 4. 55 Flexural Strength & Applied Force (Untreated – F20%, S20% and E60%)

COMPOSITE TWELVE: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **25% Flax 15% Sisal and 60% Epoxy**. Meaning it has 37.5% / 62.5% flax and Sisal fiber composition. For this composite three specimen were tested according to ASTM D7079.

The result of the test is as follows.

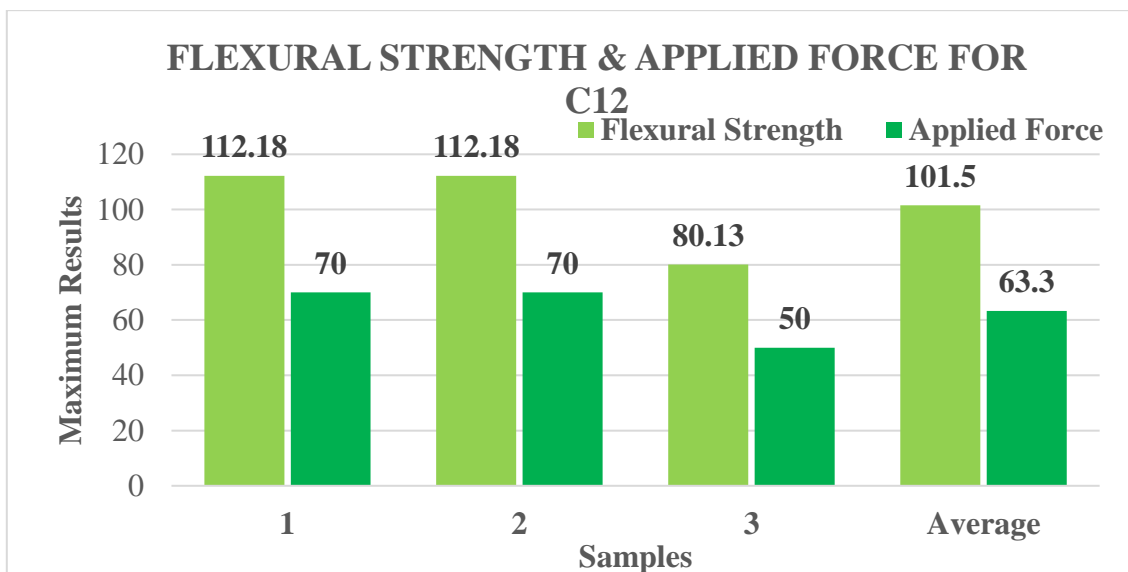


Figure 4. 56 Flexural Strength & Applied Force (Untreated – F25%, S15% and E60%)

COMPOSITE THIRTEEN: Is an **Untreated** composite having chopped reinforced hybrid fibers with composition of **10% Flax 20% Sisal and 70% Epoxy**. ASTM D790.

The result of the test is as follows.

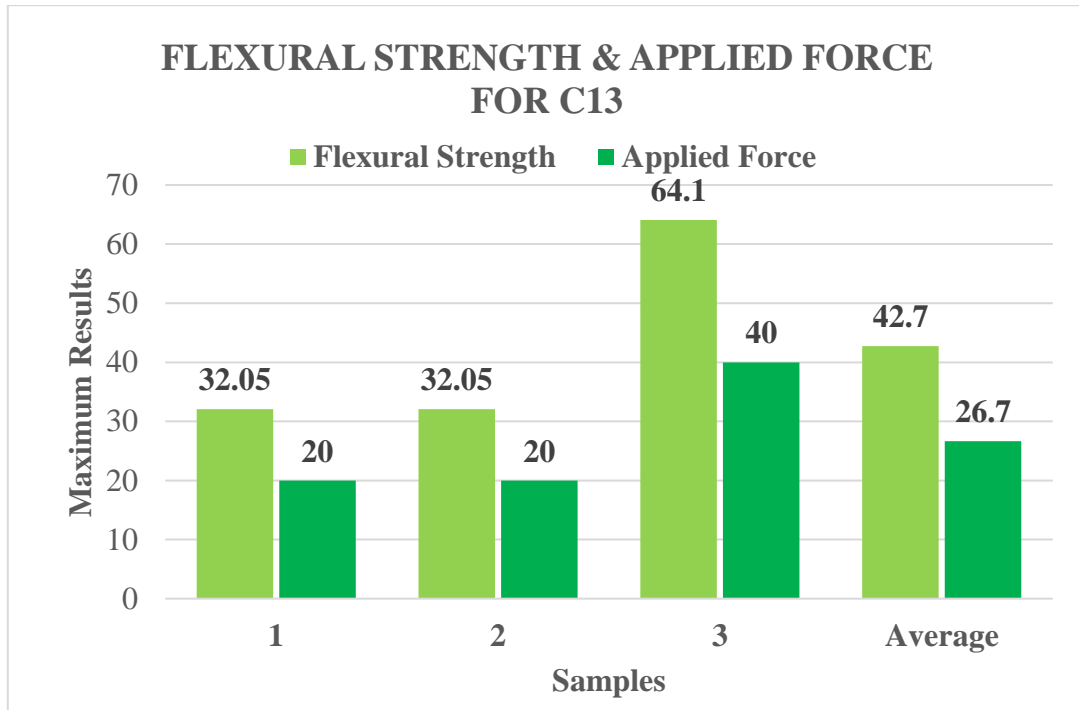


Figure 4. 57 Compression Stress – Strain Curve for Sample One of Composite thirteen (Untreated – Flax 10%, Sisal 20% and Epoxy 70% composition)

Overall, the Flexural strength and maximum test forces obtained are shown in figure 4.58 and Figure 4.59 respectively.

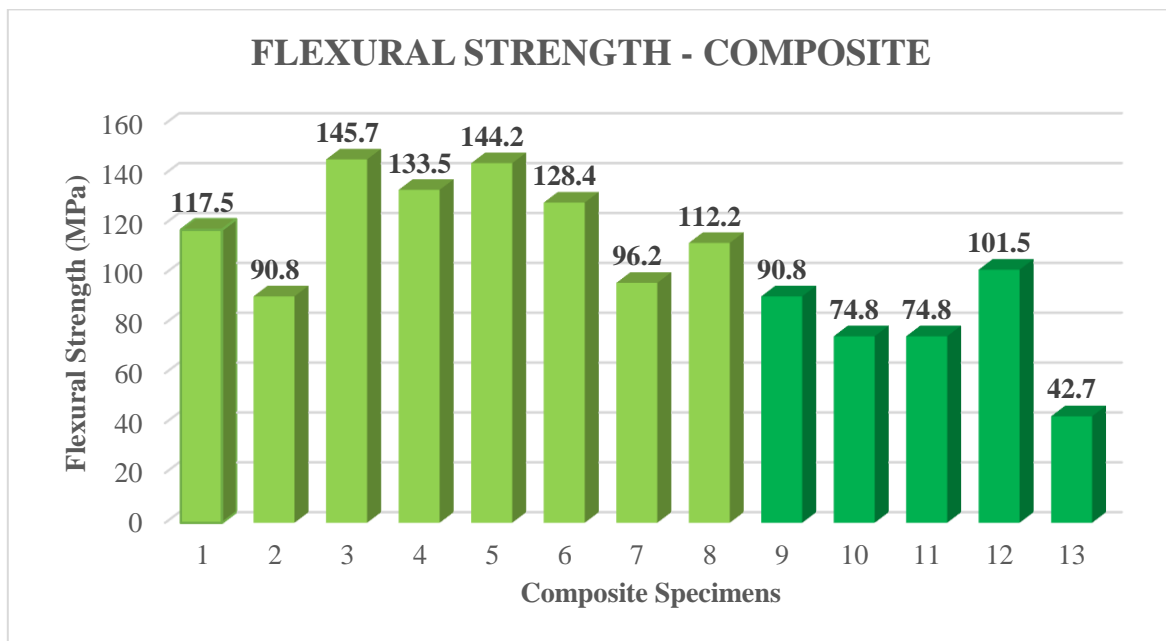


Figure 4. 58 Flexural Strength Vs Composite for all Flax/Sisal – Epoxy Composite

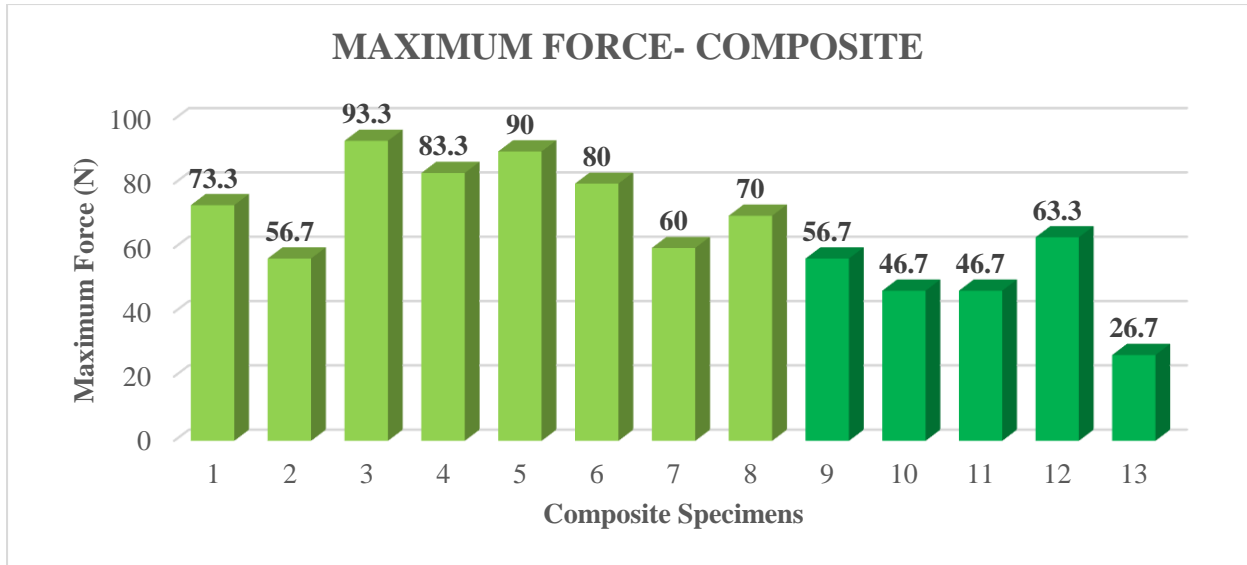


Figure 4. 59 Maximum Testing Force Vs Composite for all Flax/Sisal – Epoxy Composite

Table 4. 1 Flexural Strength and Maximum Test Force

No.	Composition	Dimension (mm)			Treatment	Maximum test force (N)	Flexural strength (MPa)
		L	W	T			
1	F20% S20% E60%	125	13	3	Treated	73.3	117.5
2	F15% S25% E60%	125	13	3	Treated	56.7	90.8
3	F25% S15% E60%	125	13	3	Treated	93.3	145.7
4	F20% S15% E65%	125	13	3	Treated	83.3	133.5
5	F15% S20% E65%	125	13	3	Treated	90	144.2
6	F10% S20% E70%	125	13	3	Treated	80	128.4
7	F20% S10% E70%	125	13	3	Treated	60	96.2
8	F15% S15% E70%	125	13	3	Treated	70	112.2
9	F20% S15% E65%	125	13	3	Untreated	56.7	90.8
10	F5% S25% E60%	125	13	3	Untreated	46.7	74.8
11	F20% S20% E60%	125	13	3	Untreated	46.7	74.8
12	F25% S15% E60%	125	13	3	Untreated	63.3	101.5
13	F10% S20% E70%	125	13	3	Untreated	26.7	42.7

4.1.4 IMPACT TEST RESULT

The results of all thirteen composite specimens are shown in the table below. From each composite, three specimen samples result were selected and reported in this thesis.

Table 4. 2 Impact Energy Result

No.	Composite Composition	Treated / Untreated	Sample No.	Impact Energy (J)
1	Flax 20% Sisal 20% Epoxy 60%	Treated	1	13.5
			2	10.5
			3	12.5
			AVERAGE	12.17
2	Flax 15% Sisal 25% Epoxy 60%	Treated	1	12.5
			2	13.5
			3	15
			AVERAGE	13.67
3	Flax 25% Sisal 15% Epoxy 60%	Treated	1	10.5
			2	9.5
			3	12.5
			AVERAGE	10.83
4	Flax 20% Sisal 15% Epoxy 65%	Treated	1	8
			2	8.5
			3	10.5
			AVERAGE	9
5	Flax 15% Sisal 20% Epoxy 65%	Treated	1	6.5
			2	8.5
			3	8.5
			AVERAGE	7.83
6	Flax 10% Sisal 20% Epoxy 70%	Treated	1	6
			2	7.5
			3	4.5
			AVERAGE	6
7	Flax 20% Sisal 10% Epoxy 70%	Treated	1	6
			2	4.5
			3	5.5
			AVERAGE	5.33

8	Flax 15% Sisal 15% Epoxy 70%	Treated	1	7
			2	8.5
			3	6
			AVERAGE	7.17
9	Flax 20% Sisal 15% Epoxy 65%	Untreated	1	10.5
			2	11.5
			3	10.5
			AVERAGE	10.83
10	Flax 15% Sisal 25% Epoxy 60%	Untreated	1	15.5
			2	18
			3	19.5
			AVERAGE	17.67
11	Flax 20% Sisal 20% Epoxy 60%	Untreated	1	10
			2	8.5
			3	9.5
			AVERAGE	9.33
12	Flax 25% Sisal 15% Epoxy 60%	Untreated	1	9.5
			2	7
			3	7
			AVERAGE	7.83
13	Flax 10% Sisal 20% Epoxy 70%	Untreated	1	3
			2	2.5
			3	2.5
			AVERAGE	2.67

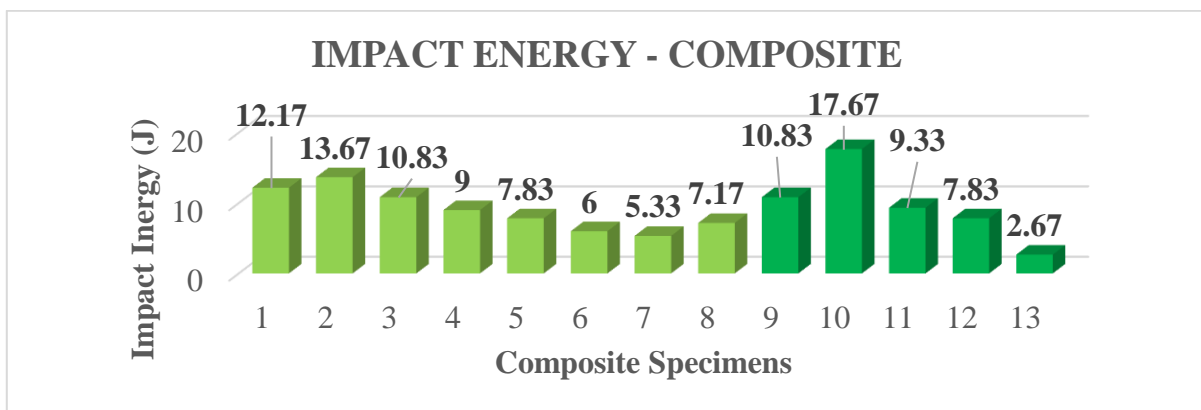


Figure 4. 60 Impact Energy Vs Composite

4.1.5 WATER ABSORPTION TEST RESULT

Under water absorption test thirteen composite were immersed into water for hrs. The mass before socking and after was measured and the water absorption percentage was calculated using the following formula.

$$\frac{W_w - W_d}{W_d} * 100 \dots\dots\dots\text{eqn. (4.4)}$$

Table 4. 3 Water Absorption Percentage of All Composites

No.	Composite Composition	Treated / Untreated	Sample No.	Water Absorption (%)
1	Flax 20% Sisal 20% Epoxy 60%	Treated	1	15.87
			2	16.22
			3	15.28
			AVERAGE	15.79
2	Flax 15% Sisal 25% Epoxy 60%	Treated	1	13.51
			2	12.82
			3	9.86
			AVERAGE	12.06
3	Flax 25% Sisal 15% Epoxy 60%	Treated	1	4.12
			2	4.55
			3	2.30
			AVERAGE	3.66
4	Flax 20% Sisal 15% Epoxy 65%	Treated	1	2.44
			2	3.39
			3	3.30
			AVERAGE	3.04
5	Flax 15% Sisal 20% Epoxy 65%	Treated	1	7.81
			2	8.62
			3	7.89
			AVERAGE	8.11
6	Flax 10% Sisal 20% Epoxy 70%	Treated	1	9.68
			2	13.85
			3	10.29
			AVERAGE	11.27

Fabrication, Characterization and Simulation of Flax-Sisal Fiber Reinforced Epoxy Hybrid Composite for Prosthetic Socket

7	Flax 20% Sisal 10% Epoxy 70%	Treated	1	3.80
			2	4.11
			3	4.60
			AVERAGE	4.17
8	Flax 15% Sisal 15% Epoxy 70%	Treated	1	3.75
			2	5.26
			3	5.33
			AVERAGE	4.78
9	Flax 20% Sisal 15% Epoxy 65%	Untreated	1	6.32
			2	9.33
			3	7.69
			AVERAGE	7.78
10	Flax 15% Sisal 25% Epoxy 60%	Untreated	1	13.48
			2	13.95
			3	13.33
			AVERAGE	13.59
11	Flax 20% Sisal 20% Epoxy 60%	Untreated	1	9.72
			2	7.95
			3	7.27
			AVERAGE	8.32
12	Flax 25% Sisal 15% Epoxy 60%	Untreated	1	12.31
			2	10.96
			3	12.20
			AVERAGE	11.82
13	Flax 10% Sisal 20% Epoxy 70%	Untreated	1	8.33
			2	6.58
			3	7.41
			AVERAGE	7.44

4.2 DISCUSSION

Table 4. 4 Overall Results obtained from the experiment

Tensile Strength (MPa)												
1	2	3	4	5	6	7	8	9	10	11	12	13
32.76	10.84	68.40	26.88	40.00	25.33	29.11	24.37	26.80	41.60	32.62	21.87	24.99
Compression Strength (MPa)												
1	2	3	4	5	6	7	8	9	10	11	12	13
21.73	26.81	45.64	24.27	22.82	42.38	44.19	28.25	23.54	57.23	38.76	34.77	22.10
Flexural Strength (MPa)												
1	2	3	4	5	6	7	8	9	10	11	12	13
117.5	90.8	145.7	133.5	144.2	128.4	96.2	112.2	90.8	74.8	74.8	101.5	42.7
Impact (J)												
1	2	3	4	5	6	7	8	9	10	11	12	13
12.17	13.67	10.83	9	7.83	6	5.33	7.17	10.83	17.67	9.33	7.83	2.67
Water Absorption (%)												
1	2	3	4	5	6	7	8	9	10	11	12	13
15.79	12.06	3.66	3.04	8.11	11.27	4.17	4.78	7.78	13.59	8.32	11.82	7.44

N.B

	= highest result
	= second highest result
	= third highest result

4.2.1 TENSILE TEST DISCUSSION

Result from three specimen samples were obtained and their average value were taken as its tensile strength property for each composite specimen fabricated. From this, the composite that exhibits the highest tensile strength of **68.40MPa** is **C3** which is **treated** hybrid flax-sisal fiber reinforced epoxy composite with **flax 25%, Sisal 15% and Epoxy 60%**.

