

Fabrication and Testing of Polymer Matrix Composite Reinforced with Pineapple Fiber and Cardamom Husk



Tigist Girma Shoa

A Thesis Submitted to the department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in
Manufacturing Engineering

Office of Graduate studies
Adama Science and Technology University

July, 2024

Adama, Ethiopia

**Fabrication and Testing of Polymer Matrix Composite Reinforced
with Pineapple Fiber and Cardamom Husk**

Tigist Girma Shoa

Thesis Advisor: Dr. Moera Gutu Jiru (Asso.prof.)

A Thesis Submitted to the department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in
Manufacturing Engineering

Office of Graduate studies
Adama Science and Technology University

July, 2024

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled " **Fabrication and Testing of Polymer Matrix Composite Reinforced with Pineapple Fiber and Cardamom Husk**" is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Tigist Girma

Name of student

Signature

Date

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have closely advised the student while developing this thesis entitled " **Fabrication and Testing of Polymer Matrix Composite Reinforced with Pineapple Fiber and Cardamom Husk**" prepared under my guidance by Tigist Girma Shoa. Therefore, I recommend the submission of revised version of the thesis to the department for further review and evaluation.

Dr. Moera Guta Jiru

Major Advisor/Supervisor

Signature

Date

APPROVAL

I, the advisors of this thesis entitled " **Fabrication and Testing of Polymer Matrix Composite Reinforced with Pineapple Fiber and Cardamom Husk**" and developed by Tigist Girma Shoa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated in to the final version of the thesis.

Dr. Moera Gutu Jiru

Major Advisor/Supervisor

Signature

Date

We, the undersigned, members of the Board of Reviewers of the thesis by Tigist Girma Shoa have read and evaluated the thesis entitled "Fabrication and Testing of Polymer Matrix Composite Reinforced with Pineapple Fiber and Cardamom Husk" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of science in manufacturing engineering.

Chairperson

Signature

Date

Internal Examiner

Signature

Date

External Examiner

Signature

Date

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

Department Head

Signature

Date

School Dean

Signature

Date

Office of Postgraduate Studies, Dean

Signature

Date

ACKNOWLEDGMENT

First and for most, Glory to the almighty God, for protecting, yielding strength and courage me to complete my study. Next, I would like to express my special appreciation and gratefulness to my advisor Dr. Moera Gutu Jiru for his continued help, guidance, and support throughout this thesis. His continuous support was a source of motivation for me to undertake this research. I am grateful to the head of the Mechanical Engineering department and the lab assistance of the Material Engineering department for facilitating and providing equipment during the experimental procedures. Above all, I am indebted to my family for their unwavering support, prayers, and sacrifices that have helped me grow and prepare for the future. Without their assistance, this achievement would have been difficult to attain. Lastly, my sincere thanks go to all those who have contributed to the completion of this thesis work.

Table of Contents

DECLARATION	i
RECOMMENDATION	ii
APPROVAL	iii
ACKNOWLEDGMENT.....	iv
LIST OF TABLES	ix
LIST OF FIGURES	xi
NOMENCLATURE	xiv
LIST OF ACRONYMS AND ABBREVIATIONS	xvi
<i>ABSTRACT</i>	xvii
CHAPTER ONE	1
INTRODUCTION	1
1.1 Back Ground of Study.....	1
1.1.1 Pineapple	2
1.1.2 Cardamom (Korarima)	3
1.2 Types of Composite Materials	4
1.2.1 Classification of composites based on the matrix material.	4
1.2.2 Classification of composites based on the reinforcement.	6
1.3 Statement of Problem	8
1.4 Objectives of the Study	8
1.4.1 General objectives	8
1.4.2 Specific objectives	8
1.5 Scope of the Study.....	9
1.6 Significant of the Study.....	9
1.7 Expected Outcome of the Study	9
1.8 Organization of the Thesis	10
CHAPTER TWO	11
LITERATURE REVIEW	11
2.1 Introduction	11
2.2 Fiber	11
2.3. Natural Fiber	11

2.3.1 Types of natural fiber	12
2.3.2. Properties of natural fiber	12
2.3.3 Chemical composition of natural fiber	13
2.3.4 Chemical treatment of natural fiber.....	14
2.3.5. Extraction method of natural fiber.....	15
2.4. Fabrication Method of Natural Fiber Composite	15
2.4.1. Hand layup.....	17
2.4.2. Spray layup	17
2.4.3 Compression molding.....	18
2.4.4. Injection molding.....	18
2.5. Related Works on Natural Fiber Polymer Composites.	19
2.6 Taguchi Optimization Based Grey Relational Analysis	24
2.7. Summary of Literatures.....	27
2.8. Research Gaps	28
CHAPTER THREE	29
MATERIALS AND METHODS.....	29
3.1 Introduction	29
3.2 Materials.....	29
3.2.1 Pineapple leaf fiber	29
3.2.2 Cardamom husk.....	30
3.2.3 Polyester resin.....	31
3.2.4 Hardener (Catalyst).....	32
3.2.5 Sodium Hydroxide (NaOH).....	32
3.2.6 Distilled water.....	32
3.2.7 Mold.....	33
3.2.8 Mold release	33
3.3. Process Parameter	34
3.3.1 Design of experiment.....	34
3.3.2 Fiber, particle, and matrix mass fraction	35
3.3.3 Calculation of mass of fiber, particulate and matrix for each sample	36
3.4 Preparation of Specimen	38

3.4.1. Extraction process of PALF	38
3.4.2. Alkaline treatment of PALF	39
3.4.3. Fiber orientation	39
3.4.4. Preparation of cardamom husk	41
3.4.5. Alkaline treatment of cardamom husk.....	41
3.4.6. Preparation of cardamom husk filler	41
3.5. Sample Preparation Method	43
3.6. Equipment's and Machine Used	46
3.6.1 High energy mixer/mill	46
3.6.2 Analytical (digital) balance	47
3.6.3. 200 Mesh size testing sieves.....	47
3.6.4 Universal testing machine (UTM).....	48
3.6.5 Hardness testing machine	49
3.6.6 Pendulum impact testing machine.....	50
3.6.7 SEM testing machine.....	50
3.7 Characterization of Composites	51
3.7.1 Tensile strength test.....	51
3.7.2 Compression strength test.....	52
3.7.3 Flexural strength test	52
3.7.4 Impact strength test.....	54
3.7.5 Vickers hardness test	54
3.7.6 Density and void fraction	54
3.7.7 Water absorption.....	55
CHAPTER FOUR.....	57
RESULTS AND DISCUSSION	57
4.1 INTRODUCTION.....	57
4.2 Tensile Test	57
4.3 Flexural Test.....	61
4.4 Compression Test.....	65
4.5 Impact Test.....	69
4.6 Hardness Test	73

4.7 Water Absorption Test	78
4.8 Density and Void fraction	82
4.9 Grey Relational Analysis of Mechanical and Physical properties	86
4.10 Morphological Analysis	92
4.11 Comparison of Existing Interior Door Panel.....	92
4.12 Comparison with Previous Work	93
CHAPTER FIVE	94
CONCLUSION AND RECOMMENDATIONS	94
5.1 Conclusion.....	94
5.2 Recommendations	95
5.3 Future Work	95
REFERENCES	97
Appendix A.....	106
Appendix B.....	108
Appendix C	111

LIST OF TABLES

Table 2.1 Advantage and disadvantage of natural fibers and NFRC (Balla <i>et al.</i> , 2019).....	13
Table 2.2 Types of fabrication method	16
Table 2.3 Summary of literatures.....	27
Table 3.1 Physical composition of PALF (Asim <i>et al.</i> , 2015).....	30
Table 3.2 Chemical composition of PALF (Potluri, 2019).....	30
Table 3.3 Mechanical properties of polyester (M <i>et al.</i> , 2015).....	31
Table 3.4 Experimental design factors and levels	35
Table 3.5 L9 Orthogonal array.....	35
Table 3.6 Composition of polyester, pineapple fiber and cardamom filler	38
Table 4.1 Tensile strength test result	57
Table 4.2 Response table for S/N ratio of tensile strength	60
Table 4.3 ANOVA table for tensile strength	61
Table 4.4 Flexural strength test result.....	61
Table 4.5 Response table for S/N ratio of flexural strength	64
Table 4.6 ANOVA table for flexural strength	65
Table 4.7 Compression test result.....	66
Table 4.8 Response table for S/N ratio of compression strength.....	68
Table 4.9 ANOVA table for compression strength	69
Table 4.10 Impact energy result.....	70
Table 4.11 Response table for S/N ratio of impact energy	72
Table 4.12 ANOVA table foe impact energy	73
Table 4.13 Hardness test result	74
Table 4. 14 Response table for S/N ratio of hardness.....	77
Table 4.15 ANOVA table for hardness.....	77
Table 4.16 Weight of the sample before immersion.....	78
Table 4.17 Water absorption result and S/N ratios	78
Table 4.18 Response table for S/N ratio of water absorption rate	81
Table 4.19 ANOVA table for water absorption rate.....	82
Table 4.20 Weight of sample in the air and in the water	82
Table 4.21 Theoretical density, measured density, and void fraction of the composites.	83

Table 4.22 Response table for S/N ratio of void content.....	86
Table 4.23 ANOVA table for void content.....	86
Table 4.24 Summary of experimental results	87
Table 4.25 S/N ratios result	88
Table 4.26 Normalizing sequence result.....	88
Table 4.27 Deviation sequence result	89
Table 4.28 Grey relational coefficients and Grey relational grade	90
Table 4.29 Response table for S/N ratios of GRG.....	91
Table 4.30 ANOVA table for GRG	91
Table 4.31 Door panel strength of different car manufacturers.....	92
Table 4.32 Effect of different processing factors on pineapple fiber reinforced composite.....	93

LIST OF FIGURES

Figure 1.1 Pineapple plant (Todkar & Patil, 2019).....	3
Figure 1.2 Cardamom plant (Pomy, 2023)	4
Figure 1.3 Types of composites	5
Figure 1.4 Particle reinforced	6
Figure 1.5 Fiber reinforced	7
Figure 1.6 (a) Laminar composites and (b) Sandwich composites	7
Figure 2.1 Classification of fiber	11
Figure 2.3 Hand layup method.....	17
Figure 2.4 Spray layup	17
Figure 2.5 Compression molding.....	18
Figure 2.6 Injection molding.....	19
Figure 3.1 Pineapple plant field	29
Figure 3.2 Cardamom husk.....	30
Figure 3.3 Polyester resin on weight balance	31
Figure 3.4 Sodium hydroxide flakes	32
Figure 3.5 Distilled water	33
Figure 3.6 Honey wax.....	33
Figure 3.7 (a) Pineapple leaf and (b) Extracted pineapple leaf fiber	38
Figure 3.8 (a) NaOH soaking of pineapple fiber and (b) NaOH treated pineapple fiber and dried	39
Figure 3.9 a) Specimen at 0° (b) Specimen at 90° and (c) Specimen at $22.5^\circ/-22.5^\circ$ d) Specimen at $67.5^\circ/-67.5^\circ$ e) Specimen at $45^\circ/-45^\circ$ (Sharan Gupta <i>et al.</i> , 2021).	40
Figure 3.10 Bidirectional oriented-pineapple fiber a) 0/90 oriented b)0/45 oriented c) 90/45 oriented	40
Figure 3.11 (a) Extracted cardamom husk and (b) Slightly crushed CH.....	41
Figure 3.12 Treated cardamom husk	41
Figure 3.13 Milled cardamom husk	42
Figure 3.14 Flow diagram of composite sample preparation	43
Figure 3.15 Weight measurement of (a) pineapple fiber, (b) cardamom husk and (c) polyester .	44

Figure 3.16 Mixture of polyester, CH, and hardener	45
Figure 3.17 a) Add mixture on the mold b) Add PALF over the mixture c) pour the mixture over the fiber.....	45
Figure 3.18 Compress and hold by using C-clamp.....	46
Figure 3.19 Fabricated sample	46
Figure 3.20 High energy mixer	47
Figure 3.21 Mass balance	47
Figure 3.22 Sieve	48
Figure 3.23 Universal testing machine	48
Figure 3.24 Hardness testing machine	49
Figure 3.25 Impact testing machine.....	50
Figure 3.26 SEM testing device.....	51
Figure 3.27 Nine sample for flexural test	53
Figure 3.28 (a)Two sample from each composition for water absorption rate and (b) Samples immersed in water	56
Figure 4.1 Tensile strength Vs PALF wt.%.....	58
Figure 4.2Tensile strength Vs CH wt.%	59
Figure 4.3 Tensile strength Vs fiber angle.....	59
Figure 4.4 Main effect plot of tensile strength.....	60
Figure 4.5 Flexural strength Vs PALF wt.%	62
Figure 4.6 Flexural strength Vs CH wt.%.....	63
Figure 4.7 Flexural strength Vs fiber angle	63
Figure 4.8 Main effect plot of flexural strength.....	64
Figure 4.9 Compression strength Vs PALF wt.%.....	66
Figure 4.10 Compression strength Vs CH wt.%.....	67
Figure 4.11 Compression strength Vs fiber angle	67
Figure 4.12 Main effect plot of compression strength.....	68
Figure 4.13 Impact energy Vs PALF wt.%.....	70
Figure 4.14 Impact energy Vs CH wt.%.....	71
Figure 4.15 Impact strength Vs fiber angle	71
Figure 4.16 Main effect plot for S/N ratio of impact energy	72

Figure 4.17 Test result of sample 6.....	74
Figure 4.18 Hardness Vs PALF wt.%.....	75
Figure 4.19 Hardness Vs CH wt.%.....	75
Figure 4.20 Hardness Vs fiber angle.....	76
Figure 4.21 Main effect plot for S/N ratio of hardness.....	76
Figure 4.22 Water absorption Vs PALF wt.%.....	79
Figure 4.23 Water absorption Vs CH wt.%.....	80
Figure 4.24 Water absorption Vs Fiber angle.....	80
Figure 4.25 Main effect plot for S/N ratio of water absorption.....	81
Figure 4.26 Void fraction Vs PALF wt.%.....	84
Figure 4.27 Void fraction Vs CH wt.%.....	84
Figure 4.28 Void fraction Vs fiber angle.....	84
Figure 4.29 main effect plot for S/N ratio of void content.....	85
Figure 4.30 Main effect plots for S/N ratios of GRG.....	90
Figure 4.31 SEM analysis of S2.....	92

NOMENCLATURE

Φ	Distinguishing coefficient
ρ_a	Actual/ measured density of composite
ρ_c	Density of composite
ρ_f	Density of fiber
ρ_m	Density of matrix
ρ_p	Density of particulate
ρ_t	Theoretical density
ρ_w	Density of water
b	Width of the sample
d	Athematic mean of two diagonals
F	Applied force for indentation
L	Number of levels
M_C	Mass of composite
M_F	Fiber mass fraction
M_f	Mass of fiber
M_f	Matrix mass fraction
M_m	Mass of matrix
M_p	Mass of particulate
M_P	Mass of polyester
S/N	Signal to noise ratio

V_v	Void content
$W\%$	Percentage of water absorption
W_a	Weight in the air
W_F	Final weight of sample after immersed
W_f	Weight of fiber
W_i	Initial weight of sample before immersed
W_M	Weight of matrix
W_p	Weight of particulate
$Wt.\%$	Weight percentage
W_w	Weight of the sample in water

LIST OF ACRONYMS AND ABBREVIATIONS

CHP	Corn husk powder
CMC	Ceramic Matrix Composite
DOE	Design of experiment
GRA	Grey relational analysis
GRC	Grey relational coefficient
GRG	Grey relational grade
HV	Vickers hardness number
IM	Impact strength
MMC	Metal Matrix Composite
NFC	Natural Fiber composite
NaOH	Sodium hydroxide
PALF	Pineapple Leaf Fiber
PE	Polyester
PMC	Polymer Matrix Composite
RH	Rice Husk
TS	Tensile strength
TM	Tensile modulus

ABSTRACT

Natural fiber reinforced polymer composites are being developed to meet the growing need for environmentally friendly, low density, rigid, and lightweight products in the automotive, aircraft component, boat hulls, tennis rackets, manufacturing, and construction industries. In Ethiopia, there are numerous fibers containing plants that can be used for the fabrication of valuable items. Natural fibers like kenaf, sisal, bamboo, and pineapple tended to be the main focus. Fiber and matrix are the two components that make up a composite, and each offers several benefits. A small-scale laboratory composite was created in this study utilizing a hand layup approach with polyester serving as the matrix and cardamom husk particles (particle size $\leq 75\mu\text{m}$) and pineapple fiber serving as reinforcing components. The fiber was taken as having a bidirectional orientation (0/90, 0/45, and 90/45) during the specimen preparation process. The weight percentage of the cardamom husk particle (0wt.%, 5wt.%, and 10wt.%) and weight percentage of pineapple fiber (10wt.%, 20wt.% and 30wt.%) were varied to create nine samples. Tensile, flexural, compression, impact strength, hardness, water absorption, void fraction, and morphological analysis were performed to assess the mechanical and physical properties of the composite. A statistical model describing the relation between the mechanical and physical properties of the composite was developed using Taguchi-based grey relational analysis. The highest tensile, flexural, compression, and impact strengths were 54.11MPa, 102.25MPa, 95.84MPa and 16.25J respectively at 20% fiber loading, 5% CH, and 90/45 fiber angle. The maximum hardness was 54.35HV at 20wt.% fiber loading, 10wt.% CH and 0/90 fiber angle. The minimum water absorption rate was 3.12% obtained at 10wt.% fiber loading, 0wt.% CH, and 0/90 fiber angle. Smaller void content of 0.775 was obtained at 10wt.% fiber loading, 5wt.% CH and 0/45 fiber angle. The optimum combination obtained through Taguchi based grey relational analysis was 20 wt.% fiber loading, 5 wt.% CH, and 90/45 fiber angle. The investigation revealed the suitability of bidirectional oriented pineapple fiber as an effective reinforcement in composite materials. The developed composite had good mechanical properties.