The **untreated** composite of the same Fiber-matrix composition but different fiber – fiber composition (**Flax 15%, Sisal 25% and Epoxy 60%**) is the second highest with tensile strength of **41.60MPa**. This shows that, this fiber – matrix composition is the best composition when using a hybrid of flax and sisal with epoxy resin as a matrix.

Generally, it is observed that varying the fiber – matrix and fiber – fiber composition has an effect on tensile property of the hybrid composite. For treated flax-sisal fiber hybrid composite,

with the epoxy at 60% by increasing the volume fraction of the flax an optimum tensile strength can be obtained.

In addition, comparing the treated with untreated comparison;

When comparing C4 and C9 (**20F 15S 65E**), their tensile strength is very slightly different. The values are 26.88 and 26.8MPa respectively. They have a **0.29%** difference with the treated composite having a higher value. For C2 and C10 (**15F 25S 60E**) here, the untreated composite has better tensile property with **73.94%** difference. For C1 and C11 (**20F 20S 60E**) both treated and untreated has a close tensile property where the treated composite has **0.43%** higher value. For C3 and C12 (**25F 15S 60E**), the treated composite has better tensile property with **68.03%** difference. And for C6 and C13 (**10F 20S 70E**), the treated composite has a little higher tensile strength value than the untreated composite with **1.34%** difference.

Overall, when comparing the treated composites with untreated composites that has the same composition, the treated composites has better tensile property. Therefore, treating this composite can give us better tensile property.

4.2.2 COMPRESSION TEST DISCUSSION

The compressive strength results are presented in figure 4.42 and it is observed that, **C10** which is untreated composite with **flax 15%, Sisal 25% and Epoxy 60%** has the highest compressive strength. As seen from the **figure 4.107** the obtained compression strength is **57.23MPa**. and the second largest compressive strength with a value of **45.64MPa** is obtained from **C3** which is the treated composite with composition of **flax 25%, Sisal 15% and Epoxy 60%**.

It can be observed that, these two composites have the same fiber-matrix composition and this shows, the best composition for obtaining optimum compressive strength when using **Sisal-Flax-Epoxy composite** is **40-60 fiber-matrix** volume ratio.

When comparing C4 and C9 (**20F 15S 65E**), the treated composite has **3%** higher compression strength value than the untreated composite. For C2 and C10 (**15F 25S 60E**), here, the untreated composite has better compression strength with **53.15%** difference. For C1 and C11 (**20F 20S 60E**) the untreated composite has **43.94%** higher compression strength. For C3 and C12 (**25F 15S 60E**), the treated composite has better compression strength property with **23.82%** difference. And for C6 and C13 (**10F 20S 70E**), the treated composite has a higher compression strength value than the untreated composite with **47.85%** difference.

Overall, here also, in average the treated composite has a higher value difference compared with the untreated composites.

4.2.3 FLEXURAL TEST DISCUSSION

On this test, **C3** has the best result. The flexural result obtained from the **treated flax 25%, Sisal 15% and Epoxy 60%** composite is **145.7MPa** which is the best composition when compared with the other twelve composite specimens fabricated. **C3** in terms of flexural strength is slightly better than composite **C5** that has strength of **144.2MPa**. In this case the untreated composite with same composition has the second lowest possible flexural strength with **74.8MPa**.

When comparing **C4** and **C9 (20F 15S 65E)**, here, the treated composite has **31.99%** higher flexural strength than untreated composite. For **C2** and **C10 (15F 25S 60E)** here again the treated composite has better flexural property with **17.62%** difference. For **C1** and **C11 (20F 20S 60E)** again the treated composite has higher flexural property, where the treated composite has **36.34%** higher value. For **C3** and **C12 (25F 15S 60E)**, the treated composite has better flexural property with **30.34%** difference. And for **C6** and **C13 (10F 20S 70E)**, the treated composite has higher flexural strength value than the untreated composite with **66.74%** difference.

Overall, when comparing the treated composites with untreated composites that has the same composition, the treated composites have a huge flexural property difference.

In addition, all the untreated composites have below **100MPa** except **C12** having **101.5MPa** flexural strength. This shows that, the untreated composites made from hybrid of flax and Sisal have poor flexural strength. Therefore, if hybrid composite of flax-Sisal with epoxy is needed for an application where compression strength is important, the fibers need to be treated with NaOH as specified in treatment of fibers section.

4.2.4 IMPACT TEST DISCUSSION

As obtained from the result of Charpy machine the best value is **17.67J**. The composite with this result is **C10** untreated fiber hybrid composite with **flax 15%, Sisal 25% and Epoxy 60%**. the second-best composite composition for impact is the treated **Flax 15%, Sisal 25% and Epoxy 60% composite**. Still like the previous mechanical properties obtained, the fiber-matrix composition of **40-60** is the best. Here, the **C3 (treated Flax 25%, Sisal 15% and Epoxy 60%)** composite specimen has the fourth highest impact energy value.

When comparing C4 and C9 (**20F 15S 65E**), the value obtained are very close. Here, the untreated composite has **16.9%** higher value of impact energy. For C2 and C10 (**15F 25S 60E**), here again, the untreated composite has better impact energy with **22.64%** difference. For C1 and C11 (**20F 20S 60E**) the treated composite has **23.34%** higher impact energy. For C3 and C12 (**25F 15S 60E**), the treated composite has better impact property with **27.7%** difference. And for C6 and C13 (**10F 20S 70E**), the treated composite has a higher impact energy value than the untreated composite with **55.5%** difference.

Overall, in average the treated composite has a higher value difference compared with the untreated composites. And all the composites have better impact energy ranging from 2.67J - 17.67J.

4.2.5 WATER ABSORPTION TEST DISCUSSION

The highest water absorption was observed from the composite **C1** with **flax 20%, Sisal 20% Epoxy 60%** having water absorption percentage of **15.76**. The second highest water absorption was from **C10 (untreated flax 15%, Sisal 25% and Epoxy 60%)**.

The composite with the lowest water absorption percentage obtained was **3.04%** from composite **C4**. C4 has a composition of **Flax 15% Sisal 20% and Epoxy 65%**. The Second lowest is obtained from **C3**.

When comparing C4 and C9 (**20F 15S 65E**), the treated composite absorbs lower water percentage than the untreated, they have **60.93%** difference. For C2 and C10 (**15F 25S 60E**), here also, the treated composite gains lower water with **11.26%** difference. For C1 and C11 (**20F 20S 60E**) in this case, the treated composite absorbs more water with the two having **47.31%** difference. For C3 and C12 (**25F 15S 60E**), here, the untreated composite gains **69.04%** more water than the treated composite. And for C6 and C13 (**10F 20S 70E**), with this composition the untreated composite absorbs **33.98%** lower water than the treated composite.

Here also, when considering water absorption of the composites, the untreated composite absorbs more water suggesting that, treating the selected hybrid composite with NaOH is better option.

Overall, from all thirteen tests observed and discussed, it can be concluded that Composite **C3 (treated flax 25%, Sisal 15% and Epoxy 60%)** has superior mechanical and physical properties of Flax – Sisal fiber reinforced epoxy composite. In addition, this thesis focuses on prosthetic socket application. Therefore, the mechanical properties like; impact, compression

and bending are essential. Also, the physical property which is water absorption should also be considered.

Considering the above-mentioned important properties for prosthetic socket, the treated composite specimen with **flax 25%, Sisal 15% and Epoxy 60%** was selected for further analysis and comparison.

4.3 COMPARISON OF RESULTS WITH LITERATURES

Even though there are few researches concerning flax and sisal as a hybrid composite following literature will validate the work executed and result obtained in this research.

Here the experimental test results for the selected material were compared with literatures;

Result of selected composition:

Tensile Strength = 68.40MPa

Flexural Strength = 145.7MPa

Compression Strength = 45.64MPa

Impact Strength = 10.83J

Water Absorption = 3.66%

4.3.1 RESEARCHES ON FLAX AND SISAL AS A HYBRID

C. M. Meenakshi and A. Krishnamoorthy; studied treated and untreated Sisal/Glass/Flax reinforced composite [91].

Table 4. 5 Result obtained by C. M. Meenakshi and A. Krishnamoorthy[91]

COMPOSITE		TENSILE (MPa)	FLEXURAL (MPa)	IMPACT (J/m)
SGF	Untreated	30.274	95.884	13
SGF	Treated	46.3046	198.48	20

G. Rajamurugan et. al, Studied the drilling and mechanical effect of Flax-Sisal hybrid composite embedded with perforated aluminum foil. Six compositions were studied, the results are as follow [71].

Table 4. 6 Result obtained by G. Rajamurugan et. al. [71]

COMPOSITE	Al	FLAX	SISAL	EPOXY	TENSILE (MPa)	FLEXURAL (MPa)
SF1	0.65	9.29	6.71	83.33	21.5	76
SF2	0.76	9.23	6.66	83.33	23	72.5
SF3	0.85	9.18	6.64	83.33	24.5	65
SF4	0.63	9.31	6.72	83.33	27.5	62.5
SF5	0.74	9.24	6.67	83.33	27.8	52.5
SF6	0.82	9.19	6.64	83.33	31	50

Both literatures mentioned above have used woven flax and sisal fiber. For the first literature mentioned, when compared with this experimental result there isn't much difference. This also shows that different orientation of sisal/flax composite has an effect on its mechanical and physical properties. It can be concluded that, treated and chopped flax/sisal fiber has better tensile properties when compared with treated and untreated woven flax/sisal fiber reinforced composite.

Also, the second literature has good Flexural strength but very low tensile strength when compared with the result of this thesis work. The reason for the low tensile property might be from the percentage composition of the matrix epoxy and orientation of the reinforcements.

4.3.2 RESEARCHES ON MATERIALS FOR PROSTHETIC APPLICATIONS

Table 4. 7 Researches on Materials for Prosthetic Applications [12]

Researcher	Work	Tensile (MPa)	Flexural (MPa)
Odusote et al. [87]	<ul style="list-style-type: none"> • pineapple leaf fiber for application of prosthetic • suggested PLEC can replace the glass fiber prosthetic socket. 	PLEC: 76.47 PLPC: 62.09 GFPC: 59.03	PLEC: 81.22 PLPC: 53.02 GFPC: 66.10
Nazik et al. [79]	<ul style="list-style-type: none"> • layers of 3pyrlon,3carbon,3Pylon, • has proposed to use this material as a prosthetic socket 	33	
Maria J et. al [92]	<ul style="list-style-type: none"> • polyethylene terephthalate material 	53.7	
Imran Ali et. al [93]	<ul style="list-style-type: none"> • Polypropylene, PP (90%)/PE HDPE, LDPE 	80, 39, 37 and 25	
Jamiu K. et. al [88]	<ul style="list-style-type: none"> • pseudo stem fiber reinforced epoxy composite (40% fiber load) • suggested to use pseudo stem/Epoxy composite with 40/60 composition to use for prosthetic socket 	65.93	72.31
Irawan et. al [85]	<ul style="list-style-type: none"> • Ramie/epoxy and Ramie/Polyester 	RE: 86 RP: 67	

<p>Sam L. Philips et. al [94]</p>	<ul style="list-style-type: none"> stated typical material used as an orthotics and prosthetics fabrications 	<p>Nylon = 55.83 Polyethylene = 7.45 Polypropylene = 28.41</p>	
--	---	---	--

The materials mentioned above have been suggested as an alternative material for the application of prosthetic socket by the researchers. and when comparing their result with the result that is obtained from this thesis, it can be observed that flax/sisal/epoxy hybrid composite has better mechanical properties than the above-mentioned materials therefore, flax/sisal/epoxy hybrid composite with a composition of 25%Flax, 15%Sisal and 60% Epoxy can definitely be used for the application of prosthetic socket.

4.4 SIMULATION OF PROSTHETIC SOCKET

4.4.1 FINITE ELEMENT MODELING AND ANALYSIS

For the analysis of Prosthetic Socket Material (**F25/S15/E60**) FEM was conducted using the **ANSYS 2020** Software package. ANSYS is a self-contained general purpose FEM analysis tool incorporating pre-processing such as creation of geometry and meshing, solver and post processing modules in a unified graphical user interface.

The general static – structural analysis of prosthetic socket using ANSYS has four distinct steps: **building the model, applying the boundary conditions and load, obtaining the solution, and result review.**

In the analysis of prosthetic socket, steps like Modeling, meshing, applying boundaries and loads and analyzing the model was executed. The static analysis was done for equivalent stress and deformation.

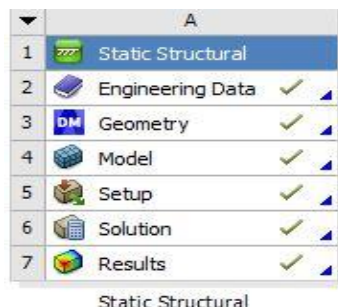


Figure 4. 61 Steps in ANSYS Analysis

4.4.1.1 DEFINING ENGINEERING DATA FOR THE MATERIAL

The defining process in ANSYS is done by selecting the engineering tab located at the top of working space. After selection of this tab. A new Material should be inserted that describes the

name of the material. In this case, **Flax – Sisal fiber reinforced epoxy hybrid composite (F25%/S15%/E60%)** was used as the name of new material.

Before inputting the needed data, the following assumptions are taken;

Assumptions

The prosthetic socket has complex shape depending on the residual limb of the user. Therefore, assumptions are needed to make the simulation more practical. So, the following are the assumptions made;

- The shape of the prosthetic was designed uniform
- It was assumed that the material is linearly elastic isotropic material by assuming all the fiber and matrix are mixed uniformly.
- Free of void material
- Perfect bind between matrix and fiber
- Homogenous

In this analysis, the selected composite properties (F25/S15/E60) were inserted into the data. Density, tensile strength, compression strength, young’s modulus and Poisson’s ratio are the properties obtained from experimental tests and used as input for the analysis.

Density = 1.1904g/cm³

Young’s Modulus = 2196.47MPa

Tensile strength = 68.40MPa

Poisson’s Ratio = 0.144

Compression Strength = 45.64MPa

Outline of Schematic A2: Engineering Data				
	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			
3	Flax-Sisal Fiber Reinforced Epoxy Hybrid Composite (F25%/S15%/E60%)			E:\Luna Final\Luna Final\testing\Prosthetic Final

Properties of Outline Row 3: Flax-Sisal Fiber Reinforced Epoxy Hybrid Composite (F25%/S15%/E60%)				
	A	B	C	D
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	1.2216	g cm ⁻³	
4	Isotropic Elasticity			
5	Derive from	Young's Modulus a...		
6	Young's Modulus	2196.5	MPa	
7	Poisson's Ratio	0.144		
8	Bulk Modulus	1.0283E+09	Pa	
9	Shear Modulus	9.6E+08	Pa	
10	Tensile Yield Strength	68.4	MPa	
11	Tensile Ultimate Strength	68.4	MPa	
12	Compressive Ultimate Strength	45.64	MPa	

Figure 4. 62 Material Engineering Data of Flax/Sisal/Epoxy

4.4.1.2 MODELING OF PROSTHETIC SOCKET IN ANSYS.

Considering literature [8] the prosthetic socket was modeled on **ANSYS 2020 DesignModeler**. **DesignModeler** is a 3D modeling application that is integrated within the ANSYS workbench Software.

The prosthetic has the following overall geometry.

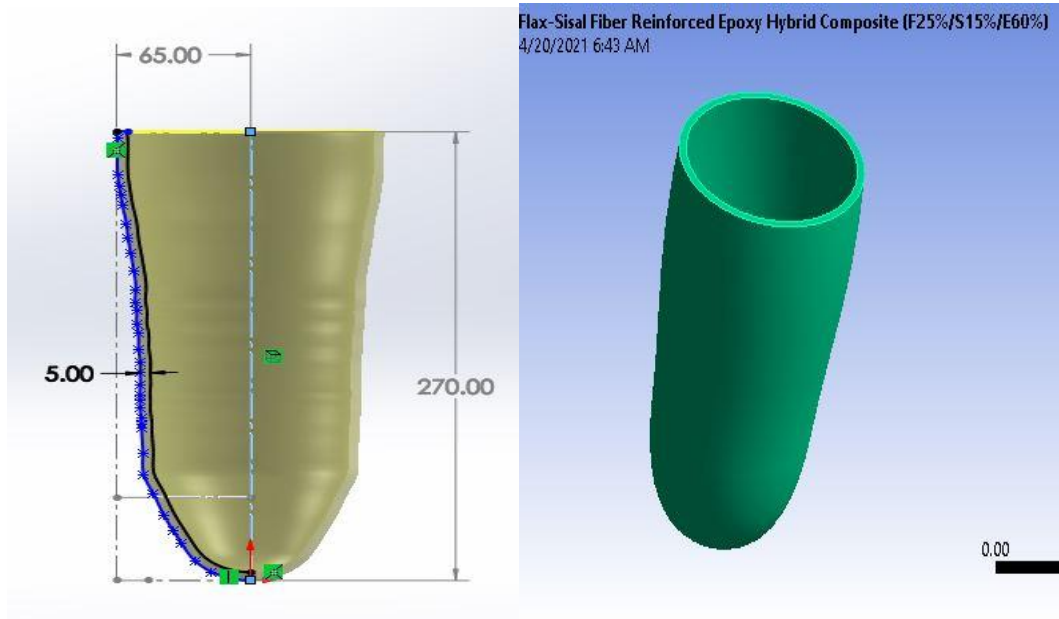


Figure 4. 63 Overall geometry and 3D model of Prosthetic Socket

4.4.1.3 MESH GENERATION

It is subdividing of a continuous geometric space into discrete geometric and topological cells. Here the sizing of meshing was done with fine meshing was used and default mesh controls are set for the model.

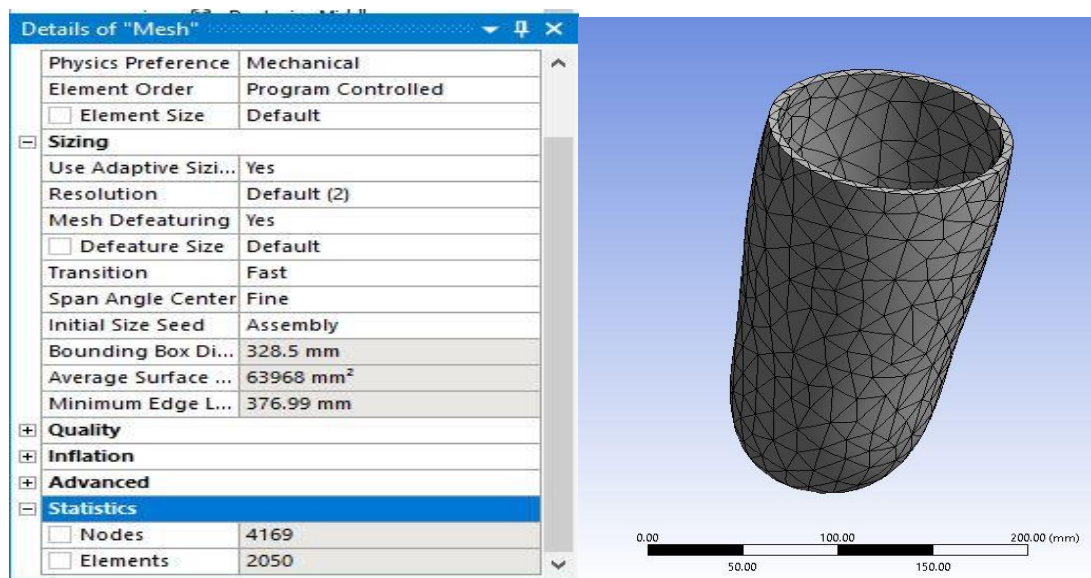


Figure 4. 64 Meshing details and Meshed Prosthetic Model

4.4.1.4 APPLYING BOUNDARY CONDITIONS AND LOAD CONDITIONS

The next step in ANSYS is applying appropriate loading and boundary conditions.

For analyzing the prosthetic socket, **one fixed support** was used at the bottom of the socket. in addition, **twelve surface pressures** on different regions of the socket and **one downward force** were applied at the bottom.

The Pressure and force are obtained from literature study done by [79]. The study involved **85KG male** with a height of **175cm**. From the interface pressure measured, the following values are obtained and was used in this analysis.

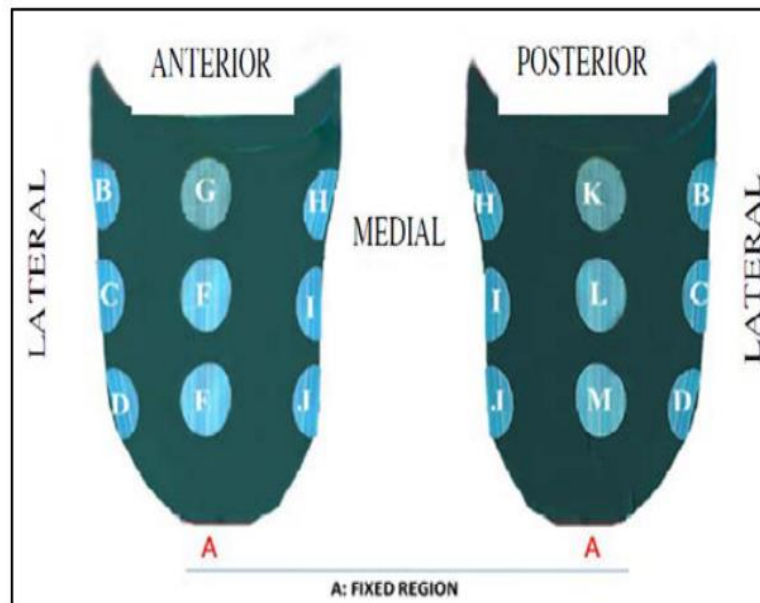


Figure 4. 65 Regions where pressure are applied [80]

Table 4. 8 Applied Pressures on the Prosthetic

REGION ON SOCKET	UPPER (KPa)		MIDDLE (KPa)		LOWER (KPa)	
ANTERIOR	220	G	260	F	175	E
MEDIAL	175	H	197	I	103	J
POSTERIOR	184	K	264	L	201	M
LATERAL	515	B	189	C	235	D

A is the position where **850N** is applied considering the mass of the subject which is **85Kg**.

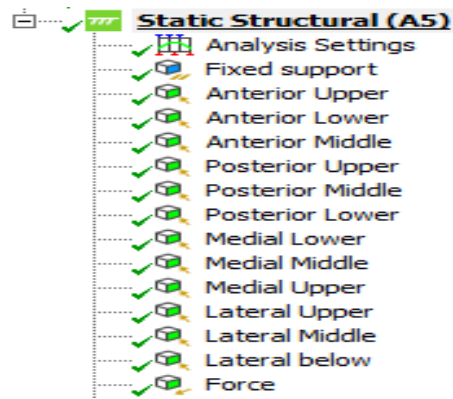


Figure 4. 66 Applied Boundaries

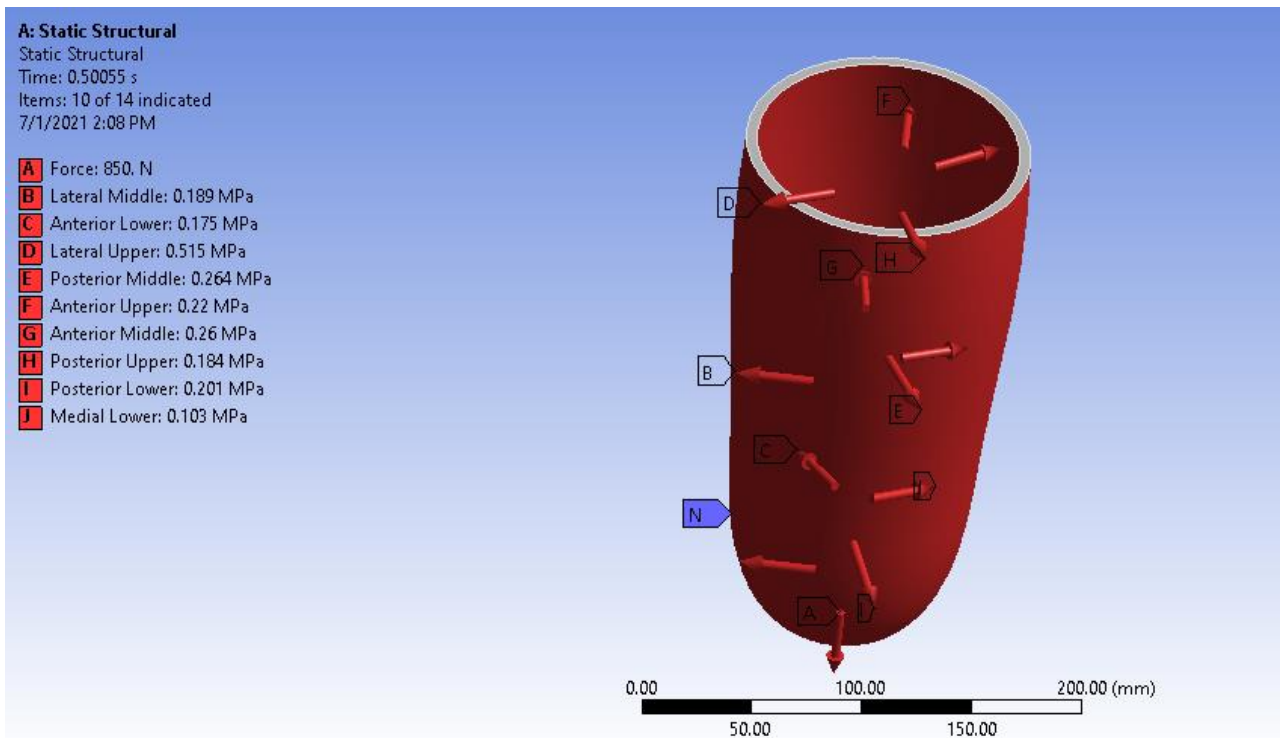


Figure 4. 67 Applied Loads and Boundary Conditions

4.4.1.5 GENERATING SOLUTIONS

In this static structural analysis, the total deformation, equivalent Elastic von Mises Stress were generated based on input parameters.

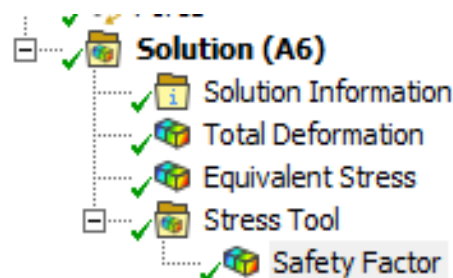


Figure 4. 68 Solution Tab

4.4.2 RESULT

EQUIVALENT VON MISES STRESS: The Equivalent von mises stress obtained for the prosthetic socket material of Flax/Sisal/Epoxy hybrid composite has maximum value of **2.214MPa** and minimum Value of **1.181MPa**.

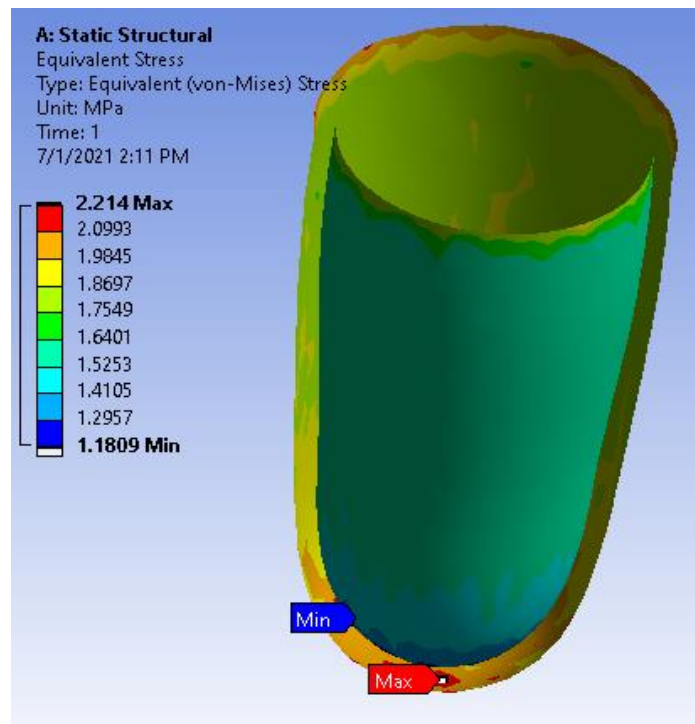


Figure 4. 69 Result of the Equivalent Von Mises Stress

DEFORMATION: The deformation obtained for the prosthetic socket material of Flax/Sisal/Epoxy hybrid composite has maximum value of 0.0064mm and minimum Value of 0MPa.

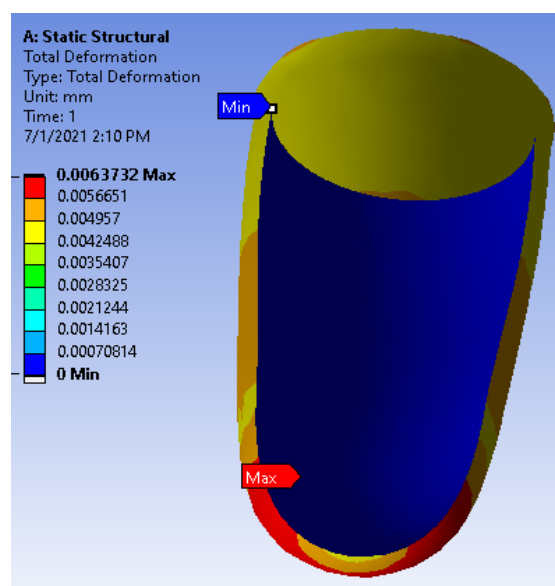


Figure 4. 70 Result of Deformation

4.4.3 DISCUSSION

EQUIVALENT VON MISES STRESS: As it can be seen from the result maximum stress occurs at the very bottom of the socket. but still when compared with the yield strength of the material and the stress value obtained Flax/Sisal/Epoxy composite with composition of 25/15/60 is very capable of being a replacement for the conventional material used for manufacturing of prosthetic socket.

DEFORMATION: The deformation value obtained here also is very low and it indicates that the material is capable of withstanding the load applied by the user of the prosthetic socket. in addition, it shows the composite material can be a good replacement for the conventional material used for manufacturing prosthetic socket.

4.4.4 COMPARING RESULT WITH LITERATURE

The following researchers has also used the ANSYS software package to analyze the properties of different materials that can be used for prosthetic socket.

Table 4. 9 Result obtained using ANSYS Software for Prosthetic Socket

NO.	MATERIAL USED	VON MISES STRESS	DEFORMATION	RESEARCHER
1	Perlon/carbon	18.5E7 MPa	0.0604mm	Nazik
2	Bamboo/Carbon	1.7973 MPa	0.00778872mm	Jumma chiad
3	Carbon	7.42 Pa	0.0007344mm	Abbas
4	Carbon/glass/PMMA/Epoxy	6.0361MPa	2.3055mm	Kahtan Al-Khaza
5	Flax/Sisal/Epoxy	2.214MPa	0.0064mm	Current

The above ANSYS analysis results of other literatures indicate that the material Flax/Sisal/Epoxy composite with composition of 25/15/60 is appropriate for the application of Prosthetic socket.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Nowadays, the need for prosthetics is increasing because of war and other health related problems. Especially, in Ethiopia the need has been increasing exponentially. Prosthetics in Ethiopia is mostly made from plastic material named Polypropylene. To reduce the problems and effects of this material on the user, this research work focused on characterization of Natural fiber reinforced composites.

This study has presented tensile, flexural, compression, impact and water absorption properties of flax/sisal/epoxy hybrid composite with different compositions. It has also suggested appropriate composition with 25%F,15%S, 60%E in which fibers are chopped in 30mm length and treated with 5% NaOH to be used as an alternative material for an application of prosthetic socket. The conclusion of this work is as follows.

- Successful fabrication of the hybrid composite using flax-sisal fiber reinforced epoxy has been achieved using hand lay-up technique
- Alkaline treatment has been found to have an effect on the mechanical and physical property of Flax/Sisal/Epoxy hybrid composite.
- The highest tensile strength was obtained from treated composite C3 with 25%F,15%S, 60%E composition having 68.40MPa.
- The highest flexural strength was obtained from treated composite C3 with 25%F,15%S, 60%E composition having 145.7MPa.
- The highest compression strength was obtained from untreated composite C10 with 15%F,25%S, 60%E composition having 57.23MPa.
- The highest impact strength was obtained from composite C10 with 15%F,25%S, 60%E composition having 17.67J
- The lowest water absorption percentage was obtained from treated composite C4 with 20%F,15%S, 65%E composition having 3.04%.
- From the thirteen-specimen composite of flax/sisal/epoxy hybrid composite the material with 25%F,15%S, 60%E composition which is treated with 5% NaOH and 30mm chopped reinforcement has the superior mechanical and physical properties.

- Suggested composition has tensile strength of 68.40MPa, compression strength of 45.64MPa, flexural strength of 145.7MPa, impact strength of 10.83J and water absorption percentage of 3.66%.
- In the analysis of prosthetic socket using ANSYS the higher stress exhibited was at the lower posterior region.
- In the analysis of prosthetic socket model using the selected material, the maximum von mises stress obtained is 2.214MPa and deformation is 0.0064mm which indicates the material can withstand the load applied by the user of the socket.
- Finally, it can be concluded that, Flax-Sisal fiber reinforced epoxy composite with 25%F,15%S, 60%E can be an alternative material used for prosthetic socket.

5.2 RECOMMENDATION

- Better extraction method gives better mechanical, physical and thermal properties., so it is recommended to moderate the extraction process.
- Using of manufacturing technique other than hand layup process.
- Using of suggested material to replace the current polypropylene prosthetic socket material.
- Investigate flax/sisal/epoxy with another composition and orientation.
- The selected material is recommended to be used for different application areas.
- Addis Ababa Institute of technology needs to have composite material testing machines, all the raw material used to fabricate composites. Overall, the institute should focus on modern technologies and composite materials.

5.3 FUTURE WORK

Under the investigation of Flax/Sisal/Epoxy hybrid composite, there is lots of potential study areas for researchers. Some of them are suggested below;

- Further investigation by manufacturing prosthetic socket using flax-sisal fiber reinforced epoxy composite.
- Investigate the thermal analysis of suggested material.
- Investigate the interfacial bonding between fiber and matrix.
- Investigate the fatigue failure of flax-sisal fiber reinforced epoxy composite.