Keywords: Composite, Matrix, Reinforcement, Taguchi, Grey relational analysis

CHAPTER ONE

INTRODUCTION

1.1 Back Ground of Study

Most Engineering materials can be classified into one of the three categories metals, ceramics, and polymers. In addition to the three basic categories there are composites. Composite is a material consisting of two or more phase that are processed separately and bonded together to achieve superior properties to those of its constituents. Structure of composite consists of particles or fibers as first phase mixed with second phase called matrix (polymer, metal, or ceramics matrix). Some composite combine high strength with light weight and suited to different application such as aircraft component, car bodies, boat hulls, tennis rackets, and fishing rod (Groover, 2020).

Materials are used in structural and nonstructural, electrical, electrochemical, biological, biomedical, thermal, and other applications to improve human productivity and living conditions. Many automobile industries are using metals to manufacture vehicle frame components due to its availability and simplicity to manufacture. The weight of the material inside the car production sector influences the fuel consumption that is directly associated with the corresponding amount of emission to the ecosystem.

Metal matrix composite, ceramics matrix composite, and polymer matrix composite are classification of composites. Polymer matrix composite (PMC) is composed of different types of organic polymer containing of short or continuous fibers with the variety of reinforcing agents which makes it possible to improve the properties such as fracture toughness, high strength and stiffness. A polymer matrix reinforced with natural fiber contains a good resistance and inter facial bonding between them helps to maintain their mechanical and chemical identities (Sajan & Philip Selvaraj, 2021). PMC are intended to pass loads among fibers of a matrix. Some of the benefits of PMC included their high rigidity, high strength and light weight along the route of their reinforcements (B a *et al.*, 2022).

Natural fibers are classified into animal, mineral, and plant fiber. Plant fiber is the most natural form and widespread natural fibers. Plant fibers are categorized in to bast fibers, fruit/seed fibers,

grass/reed fibers, and leaf fibers. Common types of leaf fibers are sisal, pineapple, banana, and abaca (Benin *et al.*, 2020). Agricultural waste and forestry derived natural fibers reinforced polymer composites are attracting the attention of the researchers, professionals, engineers, and scientists than synthetic fiber reinforced composites. The fibers from the natural sources offer certain advantages over synthetic reinforcement fibers for instance low cost, non-toxicity, comparable strength, small density; also, minimum waste disposal problems. Bio-composite materials which are also known as green composites as the name suggests eco-friendly materials manufactured by a matrix and reinforcement of natural fiber. They can be fully bio – materials or partial bio-materials based on the type of fiber reinforcement and the matrix used. Natural fibers are affordable, degradable, manageable, recyclable, and renewable. The structure and chemical composition of natural fibers are greatly dependent on climatic condition, soil type, and age of plant and the individual characteristics of each plant variety. The major drawback of the natural fibers is their hydrophilic nature. This phenomenon reduces the interfacial bonding between the polymer matrix and fiber which has an impact on mechanical properties. This problem should be solved by treating the fiber, which helps to remove the impurities like pectin, fats and lignin in the fiber, resulting in improvement of the bond between fiber and matrix; also increases mechanical properties of fabricated component (Faruk *et al.*, 2012). In general, natural fiber has most effective and popular materials to develop bio composites due to their excellent cost performance, abundant availability, less weight to strength ratio, low density, biocompatible, non-corrosive, non-toxicity, low carbon emissions and eco-friendly with nature (Saha *et al.*, 2021).

1.1.1 Pineapple

Pineapple is a member of monocotyledons subclass. It is known as Queen of the fruit crops. It is considered as one of the tropical fruits of the world and amongst few monocotyledonous fruits like banana (Todkar & Patil, 2019). Among various natural fibers pineapple leaf fibers are superior mechanical properties because it consists high cellulose content. These fibers are multicellular and lignocellulose. Currently pineapple leaf is a waste product of pineapple production after the fruit has been harvested. The origin of pineapple is in the Amazon Basin of Brazil and Paraguay. Brazil is in the leading position in pineapple cultivation, followed by Thailand and the Philippines, and they supply 52% of the total output to the world. PALF have a ribbon-like structure, consist of a vascular buddle system, and are present in the form of bunches

of fibrous cells. The leaves of the plant, after harvesting, generally remain in the field itself, and sometimes the huge number of leaves creates disposal problems for the farmers. Pineapple plant and its fiber are shown in Figure 1.1.



Figure 1.1 Pineapple plant (Todkar & Patil, 2019)

1.1.2 Cardamom (Korarima)

Korarima, also called Ethiopian cardamom, is native to Ethiopia and well known in every Ethiopian diet. It is mainly grown in southern, south-western and western Ethiopia, and belongs to the family Zingiberaceae, the genus *afmomum*. Korarima was commonly used as an ingredient in berbere, mitmita, awaze and used as traditional medicine (Van *et al.*, 2021). In Ethiopia, there are three major zones where korarima is grown: GamoGofa, Debub Omo, and Kaffa. Korarima seeds, pods, leaves, rhizomes, and flowers are used in Ethiopia as traditional medicine for human and animal ailments caused by unknown agents and are particularly used to treat any part of the animal body upon swelling (Zakir, 2018). Cardamom can have multiple features. One of the most striking features of cardamom is that it contains a considerable amount of valuable natural antioxidants and volatile constituents with multiple bioactivities.

Morphological characteristics are scaly underground rhizomes and leafy stems, growing up to a height of 1-2 m. They are brownish in color, a flask-like shape, 3-6 cm long and 1.5-3 cm in diameter. The dried fruits are commonly sold in markets (Hymete *et al.*, 2006). There are two types of cardamom: black cardamom and green cardamom. Black cardamom has a larger pod that is dark brown and more available in our environment (Noumi *et al.*, 2018). Cardamom husk of the plant is enriched in lignocellulose and other constituents. After extraction of oils, the remaining pod husk will be treated as waste, and it consists of cellulosic and hemicellulose

content. The abundance of lignocelluloses in the cardamom pods makes them useful (Veerakumar *et al.*, 2018). Cardamom husk has very low oil content and rich in crude fibers (31%) (Bhutani & Majumdar, 2017). Figure 1.2 show cardamom plant.



Figure 1.2 Cardamom plant (Pomy, 2023)

1.2 Types of Composite Materials

Composites are commonly classified in to two phases.

Matrix Phase: the primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it (Shaikh *et al.*, 2019).

Reinforcement Phase: the second phase is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase (Shaikh *et al.*, 2019).

1.2.1 Classification of composites based on the matrix material.

Composite material is mainly categorized in to three types based on the matrix type metal matrix composites, polymer matrix composites and ceramic matrix composites, as shown in Figure 1.3 below (Cabanac *et al.*, 2021).

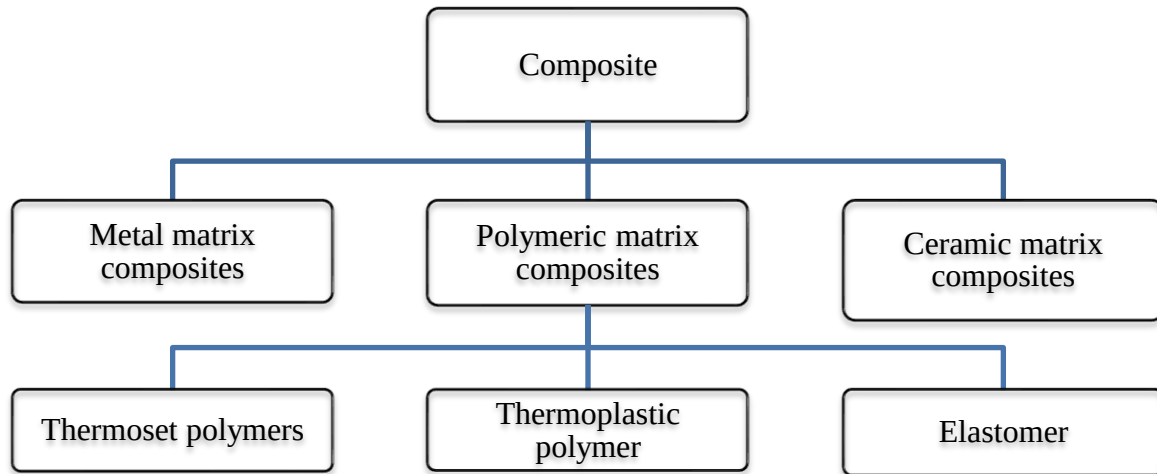


Figure 1.3 Types of composites

Metal Matrix Composites (MMC): Metal matrix composites are widely recognized as advanced materials. MMC are better than conventional materials in terms of enhanced mechanical and thermal properties, including excellent thermal conductivity and strong wear resistance. Currently, common matrix metals are Aluminum, Copper, Iron, Magnesium, Nickel, and Titanium (Sharma *et al.*, 2020).

Ceramic Matrix Composites (CMC): Ceramic matrix composites are a mixture of ceramic particles, fibers, and whiskers in a matrix of another ceramic. The ceramic matrix can be reinforced by ceramics, metals, glasses, and polymers. The ceramic-based matrix materials have exceptional corrosion resistance, high melting points, superior compressive strength, and stability at high temperatures. Ceramic matrices are the common choice for high-temperature applications (Sharma *et al.*, 2020).

Polymer Matrix Composites (PMC): The most commonly used matrix materials consist of polymers (thermosets and thermoplastics) and a variety of continuous and discontinuous reinforcements or fillers that are used to improve the performance of the materials. **Thermoset polymers** are polymers that are cured into a solid form and are unable to return to their unusual uncured form. They have very good fatigue strength. **Thermoplastic polymers** are polymers that can be molded, melted, and remolded without altering their physical properties. In comparison to

thermosets, thermoplastic matrix composites are tougher and less brittle, with excellent impact resistance and damage tolerance. In this study, the experimental investigation of a polymer matrix composite reinforced with pineapple leaf fiber and cardamom husk filler material (Sharma *et al.*, 2020).

1.2.2 Classification of composites based on the reinforcement.

Particle-Reinforced: Particle-reinforced composites use short particulates as reinforcements. It is categorized as either large particulates or dispersion-strengthened composites depending on the average size of the reinforcements, as shown in the Figure 1.4. Dispersion-strengthening composites use nanometer-sized particles, causing the matrix to bear the majority of the load when subjected to mechanical stress (Egbo, 2021).

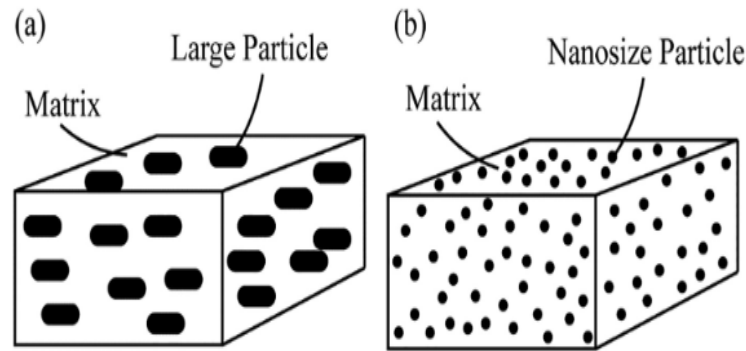


Figure 1.4 Particle reinforced

Fiber Reinforced: Composite consist of fiber in the matrix structure and can be classified according to fiber length, as shown in the Figure 1.5. Composites with long fiber reinforcements are termed as continuous fiber reinforcement composites, while composites with short fiber reinforcements are termed as discontinuous fiber reinforcement composites. Discontinuous fibers must have sufficient length for effective load transfer. Hybrid fiber-reinforced composites are consist two or more types of fiber are reinforced in a single matrix (Rajak *et al.*, 2019).

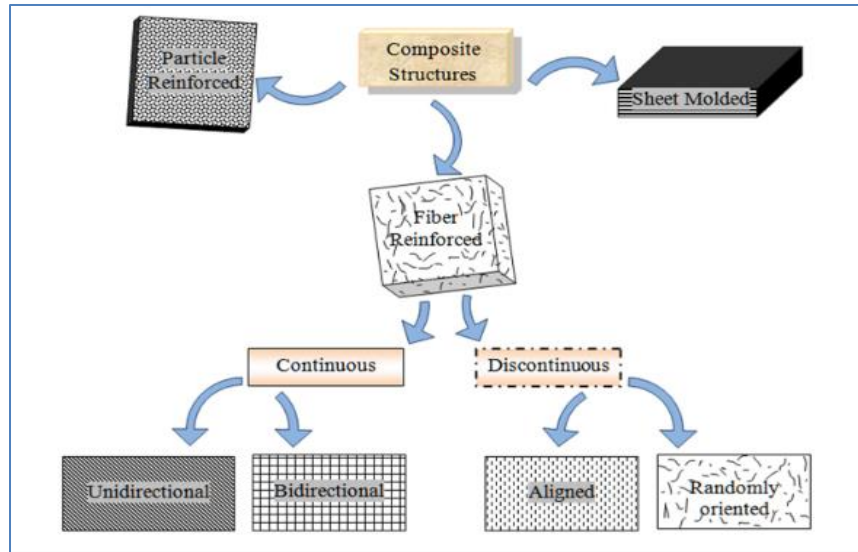


Figure 1.5 Fiber reinforced

Structural Reinforced: structural composites are a system of composites carefully arranged and held together with a homogenous adhesive material. Two main types of structural composites exist laminar composites and sandwich composites, as shown in the Figure 1.6. A laminar composite is made from two dimensional sheets with different preferred high strength directional stalked and laminated by an adhesive. A sandwich panels are made of a high strength exterior and relatively soft core (Egbo, 2021).

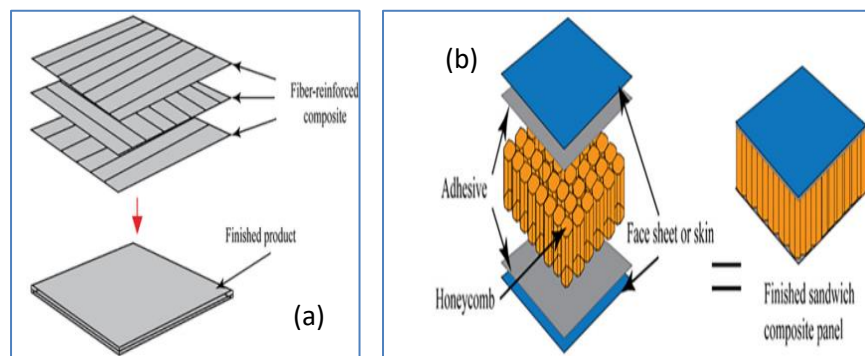


Figure 1.6 (a) Laminar composites and (b) Sandwich composites

1.3 Statement of Problem

In Ethiopia, there are numerous fibers containing plants that can be used for the fabrication of valuable items. Natural fibers like kenaf, sisal, bamboo, and pineapple tended to be the main focus. Natural fibers are abundantly available and are currently considered waste. The major challenge in automobile industry was the weight of the vehicles, which has a direct influence on fuel consumption. A significant rise in the amount of energy used by vehicles is due to the use of more steel, which increases the weight of the vehicle. Automobile fuel consumption and emissions were also issue in the automotive industry. Most of the time, automobile bodies and spare parts have been imported from industrialized nations abroad into developing countries including Ethiopia. These imported materials are heavy, expensive and have an impact on the environment. Nowadays natural fiber composite has been replacing heavy metals and glass fiber composites, which have positive environmental effects after disposal and require less manufacturing costs, in aerospace, automotive, and marine applications due to their beneficial features. Pineapple leaves are the waste product of pineapple cultivation after the pineapple fruit is harvested. The remaining pineapple leaves are burned, but this is not accepted based on health and the environment. Cardamom husk is a waste byproduct and easily available on the local market, but the cardamom seeds are used as spices, in traditional medicine, and to extract essential oils. To address this issue, the present study develops a pineapple leaf fiber and cardamom husk-reinforced polymer matrix composite with unique physical and mechanical properties. This innovative technology also provides a less expensive and lighter-weight polymer composite. and also solve the problem of agricultural wastes being turned into useful products like fiber, fiber board, charcoal, and biofuel.

1.4 Objectives of the Study

1.4.1 General objectives

The general objective of this thesis was mechanical and physical properties evaluation of cardamom husk filled pineapple fiber polyester composite for automotive body application.

1.4.2 Specific objectives

1. To fabricate cardamom husk filled pineapple fiber reinforced polyester composite materials with different weights fraction and fiber orientations.

2. To conduct mechanical test such as tensile, compression, flexural, impact, and hardness test on fabricated composites.
3. To investigate void fraction, water absorption and morphological analysis of composites specimens.
4. To investigate the influence of fabrication process parameters like fiber content, filler content, and fiber orientation on physical and mechanical properties of composites and optimize process parameters using Taguchi and Gray relational analysis method.

1.5 Scope of the Study

In this research, a number of experiments will be expected, such as the fabrication of pineapple fiber and cardamom husk-reinforced polyester composites by varying the weight percentage of the reinforcement. The influence of two fabrication process parameter, pineapple fiber content and cardamom husk content, was evaluated and optimized. It also focused on testing the mechanical properties, physical properties and characterization of composites.

1.6 Significant of the Study

- Utilization of waste natural fiber that reduced environmental impact.
- The effect of pineapple fiber content and cardamom husk content on the composite strength and other properties.
- Options for new production technologies and materials. Generally, natural fibers reinforced polymer composites are appealing for a variety of reasons, including their high specific properties, low density, affordability, biodegradability, and recyclability when compared to synthetic composites product.

1.7 Expected Outcome of the Study

- Mainly concentrates to fabricate light weight and harder pineapple fiber and cardamom husk reinforced polymer matrix.
- Improving the properties and characterization of composite fabricated with different weight ratio of reinforcement.

1.8 Organization of the Thesis

This work is organized into five chapters. The first chapter introduces the thesis background, problem of the statement, objectives, significance, and scope. The second chapter presents a literature review on composite materials and past research activities. The third chapter deals the experimental methods and conditions which include topics like materials, sample preparations, methods, and test setup for the mechanical and physical test of polymer matrix reinforced composite with pineapple fiber and cardamom pods. The fourth chapter addressed experimental test results and discussion. This implies that the result for every response in addition to this the optimization of parameters were include using the Taguchi method and gray relational analyses. The last chapter presents to give conclusions, recommendations, and future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review of natural fiber particularly pineapple fiber reinforced polymer composite material, processing, manufacturing, characteristics, as well as alternative ways of improving natural fiber reinforced polymer mechanical and physical properties using filler. The summary and research gaps of the literature were all covered in this literature review.

2.2 Fiber

Fibers are classified into two main categories: man-made and natural fibers. Natural fibers are produced from crops, whereas man-made fibers are manufactured using chemical manufacturing processes that shown in Figure 2.1 (Treilles *et al.*, 2020).

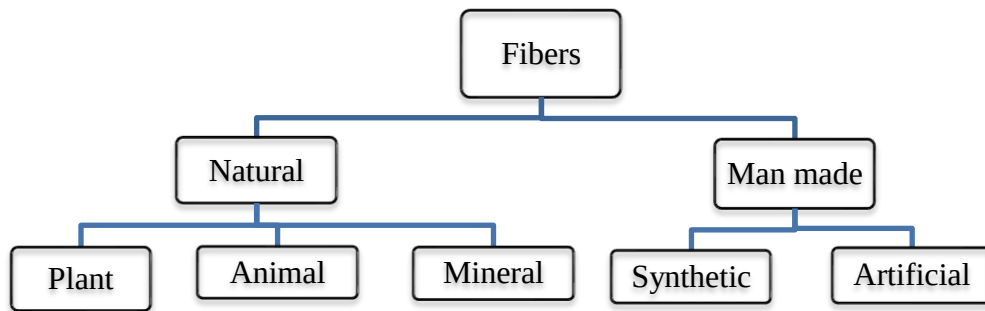


Figure 2.1 Classification of fiber

2.3. Natural Fiber

Natural fibers are the fibers that are obtained from plants, animals or mineral sources. Natural Fiber composites, also referred to as bio composites, offer an alternative to the existing synthetic fiber composites due to their advantages such as abundance in nature, relatively low cost, light weight, high strength-to-weight ratio, and most importantly, their environmental aspects such as biodegradability, renewability, recyclability, and sustainability. It replaced many synthetic fiber-reinforced polymers for building materials, aerospace composite materials, and automotive. Natural fibers can be classified based on their origin shown in the Figure 2.2 (Alhijazi *et al.*, 2020).

2.3.1 Types of natural fiber

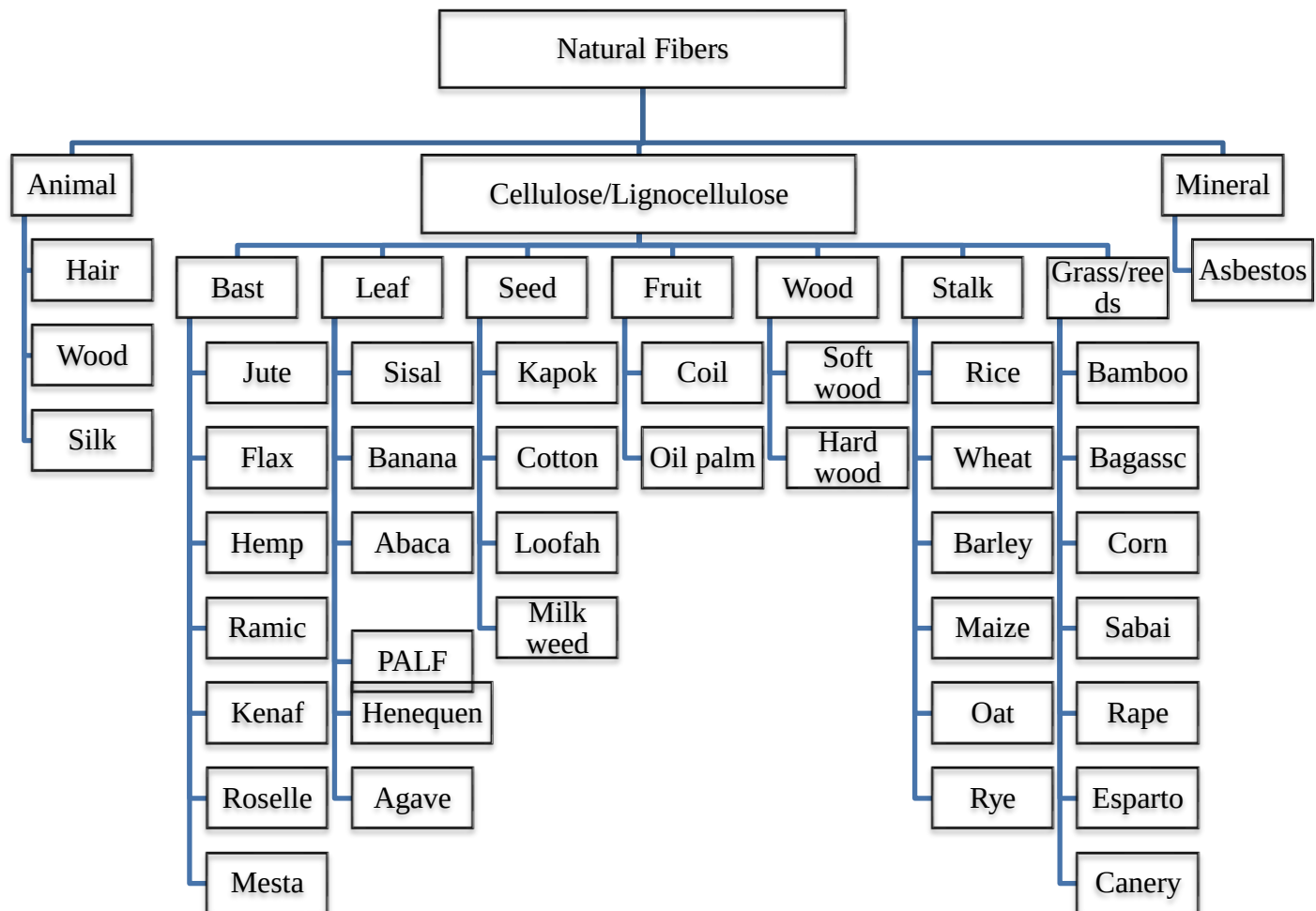


Figure 2.2. Classification of Natural fibers

2.3.2. Properties of natural fiber

The physical and mechanical properties of natural fiber play an important role in determining the properties of their composites (Sahu & Gupta, 2020).

Physical properties: the fiber's physical qualities are its diameter, length, and density. This varies from fiber to fiber (Sahu & Gupta, 2020).

Mechanical properties: superior mechanical properties are desirable when high cellulose content in the reinforcement. Surface modification of natural fibers can increase the cellulose

content while decreasing the hemicellulose and lignin content. Factor affecting mechanical properties of natural fiber composites are listed below (Sahu & Gupta, 2020).

- Fiber treatment
- Fiber orientation and geometry
- Moisture absorption and swelling effect
- Porosity and wettability

Table 2.1 Advantage and disadvantage of natural fibers and NFRC (Balla *et al.*, 2019).

Effect	Advantage	Disadvantage
Physical	Light weight and soft	High moisture absorption leading to swelling.
Mechanical	High specific strength, Excellent thermal insulation	Lower strength than glass fiber composites,
Environmental	Renewable resource and infinite supply	Low durability because of fungal and insect attack

2.3.3 Chemical composition of natural fiber

The main constituents in natural fibers are mainly three polymers such as cellulose, hemicelluloses, amorphous lignin, and moisture. Apart from these constituents, the natural fiber also contains pectin, wax, protein, tannins, inorganic salts, and water-soluble compounds (S. Kumar *et al.*, 2021).

The chemical composition of natural fiber affects the properties of natural fiber-reinforced composites. Cellulose content in natural fiber determines the mechanical properties of that fiber, which in turn affects the properties of a natural fiber-reinforced composite. The amount of hemicellulose and lignin also affects the properties of natural fibers. A large amount of hemicellulose and lignin in natural fiber is not desirable as it leads to high moisture absorption and biodegradation of the fiber. For developing a composite with good mechanical properties, we have to use natural fiber with high cellulose content and low hemicellulose and lignin content (Kerni *et al.*, 2020).

Cellulose: The plant contains cellulose, which is the primary structure of the cell wall. It has a crystalline structure that gives high strength to the plant and a long polymer chain with a high degree of polymerization (S. Kumar *et al.*, 2021).

Hemicelluloses: plants have another cell wall known as hemicellulose. It has a random, unshaped structure that has low strength, a low degree of polymerization, and is highly hydrophilic in nature (S. Kumar *et al.*, 2021).

Lignin: Lignin is a complex aromatic hydrocarbon polymer that imparts rigidity to plants. Without lignin, plants could not attain great heights. Lignin is a three-dimensional polymer with an amorphous structure and a high molecular weight. It serves as a chemical adhesive within and between fibers (Karimah *et al.*, 2021).

2.3.4 Chemical treatment of natural fiber

The natural fiber-reinforced composites have short comings like poor wettability and low fiber/polymer matrix performance, and they also absorb more moisture. The hydrophobic polymer matrix and the fibers interfacial bonding are affected by the presence of cellulose because cellulose is hydrophilic by nature. One method to improve the interaction between the fibers and the polymer matrix is to chemically modify the natural fibers (Sathish *et al.*, 2021). It is necessary to separate the cellulose substance from non-cellulosic materials through various chemical treatments like alkali treatment, mercerization, benzylation, latex coating, gamma irradiation, silane treatment, isocyanate treatment, acetylation, and peroxide treatment to remove hydrophobicity so that the fiber surface can be kept clean, stop moisture absorption, and improve the surface roughness (Madhu *et al.*, 2019).

Alkali treatment: the alkaline treatment is a chemical treatment in which the natural fibers are immersed in a known concentration of aqueous sodium hydroxide (NaOH) for a given temperature and period of time. It increases the density of fiber by removing noncellulosic components, which are less dense. During the alkaline treatment, the fibers are separated from one another, resulting in an increase in the effective surface area available for wetting by the resin (Ouarhim *et al.*, 2018). Among different methods, alkali treatment is considered to be the most cost-effective and efficient strategy, resulting in changes in the fiber surface just as removing amorphous hemicelluloses and lignin does. It is a typical method to clean and adjust

the fiber surface to lower surface strain and improve the interfacial attachment between natural fiber and a polymer matrix (Khalid *et al.*, 2021).

2.3.5. Extraction method of natural fiber

Natural fiber extraction process is extremely important, as it is the key factor in determining the fiber quality, quantity, structure, chemical composition, and physical properties of fiber. Pineapple leaf have waxy coating on the surface of the fiber, extraction of fiber can be done manually or mechanically. Fiber is stripped from the leaf by means of a broken plate or coconut shell during the manual extraction method. The process is known as scratching. After extracting the fiber, it is washed and dried in the open air. The fibers are waxed to remove the entanglements after drying and getting knotted. During the knotting process, each fiber is separated from each other and knotted end to end to form a continuous strand. Good-quality fibers are produced by manual extraction in comparison with mechanical extraction (Jose *et al.*, 2016). Based on different literature there are different types of extraction method for pineapple fiber.

Scrapping: this process is worked out by the preparation of a plate with different shapes. This plate is used for scratching the pineapple leaf on a flat surface to extract fibers. Washout the fiber by use of a clamshell for the removal of remaining gummy substances on the fiber surface and whitening the fiber (Gebino & Muhammed, 2018).

Retting: the leaves were immersed in a water container and kept for 30-35 days to ret. The leaves were not exposed to sunlight, rain, or wind for uniform retting of all leaves. The process is carried out with or without chemical (Gebino & Muhammed, 2018).

Mechanical method: it is the extraction of fiber using a decorticator machine. The shivers are mechanically split up into smaller pieces of fiber bundles (Mohankumar *et al.*, 2021). In a short time, a high amount of fiber is extracted; however, it is expensive and machines are not available.

2.4. Fabrication Method of Natural Fiber Composite

The fabrication process of the natural fiber-reinforced composites refers to the processes of preparing the preforms and then reinforcing the preforms with the polymer matrices. The

fabrication of composite materials uses a wide range of processing processes. Different types of composite fabrication methods can be classified according to the methods of polymer matrix and reinforcement application to the mold. All of these techniques can be broadly classified as open molding or closed molding techniques, as shown in Table 2.2 (Faruque & Bilisik, 2020).

- A) Open molding:** the most common method of making composites is using open molding processes. Due to their simplicity, low processing costs, simple procedures, and availability of suitable reinforcements and laminating systems, they have been frequently used.
- B) Closed molding:** For creating better-quality 3-dimensional composite parts, reducing material waste, and achieving perfect and beautiful finishing of the parts, closed molding processes are chosen. The majority of this molding process is automated, resulting in lower costs for materials, labor, and waste disposal as well as higher production.

Table 2.2 Types of fabrication method

Composite molding	
Open molding	Hand Lay up
	Spray -up
	Filament winding
Closed molding	Pultrusion molding
	Injection molding
	Compression molding
	Resin film infusion
	Vacuum-assisted resin transfer molding
	Resin Transfer Molding
	Vacuum bag molding

2.4.1. Hand layup

Hand layup is the most common and widely used open-mold composite manufacturing process. Initially, fiber preforms are placed in a mold, where a thin layer of antiadhesive coat is applied for easy extraction. The resin material is poured or applied using a brush to a reinforcement material. The roller is used to force the resin into the fabrics to ensure enhanced interaction between the successive layers of reinforcement and the matrix material.

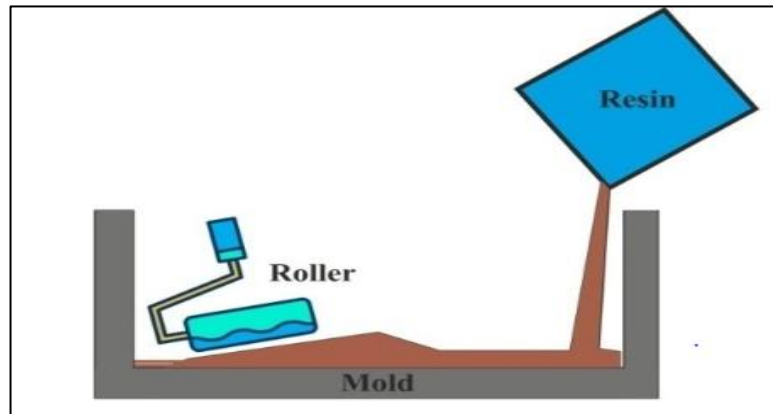


Figure 2.3 Hand layup method

2.4.2. Spray layup

Spray-up techniques are no different than hand layup. However, it uses a handgun that sprays resin and chopped fibers on a mold. Simultaneously, a roller is used to fuse these fibers into the matrix material, as shown in Figure 2.4 (Rajak *et al.*, 2019).

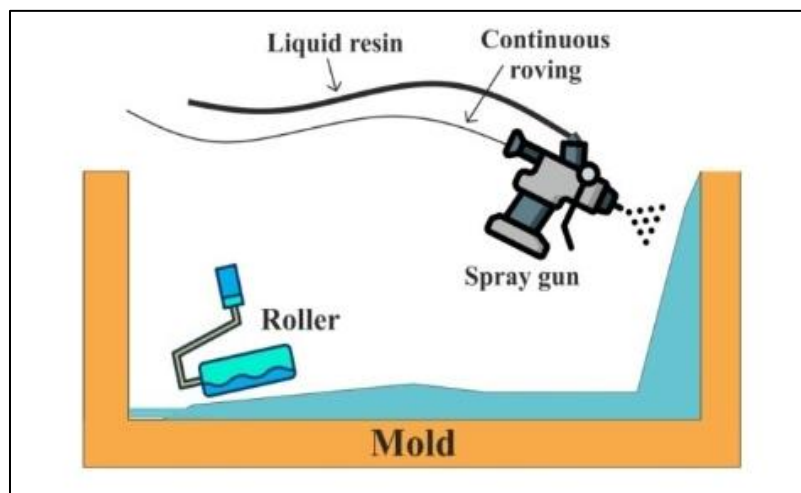


Figure 2.4 Spray layup

2.4.3 Compression molding

Compression molding uses preheated molds mounted on a hydraulic or mechanical press. A prepared reinforcement package from prepreg is placed in between the two halves of the mold, which are then pressed against each other to get the desired shape of the mold. It offers a short cycle time, a high degree of productivity, and automation. With its dimensional stability, it finds diverse applications in the automobile industry, as shown in Figure 2.5 (Rajak *et al.*, 2019).

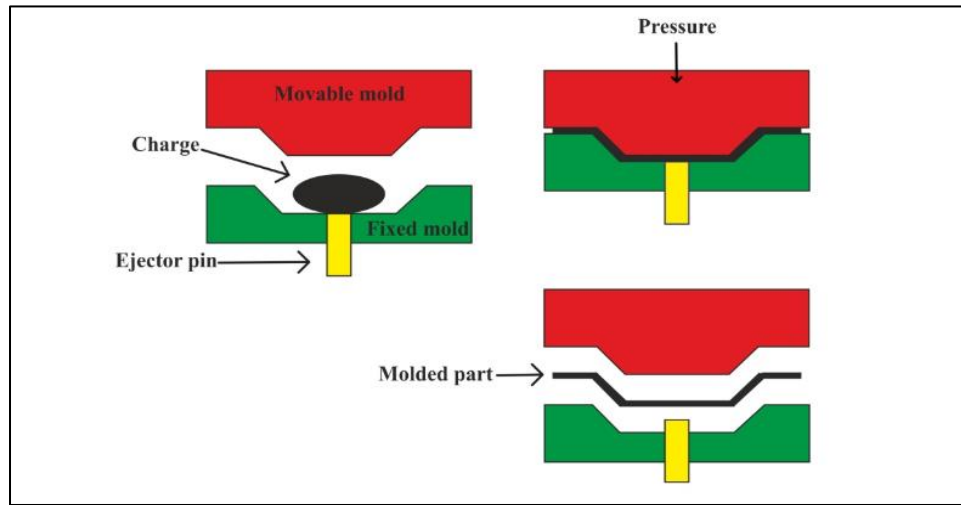


Figure 2.5 Compression molding

2.4.4. Injection molding

Injection molding has the ability to fabricate composite parts with high precision and at very low cycle times. In a typical injection molding process, fiber composites in the form of pellets are fed through a hopper, and then they are conveyed by a screw with a heated barrel. Once the required amount of material is melted in a barrel, the screw injects the material through a nozzle into the mold, where it is cooled and acquires the desired shape. Injection molding has been found to be very effective for the thermoplastic encapsulation of electronic products required in the medical industry, as shown in Figure 2.6 (Rajak *et al.*, 2019).