REFERENCE

- [1] P. V Sneha, M. N. Pratiksha, and B. K. Abhijit, "Design and Development of Prosthetic Legs," *Int. J. Eng. Manag. Res.*, no. April, pp. 91–95, 2019, doi: 10.31033/ijemr.9.2.04.
- [2] D. A. Berry, "Composite Materials for Orthotics and Prosthetics," *J. Prosthetists Orthot.*, vol. 40, no. 4, pp. 35–43, 1987.
- [3] M. H. Nurhanisah, N. Saba, M. Jawaid, and M. T. Paridah, "Design of prosthetic leg socket from kenaf fibre based composites," in *Green Energy and Technology*, no. 9783319493817, 2017, pp. 127–141.
- [4] M. Dessie, "Preventable amputations in Ethiopia I *," vol. 27, 2002.
- [5] P. M. T. Rosalam Che Me; Rahinah Ibrahim, "Natural Based Biocomposite Material for Prosthetic Socket Fabrication," *Alam Cipta*, vol. 5, no. June, pp. 27–34, 2012.
- [6] A. H. M. Ali, M. S. Shlaby, and E. F. Elfaki, "Mechanical properties of the prosthesis limp from PVC glass fiber sandwich," *Int. J. Mech. Prod. Eng.*, vol. 4, no. 5, pp. 41–45, 2016.
- [7] M. R. Pitkin, "Biomechanics of lower limb prosthetics," *Biomech. Low. Limb Prosthetics*, no. Torres 1994, pp. 1–141, 2010, doi: 10.1007/978-3-642-03016-1.
- [8] A. I. Campbell, S. Sexton, C. J. Schaschke, H. Kinsman, B. McLaughlin, and M. Boyle, "Prosthetic limb sockets from plant-based composite materials," *Prosthet. Orthot. Int.*, vol. 36, no. 2, pp. 181–189, 2012, doi: 10.1177/0309364611434568.
- [9] C. Quintero-Quiroz and V. Z. Pérez, "Materials for lower limb prosthetic and orthotic interfaces and sockets: Evolution and associated skin problems," *Rev. Fac. Med.*, vol. 67, no. 1, pp. 117–126, 2019, doi: 10.15446/revfacmed.v67n1.64470.
- [10] K. Balasubramanian, S. purty, R. khan, and N. ahmad, "a Review on Recent Application of Hybrid Composites," vol. IX, no. 193.
- [11] M. Z. R. Khan, S. K. Srivastava, and M. K. Gupta, "Tensile and flexural properties of natural fiber reinforced polymer composites: A review," *J. Reinf. Plast. Compos.*, vol. 37, no. 24, pp. 1435–1455, 2018, doi: 10.1177/0731684418799528.
- [12] R. Badrinath and T. Senthilvelan, "Comparative Investigation on Mechanical Properties of Banana and Sisal Reinforced Polymer based Composites," *Procedia Mater. Sci.*, vol. 5, pp. 2263–2272, 2014, doi: 10.1016/j.mspro.2014.07.444.
- [13] B. Y. H. Woldeyes, "Satisfaction of Lower Prosthesis Limb Users," 2016.
- [14] P. Kesarwani, S. Jahan, and K. Kesarwani, "Composites : Classification and its manufacturing process," *Int. J. Appl. Res.*, vol. 1, no. 9, pp. 352–358, 2015.
- [15] M. Boopalan, M. J. Umapathy, and P. Jenyfer, "A Comparative Study on the Mechanical Properties of Jute and Sisal Fiber Reinforced Polymer Composites," *Silicon*, vol. 4, no. 3, pp. 145–149, 2012, doi: 10.1007/s12633-012-9110-6.
- [16] E. Yasa and K. Ersoy, "A Review on the Additive Manufacturing of Fiber Reinforced Polymer Matrix Composite," *Solid Free. Fabr. Symp.*, pp. 1024–1033, 2018, [Online]. Available: <http://sffsymposium.engr.utexas.edu/sites/default/files/2018/084AReviewontheAdditiveManufacturingofFiberRe.pdf>.

- [17] T. P. Sathishkumar, J. Naveen, and S. Satheeshkumar, "Hybrid fiber reinforced polymer composites - A review," *J. Reinf. Plast. Compos.*, vol. 33, no. 5, pp. 454–471, 2014, doi: 10.1177/0731684413516393.
- [18] S. S. Mathapati, M. Tech, and M. Engineering, "Original Article Analysis and characterization of Tensile and Compressive Properties of the Chopped Strand Mat E-Glass Fiber Reinforced Epoxy Composites," vol. 4, no. 3, pp. 29–33, 2014.
- [19] E. Eskezia, "Finite Element Analysis of Internal Door Panel of a Car by using Bamboo Fiber Reinforced Epoxy Composite," 2016.
- [20] C. Baley, A. Le Duigou, A. Bourmaud, P. Davies, M. Nardin, and C. Morvan, "Reinforcement of Polymers by Flax Fibers: Role of Interfaces," *Bio-Based Compos. High-Performance Mater.*, pp. 87–112, 2014, doi: 10.1201/b17601-7.
- [21] N. Abilash and M. Sivapragash, "Environmental Benefits of Eco-friendly Natural Fiber Reinforced Polymeric Composites Materials," *Int. J. Appl. or Innov. Eng. Manag.*, vol. 2, no. 1, pp. 2319–4847, 2013, [Online]. Available: <http://www.ijaiem.org/volume2Issue1/IJAIEM-2012-01-06-008.pdf>.
- [22] Oxyblack, "Laminates & Sandwiches," 2017. <https://www.oxyblack.com/index.php/en/composites/laminates-sandwiches> (accessed Jun. 30, 2021).
- [23] L. Rebhi, M. Dinulovic, P. Andric, M. Dodic, and B. Krstic, "On the effective shear modulus of composite honeycomb sandwich panels," *Sci. Tech. Rev.*, vol. 66, no. 4, pp. 59–65, 2016, doi: 10.5937/str1604059r.
- [24] J. G. Murali, "Review on Hybrid Composite Materials and its Applications," *Int. Res. J. Eng. Technol.*, vol. 4, no. 2, pp. 1921–1925, 2017.
- [25] G. V Mahajan and V. S. Aher, "Composite material: A review over current development and automotive application," *Int. J. Sci. Res. Publ.*, vol. 2, no. 11, pp. 2250–3153, 2012, [Online]. Available: www.ijsrp.org.
- [26] B. Sujeet Kumar and S. Biswas, "Study on Mechanical Behaviour of Banana Fiber Reinforced Epoxy Composites a Thesis Submitted in Partial Fulfillment of the Requirements for the Degree," 2014, [Online]. Available: <http://ethesis.nitrkl.ac.in/5886/1/E-76.pdf>.
- [27] L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A Review on Natural Fiber Reinforced Polymer Composite and Its Applications," *Int. J. Polym. Sci.*, vol. 2015, 2015, doi: 10.1155/2015/243947.
- [28] T. Madhusudhan and K. S. G, "A Review on Mechanical Properties of Natural Fiber Reinforced Hybrid Composites," *Int. Res. J. Eng. Technol.*, vol. 03, no. 04, pp. 2247–2251, 2016, doi: 10.1177/0731684419856686.
- [29] V. Mittal, R. Saini, and S. Sinha, "Natural fiber-mediated epoxy composites - A review," *Compos. Part B Eng.*, vol. 99, pp. 425–435, 2016, doi: 10.1016/j.compositesb.2016.06.051.
- [30] M. Ramesh, K. Palanikumar, and K. H. Reddy, "Comparative evaluation on properties of hybrid glass fiber-sisal/jute reinforced epoxy composites," *Procedia Eng.*, vol. 51, no. NUICONE 2012, pp. 745–750, 2013, doi: 10.1016/j.proeng.2013.01.106.

- [31] L. Prabhu, V. Krishnaraj, S. Gokulkumar, S. Sathish, and M. Ramesh, “Mechanical, Chemical and Acoustical Behavior of Sisal – Tea Waste – Glass Fiber Reinforced Epoxy Based Hybrid Polymer Composites,” *Mater. Today Proc.*, vol. 16, pp. 653–660, 2019, doi: 10.1016/j.matpr.2019.05.142.
- [32] P. Antov, V. Savov, and N. Neykov, “Utilization of Agricultural Waste and Wood Industry Residues in the Production of Natural Fiber-Reinforced Composite Materials,” *Wood, Des. Technol.*, no. March, pp. 63–71, 2018.
- [33] A. Komuraiah, N. S. Kumar, and B. D. Prasad, “Chemical Composition of Natural Fibers and its Influence on their Mechanical Properties,” *Mech. Compos. Mater.*, vol. 50, no. 3, pp. 359–376, 2014, doi: 10.1007/s11029-014-9422-2.
- [34] M. Ramesh, K. Palanikumar, and K. H. Reddy, “Plant fibre based bio-composites: Sustainable and renewable green materials,” *Renew. Sustain. Energy Rev.*, vol. 79, no. May, pp. 558–584, 2017, doi: 10.1016/j.rser.2017.05.094.
- [35] H. E. M. Saleh *et al.*, “Polyester Edited by Hosam El-Din M. Saleh,” *Polyester*, p. 432, 2012, doi: 10.5772/48697.
- [36] A. Ç. Kilinç, C. Durmuşkahya, and M. Ö. Seydibeyoğlu, “Natural fibers,” in *Fiber Technology for Fiber-Reinforced Composites*, 2017, pp. 209–235.
- [37] K. Debnath, I. Singh, and A. Dvivedi, “Drilling characteristics of sisal fiber-reinforced epoxy and polypropylene composites,” *Mater. Manuf. Process.*, vol. 29, no. 11–12, pp. 1401–1409, 2014, doi: 10.1080/10426914.2014.941870.
- [38] T. J. Singh, “Characterization of Natural Fiber Reinforced Composites-Bamboo and Sisal: a Review,” *Int. J. Res. Eng. Technol.*, vol. 03, no. 19, pp. 187–195, 2014, doi: 10.15623/ijret.2014.0319034.
- [39] L. Bacci, S. Di Lonardo, L. Albanese, G. Mastromei, and B. Perito, “Effect of different extraction methods on fiber quality of nettle (*Urtica dioica* L.),” *Text. Res. J.*, vol. 81, no. 8, pp. 827–837, 2011, doi: 10.1177/0040517510391698.
- [40] N. Dhirhi, R. Shukla, N. B. Patel, H. Sahu, and N. Mehta, “Extraction method of flax fibre and its uses,” *Plant Arch.*, vol. 15, no. 2, pp. 711–716, 2015.
- [41] Z. Mahboob, I. El Sawi, R. Zdero, Z. Fawaz, and H. Bougherara, “Tensile and compressive damaged response in Flax fibre reinforced epoxy composites,” *Compos. Part A Appl. Sci. Manuf.*, vol. 92, pp. 118–133, 2017, doi: 10.1016/j.compositesa.2016.11.007.
- [42] P. Peças, H. Carvalho, H. Salman, and M. Leite, “Natural Fibre Composites and Their Applications: A Review,” *J. Compos. Sci.*, vol. 2, no. 4, p. 66, 2018, doi: 10.3390/jcs2040066.
- [43] J. Zhu, H. Zhu, J. Njuguna, and H. Abhyankar, “Recent development of flax fibres and their reinforced composites based on different polymeric matrices,” *Materials (Basel)*, vol. 6, no. 11, pp. 5171–5198, 2013, doi: 10.3390/ma6115171.
- [44] C. Yu, “Natural Textile Fibres: Vegetable Fibres,” *Text. Mater. Des. Technol.*, pp. 29–56, 2015, doi: 10.1016/B978-1-84569-931-4.00002-7.
- [45] Olddogsnewtruck, “Homemade Flax Break,” 2017. <https://olddogsnewtruck.wordpress.com/tag/homemade-flax-break/> (accessed Jun. 30,

- 2021).
- [46] N. Chand and M. Fahim, *Tribology of natural fiber polymer composites*, vol. 66. 2008.
- [47] M. S. Salit, M. Jawaid, N. Bin Yusoff, and M. E. Hoque, *Manufacturing of natural fibre reinforced polymer composites*. 2015.
- [48] V. J. J. Prasad and P. Suresh Kumar, “A Review of Recent Developments in Natural Fiber Composites and their Mechanical, Thermal & Machinability Properties,” *Adv. Mater. Res.*, vol. 1148, pp. 61–71, 2018, doi: 10.4028/www.scientific.net/amr.1148.61.
- [49] D. K. K. Cavalcanti, M. D. Banea, J. S. S. Neto, R. A. A. Lima, L. F. M. da Silva, and R. J. C. Carbas, “Mechanical characterization of intralaminar natural fibre-reinforced hybrid composites,” *Compos. Part B Eng.*, vol. 175, no. July, p. 107149, 2019, doi: 10.1016/j.compositesb.2019.107149.
- [50] L. L. Naik, K. Gopalakrishna, and B. Yogesha, “Review on Mechanical Properties of Sisal and Banana Reinforced Composites,” *Int. J. Eng. Res. Gen. Sci.*, vol. 3, no. 5, pp. 176–179, 2015.
- [51] B. Koohestani, A. K. Darban, P. Mokhtari, E. Yilmaz, and E. Darezereshki, “Comparison of different natural fiber treatments: a literature review,” *Int. J. Environ. Sci. Technol.*, vol. 16, no. 1, pp. 629–642, 2019, doi: 10.1007/s13762-018-1890-9.
- [52] S. Kalia, B. S. Kaith, and I. Kaur, “Pretreatments of Natural Fibers and their Application as Reinforcing Material in Polymer Composites—A Review,” 2011, doi: 10.1002/pen.
- [53] M. O. Seydibeyoglu, A. K. Mohanty, and M. Misra, *Fiber Technology for Fiber-Reinforced Composites*, vol. 66. 2012.
- [54] M. N. Gururaja and H. Rao, “A Review on Recent Applications and Future Prospectus of Hybrid Composites,” *Int. J. Soft Comput. Eng.*, no. 16, pp. 2231–2307, 2012.
- [55] B. Singh, M. Gupta, H. Tarannum, and A. Randhawa, “Cellulose Fibers: Bio- and Nano-Polymer Composites,” *Cellul. Fibers Bio- Nano-Polymer Compos.*, pp. 701–720, 2011, doi: 10.1007/978-3-642-17370-7.
- [56] B. Ravishankar, S. K. Nayak, and M. A. Kader, “Hybrid composites for automotive applications – A review,” *J. Reinf. Plast. Compos.*, 2019, doi: 10.1177/0731684419849708.
- [57] A. Mota, “Materials of Prosthetic Limbs,” *Cal Poly Pomona*, pp. 1–7, 2017, [Online]. Available: https://broncoscholar.library.cpp.edu/bitstream/handle/10211.3/193171/MotaAnissa_LibraryResearchPaper2017.pdf?sequence=1.
- [58] M. H. Nurhanisah, M. Jawaid, R. Ahmad Azmeer, and M. T. Paridah, “The AirCirc: design and development of a thermal management prototype device for below-knee prosthesis leg socket,” *Disabil. Rehabil. Assist. Technol.*, vol. 14, no. 5, pp. 513–520, 2019, doi: 10.1080/17483107.2018.1479782.
- [59] V. Rajt’úková, M. Michalíková, L. Bednarcíková, A. Balogová, and J. Živčák, “Biomechanics of lower limb prostheses,” *Procedia Eng.*, vol. 96, pp. 382–391, 2014, doi: 10.1016/j.proeng.2014.12.107.
- [60] L. Paternò, M. Ibrahimi, E. Gruppioni, A. Menciacchi, and L. Ricotti, “Sockets for limb

- prostheses: A review of existing technologies and open challenges,” *IEEE Trans. Biomed. Eng.*, vol. 65, no. 9, pp. 1996–2010, 2018, doi: 10.1109/TBME.2017.2775100.
- [61] M. H. Nurhanisah, F. Hashemi, M. T. Paridah, M. Jawaid, and J. Naveen, “Mechanical properties of laminated kenaf woven fabric composites for below-knee prosthesis socket application,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 368, no. 1, 2018, doi: 10.1088/1757-899X/368/1/012050.
- [62] M. Ramesh, K. Palanikumar, and K. H. Reddy, “Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites,” *Compos. Part B Eng.*, vol. 48, pp. 1–9, 2013, doi: 10.1016/j.compositesb.2012.12.004.
- [63] R. S. Rana, A. Kumre, S. Rana, and R. Purohit, “Characterization of Properties of epoxy sisal / Glass Fiber Reinforced hybrid composite,” *Mater. Today Proc.*, vol. 4, no. 4, pp. 5445–5451, 2017, doi: 10.1016/j.matpr.2017.05.056.
- [64] A. A. Betelie, Y. T. Megera, D. T. Redda, and A. Sinclair, “Experimental investigation of fracture toughness for treated sisal epoxy composite,” *AIMS Mater. Sci.*, vol. 5, no. 1, pp. 93–104, 2018, doi: 10.3934/matpr.2018.1.93.
- [65] B. A. Muralidhar, “Study of flax hybrid preforms reinforced epoxy composites,” *Mater. Des.*, vol. 52, pp. 835–840, 2013, doi: 10.1016/j.matdes.2013.06.020.
- [66] H. Assaedi, T. Alomayri, F. U. A. Shaikh, and I. M. Low, “Characterisation of mechanical and thermal properties in flax fabric reinforced geopolymer composites,” *J. Adv. Ceram.*, vol. 4, no. 4, pp. 272–281, 2015, doi: 10.1007/s40145-015-0161-1.
- [67] M. Ghasemzadeh-Barvarz, C. Duchesne, and D. Rodrigue, “Mechanical, water absorption, and aging properties of polypropylene/flax/glass fiber hybrid composites,” *J. Compos. Mater.*, vol. 49, no. 30, pp. 3781–3798, 2015, doi: 10.1177/0021998314568576.
- [68] G. R. Kalagi *et al.*, “Experimental Study on Damping Properties of Sisal / Flax Fibre Reinforced,” *Int. J. Mech. Eng. Technol.*, vol. 8, no. 2, pp. 70–81, 2017, [Online]. Available: <http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=8&IType=2%0A1>.
- [69] G. R. Kalagi and R. Patil, “Mechanical Properties and SEM Analysis of Flax / Sisal / Sic Nano Powder Reinforced Hybrid Composites,” *Int. J. Adv. Sci. Res. Eng.*, vol. 3, no. Special Issue 1, pp. 124–129, 2017, [Online]. Available: http://www.ijasre.net/uploads/1/3394_pdf.pdf.
- [70] S. M. Naik, “Experimental Study on Flax and Sisal Hybrid Composites Reinforced With Epoxy Resin,” vol. 3, no. 10, pp. 2536–2540, 2016.
- [71] G. Rajamurugan, A. P. Sanjay, P. Krishnasamy, B. Muralidharan, and S. Jain, “Drilling and mechanical performance analysis on flax-sisal hybrid composite embedded with perforated aluminum foil,” *J. Reinf. Plast. Compos.*, vol. 39, no. 23–24, pp. 902–917, 2020, doi: 10.1177/0731684420937070.
- [72] C. M. Meenakshi and A. Krishnamoorthy, “Study on the effect of surface modification on the mechanical and thermal behaviour of flax, sisal and glass fiber-reinforced epoxy hybrid composites,” *J. Renew. Mater.*, vol. 7, no. 2, pp. 153–169, 2019, doi: 10.32604/jrm.2019.00046.
- [73] B. Gebreslassie, K. Gebreselassie, and R. Esayas, “Patterns and Causes of Amputation