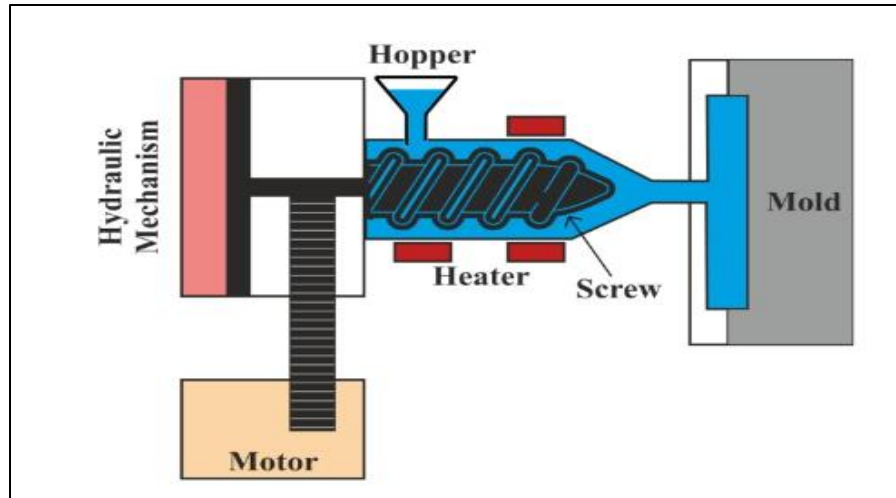


Figure 2.6 Injection molding

2.5. Related Works on Natural Fiber Polymer Composites.

Hossain *et al.*, (2022) Investigated the PALF, which was treated with sodium hydroxide to clean the surface. 10%, 15%, 20%, 25%, and 30% PALF-based epoxy composites were fabricated by hand-layup techniques. The mechanical properties of composites, such as tensile strength (TS), percentage of elongation at break (%Eb), and impact strength (IM), were found to increase with increasing fiber content. The highest TS, %Eb, and IM for a 30% PALF-based epoxy composite were 51.6 MPa, 15.882%, and 14.189 *kg/cm*, respectively, but the tensile modulus (TM) decreased with increasing fiber content.

B A *et al.*, (2022) studied Pineapple leaf fiber with different weight percent, 10%, 20%, 30%, and 40% reinforced polyester resin composites, was fabricated by hand layup process. The effect of pineapple leaf fiber loading in polyester resin composites on tensile, flexural, and water absorption properties was investigated. The highest tensile strength, percentage of elongation, young modulus, and impact strength for a 40% PALF were 62.1 MPa, 4.5%, 2490 MPa, and 41 *kJ/m²*, respectively, but 79 MPa flexural strength and 42 GPa flexural modulus at a 30% PALF.

Saha *et al.*, (2021) Investigated fabrication of PALF fiber and PALF particulates are reinforced with epoxy matrix and effect of particulates on the mechanical properties of the developed composites. The hybrid composite developed by constant weight fraction (30%) PALF and different weight fraction (2.5%, 5%, 7.5%, 10%) of particulate are taken. The result demonstrated that 7.5% of particulates has highest tensile strength and tensile modulus 89.432

MPa and 3.032 GPa respectively and also highest flexural and compressive properties, 103.65 MPa flexural strength, 8.965 GPa flexural modulus, 98.53 MPa compressive strength, and 6.41 GPa compressive modulus are recorded respectively. But highest impact strength recorded (88.63J/m) is due to the addition of 2.5% of PALF particulates.

Praveena *et al.*, (2020) evaluated unidirectional pineapple and banana fiber mats were mixed with polyester resin to create composites of different volume fractions by using hand layup method. Banana/pineapple percent weight fraction is 0/40, 13/26, 26/13, and 40/0. The result indicated that increase in fiber weight fraction of banana fiber has resulted in increase of tensile strength however, further increase in banana fiber has resulted in decrease of tensile strength.

Feng *et al.*, (2020) evaluated the mechanical properties and water absorption of kenaf/PALF-reinforced hybrid composites with various fiber ratios 100:0, 75:25, 50:50, 25:75, and 0:100. The result demonstrated that nonhybrid PALF-based composites had highest mechanical properties compared to hybrid and nonhybrid kenaf-based composites. The tensile and flexural strength of nonhybrid PALF-based composite were 18.85% and 17.86% higher than nonhybrid kenaf-based composites. Kenaf fiber in the hybrid composites was able to improve the resistance against moisture uptake due to lower cellulose.

Ismail *et al.*, (2020) studied the mechanical properties of bi-directional glass fiber and rice husk with epoxy using hand layup method. The weight distribution for rice husk ranged from 5, 10, and 15 wt.% and 25, 20, and 15 wt.% glass fiber in bi-directional orientation. The result show that the best combination is 5 wt.% of RH and 25 wt.% of glass fiber with a tensile strength of 215.42 MPa, a tensile modulus of 1.8 GPa, a flexural strength of 275.51 MPa and, an impact strength of 447.19 J/m. It was indicated that when rice husk exceeds 5 wt.%, the mechanical properties of the composites is decreased.

N. Kumar & Singh, (2020) studied the mechanical properties of bidirectional basalt fiber mat-based epoxy composite. The specimens were prepared by varying fiber orientation of 45°, 60° and 90° by hand layup technique. Mechanical properties such as tensile strength, tensile 14 modulus, flexural strength and flexural modulus, impact strength (Charpy and Izod) as well as micro hardness were evaluated experimentally. The result indicated that maximum mechanical

properties were obtained for 90° fiber orientation; Lower value was obtained for 45° fiber orientation.

Senthilkumar *et al.*, (2019) studied 25%, 35%, and 45% pineapple leaf fiber (PALF)-reinforced polyester (PE) composites fabricated by hand layup using randomly oriented PALF in a PE matrix. The mechanical properties of composites, such as tensile strength (TS), tensile modulus (TM), percentage of elongation, flexural modulus, and compressive strength, were found to increase with increasing fiber content. The highest TS, TM, %Eb, flexural modulus, and compressive strength for a 45% PALF-based polyester composite were 33.13 MPa, 1.553 GPa, 4.11%, 6.379 GPa, and 23.5 MPa, respectively, but 82.97 MPa flexural strength at 35% PALF.

S. Kumar *et al.*, (2019) studied corncob husk filler was used as reinforcement and epoxy resin was used as a matrix, to fabricate composite material specimens with six different percentages of filler by weight variation and investigate the various mechanical properties. Flexural and tensile tests, as well as microstructural analysis with a scanning electron microscope (SEM), were used in this study. According to the experimental findings, corncob husk-reinforced polymer composites could be produced successfully and had better tensile and flexural performances. The maximum values of strength, modulus, and strain at 1mm/min cross speed are found at 7.5 percent filler contents, 12.5 percent filler contents, and 7.5 percent filler contents, respectively. To enhance its mechanical properties, corn fiber was not chemically treated.

Sudarsono *et al.*, (2019) Investigated the mechanical properties of coconut shell and palm fruit particulate polyester composites. The corresponding weight of 95g, 90g, 85g, 80g, 75g, and 70g of polyester resin received additions of reinforcement particles with varying weight fractions (5, 10, 15, 20, 25, and 30,) wt.%. the ultimate tensile strength of the palm fruit particle polyester composite was 62.5 MPa, compared to 70 MPa for the coconut shell particulate polyester composites. While palm fruit particle polyester composite had a higher impact strength of 4.60J, coconut shell particulate polyester composite had a higher impact strength of 4.76J. the hardest particulate polyester composites were made of coconut shell, which had a hardness value of 208 BHN, and palm fruit, which had a hardness value of 182.30 BHN.

Prasad *et al.*, (2019) studied the mechanical properties of banana and jute fiber reinforced polyester composite. Composite samples were fabricated by varying the volume fraction of the

5%, 10%, 15%, 20% and 25% and length of 10mm for both banana and jute fibers. The thickness of the fabricated samples varied from 3mm to 5mm. Tensile and flexural tests were conducted. Results revealed that there was an increase in tensile strength of BFRPC and JFRPC with an increase in fiber volume fraction and the optimum tensile strength was achieved at a fiber volume fraction of 25%. The flexural strength of BFRPC and JFRPC also increases with the increase in fiber volume fraction up to 20% and further increase decrease the flexural strength.

Motaleb *et al.*, (2018) evaluated Pineapple leaf fiber (PALF) reinforced polypropylene (PP) composites were prepared by compression molding. The fiber content varied from 25% to 45% by weight. The mechanical properties of composites with varying fiber content, focusing on tensile strength, modulus, elongation at break, bending strength, and impact strength. The 45 wt.% PALF/PP composite showed the best mechanical properties. The composite treated with 7(w/v) % NaOH showed an increase in tensile strength, modulus, and bending strength, but a decrease in tensile strength due to overexposure to NaOH.

Indra Reddy *et al.*, (2018) Fabricated composites reinforced with pineapple leaf fiber, glass fiber, and jute were fabricated and mixed 1:1:1 with epoxy resin. The fiber content was varied from 0.18 to 0.42 by volume fraction. The tensile and flexural properties of the composites increased with fiber content. As a result, the tensile strength of the composites at maximum fiber content (0.42 volume fraction of fiber) is 71.66 MPa, and the flexural strength of the composites at maximum fiber content is 239.37 MPa. The pineapple leaf fiber, glass fiber, and jute epoxy composites were lightweight and had superior mechanical qualities.

Karthick *et al.*, (2018) evaluated tensile, flexural, impact and hardness tests of banana fiber reinforced epoxy hybrid composites by varying the fiber length and weight percentage. Chopped random banana fiber strand of (5, 10 and 15mm) length was used as filler in polyester matrix. Hybrid banana/glass fiber polyester composite was made through hand layup method. The maximum tensile and impact strength was obtained at 15mm length and 20wt.% fiber loading. For flexural strength and hardness maximum value was obtained at 10mm length and 15wt.% fiber loading. The result showed that, the best mechanical properties were found for composite specimen of 10mm fiber length and 15wt.% of fiber loading.

Omkumar & Selvakumar, (2018) Investigated the influence of corn husk powder on the impact of pineapple leaf fiber-reinforced epoxy composites. Composites were fabricated with three different fiber and powder volume fractions (10:20, 15:15, and 20:70 ratios of PALF/CHP, respectively). The influence of corn husk powder resulted in the impact property of composites being maximized, indicating that composites (20% PALF and 10% CHP) have a maximum tensile strength of 13.39 MPa, a maximum flexural strength of 76.26 MPa, and an impact strength of 1.96 joules.

Huang *et al.*, (2018) Investigated the use of coffee husk filler (CHF) from the coffee industry as reinforcing filler in the preparation of a cost-effective thermoplastic-based composite. The chemical composition and thermal characteristics of the CHF were investigated and compared with those of wood fiber (WF). These composites' processing characteristics, mechanical behavior, water absorption, and thermal performance were studied. According to the experimental findings, increasing the CHF loading in the HDPE matrix increased the composites' modulus and thermal characteristics but decreased their water resistance. This work provides an environmentally-friendly alternative for using waste coffee husk filler produced by the coffee industry as a potential component in polymer composites.

Yahaya *et al.*, (2016) investigated the influence of fiber orientation on mechanical properties of hybrid composites. The tensile strength of kenaf hybrid composite was found to be approximately 20.78% and 4.55% higher for unidirectional and bidirectional composites. It was also found that Charpy impact strength of woven kenaf fiber composite was 19.78% significantly greater and 52% larger than unidirectional and mat kenaf composites.

Mehamud *et al.*, (2016) studied the mechanical properties such as tensile, flexural and impact strength of various Ethiopia banana fiber reinforced epoxy composite. The specimens were prepared with various volume fractions of banana fiber (5%, 10%, 15% and 20%), epoxy matrix (95%, 90%, 85% and 80%) and all the fibers were in 0/900 (unidirectional). The result showed that, banana fiber had very good mechanical property which increases with respect to epoxy content. They concluded that the optimum result of experiment exists at 20% banana and 80% epoxy resin.

Vikas Sahu, (2015) studied sisal and pineapple fibers were mixed in various weight fraction ratios to produce the hybrid composites that were the focus of the study, including 100/0, 70/30, 50/50, 30/70, and 0/100. The total weight percentage of fiber was set at 20 grams. Tests are conducted to measure the tensile and bending strengths of specimens created using the hand layup procedure with fibers arranged in a unidirectional pattern. Based on the test results, the research determines that, when compared to other sisal and pine fiber compositions, a composite formed of 50/50 sisal and pineapple fibers has the best impact strength (47.2 N/mm²). This substance has a stronger tensile and bending strength than sisal fibers while being less dense.

Prabhakar *et al.*, (2015) Investigate the mechanical properties of groundnut shell particulate polyester composites by varying the amount of groundnut shell (5, 10, 15, and 20 wt.%). The result showed that the optimum tensile strength and flexural strength are 79.91 MPa and 3200 MPa, respectively at 15 wt.% of groundnut shell particulates. The highest volume of groundnut shell has the most consistent rate of water absorption. This is due to the higher content of groundnut shell in the composites, which forms agglomeration and makes it difficult to achieve a homogeneous dispersion.

2.6 Taguchi Optimization Based Grey Relational Analysis

Taguchi optimization is a DOE approach for optimizing the experiments with smaller number of trials. Taguchi approach provides an efficient and systematic approach for conducting experiments to determine the optimum setting of design parameters for performance and cost. It uses orthogonal arrays to study a large number of variables using a small number of experiments. However, the Taguchi method only works effectively for optimization of single performance characteristic. For applying Taguchi optimization first select factors and Taguchi orthogonal array next measure the response and analyze the result by using signal-to-noise ratio there are three standard types of S/N ratios depending on the desired performance response (Onyekwere *et al.*, 2021).

$$\text{Smaller the better} = -10 \log \frac{1}{n} \sum_{i=1}^n Y_i^2 \quad (2.1)$$

$$\text{Larger the better} = -10 \log \frac{1}{n} \sum_{i=1}^n \frac{1}{Y_i^2} \quad (2.2)$$

$$\text{Nominal the better} = -10 \log \frac{Y}{S^2 Y} \quad (2.3)$$

Grey relational analysis (GRA) was used for optimizing multi-response. After obtaining the signal to noise ratio from Taguchi use GRA multi-response optimization it has three steps.

Step 1: Normalizing S/N ratio

In the GRA optimization process, the S/N ratio obtained from Taguchi analysis was normalized to the range of 0 to 1. Use the following equation in order to normalize.

$$\text{For Larger the better } X_{ij} = \frac{Y_{ij} - \min Y_{ij}}{\max Y_{ij} - \min Y_{ij}} \quad (2.4)$$

$$\text{For Smaller the better } X_{ij} = \frac{\max Y_{ij} - Y_{ij}}{\max Y_{ij} - \min Y_{ij}} \quad (2.5)$$

Where X_{ij} is normalized S/N ratio, Y_{ij} is S/N ratio obtained from Taguchi analysis. $\min(Y_{ij})$ and $\max(Y_{ij})$ are the minimum and the maximum values of signal-to-noise ratio, respectively.

Step 2: Grey relational coefficients

To obtain gray relational grade, gray relational coefficient was first calculated according to equation 2.2

$$GC_{ij} = \frac{\Delta_{\min} + \phi \Delta_{\max}}{\Delta_{ij} + \phi \Delta_{\max}} \quad (2.6)$$

Where GC_{ij} is the gray relational coefficient, $\Delta_{\min}$ and $\Delta_{\max}$ are the minimum and maximum absolute difference, respectively, which is a deviation from the target value. ϕ is the distinguishing coefficient. The distinguishing coefficient can be used to distinguish the important of each response based on the particular application. ϕ is a constant value between 0.5 and 1. In this case assumed as 0.5 for all responses.

Step 3: Grey relational grade

High value of gray relational grade indicates stronger relational degree between ideal sequence and present sequence. The ideal sequence is the best response. Higher gray grade indicates closer to the optimal response in the process. Grey relational grade is obtained from the relational coefficient according to equation 2.4 (Sumesh & Kanthavel, 2022).

$$GRG = \frac{1}{m} \sum_{i=1}^m GC_{ij} \quad (2.7)$$

Where GRG is the gray relational grade, m is the number of response and GC_{ij} is the grey relational coefficient. Grey relational grade was calculated by factor level and analyzed by ANOVA and optimal parameter settings determined. The best quality characteristic 'larger the better' was used for further analysis. After identifying the optimal process parameter, a confirmation test was conducted to validate the analysis.

2.7. Summary of Literatures

Table 2.3 Summary of literatures

Authors	Title	Their works	Result
Hossain et al. (2022)	Preparation and Characterization of Pineapple Leaf Fiber Reinforced Epoxy Composites	PALF was cleaned with sodium hydroxide, and various epoxy composites were fabricated using hand-layup techniques, with varying percentages of 10%, 15%, 20%, 25%, and 30%.	The study found that composites' mechanical properties, including tensile strength, elongation at break, and impact strength, increased with fiber content, with the highest values observed for 30% PALF-based epoxy composite.
Saha et al. (2021)	Influence of Pineapple Leaf Particulate on Mechanical, Thermal and Biodegradation Characteristics of Pineapple leaf fiber Reinforced polymer composite.	PALF fiber and PALF particulate are reinforced with epoxy matrix with constant weight fraction 30% PALF and different weight fraction 2.5, 5, 7.5, and 10% particulate are taken	The study found that 7.5% of particulates have the highest tensile strength, flexural and compressive properties, with the highest impact strength (88.63J/m) due to the addition of 2.5% PALF particulates.
B A et al. (2022)	Physical and Mechanical Properties, Morphological Behavior of Pineapple Leaf Fiber Reinforced Polyester Resin Composites.	Pineapple leaf fiber with different weight percent's, 10%, 20%, 30%, and 40% reinforced polyester resin composites, examining its impact on tensile, flexural, and water absorption properties.	The study found that a 40% PALF material exhibited the highest tensile strength, elongation percentage, young modulus, and impact strength, while a 30% PALF material had a flexural strength of 79 MPa.

2.8. Research Gaps

Based on the literature, several scholars investigate and characterized natural fiber and husk filler polymer composites. In this study, adding cardamom husk as a filler to the pineapple leaf fibers improve their mechanical and physical properties, enabling a wider range of applications. Several researchers have carried out experimental investigation on pineapple fiber reinforced polymer composite. However, no experimental study is carried out on cardamom husk filled pineapple fiber reinforced polymer composite through hybrid Taguchi and GRA yet. Various researchers optimized some parameters of pineapple fiber reinforced composites; however, they are not able to eliminate the limitation of the Taguchi method which is optimization of single response at a time. But this research had overcome this limitation by making optimization of multi responses through hybrid Taguchi and grey relational analyses. In order to attain superior mechanical and physical properties, variable weight percentages of cardamom and pineapple leaf fiber are used with different fiber orientation. Both of these plants are commonly available and wasteful in our environment. Hybridization of one type of fiber with another type of natural fiber results in better physical, chemical, thermal and mechanical property compared to single fiber-reinforced composites. By using cardamom and pineapple leaf fiber as reinforcement, lighter and stronger composites are produced.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, materials and experimental methodologies are utilized to provide the necessary output. The range of the variable parameter and orientation were determined before the materials were processed, which was then used as input to create the design point. In addition to this, the equipment and machines used to conduct mechanical tests, physical tests, and morphological analysis were presented.

3.2 Materials

In this part, materials are listed according to how they are applied for the preparation of composites: these are the materials that are utilized directly and the materials that require additional processing.

3.2.1 Pineapple leaf fiber

Pineapple leaf fiber is one kind of fiber derived from plants (vegetable fiber), which is derived from the leaves of the pineapple plant. Pineapple, which also has another name, that Comosus Ananas (Gebino & Muhammed, 2018). In this study, among various natural fibers pineapple leaf fibers are superior mechanical properties because it consists high cellulose content. the pineapple leaves were harvested manually from Wolayta city. The fiber was extracted using the manual method. The pineapple plant field shown in Figure 3.1. Then the fiber was treated with 5% NaOH to improve the physical, chemical, and mechanical properties of fiber. Again, it was washed with distilled water to neutralize the chemicals and dried in the air for three days.



Figure 3.1 Pineapple plant field

Table 3.1 Physical composition of PALF (Asim *et al.*, 2015)

Fiber Name	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Dia. (μm)
PALF	1.44	413-1627	34.5-82.5	1.6	20-80

Table 3.2 Chemical composition of PALF (Potluri, 2019)

Fiber Name	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Ash (%)	Wax (%)
PALF	67.1-82	9.45-18.8	4.4-15.4	1.2-3	0.9-2.7	3.2- 4.2

3.2.2 Cardamom husk

Ethiopian cardamom, or false cardamom, is obtained from the plant's seed (usually dried) and is extensively used in Ethiopian cuisine (Zakir, 2018). In this study, cardamom husk was selected and used as filler because it enriched in lignocellulose, crude fiber around 31% and other constituents. So, the use of cardamom husk as filler in composites promotes environmental protection and waste management. It contains 24.83% cellulose, 10.41% hemicellulose, 19.23% lignin, and 1.50% ash (Rahmawati *et al.*, 2022). CHF was treated with NaOH to remove a certain amount of lignin, wax, and, oil covering. Then the treated filler was dried in sunlight for three days. Next, it was milled and sieved at 200 mesh ($75\mu m$) to get a fine powder of CH. So, the use of cardamom husk as filler in composites promotes environmental protection and waste management, shown in the Figure 3.2.



Figure 3.2 Cardamom husk

3.2.3 Polyester resin

Polyester resin is the most widely used resin for producing industrial and commercial fiber-reinforced polymer composites. It has several advantages due to their good insulators, rapid curing, and the fact that they do not conduct heat or electricity, provided that they have low void ratios and also relatively low prices (Camlibel, 2018). The GP resin 1003 brand of polyester resin shown in the Figure 3.3, which was purchased from a local market in Addis Abeba, Ethiopia, was used as the matrix material in this experiment. Compared to the epoxy matrix, it possesses good properties, is less expensive, and takes less energy to produce. Because of this, it is selected as a matrix material.

Table 3.3 Mechanical properties of polyester (M *et al.*, 2015)

Property	Range
Density (kg/m^3)	1.2-1.5
Young Modulus (GPa)	2-4.5
Tensile Strength (MPa)	40-90
Compressive Strength (MPa)	90-250
Tensile Elongation at break (%)	2
Water Absorption 24h at 20 °C	0.1-0.3



Figure 3.3 Polyester resin on weight balance

3.2.4 Hardener (Catalyst)

The catalyst agent creates a chemical reaction that allows the resin to change from a liquid to a solid state. This transformation is referred to as “curing” or “polymerization.” Methyl Ethyl Ketone Peroxide (MEKP) is the chemical hardener used with polyester resin. In this study the polyester resin to hardener ratio used was 100g polyester to 1.5ghardener. Finally, polyester and hardener are combined and agitated with glass rod for short time.

3.2.5 Sodium Hydroxide (NaOH)

Sodium hydroxide, also known as caustic soda, is an organic compound with the chemical formula NaOH. It is a white solid with a highly caustic metallic base and alkali salt. It is available in pellets, flakes, granules, and as a 50% saturated solution. Sodium hydroxides are soluble in water, ethanol, and methanol and also adsorb moisture and carbon dioxide in the air. As shown in the Figure 3.4 NaOH was purchased from local suppliers under the brand name caustic soda flakes.



Figure 3.4 Sodium hydroxide flakes

3.2.6 Distilled water

Distilled water is neutral water having PH of 7, was used for treating and washing the fiber after treatment. Figure 3.5 shows the distilled water used for modifying the fiber surface.



Figure 3.5 Distilled water

3.2.7 Mold

The mold is made up of metal and it contains the cover frame. the cover and base surfaces of the mold and the walls are coated with mold-release wax and allowed to dry. The function of the cover plate is to cover, compress, and avoid debris from entering the composite parts during the curing time.

3.2.8 Mold release

To stop the molding material from sticking to the mold, chemical release wax is utilized shown in the Figure 3.6. Mold release is essential when disassembling the composite. Several mold releases can be utilized, depending on the mold type and the quality of the finished components. The most popular kind and the one that was used for this thesis work was HONEY WAX 250, which was bought from Addis Ababa, Ethiopia.



Figure 3.6 Honey wax

3.3. Process Parameter

The process parameters are the factors that varied in this process and were selected based on literature reviews. Pineapple leaf fiber, cardamom husk, and fiber orientation were the factors that affect the strength of composite materials. In this experimental investigate, all the process parameters were utilized to investigate the effect of each parameter on the composites and obtain the optimum process parameter from the selected factors. Design variable selection: PALF weight, CHF weight, and fiber orientation was chosen as the factors that could influence the composite's response, which include tensile, flexural, impact, and water absorption. Design variable range: In this instance, use two numerical variables with a range of 10% to 30% for the weight of pineapple fiber. Cardamom husk filler has a weight range of 0% to 10%. Effective water absorption reduction and mechanical strength improvement depend on these variables and their respective ranges. Controlled variable: the main variable that can be controlled in the manufacture of this composite is NaOH of 5% for 24 hours and drying for three days, at room temperature.

3.3.1 Design of experiment

The design of an experiment is a technique for defining and investigating all possible conditions involving variables, multiple factors and parameters in an experiment. To observe the most influential process parameter in the fabrication of pineapple fiber and cardamom filler-reinforced polyester composite, the selected process parameter levels and their values at different levels are shown in Table 3.4. Orthogonal arrays are the best and most common types of Taguchi arrays. There are options for creating Taguchi arrays for the design of experiments, depending on how many times you choose to test each level of each parameter. The selection of a particular orthogonal array was based on the number of levels of various factors. To conduct the experiment, three factors at three levels were selected (Cimbala, 2014). Thus, nine experiments were performed according to Taguchi Design L_9 orthogonal arrays along with Mini Tab software shown in Table 3.5. Nine composites were fabricated with different parameters and different levels.

Table 3.4 Experimental design factors and levels

Factor	Designation	Level 1	Level 2	Level 3
Pineapple fiber	A	10	20	30
Cardamom husk	B	0	5	10
Fiber orientation	C	0/90	0/45	90/45

Table 3.5 L9 Orthogonal array

Expt. No	A	B	C
1	10	0	0/90
2	10	5	0/45
3	10	10	90/45
4	20	0	0/45
5	20	5	90/45
6	20	30	0/90
7	30	10	90/45
8	30	20	0/90
9	30	30	0/45

3.3.2 Fiber, particle, and matrix mass fraction

The weight fractions of the cardamom husk, pineapple fiber, and matrix were expressed as mass fractions to obtain composition during the fabrication of composites. And also, it is easier than volume fractions. The mass of composite matrix and reinforcement were calculated.

Total mass of composite = mass of particulate + mass of fiber + mass of matrix

$$M_C = M_m + M_f + M_p \quad (3.1)$$

$$\text{Fiber mass fraction} = \frac{\text{mass of fiber}}{\text{total mass}} = M_F = \frac{M_f}{M_t}$$

$$\text{Particulate mass fraction} = \frac{\text{mass of particulate}}{\text{total mass}} = M_p = \frac{M_p}{M_t}$$

$$\text{Matrix mass fraction} = \frac{\text{mass of matrix}}{\text{total mass}} = M_M = \frac{M_m}{M_t}$$

$$M_p + M_f + M_m = 1 \quad (3.2)$$

Where, M_F is fiber mass fraction, M_f is mass of fiber, M_t is total mass, M_p is particulate mass fraction, M_p is mass of particulate, M_M is matrix mass fraction M_m is mass of matrix.

3.3.3 Calculation of mass of fiber, particulate and matrix for each sample

The volume of the composites was calculated by multiplying the length, width and thickness of the mold prepared for molding the composite material.

$$\text{Volume of the die} = L \times W \times t \quad (3.3)$$

Where, L is length, W is width, and t is thickness of mold.

Density of pineapple fiber, cardamom husk, and polyester resin:

$$\text{Pineapple fiber} = 1.44 \text{ g/cm}^3$$

$$\text{Cardamom husk} = 1.11 \text{ g/cm}^3$$

$$\text{Polyester resin} = 1.15 \text{ g/cm}^3$$

For sample 1

Polyester resin = 90wt.%

Pineapple fiber = 10wt.%

Cardamom husk = 0wt.%

The density of the composite can be calculated by the rule of law of mixture method and obtained first by adding the volume fraction of the polyester resin, pineapple fiber, and cardamom husk for each sample. Then the mass of polyester, particulates and fiber was calculated and shown in Table 3.6.

$$\frac{M_c}{\rho_c} = \frac{M_{\text{polyester}}}{\rho_{\text{polyester}}} + \frac{M_{\text{pineapple}}}{\rho_{\text{pineapple}}} + \frac{M_{\text{cardamom}}}{\rho_{\text{cardamom}}} \quad (3.4)$$

Where, M_c is mass of composites, ρ_c is density of composite, $M_{\text{polyester}}$ is mass of polyester, $\rho_{\text{polyester}}$ is density of polyester, $M_{\text{pineapple}}$ is mass of pineapple, $\rho_{\text{pineapple}}$ is density of pineapple, M_{cardamom} is mass of cardamom, and ρ_{cardamom} is density of cardamom.

From the equation 3.4 density of composite material can be calculated as follows:

$$\frac{1}{\rho_c} = \frac{0.9}{1.15} + \frac{0.1}{1.44} + \frac{0}{1.11}$$

$$\rho_c = 1.17 \text{ g/cm}^3$$

$$M_c = \rho_c \times V_c \quad (3.5)$$

Where, M_c is mass of composite, ρ_c is density of composite and V_c is volume of composite.

Volume of the die = $L \times W \times t$

$$= 180 \times 150 \times 5 = 135 \text{ cm}^3$$

After calculating the density and volume of the composite, the mass can be obtained by substituting in volume fraction equation.

$$m_c = \rho_c \times V_c$$

$$= 1.17 \text{ g/cm}^3 \times 135 \text{ cm}^3$$

$$= 157.95 \text{ g}$$

To obtain the mass of Cardamom husk, polyester resin and pineapple fiber mass of composite can be multiplied by each weight percentage.

Mass of polyester resin = mass of composite * 0.9

$$= 142.6 \text{ g}$$

Mass of pineapple apple fiber = mass of composite * 0.1 = 15.84 g

Table 3.6 Composition of polyester, pineapple fiber and cardamom filler

Designation	Composition (wt.%)			Mass (g)		
Expt. No	Polyester	PAF	CHF	Polyester	PAF	CHF
S ₁	90	10	0	143	15.84	0
S ₂	85	10	5	135	15.7	7.89
S ₃	80	10	10	127	15.78	15.78
S ₄	80	20	0	32.34	129.38	0
S ₅	75	20	5	122	32.2	8.05
S ₆	70	20	10	113	32.2	16
S ₇	70	30	0	116	49.5	0
S ₈	65	30	5	108	49.47	8.24
S ₉	60	30	10	99	49.41	16.47

3.4 Preparation of Specimen

3.4.1. Extraction process of PALF

The pineapple (AnanasComosus) leaf used in this research was collected from the farmer's fields of the Wolayta zone. Select the manual extraction method to get better-quality fiber than other methods. To remove fibers from the heavy hydrophobic wax coating of the leaves, use manual labor by scraping with a knife and timber. The extracted fibers were washed with water and dried by air for 24 hours to eliminate impurities and to remove moisture.



Figure 3.7 (a) Pineapple leaf and (b) Extracted pineapple leaf fiber

3.4.2. Alkaline treatment of PALF

This process involves removing hemicellulose, lignin, pectin, and fatty components from pineapple leaf fiber for surface modification and enhancing the properties of PALF, such as water absorption, rigidity, and stiffness of the fiber. Chemical treatment is performed by adding 5% by weight of NaOH to an aqueous solution. First, a NaOH aqueous solution is prepared in a beaker by dissolving 5g of NaOH in 100ml of distilled water, which is then properly mixed with the help of a stirrer for 15 to 20 minutes. The fiber was immersed in the alkali solution for 12 hours at room temperature. After that, it is washed with distilled water, which helps in lowering the pH value and maintaining a neutralized value of pH 7. The treated PALF is then exposed to air for three days to dry. This specific chemically treated PALF is utilized to create composites.



Figure 3.8 (a) NaOH soaking of pineapple fiber and (b) NaOH treated pineapple fiber and dried

3.4.3. Fiber orientation

Fiber orientation refers to the optimal structure arrangement of individual fibers in the development and manufacture of advanced composites materials and fiber-reinforced composites. There are four the most common type of orientations in fiber-reinforced composites are unidirectional, bidirectional, random, and multi-directional. By binding the fiber together, the polymer matrix transfers load to the reinforced fiber and shields them from environmental damage. Fibers are often used as continuous reinforcement in unidirectional or bidirectional forms by aligning a large number of them in thin plate shown in Figure 3.9. Unidirectional fiber orientation has maximum stiffness and strength along the fiber direction and minimum properties in a direction perpendicular to fibers, However, a bidirectional fiber orientation has maximum stiffness and strength along every direction (Thakur *et al.*, 2019).

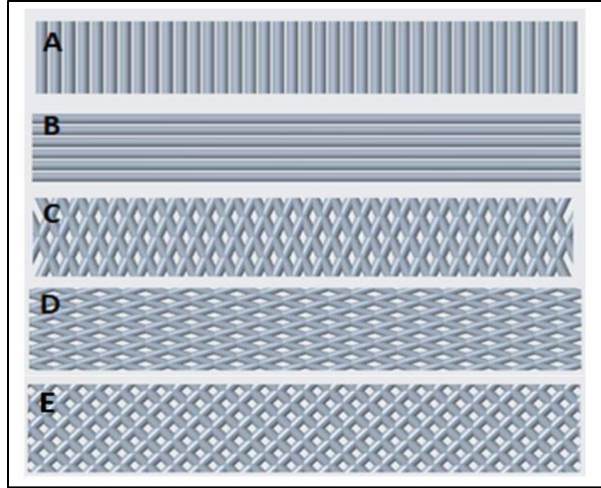


Figure 3.9 a) Specimen at 0° (b) Specimen at 90° and (c) Specimen at 22.5° (d) Specimen at 67.5° (e) Specimen at 45° (Sharan Gupta *et al.*, 2021).

Woven preparation

Woven fabric is any fabric made by interlacing two or more threads at right angles to one another. Woven fabrics can be made of natural fibers, synthetic fibers, or a mixture of both. In this study, after the pineapple fiber treated by NaOH, prepare open square wood and kick nails on all sides, 5mm apart, and tauten the fiber one side to other side. A square has four right angles; each diagonal splits a corner into two angles of 45° . The mat was prepared by twisting the fiber and arranging it crosswise to one another to create a bidirectional layer with (0/90), (0/45), and (90/45) degree orientation for different weights of fiber.

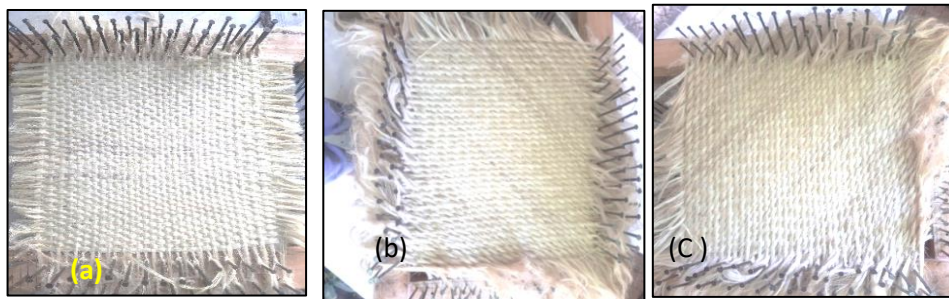


Figure 3.10 Bidirectional oriented-pineapple fiber a) 0/90 oriented b)0/45 oriented c) 90/45 oriented

3.4.4. Preparation of cardamom husk

The cardamom husk used in this research is simply collected from the local market. It is a waste product left over after the seed is used. Cardamom husk is a fibrous material that is produced when cardamom capsules are used for different purposes. The capsules include seed and husk. It has no marketable application and causes environmental risk. This cardamom husk was extracted, slightly crushed, and treated with NaOH before being milled with a grinder and sieved.