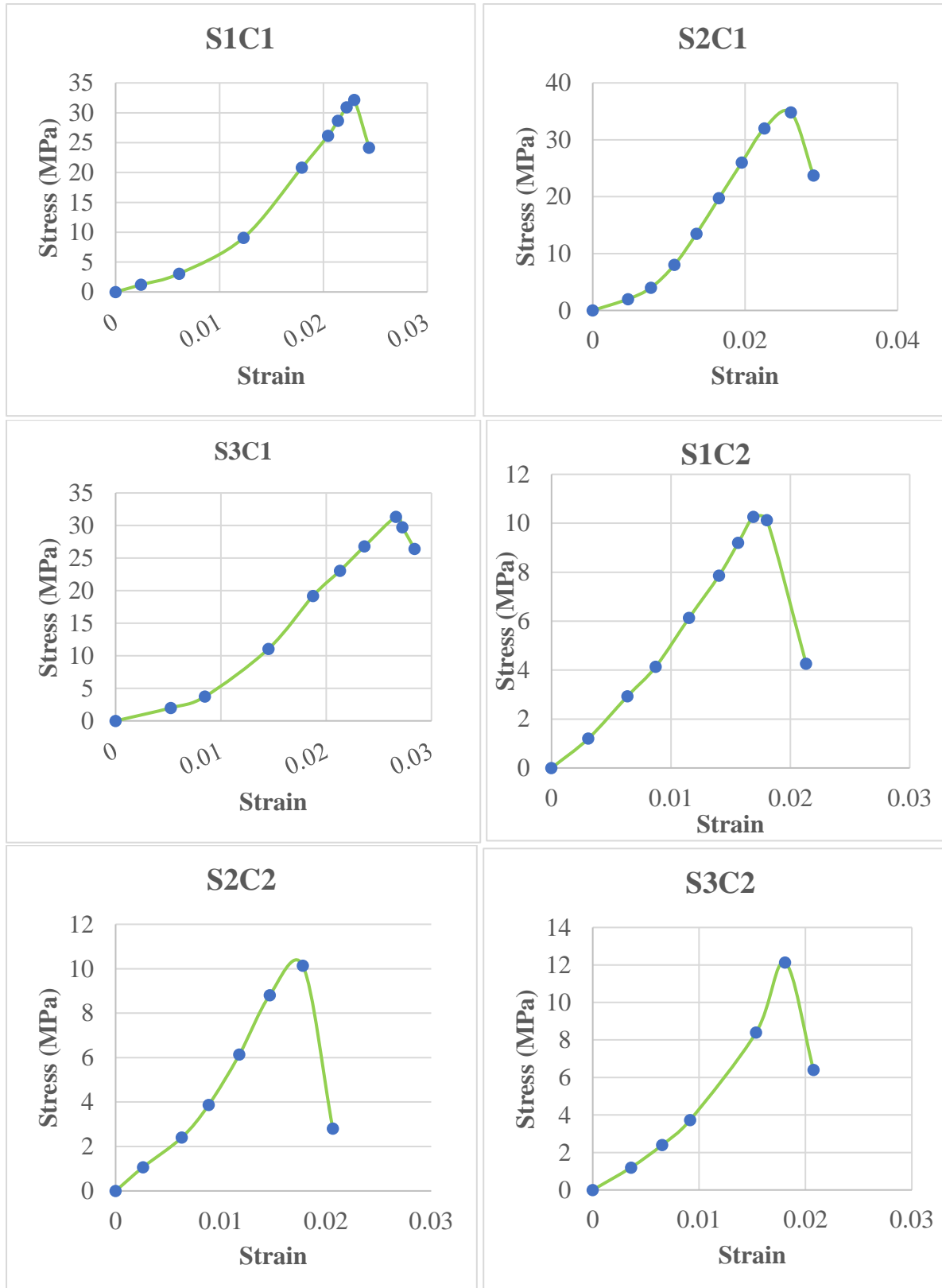
- in Ayder Referral Hospital, Mekelle, Ethiopia: A Three-Year Experience,” *Ethiop. J. Health Sci.*, vol. 28, no. 1, pp. 31–36, 2018, doi: 10.4314/ejhs.v28i1.5.
- [74] B. S. Harsimran Jeet Singh Sidhu , T.K Garg, “Design Of E-Glass Epoxy Prosthetic Leg,” *Int. J. Eng. Res. Technol.*, vol. 2, no. 3, pp. 1–10, 2013.
- [75] S. M. Abbas, “Effects of Composite Material Layers on the Mechanical Properties for Partial Foot Prosthetic Socket,” *Al-Nahrain J. Eng. Sci.*, vol. 21, no. 2, pp. 253–258, 2018, doi: 10.29194/njes21020253.
- [76] M. Mahjoob, A. K. A. Alameer, and M. A. Al-shammari, “Material Characterization and Fatigue Analysis of Lower Limb Prosthesis Materials,” *Assoc. Arab Univ. J. Eng. Sci. (PISSN 1726-4081)*, vol. 25, no. 3, pp. 137–154, 2018.
- [77] D. Chandramohan and A. J. P. Kumar, “Fibre Reinforced Composites: a Promising Material for Artificial Limp,” *Data-Enabled Discov. Appl.*, vol. 1, no. 1, pp. 1–9, 2017, doi: 10.1007/s41688-017-0010-1.
- [78] M. A. Al-Shammari, E. Q. Hussein, and A. A. Oleiwi, “Material characterization and stress analysis of a through knee prosthesis sockets,” *Int. J. Mech. Mechatronics Eng.*, vol. 17, no. 6, pp. 57–64, 2017.
- [79] N. A. Jebur, F. A. Abdulla, and A. F. Hussein, “Experimental and numerical analysis of below knee prosthetic socket,” in *International Journal of Mechanical Engineering and Technology*, 2018, vol. 9, no. 8, pp. 1–8, doi: http://www.iaeme.com/MasterAdmin/uploadfolder/IJMET_09_08_001/IJMET_09_08_001.pdf.
- [80] F. M. Kadhim, A. M. Takhakh, and A. M. Abdullah, “Mechanical properties of polymer with different reinforcement material composite that used for fabricates prosthetic socket,” *J. Mech. Eng. Res. Dev.*, vol. 42, no. 4, pp. 118–123, 2019, doi: 10.26480/jmerd.04.2019.118.123.
- [81] Kahtan Al-Khazraji, Jawad Kadhim, and Payman Sahbah Ahmed, “Improving Mechanical and Fatigue Characteristic of Trans-Tibial Prosthetic Socket,” *Int. Conf. Ind. Eng. Oper. Manag.*, no. March, pp. 2399–2405, 2015.
- [82] M. J. Jweeg, Z. S. Hammoudi, and B. A. Alwan, “Optimised Analysis, Design, and Fabrication of Trans-Tibial Prosthetic Sockets,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 433, no. 1, 2018, doi: 10.1088/1757-899X/433/1/012058.
- [83] A. P. Irawan and I. W. Sukania, “Tensile and Impact Strength of Bamboo Fiber Reinforced Epoxy Composites as Alternative Materials for Above Knee Prosthesis Socket,” *Developing Sustainable Technology for a Better Future*. pp. 109–115, 2012.
- [84] A. P. Irawan and I. W. Sukania, “Gait Analysis of Lower Limb Prosthesis with Socket Made from Rattan Fiber Reinforced Epoxy Composites,” *Asian J. Appl. Sci.*, vol. 03, no. 01, pp. 8–13, 2017.
- [85] A. P. Irawan, T. P. Soemardi, K. Widjajalaksmi, and A. H. S. Reksoprodjo, “Tensile and flexural strength of ramie fiber reinforced epoxy composites for socket prosthesis application,” *Int. J. Mech. Mater. Eng.*, vol. 6, no. 1, pp. 46–50, 2011.
- [86] D. Monette, P. Dumond, I. Chikhaoui, P. Nichols, and E. D. Lemaire, “Preliminary Material Evaluation of Flax Fibers for Prosthetic Socket Fabrication,” *J. Biomech. Eng.*, vol. 143, no. 2, pp. 1–13, 2021, doi: 10.1115/1.4048079.

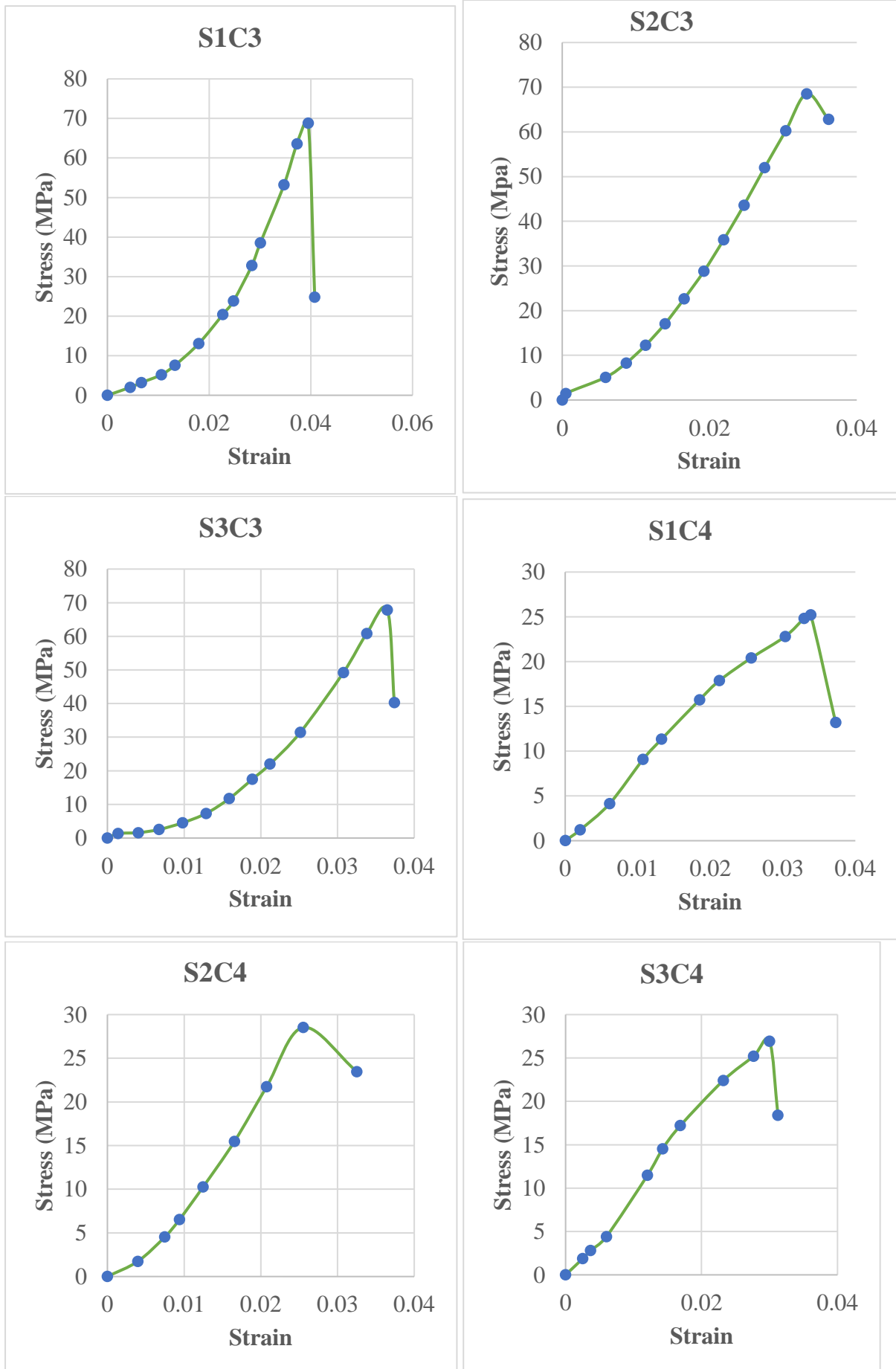
- [87] J. Odusote and V. Kumar, “Mechanical Properties of Pineapple Leaf Fibre Reinforced Polymer Composites for Application as Prosthetic Socket,” *J. Eng. Technol.*, vol. 6, no. 1, pp. 24–32, 2016, doi: 10.21859/jet-06011.
- [88] J. K. Odusote, A. T. Oyewo, J. A. Adebisi, and K. A. Akande, “Mechanical Properties of Banana Pseudo Stem Fibre Reinforced Epoxy Composite as a Replacement for Transtibial Prosthetic Socket,” *J. Assoc. Prof. Eng. Trinidad Tobago*, vol. 44, no. 2, pp. 4–10, 2016.
- [89] P. K. Lenka and A. R. Choudhury, “Analysis of trans tibial prosthetic socket materials using finite element method,” *J. Biomed. Sci. Eng.*, vol. 04, no. 12, pp. 762–768, 2011, doi: 10.4236/jbise.2011.412094.
- [90] L. Yan, N. Chouw, and X. Yuan, “Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment,” *J. Reinf. Plast. Compos.*, vol. 31, no. 6, pp. 425–437, 2012, doi: 10.1177/0731684412439494.
- [91] C. M. M. Dhanushkodi and K. Arunagri, “Experimental study on dynamic and thermal behaviour of chopped glass, sisal, and flax fiber-reinforced gears,” *Fibers*, vol. 6, no. 3, 2018, doi: 10.3390/fib6030060.
- [92] M. J. Gerschutz, M. L. Haynes, D. M. Nixon, and J. M. Colvin, “Tensile strength and impact resistance properties of materials used in prosthetic check sockets, copolymer sockets, and definitive laminated sockets,” *J. Rehabil. Res. Dev.*, vol. 48, no. 8, pp. 987–1004, 2011, doi: 10.1682/JRRD.2010.10.0204.
- [93] I. Ali, R. Kumar, and Y. Singh, “Finite Element Modelling and Analysis of Trans-Tibial Prosthetic Socket,” *Glob. J. Res. Eng. A Mech. Mech. Eng.*, vol. 14, no. 4, pp. 43–50, 2014.
- [94] S. L. Phillips and W. Craelius, “Material properties of selected prosthetic laminates,” *J. Prosthetics Orthot.*, vol. 17, no. 1, pp. 27–34, 2005, doi: 10.1097/00008526-200501000-00007.

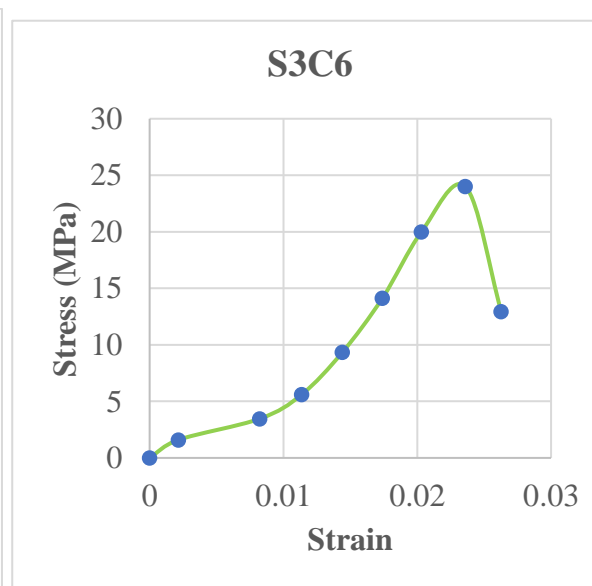
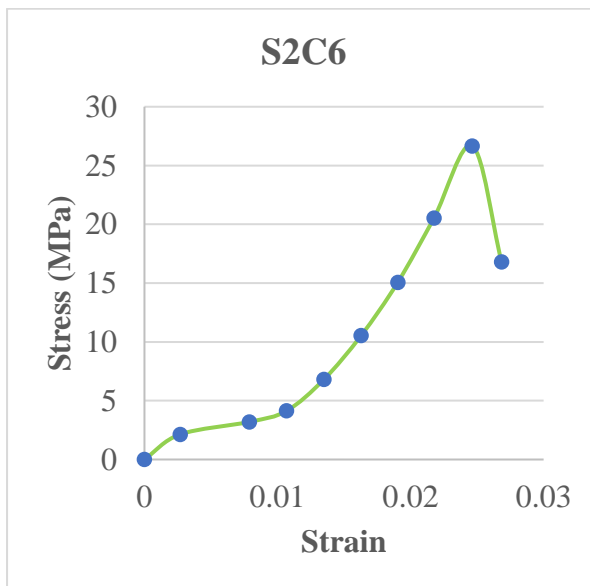
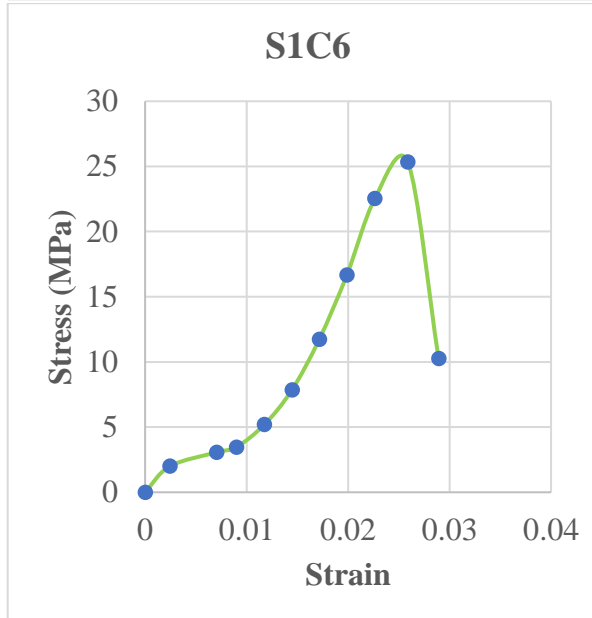
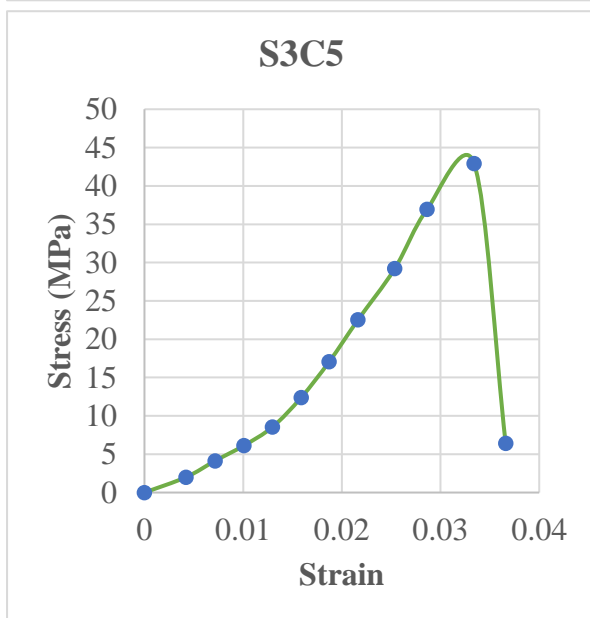
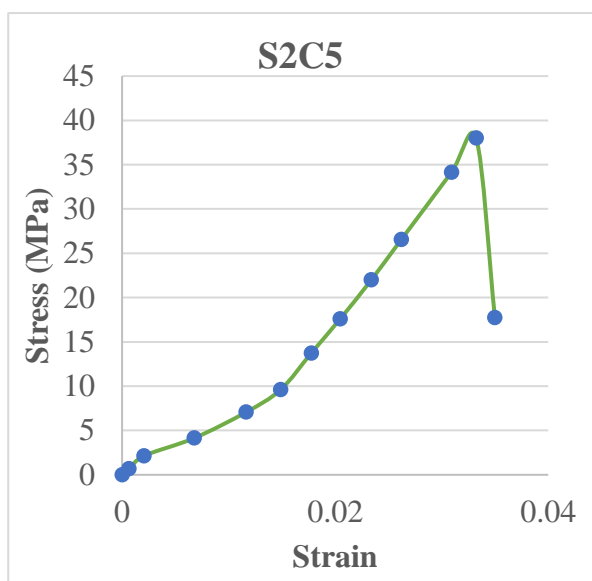
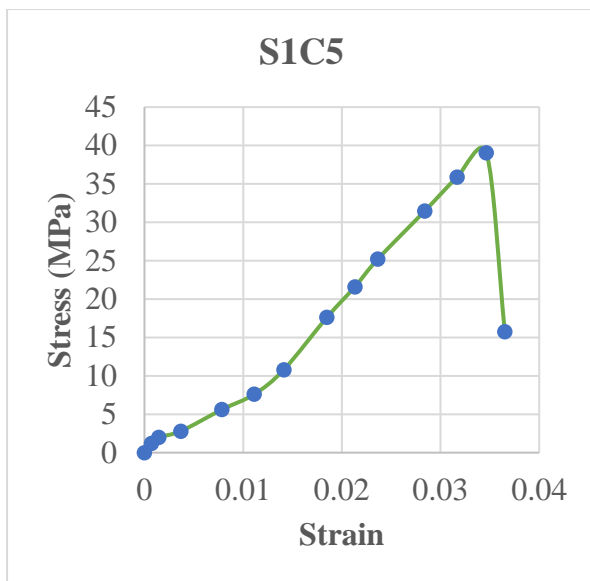
APPENDICES