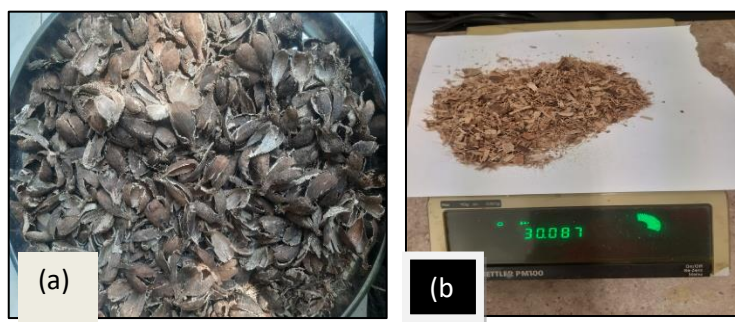


Figure 3.11 (a) Extracted cardamom husk and (b) Slightly crushed CH

3.4.5. Alkaline treatment of cardamom husk

Cardamom husk filler that had been slightly crushed was steeped in a 5-weight-percent NaOH solution for 12 hours. The surplus NaOH was then neutralized by washing the treated fillers in tap water. Following that, the treated cardamom husk filler was dried by air for three days.



Figure 3.12 Treated cardamom husk

3.4.6. Preparation of cardamom husk filler

The 5% NaOH-treated and dried cardamom husk was chopped to the required size using a milling cutter machine that is available in ASTU to make composites at different weights of

pineapple fiber particles and cardamom husk filler. Particulate size decreased while the strength of the reinforced composites increased. Particulate in the size range of 50 to 75 μm has the best particle size distribution. In this research, the treated and dried filler were milled in to 75 μm pieces before being used as reinforcement for the composites (Saha *et al.*, 2021).



Figure 3.13 Milled cardamom husk

3.5. Sample Preparation Method

The materials were selected depending on their availability, economies, and environmental factors. The selected materials, which were available on the market, were purchased, and the fiber was collected from the farm area. also, a bi-directional orientation was selected.

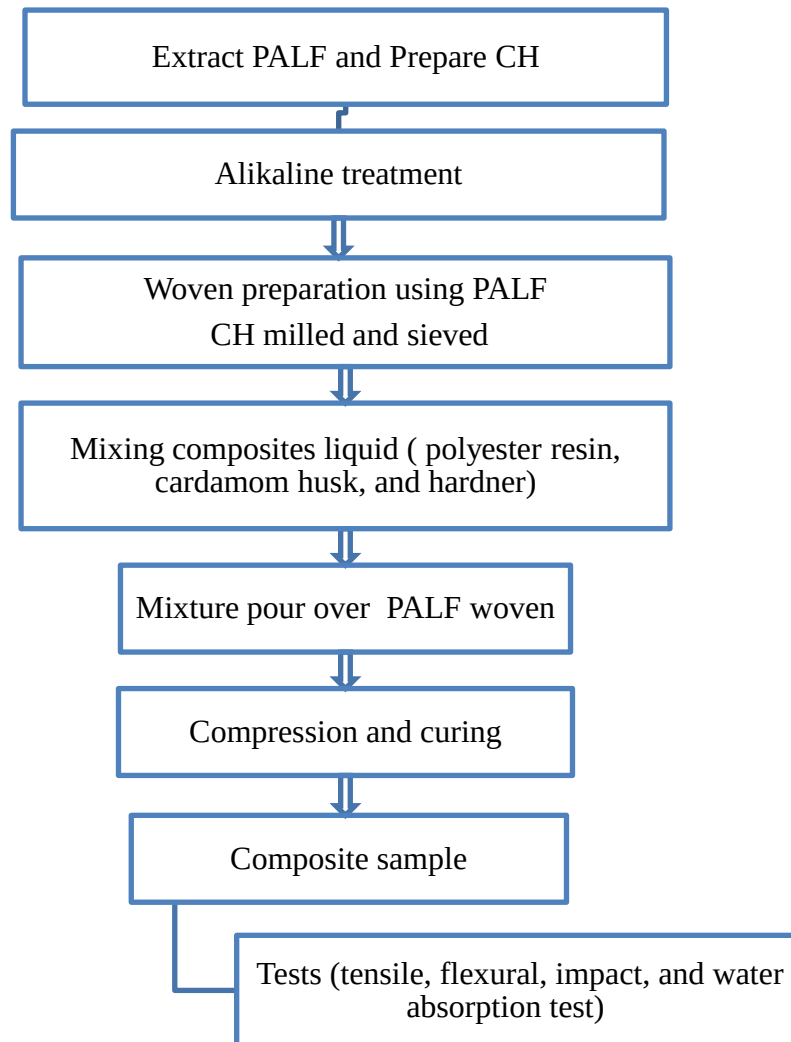


Figure 3.14 Flow diagram of composite sample preparation

Hand layup method

After choosing the suitable thermoset matrix and reinforcement, the fabrication phase is an important step which had influence on quality of the final product. There are various techniques to manufacture composites from those we have used hand layup method to fabricate the samples.

Hand lay-up is the simplest and the most popular open molding method of processing the thermoset based fiber composites. Advantage of hand lay-up are the relatively lower mold costs, the tools required for production are readily available and the mold are easy to maintain. However, hand lay-up is slow and laborious manual process, and therefore results are very subject to the user that is doing the work (Ouarhim *et al.*, 2018).

This process involves the following steps:

The first step was preparing a mold from metal, next coating the mold surface with a releasing anti-adhesive agent to avoid sticking on the surface, then applying the mixture (polyester, hardener and filler) on the mold surface next apply oriented fiber finally pour the mixture on the fiber again.

The following steps were used for fabricating composites: -

- ✓ Step 1. The masses of the pineapple fiber, cardamom husk filler, and polyester resin were measured according to the calculated weight fraction as shown in Figure 3.15.

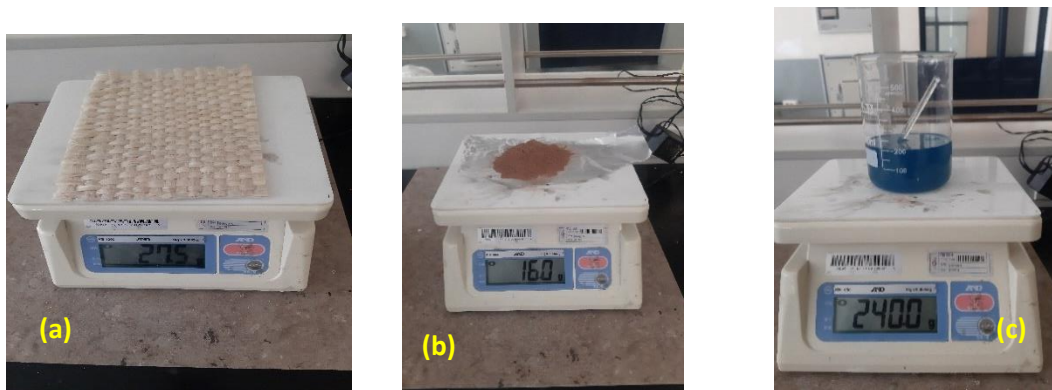


Figure 3.15 Weight measurement of (a) pineapple fiber, (b) cardamom husk and (c) polyester

- ✓ Step 2. The polyester resin and cardamom husk were mixed slowly. Next hardener was added and mixed well for 5 minutes at room temperature continuously and slowly to avoid bubbling during mixing. The mixing was performed in the beaker. Figure 3.16 shown the mixture.



Figure 3.16 Mixture of polyester, CH, and hardener

- ✓ Step 3. The mold 180*150*5 was prepared from metal. Next apply wax on the mold's upper plate surface and the surface of the base material.
- ✓ Step 4. Apply polyester resin, hardener, and cardamom husk filler mixture for each trial on the surface mold. Next add pineapple fiber oriented over the mixture. Next Pour the mixture over the fiber again (Hand layup technique) and paint the mixture by using a roller and brush, shown in the Figure 3.17.



Figure 3.17 a) Add mixture on the mold b) Add PALF over the mixture c) pour the mixture over the fiber.

Step 5. Then mixture of polyester resin, cardamom husk, hardener was placed on the surface of the mold. Next add pineapple fiber oriented over the mixture. Next Pour the mixture over the fiber again (Hand layup technique) and paint the mixture by using a roller and brush to obtain uniform thickness. The process was repeated for each sample of reinforcement and matrix till the required thickness was achieved. Releasing agent coated upper mold was placed on the top surface, and then it was gripped by c-clamp at six corners in order to apply uniform load as we

can see from Figure 3.18. Then it was compressed and hold with a load of 100N for 24 hours to be cured, after curing at room temperature, mold was opened and the fabricated composite was removed from the mold.



Figure 3.18 Compress and hold by using C-clamp

Step 7. The fabricated sample were shown in Figure 3.19, and cut properly according to ASTM standard.



Figure 3.19 Fabricated sample

3.6. Equipment's and Machine Used

The instrument and tools used for characterization of composites material were given as follows:

3.6.1 High energy mixer/mill

The ball milling machine grinds tough or fragile samples in to a fine powder for examination. It uses a grinding vessel with one or more balls that shake ferociously to produce large G-forces.

As shown in Figure 3.20. The device has a timer that can be adjusted up to 100 minutes. This machine is available in Material Engineering Department, ASTU.



Figure 3.20 High energy mixer

3.6.2 Analytical (digital) balance

The digital mass balance is a precision tool that can measure mass with great sensitivity, within range of 0.01 to 0.1 mg. this equipment is essential for accurately characterizing physical properties and measuring the mixing of composites. The material engineering department at ASTU provides this machine, and Figure 3.21 shows the mass balances used in this experiment.



Figure 3.21 Mass balance

3.6.3. 200 Mesh size testing sieves

This sieve is made of stainless-steel wire mesh fabric and a brass frame. The No. 200 mesh is a fine mesh U.S. standard with a nominal sieve aperture of 0.0029". die formed frames offer a

perfect fit, superior quality, and performance, ensuring that the American Society for Testing Materials (ASTM) requirements are always met. It is accessible in the laboratory of the ASTU Department of Material Engineering, as depicted in the Figure 3.22.



Figure 3.22 Sieve

3.6.4 Universal testing machine (UTM)

Universal testing machine used to test the tensile, compression, flexural and shear test for all kinds of material by changing the jaws and modes of operations. Components of UTM are actuator, attachment kit, safety devices frame, engine, gear, screws, crosshead grips extensometer, hardware and software control. The test data can be scored and analyzed. The UTM machine shown in Figure 3.23.

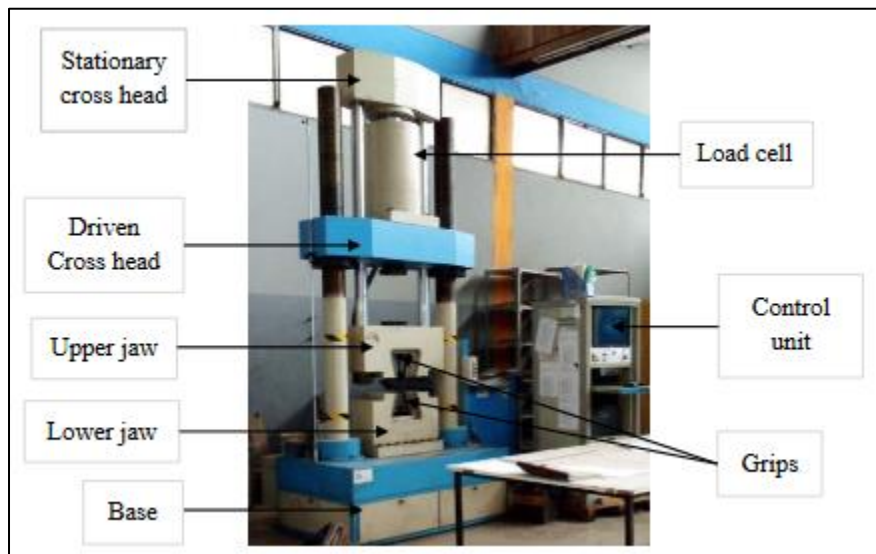


Figure 3.23 Universal testing machine

3.6.5 Hardness testing machine

In order to determine the Vickers hardness of the material, a square-based pyramid diamond indenter with an angle of 136 degrees is used. The HVS-50 machine, features in this thesis and shown in the Figure 3.24, has a measuring range of 5 to 2900 HV and a test force of 9.807, 49.03, 98.07, 196.1, 294.2, and 490.3N. it can accommodate test pieces up to a maximum height of 180 mm, with a throat depth of 125 mm. the machine offers measuring system magnifications of 125X and 250X, and the minimum scale value of the optical micrometer is 0.5m. Equation 3.23 used for this measurement was obtained from the HVS-50 machine manual.

$$\begin{aligned} HV &= \frac{\text{Constant} \times \text{Test force}}{\text{Surface indentation}} \\ &= \frac{0.102 \times 2F(\sin \frac{136^\circ}{2})}{d^2} \end{aligned}$$

Where, HV - Vickers hardness value,

F - Load in kgf

d – Arithmetic mean of the two diagonals $(\frac{d_1+d_2}{2})$, d1 and d2 in mm.



Figure 3.24 Hardness testing machine

3.6.6 Pendulum impact testing machine

The impact strength of a materials is its capability to absorb and release energy during impact or shock loading. Impact testing evaluates a materials resistance to a swinging pendulum strike. The Charpy V-notch test is a standardized high-strain-stress that analyzes how much energy is absorbed by a material during fracture.



Figure 3.25 Impact testing machine

3.6.7 SEM testing machine

SEM is the most widely used technique for visualizing a material morphology and microstructure. A low-energy electron beam is directed at the material and moves across the sample surface. When the beam enters and passes through the materials, a number of distinct interactions take place, which cause photons and electrons to be emitted close to sample surface. Several SEM modes, including X-ray mapping, secondary electron imaging, back scattered electron imaging, electron channeling, and auger electron microscopy, are available for characterization of materials. These models are used to detect the receiving signals created by the electron-sample interactions and form imaging. At the Biology Department of ASTU in Ethiopia, scanning electron microscopy was used to study the morphological analysis of particulate reinforced composites material. Figure 3.26 Shown SEM testing device.



Figure 3.26 SEM testing device

3.7 Characterization of Composites

A sample was prepared based on the dimension requirements of ASTM and ISO standards, and various mechanical and physical properties of the developed composites were tested.

3.7.1 Tensile strength test

Tensile strength is the maximum stress that a material can withstand before breaking when it is allowed to be stretched or pulled. Tensile tests were carried out on universal testing machines with a 20 KN load cell capacity at room temperature. The tensile load was applied along the longitudinal direction of pineapple fiber reinforced polyester with cardamom husk filler. The dimension requirement for tensile strength test was $150 \times 25 \times 5\text{mm}$. Tensile strength and elongation were measured until the samples became fractured or failed completely.

Tensile strength of the sample was calculated by Equation 3.6

$$\sigma_t = \frac{F}{A} \quad (3.6)$$

where, σ_t -Tensile Strength

F - Applied Force

A - Cross-sectional Area

Tensile Modulus of the sample was calculated by Equation 3.7

$$E_t = \frac{\sigma_t}{\epsilon} \quad (3.7)$$

Where, E_t - Tensile Modulus

σ_t - Tensile Stress

ϵ - Tensile Strain

3.7.2 Compression strength test

Compression testing is a method of applying compressive loads to materials without risking buckling. The dimension of the sample was according to ASTM D3410 which is 25mm*25mm*4mm. by measuring the compression and deformation at various load, the compressive stress and strain of the material can be calculated. This type of testing is crucial for understanding how materials behave under crushing stresses.

$$\sigma_c = \frac{F}{A} \quad (3.8)$$

where, σ_c – Compression Stress

F – Force applied

A – Cross-sectional area

3.7.3 Flexural strength test

Flexural strength or bending strength is defined as a materials ability to resist deformation under load. Three rods are presented for loading the two are located in the support region and the other is placed in the center point. The specimen is prepared according to ASTM-D790 standard. The dimension of the sample was 150 * 25 * 5 mm as shown in the Figure 3.27. the test was conducted in Defense university engineering collage, Bishoftu, Ethiopia.

Flexural strength is given by Equation 3.9

$$\sigma_f = \frac{3FS}{2bh^2} \quad (3.9)$$

Where, σ_f - Flexural stress

S – Support span between the two outer points

b- Width of the specimen

h- Height of the specimen

F – Applied Force

Flexural modulus is given by Equation 3.

$$E_{fm} = \frac{s^3 m}{4bt^3}$$

where, E_{fm} - Flexural modulus

S - support span

m -The slope of the load/deflection curve

b - Width of the specimen

t - thickness of the sample

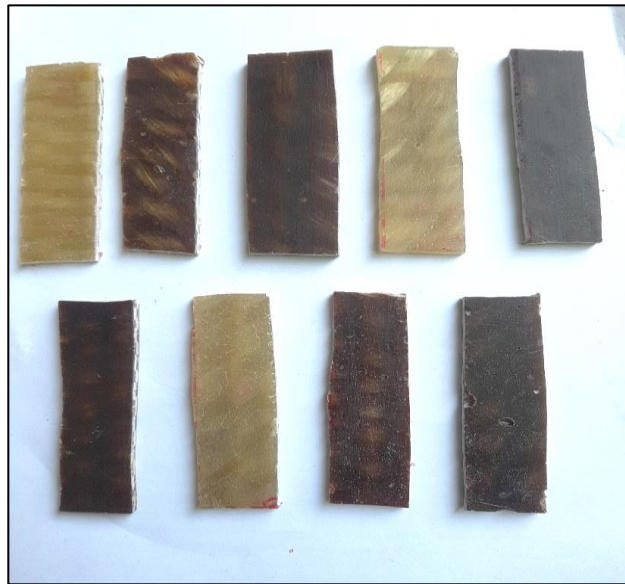


Figure 3.27 Nine sample for flexural test

3.7.4 Impact strength test

The ability of a material to withstand breaking, fracturing, or plastic deformation under sudden loads is known as impact strength. It is an important characteristic that determines whether a material has the ability to withstand sudden forces. A 30-kg weight pendulum will be used to apply impact stresses to the specimen throughout the test until it fractures. The specimen will have a 2.5-mm-deep notch cut into it with the strikers in the opposite direction pointing up, and the impact speed will be 3.8 m/s. According to ASTM D256, the test was carried out on samples with a length of 55 * 10 * (3 – 6)mm. the test was conducted in Bishoftu, Ethiopia, at the Defense University Engineering college.

The energy absorbed by the specimen can be calculated by using Equation 3.10

$$\sigma_i = \frac{E}{t \times b} \quad (3.10)$$

Where, σ_i - impact strength

E -energy absorbed by the material during test

t - thickness

b - width of the specimen

3.7.5 Vickers hardness test

The ability of a material to withstand deformation is implied by its hardness. The hardness of the specimens was measured by Vickers hardness testing machine (HVS-50) with test force of 10kgf and 10 sec of dwelling time. Two distinct indentations were made in the flat surface, and the average of their mean diagonal lengths was computed. The surface-projected diagonal lengths of the resulting impression of each sample were then measured immediately after unloading using an upright optical. One specimen for each sample, and the average value was determined. The experiment was carried out at Material science department, ASTU, Ethiopia.

3.7.6 Density and void fraction

Density is one of the most significant factors in defining the properties of composite material and defined as the mass of the material per unit volume There are different way to measure the actual density of composites. In this work to determine the actual density of the composites Archimedes principles are used. The sample was prepared according to ASTM D570 having 30mm*30mm

dimension. Distilled water is utilized as a medium throughout the measurement process. After that, a sinker was attached to the wire to keep the sample from floating and to make sure it was completely submerged in the water. By measuring the weight of the sample in the air and then again while it is suspended on the wire and submerged in the water, this used to obtain accrete sample density. The actual density of the composites is given by (G. Das & Biswas, 2016).

$$\rho_a = \frac{\rho_w w_a}{w_a - w_w} \quad (3.11)$$

Where, ρ_a – Actual density composite, ρ_w (density of water), w_a (weight of sample in air), w_w (weight of sample in water), ρ_t (Theoretical density of composite). The theoretical density of composite (ρ_t) materials in terms of weight fraction can obtained by the following Equation 3.12.

$$\rho_t = \frac{1}{w_f/\rho_f + w_m/\rho_m + w_p/\rho_p} \quad (3.12)$$

$$W_f = \left(\frac{\frac{\rho_f}{\rho_c}}{\frac{\rho_f}{\rho_c} \times V_f + V_c} \right) \times V_f = \frac{m_f}{m_c} \quad (3.13)$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, p, and m stand for the fiber, particulate and matrix material respectively. The presence of voids will add to the total volume, but not the weight of the composite. (V_v) is the void content which is the expressed as:

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \quad (3.14)$$

3.7.7 Water absorption

The amount of water a material absorbs is computed by dividing the weight of the absorbed water by the weight of the dry material. The water absorption test of pineapple fiber and cardamom husk-reinforced polyester composite was done by immersing the sample in distilled water for eight days at room temperature, as shown in the Figure 3.29. The specimens were weighted before being immersed in water then the specimen is removed from water, cleaned with dry material, and measured at a 24-hour interval by using a precision digital scale to

determine the amount of water absorbed. Using Equation 3.15, the water absorption rate of the sample was calculated (Somaiah Chowdary *et al.*, 2022).

$$W\% = \frac{w_a - w_b}{w_b} \times 100 \quad (3.15)$$

Where, W% is percentage of water absorption, w_b = weight of the sample before soaking in water and w_a = weight of the sample after soaking in water, and absorption coefficients are calculated by using the formula.

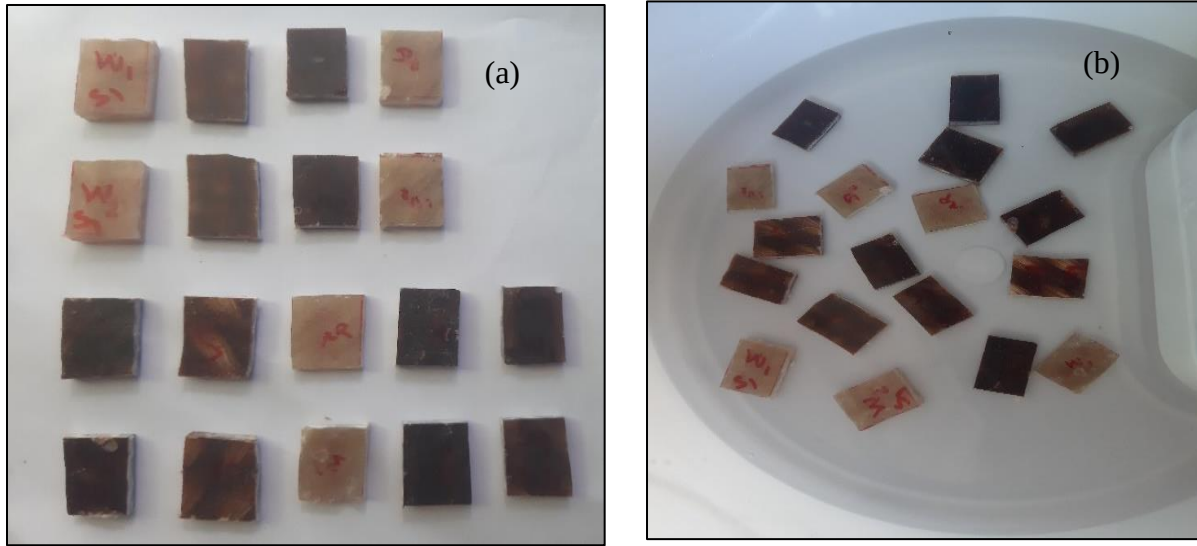


Figure 3.28 (a) Two sample from each composition for water absorption rate and (b) Samples immersed in water

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results of the experimental works were discussed in detail. In different sub class tensile, flexural, compression, impact, hardness, density and void content, water absorption, and SEM analysis test result were discussed. Hybrid Taguchi based grey relational analysis method of optimization was discussed for multiple response optimization.

4.2 Tensile Test

Tensile strength is the maximum stress that a material can withstand before breaking when it is allowed to be stretched or pulled. Cardamom husk-filled pineapple fiber-reinforced polyester composites were fabricated by varying the weight percentage of pineapple fiber and cardamom husk and also by varying fiber orientation with different fiber angles. Nine samples were tested with different combination. Two specimens for each sample and average test result were taken. The tensile strength and S/N ratios were shown in Table 4.1.

Table 4.1 Tensile strength test result

Expt. No	PALF	CH	Fiber angle	Average Tensile strength (MPa)	S/N ratio
1	10	0	0/90	21.4	26.61
2	10	5	0/45	35.95	31.11
3	10	10	90/45	42.3	32.53
4	20	0	0/45	39.5	31.93
5	20	5	90/45	54.11	34.66
6	20	10	0/90	45.96	33.24
7	30	0	90/45	22.3	26.96
8	30	5	0/90	30.35	29.64
9	30	10	0/45	20.4	26.19

Tensile strength test result for nine samples was shown in Table 4.1. Sample 5 has maximum tensile strength of 54.11MPa and sample 9 has minimum tensile strength of 20.4 MPa. Sample 2, sample 4, and sample 8 have medium tensile strength means medium elongation. The tensile strength of the composites increased with the fiber loading, up to 20wt.%. The average tensile strength increased from 33.22MPa to 46.52MPa, as shown in the Figure 4.1 but increasing fiber loading from 20wt.% to 30wt.% reduced the tensile strength from 46.52MPa to 24.35MPa because, at high levels of PALF contents, fibers get agglomerated within the matrix, which produces non-uniform stress transfer capacity and insufficient polyester resin for 30wt.% fiber and additional filler. At 10wt.% fiber content load transfer capacity among fiber is low because of insufficient fiber content to share applied load. This result was in line with (S. C. Das *et al.*, 2018). Addition of cardamom husk also increased the tensile strength of the composite as shown in Figure 4.2. but addition of more cardamom husk in the matrix causes reduction in tensile strength due to filler-filler interaction and insufficient blending of fiber and resin. The result shown that 5wt.% CH enhanced the tensile strength and reached optimum condition due to enhancement of load transfer between the matrix and fiber interface. The result also well agreed with (Kuan *et al.*, 2021). Regarding fiber angle the maximum tensile strength obtained was 54.11MPa at 90/45 fiber angle as shown in Figure 4.3.

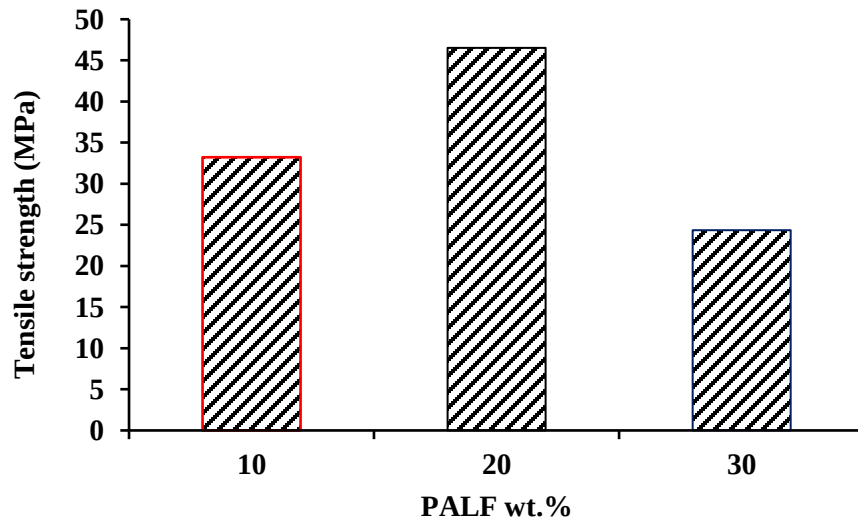


Figure 4.1 Tensile strength Vs PALF wt.%

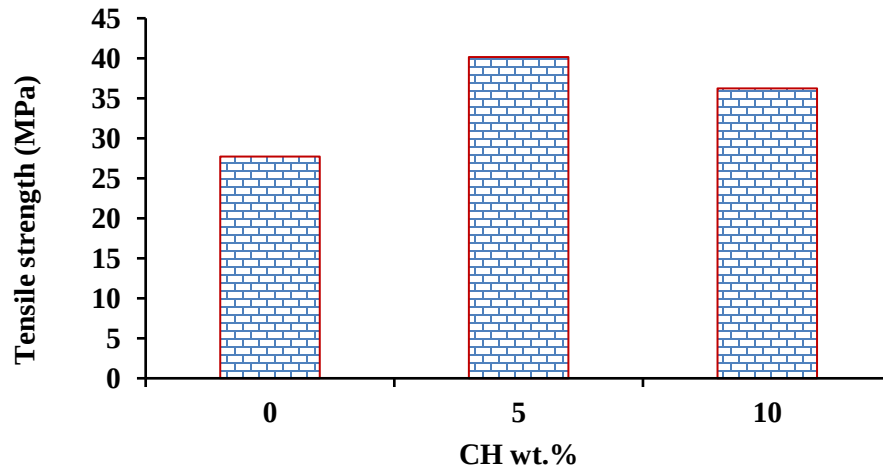


Figure 4.2 Tensile strength Vs CH wt. %

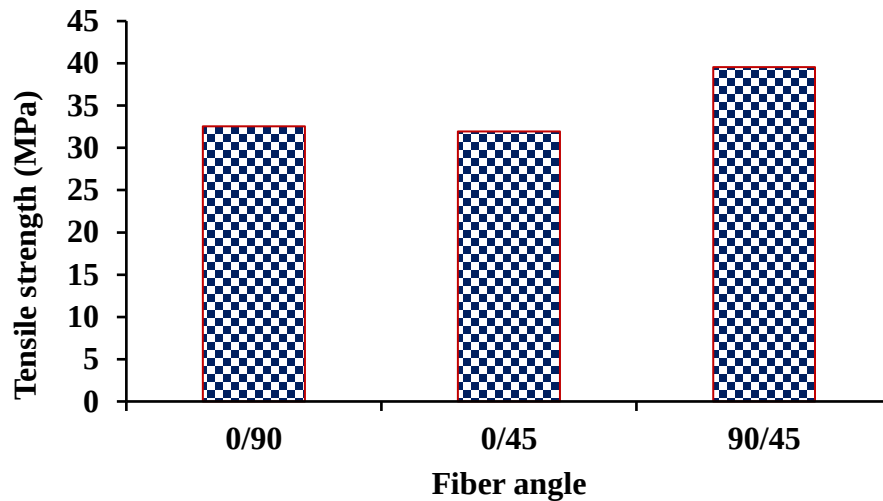


Figure 4.3 Tensile strength Vs fiber angle

Analysis of main effect plot, response table, and ANOVA table for tensile strength

Figure 4.4 shows the main effect plot for S/N ratios of tensile strength. The graph implies that the optimum condition for tensile strength was 20wt.% PALF loading, 5wt.% CH and 90/45 fiber angle orientation. Using these combination better results can be obtained for tensile strength.

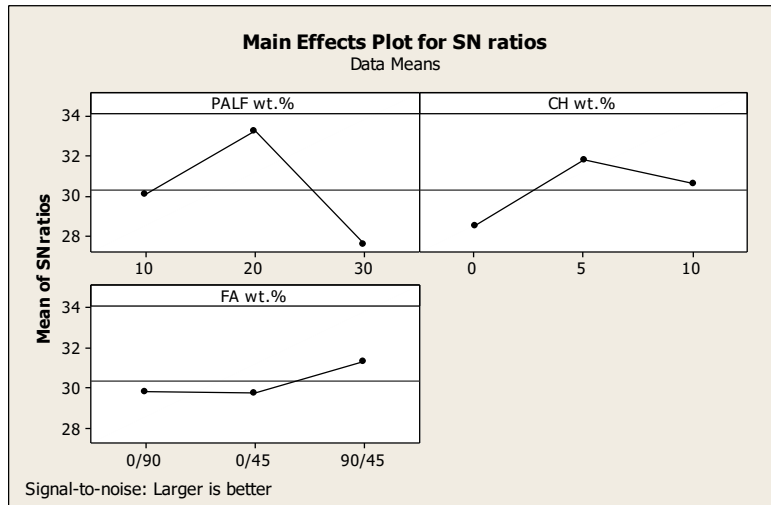


Figure 4.4 Main effect plot of tensile strength

Response table for S/N ratio of tensile strength was shown in Table 4.2 indicates pineapple fiber had the highest effect for the increase in the tensile strength of the composite with delta number of 5.86. whereas cardamom husk filler was the second most contributing factor in increasing the tensile strength with delta value 3.31 and fiber angle ranked third contributing factor with delta value of 1.64.

Table 4.2 Response table for S/N ratio of tensile strength

Level	PALF wt. %	CH wt. %	FA wt. %
1	30.08	28.50	29.83
2	33.28	31.81	29.75
3	27.60	30.66	31.39
Delta	5.68	3.31	1.64
Rank	1	2	3

Table 4.3 ANOVA table for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	747.34	747.34	373.67	17	0.056	65.56%
CH wt. %	2	241.21	241.21	120.60	5.49	0.154	21.16%
FA	2	107.45	107.45	53.72	2.44	0.290	9.43%
Error	2	43.96	43.96	21.98			3.86%
Total	8	1139.96					100%

The ANOVA table for tensile strength was shown in Table 4.3. It shows that pineapple fiber wt.% had the highest effect for the increase in tensile strength with percentage contribution of 65.56%. The second influencing parameter was cardamom husk wt.% with percentage contribution of 21.16%. The third contributed factor was fiber orientation angle with percentage contribution of 9.43%. P-value shows that factor A and B are highly significant and factor C is less significant.

4.3 Flexural Test

Flexural strength is the ability of the material to withstand the bending force applied perpendicular to its longitudinal axis. Average flexural strength test result of different PALF, CH filler loading and fiber orientation were shown in Table 4.4.

Table 4.4 Flexural strength test result

Expt. No	PALF	CH	Fiber angle	Average Flexural strength (MPa)	S/N ratio
1	10	0	0/90	70.25	36.93
2	10	5	0/45	57.25	35.15
3	10	10	90/45	79.75	38.03
4	20	0	0/45	57.25	35.15
5	20	5	90/45	102.25	40.19
6	20	10	0/90	68.5	36.71
7	30	0	90/45	57.25	35.15
8	30	5	0/90	52.75	34.44
9	30	10	0/45	50.5	34.06

The effect of fiber loading on flexural strength was observed in Figure 4.5. The result shows that flexural strength increased with increase in fiber loading. But further fiber addition resulted in reduced of flexural strength because of lower interfacial adhesion of fiber-matrix interface and non-uniform stress transfer due to fibers touching each other within the matrix. The maximum average flexural strength obtained at 10, 20, and 30wt.% was 69.09MPa, 76MPa, and 53.5MPa respectively. This results was well agreed with (Daraloma *et al.*, 2017). The effect of CH filler on the flexural strength of the composite was shown in Figure 4.6. the result shown addition of 5wt.% CH in the matrix enhanced the flexural strength of the composite but further addition of CH reduced the flexural strength due to agglomerate formation at higher concentrations of filler. Regarding the effect of fiber orientation angle on flexural strength the result was shown in the Figure 4.7. The maximum flexural strength 79.75MPa obtained at 90/45 fiber orientation angle. This is due to flexural strength significantly influence by fiber orientation angle. Minimum flexural strength obtained at 0/45 fiber orientation angle was 55MPa this is due to decrease fiber orientation angle from 0/90 to 0/45. The result was well agreed with (N. Kumar & Singh, 2020).