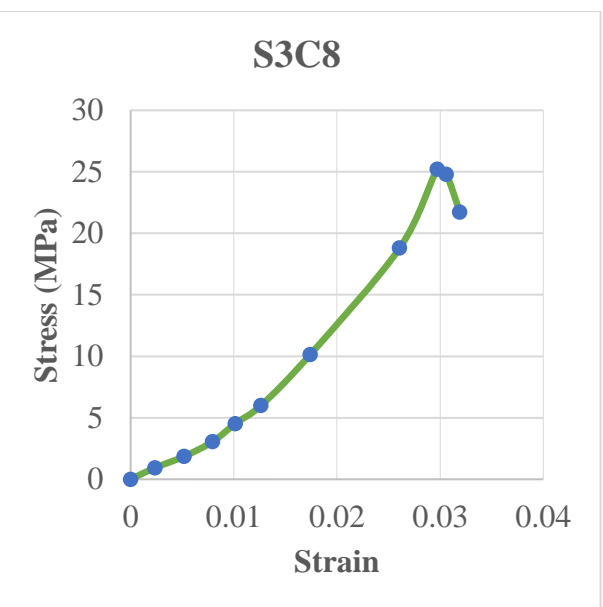
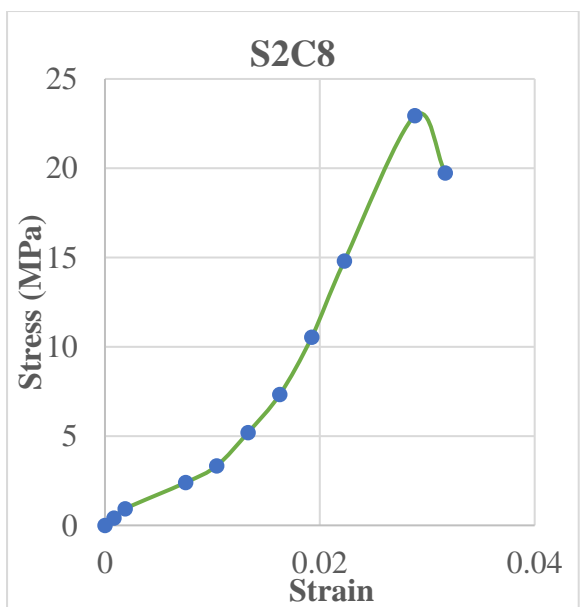
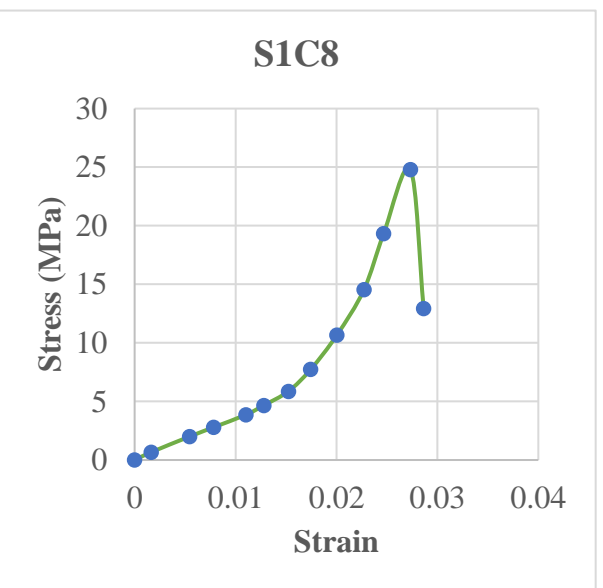
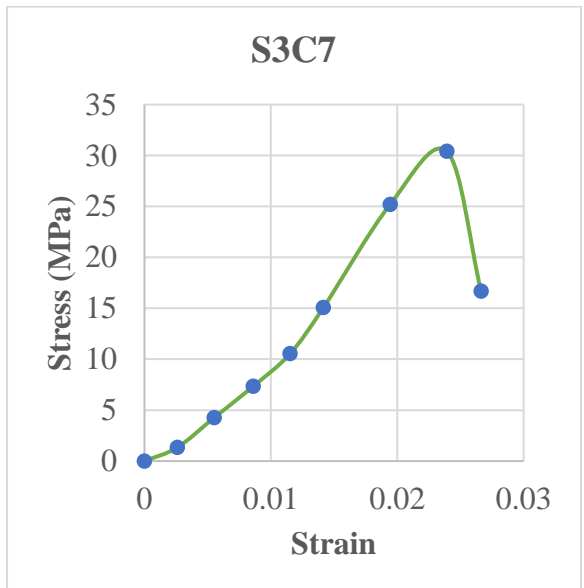
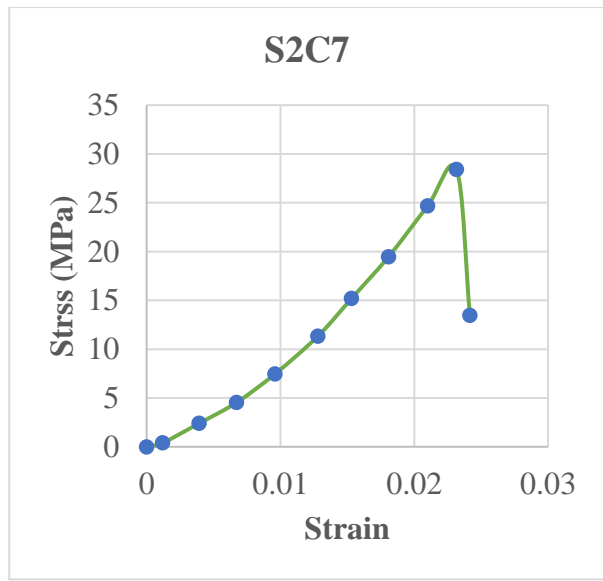
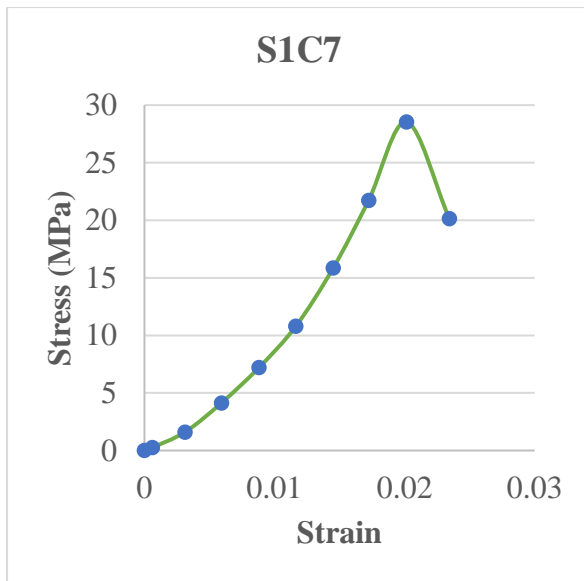
APPENDIX A

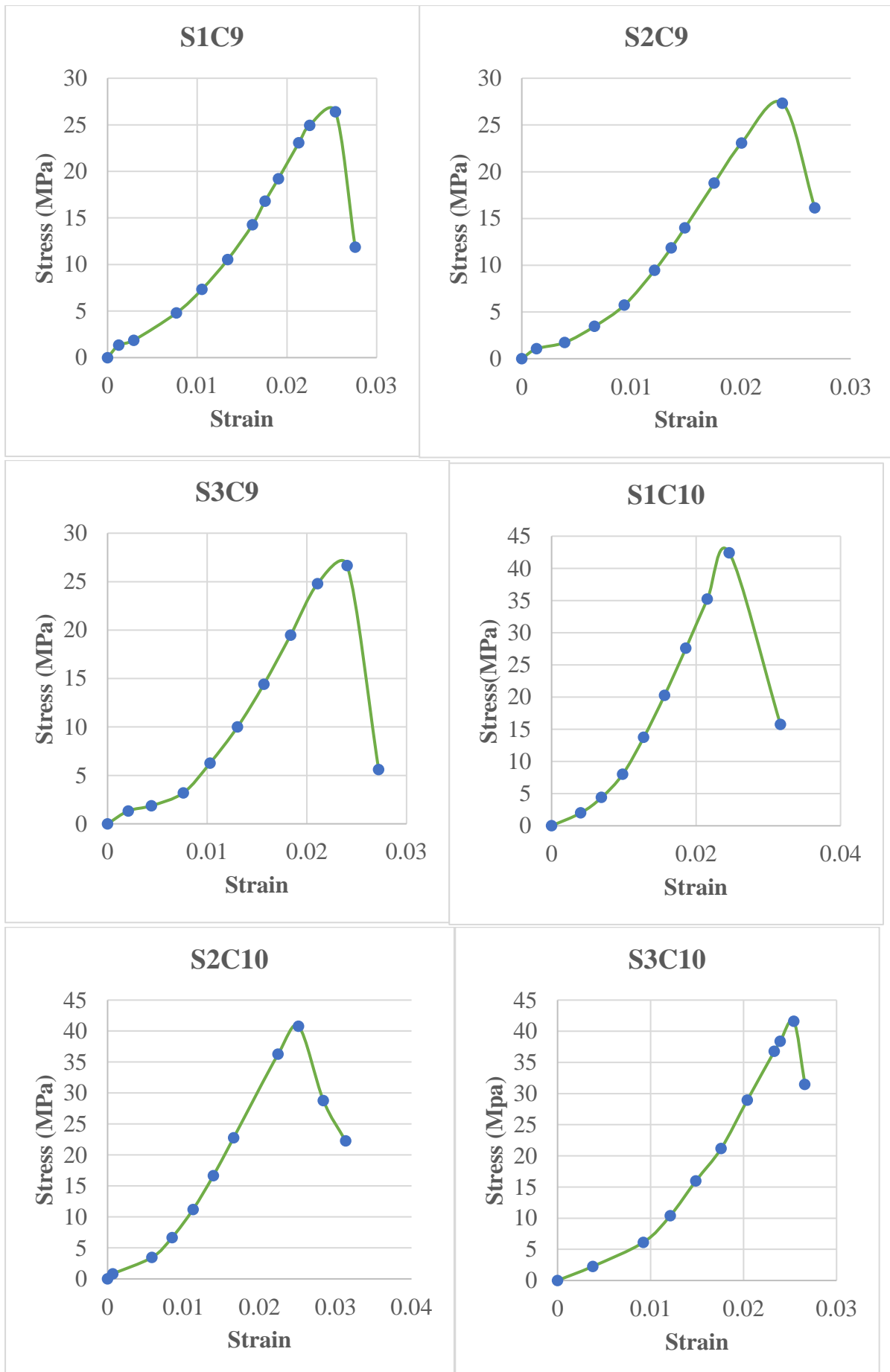
TENSILE TEST RESULTS FOR EACH SAMPLES

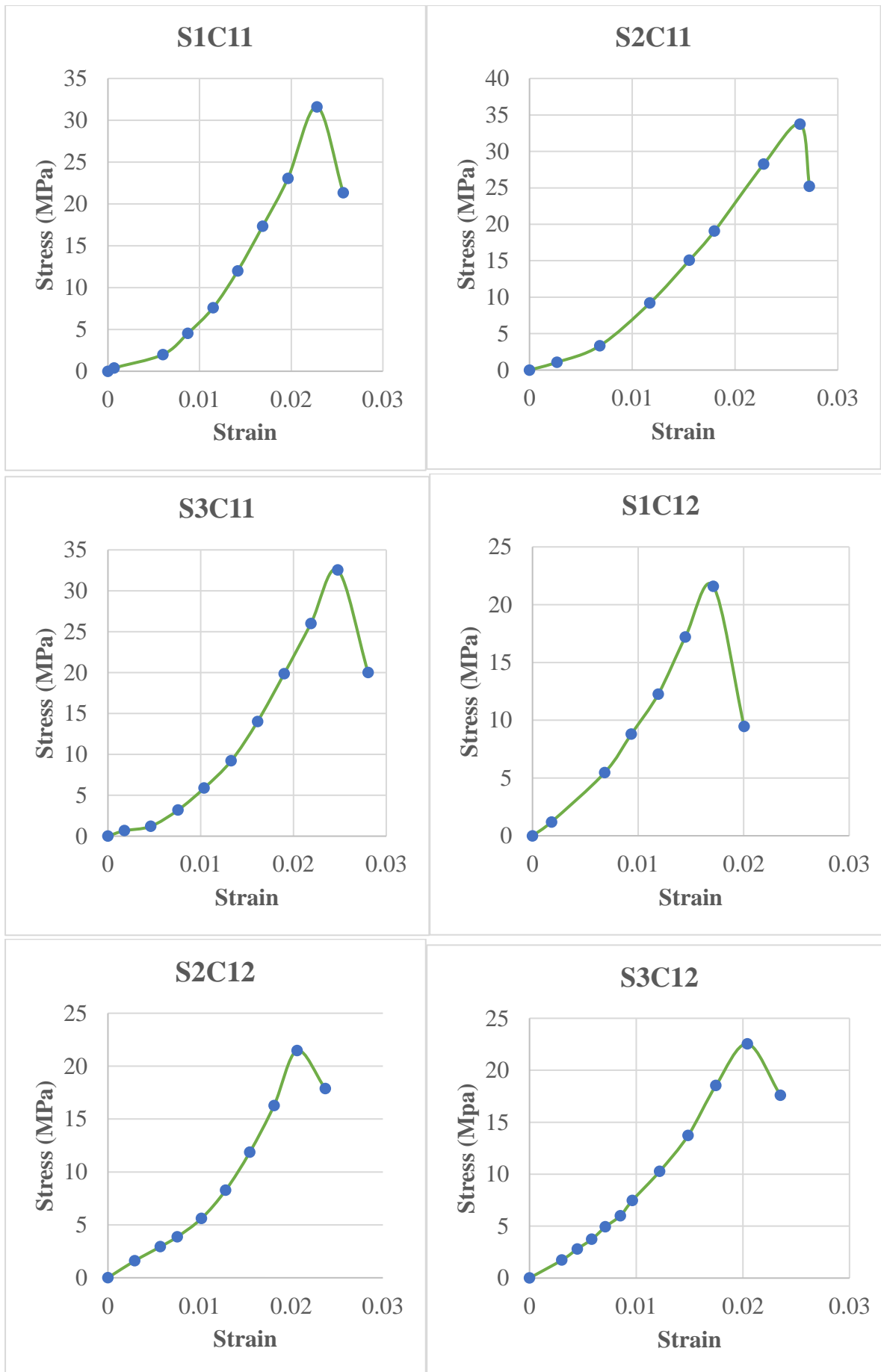












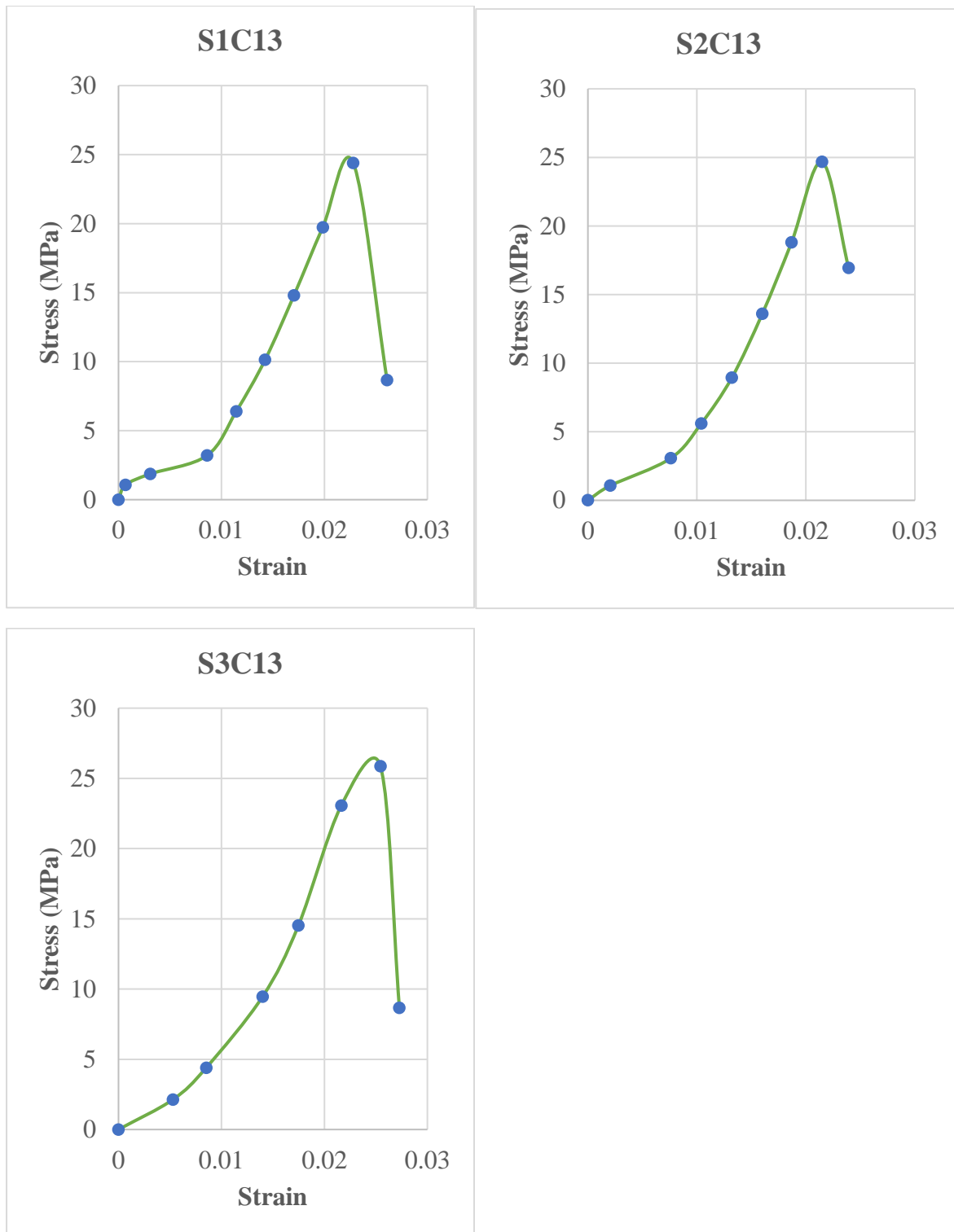
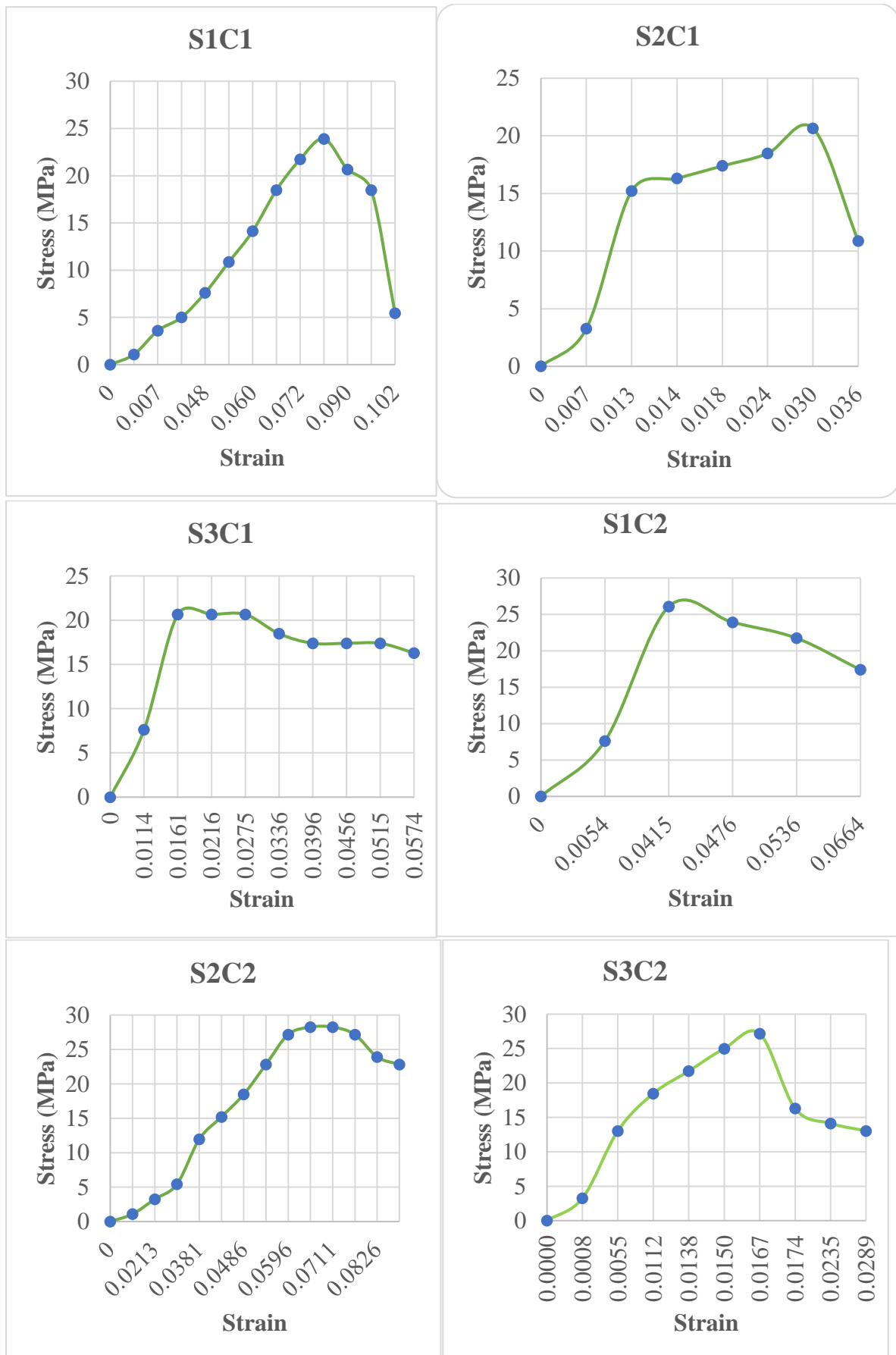
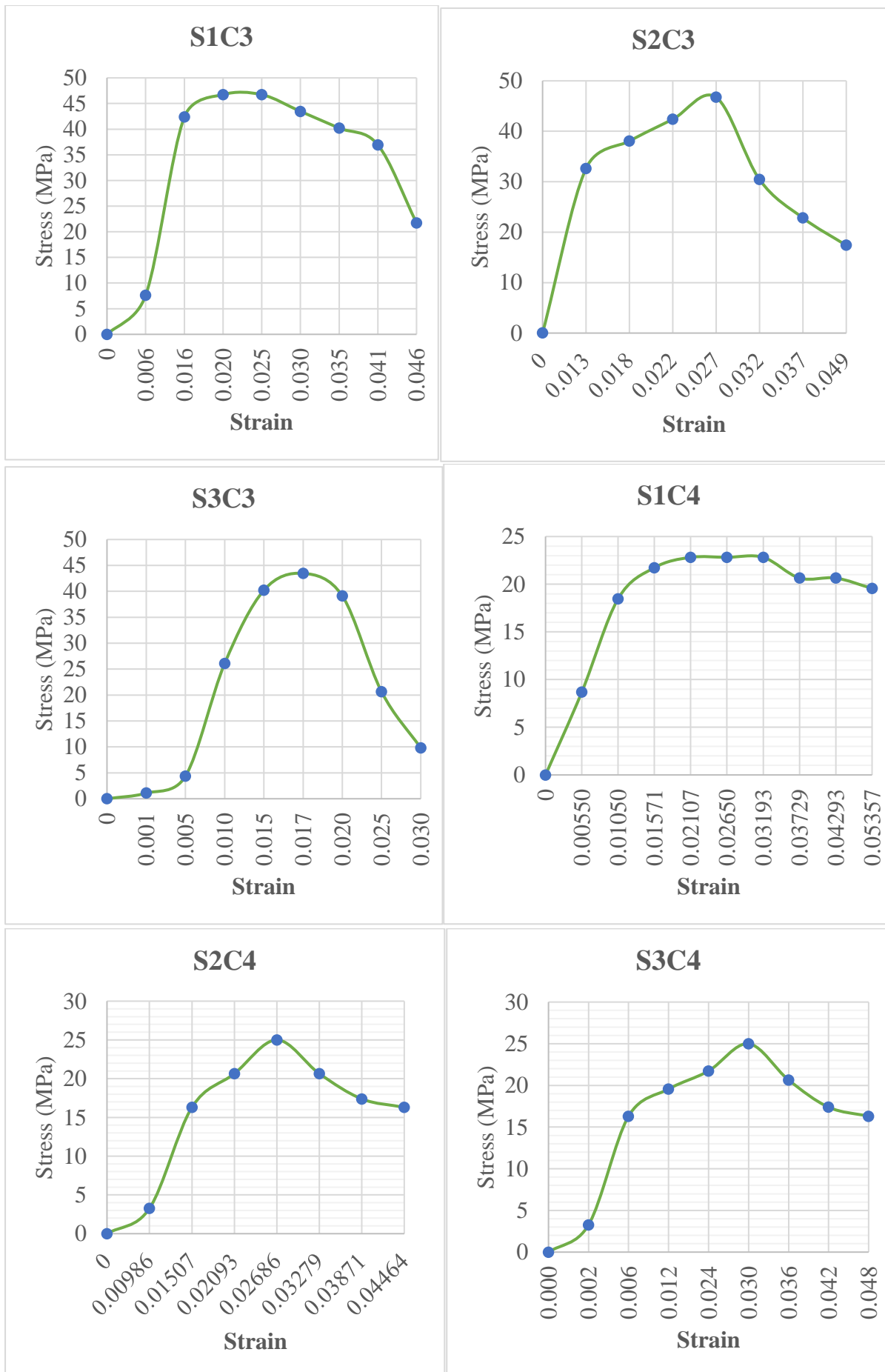
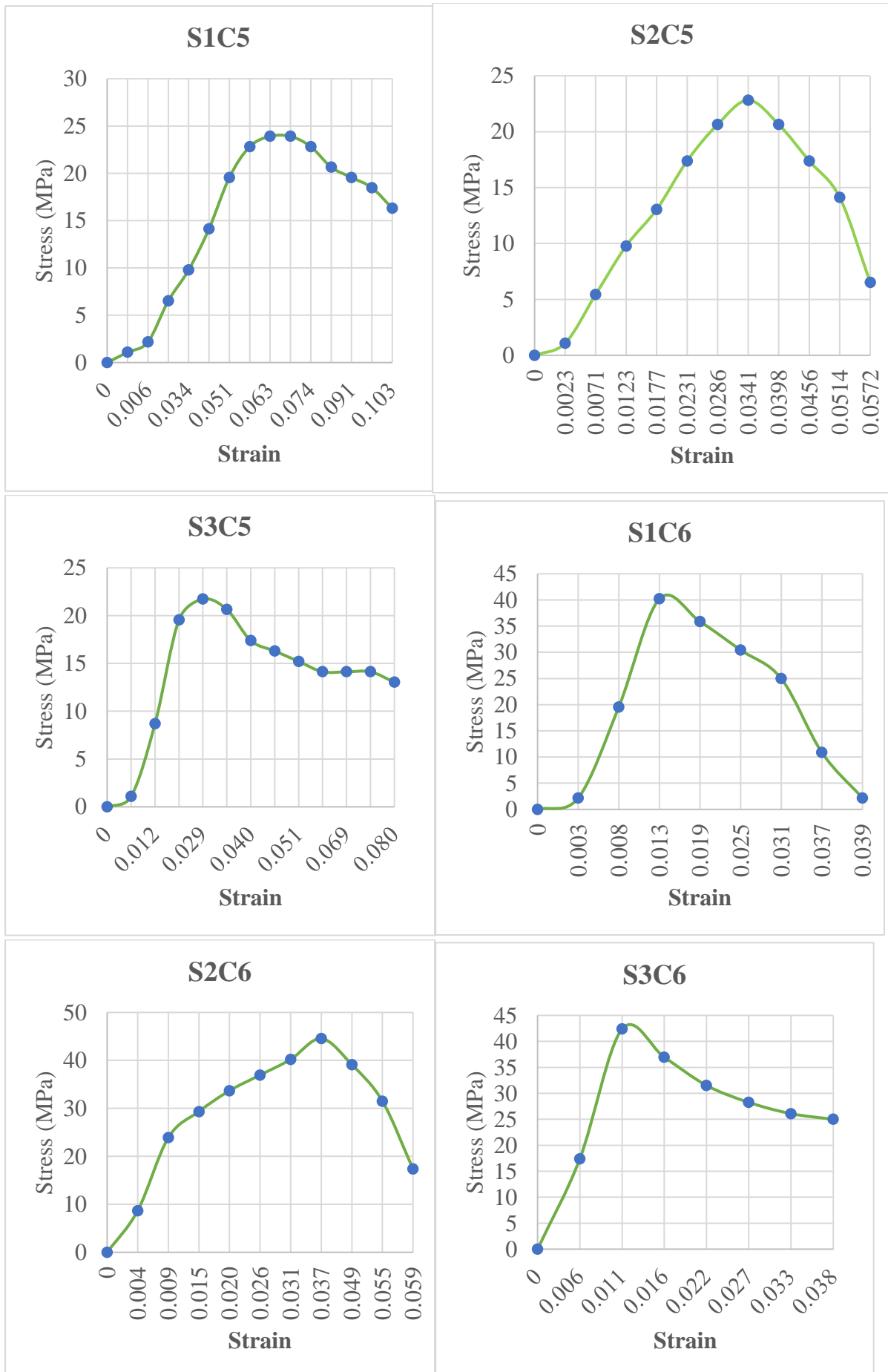


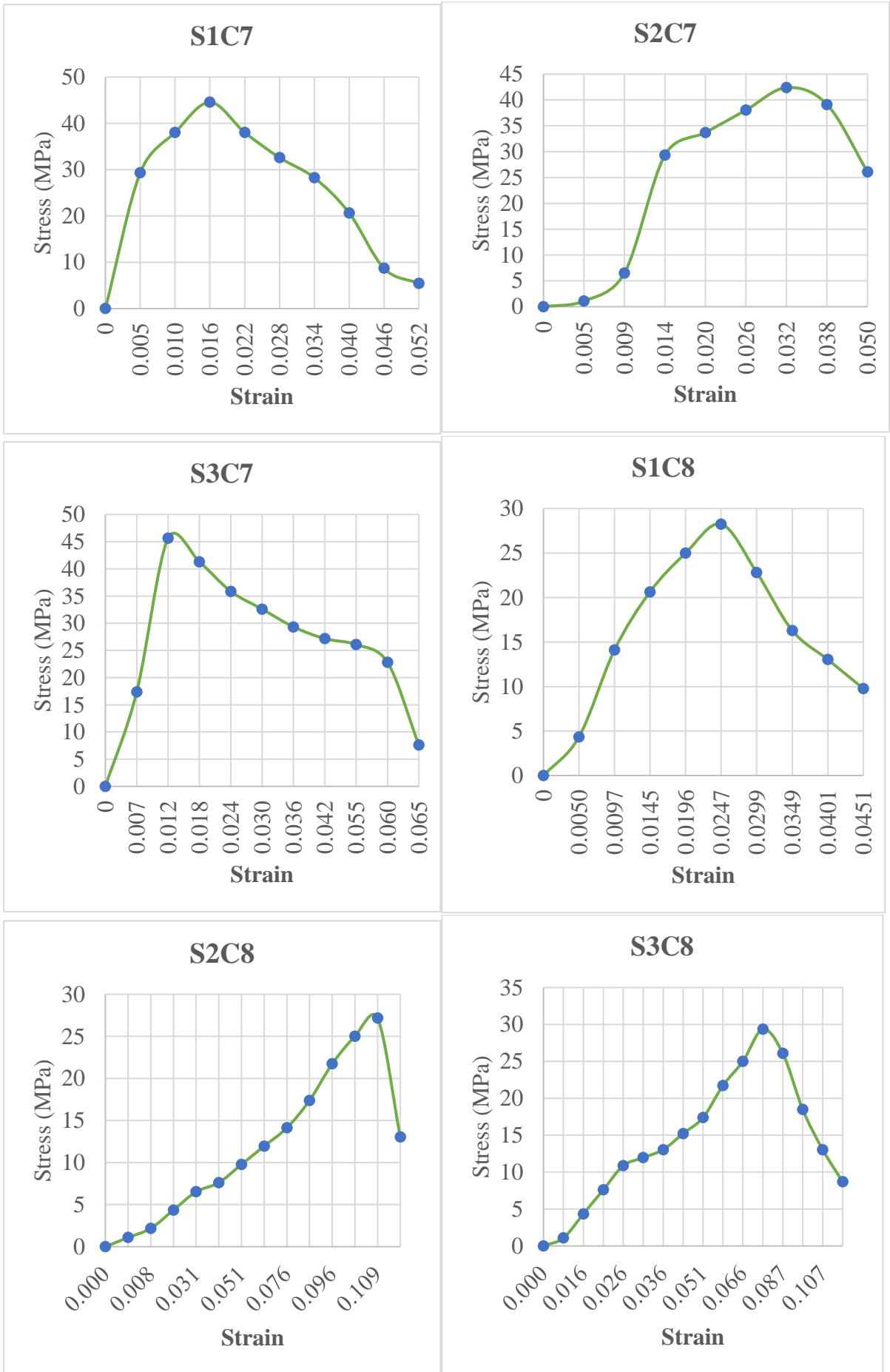
Figure A.1 Tensile Test Graphs

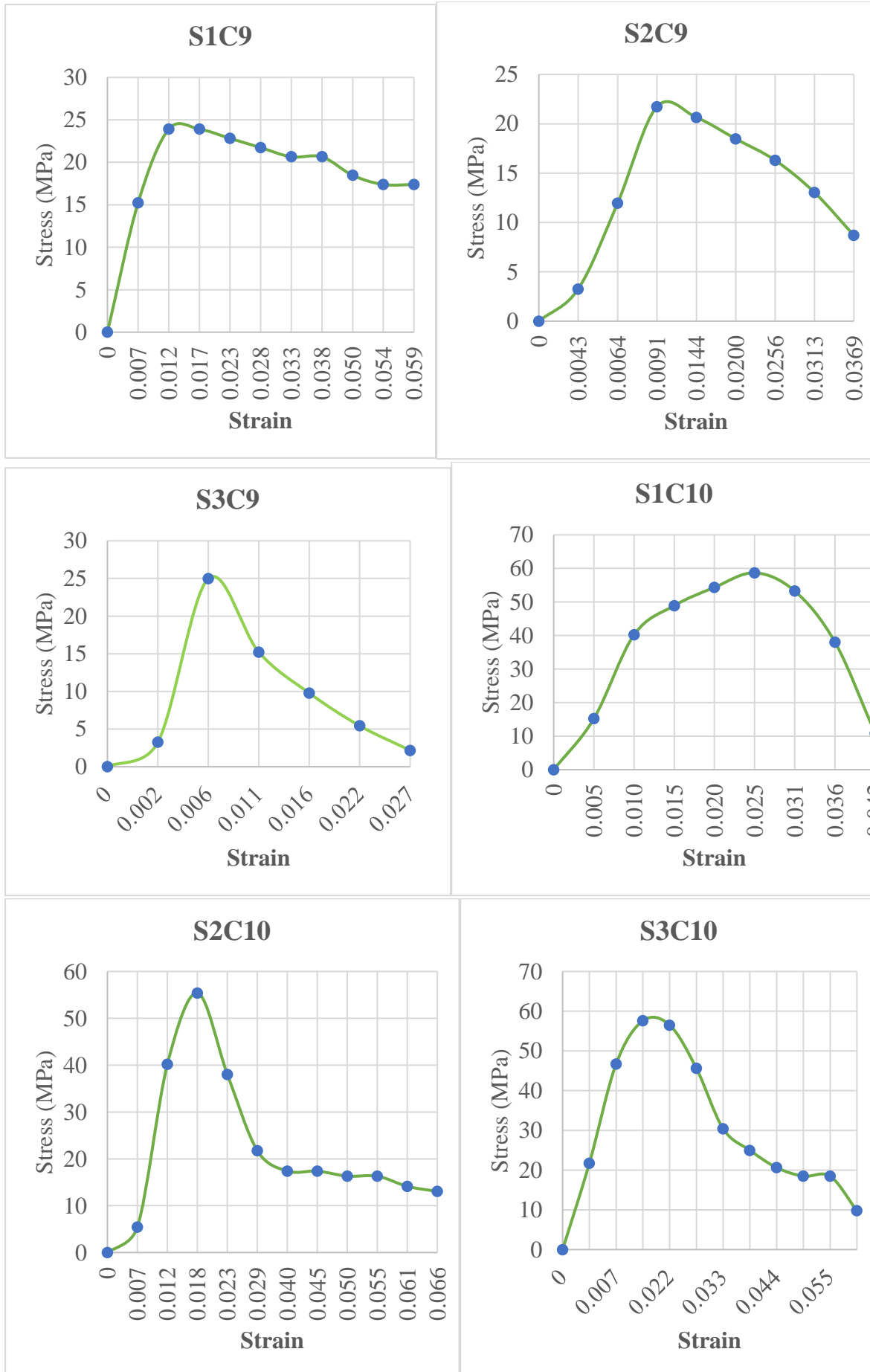
Compression Test Results For each Samples

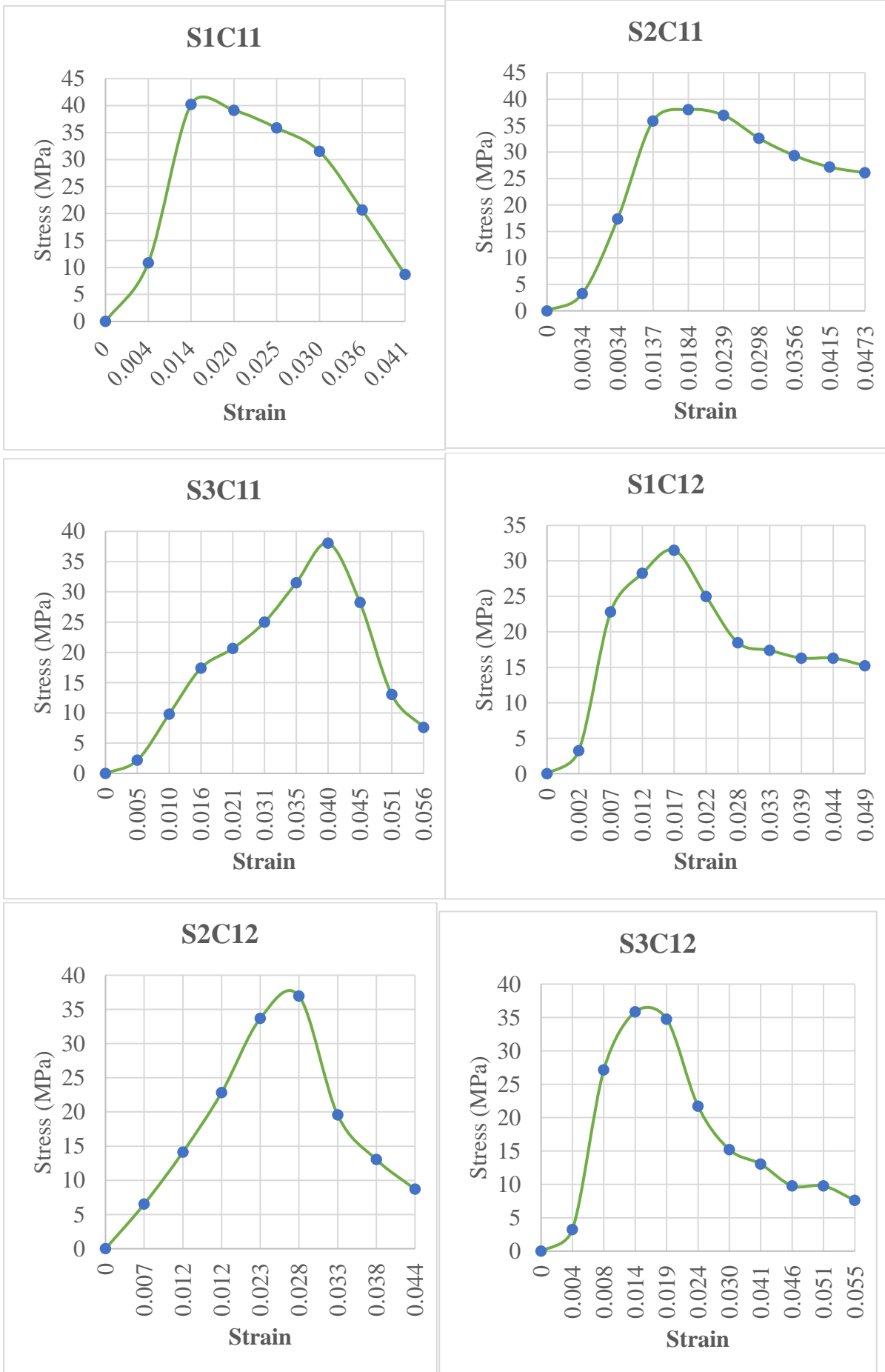












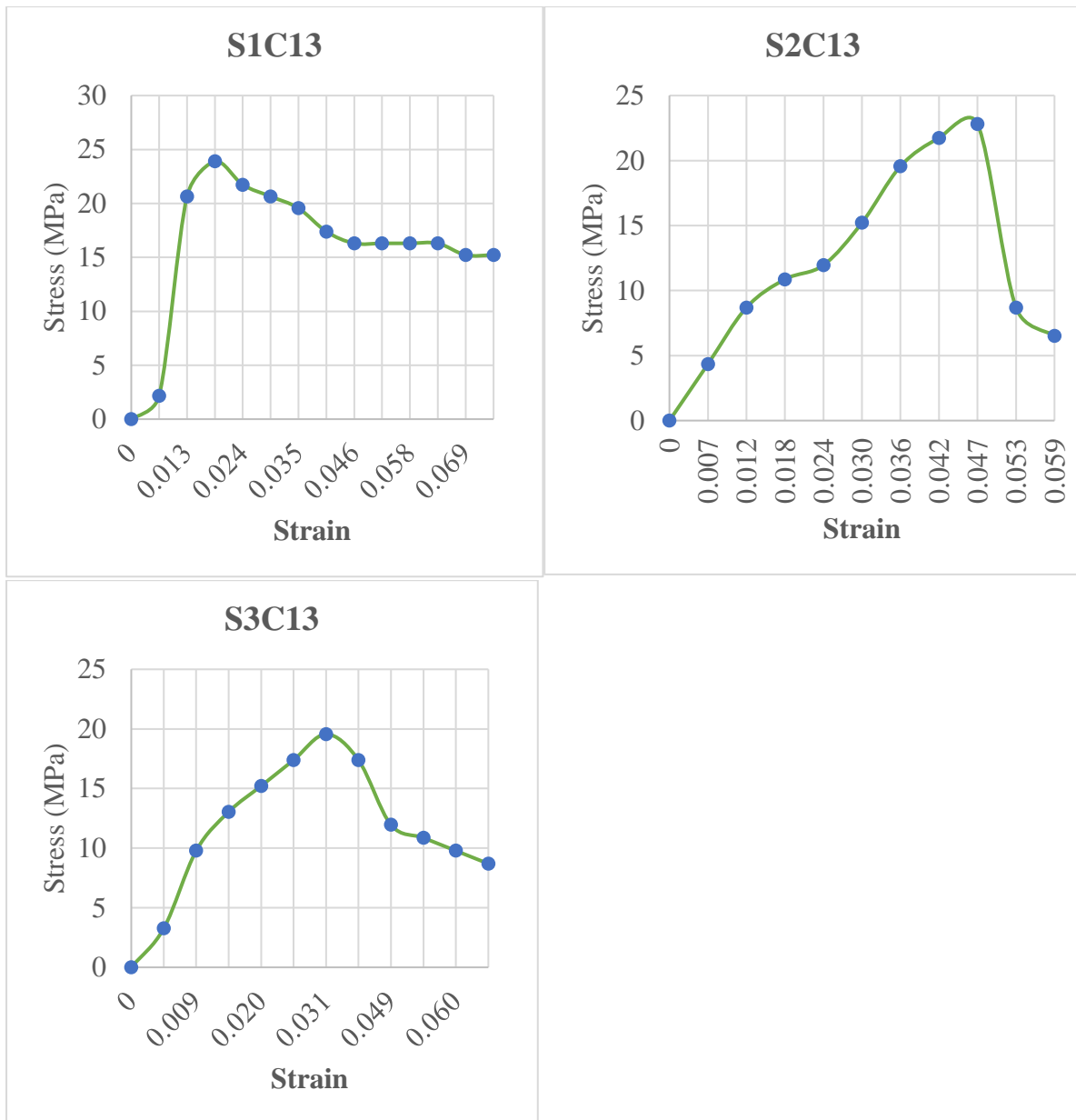


Figure A.2 Compression Test Graphs

APPENDIX B



Figure B.1 Flax and Sisal Fiber Ready for Testing of Elongation, Tenacity, Tensile

ETHIOPIAN TEXTILE INDUSTRY DEVELOPMENT INSTITUTE Research and Testing Laboratories Physical Testing Laboratory								Issue Date: 2018/12/30	Rev: 1
Test Report								Page# 1 of 1	
PHYSICAL QUALITY EVALUATION									
Name & Address of client						Report No PTL /125/12			
Addis Ababa Institute of Technology						Client's Reference No:			
School of Mechanical and Industrial Engineering						Date:			
Tel. +251-111232414,0927716859									
Sample Description: 3 Fiber samples identified with code									
Date (s) of Test performed: 07/08/2020									
Sample Conditioning: Temp. : 22°C RH:65%									
Date of sample receiving : 06/08/2020				Date of results reporting: 07/08/2020					
S.No	Test Parameters	Test Method	Laboratory Sample Code						
			13022004		13022005		13022006		
			SISAL		BANANA		FLAX		
			Mean	CV	Mean	CV	Mean	CV	
1	Average Force(N)	ASTM D2256 USTER 5000	9.41	65	2.96	35.7	7.29	69	
2	Average Elongation(%)		1.74	35	1.13	38.8	0.7		
3	Average Tenacity (cN/tex)		33.46	65	15.55	35.7	4.94		

Any observation/comments:
Remark: This test report applies for the sample submitted by the client. It does not serve as a certificate.

Prepared by	Approved by
Name:- Eyob Alemayehu	Name:- Simegnew Mersha
Position:- Lead Testing Analyst	Position:- Lead Testing Technician
+251-11 439 43 51	+251-11 439 50 03- 5637
+251-11 439 50 07	+251-11 439 50 19
+251-11 439 50 08	Addis Ababa Ethiopia

Figure B.2 Result of Property Test

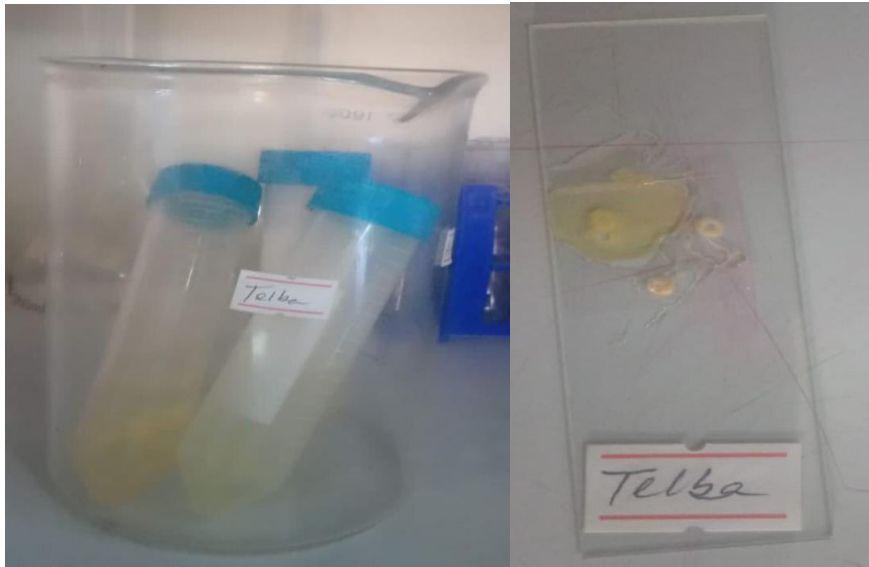


Figure B. 3 Flax Fiber Dimension test setup

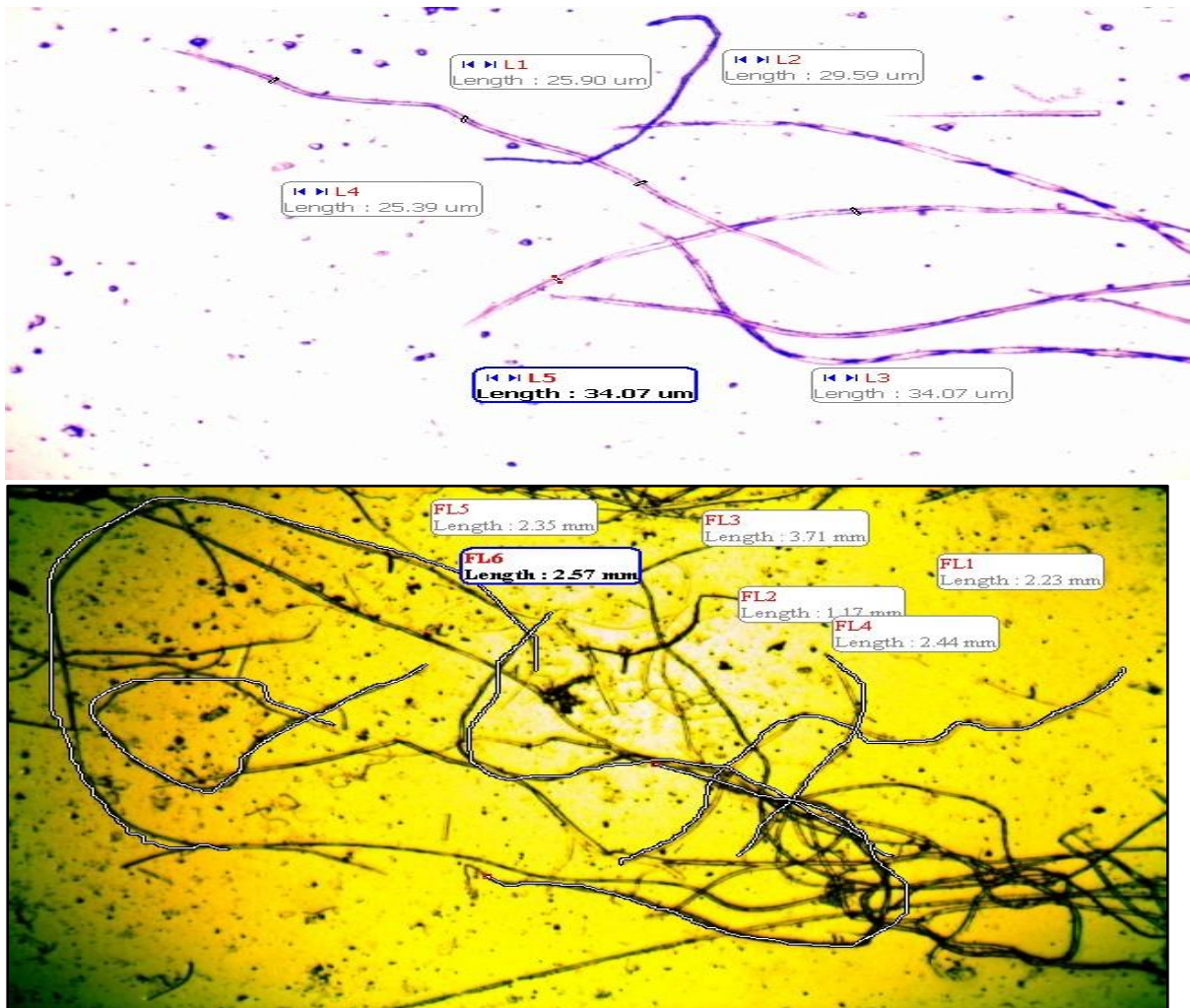


Figure B.4 Result

*Fabrication, Characterization and Simulation of Flax-Sisal Fiber Reinforced Epoxy
Hybrid Composite for Prosthetic Socket*

No.	Fiber length(mm)	Fiber width (μm)
1	2.42	46.00
2	2.33	41.88
3	3.82	36.98
4	2.15	41.88
5	4.33	32.12
6	3.52	20.92
7	3.52	32.50
8	3.11	27.35
9	2.55	34.07
10	2.28	25.90
11	3.08	28.72
12	4.13	36.98
13	3.36	32.51
14	1.76	32.50
15	1.62	25.39
16	1.43	27.33
17	3.98	18.31
16	2.11	20.92
17	2.94	25.90
18	3.99	35.92
19	3.1	20.94
20	2.68	27.35
21	2.59	32.12
22	3.67	39.65
23	2.68	25.90
24	2.59	25.90

Table B.1 Data of Flax Fiber Dimensions from Physical Test