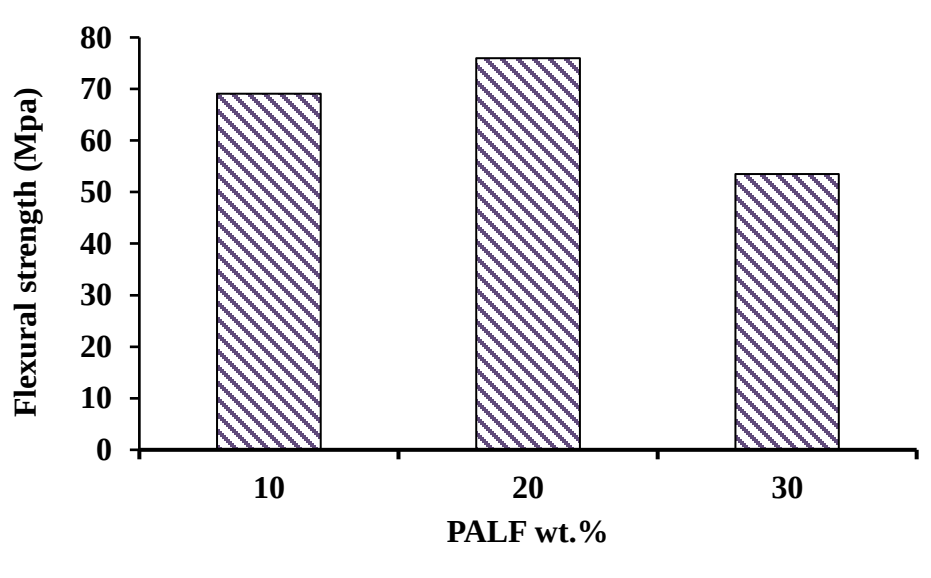


Figure 4.5 Flexural strength Vs PALF wt. %

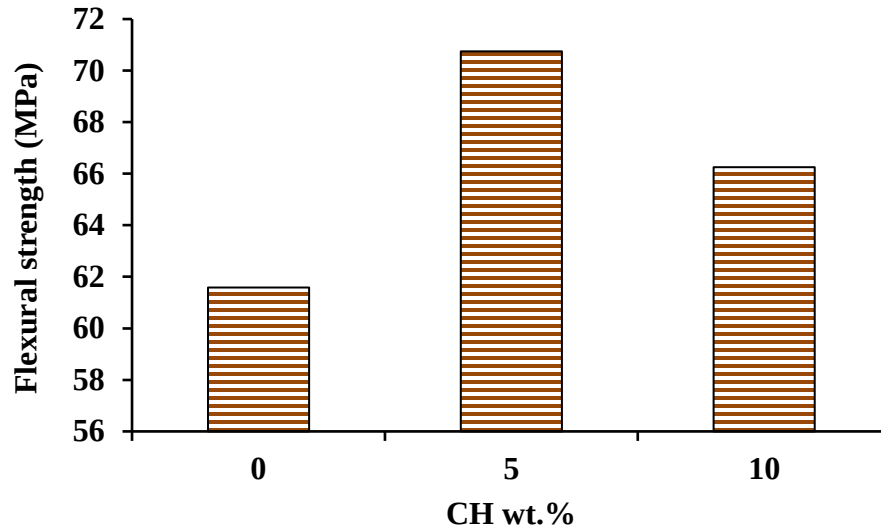


Figure 4.6 Flexural strength Vs CH wt.%

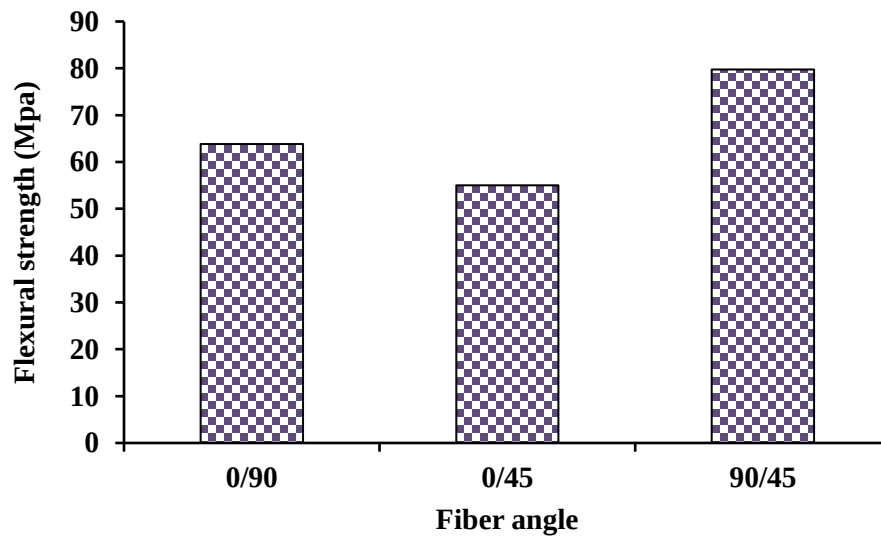


Figure 4.7 Flexural strength Vs fiber angle

Analysis of main effect plot, response table and ANOVA table for flexural strength

The main effect plot for S/N ratios of flexural strength was shown in Figure 4.8. The graph implies that the optimum condition for the flexural strength was 20 wt.% PALF, 5 wt.% CH, and 90/45 fiber orientation.

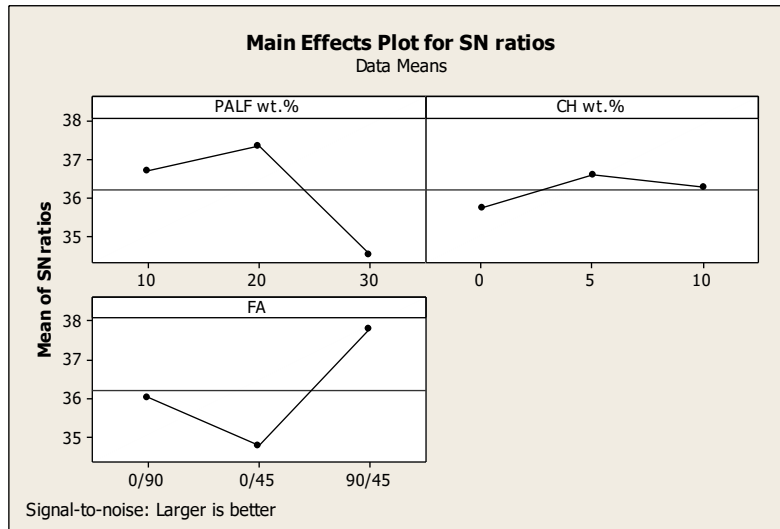


Figure 4.8 Main effect plot of flexural strength

The response table for S/N ratio of flexural strength shown in Table 4.5. The fiber angle had the highest contribution in increasing the flexural strength with delta number of 3.00. While pineapple loading was the second contributed factor with delta number of 2.80. The third contributed factor was cardamom filler with delta number of 0.85.

Table 4.5 Response table for S/N ratio of flexural strength

Level	PALF wt. %	CH wt. %	FA
1	36.71	35.75	36.03
2	37.35	36.60	34.79
3	34.56	36.27	37.79
Delta	2.80	0.85	3.00
Rank	2	3	1

Table 4.6 ANOVA table for flexural strength

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	796.9	796.9	398.47	2.61	0.277	36.68%
CH wt. %	2	126.1	126.1	63.03	0.41	0.708	5.80%
FA	2	943.9	943.9	471.97	3.09	0.245	43.45%
Error	2	305.7	305.7	152.84			14.07%
Total	8	2172.6					100%

The ANOVA table for flexural strength was shown in Table 4.6. It shows that fiber orientation angle had the highest effect for the increase in flexural strength with percentage contribution of 43.45%. The second influencing parameter was pineapple fiber wt.% with percentage contribution of 36.68%. The third contributed factor was cardamom husk wt.% with percentage contribution of 5.80%. P-value shows that factor A and C are highly significant and factor B is less significant.

4.4 Compression Test

Compressive strength is defined as the ability of material to resist the direct pressure of applied compression force. A compression test was conducted to characterize the compression strength of the pineapple fiber-reinforced polyester composite with cardamom husk filler shown in the Table 4.7.

Table 4.7 Compression test result

Expt. No	PALF	CH	Fiber angle	Average Compression strength (MPa)	S/N ratio
1	10	0	0/90	40.24	32.09
2	10	5	0/45	54.08	34.66
3	10	10	90/45	60.08	35.57
4	20	0	0/45	63.12	36.00
5	20	5	90/45	95.84	39.63
6	20	10	0/90	63.52	36.05
7	30	0	90/45	40.64	32.17
8	30	5	0/90	49.92	33.96
9	30	10	0/45	53.04	34.49

The effect of pineapple fiber loading on compression strength was shown in Figure 4.9. the result shows that compression strength increased with increase in fiber loading. But further fiber addition resulted in reduced of compression strength. The maximum compression strength obtained at 10, 15 and 20 wt.% PALF was 51.46MPa, 74.16MPa, and 47.86MPa respectively. Figure 4.10 shown that 5 wt.% cardamom husk filler loading has maximum compression strength 66.6MPa and fiber angle 90/45 has maximum compression strength 65.52MPa.

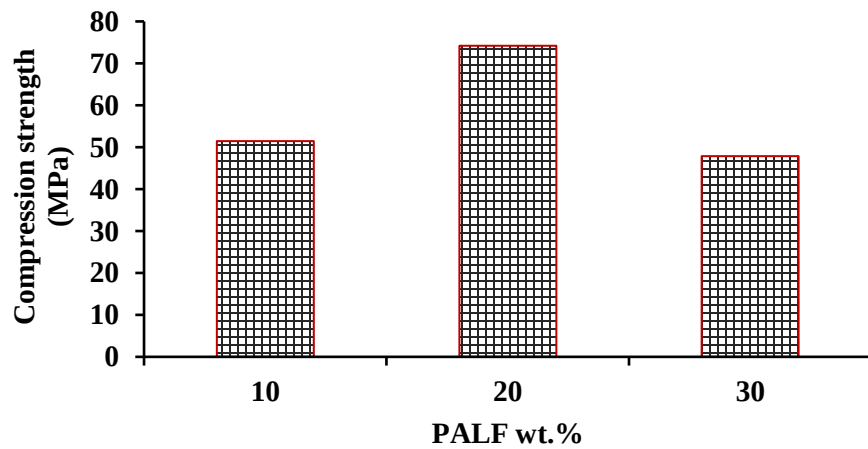


Figure 4.9 Compression strength Vs PALF wt. %

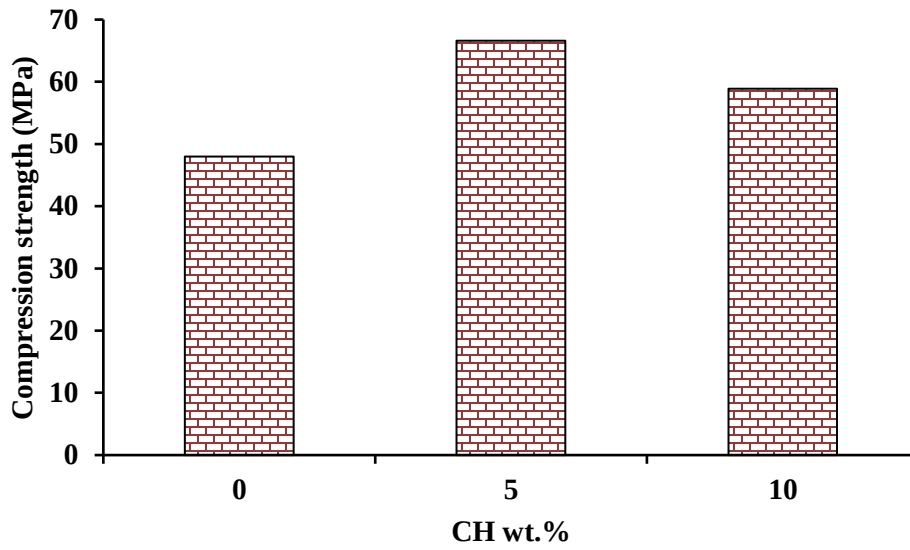


Figure 4.10 Compression strength Vs CH wt. %

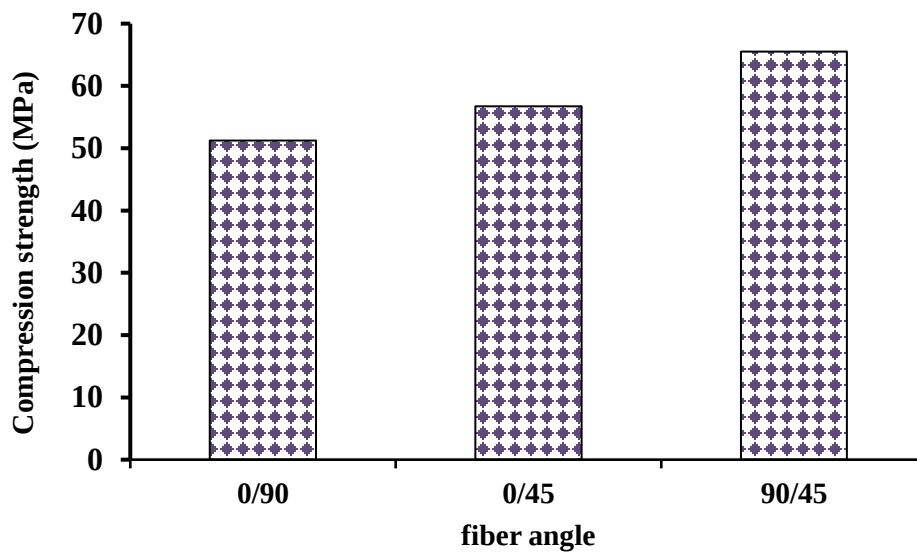


Figure 4.11 Compression strength Vs fiber angle

Analysis of main effect plot, response table ANOVA table for compression strength

The main effect plot for S/N ratios of compression strength was shown in Figure 4.12. the graph implies that the optimum condition for the flexural strength was 20 wt.% PALF, 5 wt.% CH, and 90/45 fiber orientation.

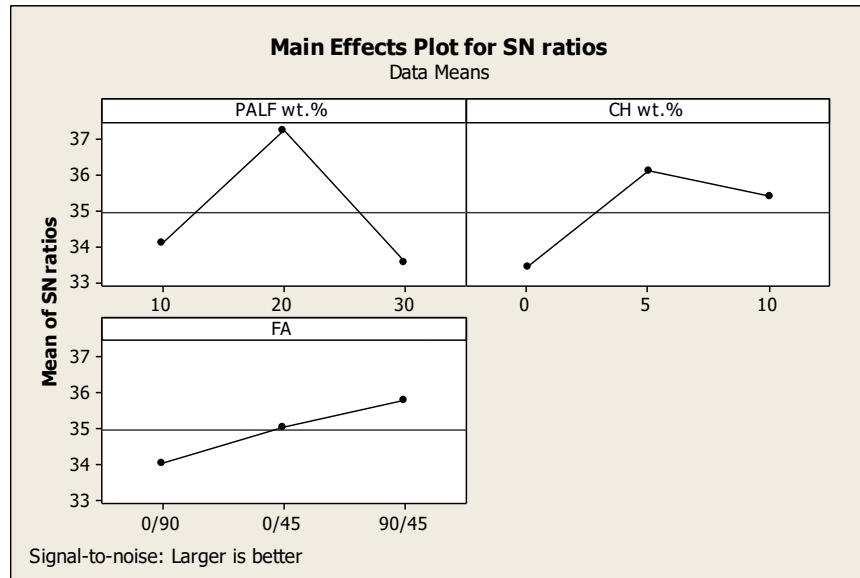


Figure 4.12 Main effect plot of compression strength

Response table for S/N ratio of compression strength shown in Table 4.8 shows that pineapple fiber loading had the highest contribution in increasing the compression strength with delta number of 3.69. While cardamom husk filler loading was the second contributed factor with delta number of 2.66. The third contributed factor was fiber orientation angle with delta number of 1.76.

Table 4.8 Response table for S/N ratio of compression strength

Level	PALF wt. %	CH wt. %	FA
1	34.11	33.43	34.04
2	37.23	36.09	35.05
3	33.55	35.37	35.79
Delta	3.69	2.66	1.76
Rank	1	2	3

Table 4.9 ANOVA table for compression strength

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	1219.3	1219.3	609.64	7.67	0.115	55.06%
CH wt. %	2	524.6	524.6	262.32	3.30	0.233	23.69%
FA	2	311.7	311.7	155.87	1.96	0.338	14.08%
Error	2	159.0	159.0	79.50			7.18%
Total	8	2214.7					100%

The ANOVA table for compression strength was shown in Table 4.9. It shows that pineapple fiber wt.% had the highest effect for the increase in compression strength with percentage contribution of 55.06%. The second influencing parameter was cardamom husk wt.% with percentage contribution of 23.69%. The third contributed factor was fiber angle with percentage contribution of 14.08%. P-value shows that pineapple fiber was more significant factor and the rest were less significant.

4.5 Impact Test

An impact test is one type of distractive test that describes the amount of energy absorbed by a material during fracture. It determines the toughness and impact strength of the composites. The maximum result at 10wt.% fiber loading 13.5J, 20wt.% fiber loading 16.25J and 30wt.% fiber loading 12.25J shown in Table 4.10.

From the result the maximum impact strength of pineapple fiber/cardamom husk polyester composites was 16.25J and minimum impact strength was 10.75J pure pineapple polyester composite. Figure 4.13 show the effect of PALF loading on impact energy of the composites. When the amount of fiber loading increase from 10wt.% to 20wt.% the impact strength increased due to sufficient amount of fiber to carry suddenly applied load but further addition 30wt.% of fiber reduced the impact energy due to poor adhesion between fiber and matrix. The maximum impact strength was 16.25J at 20wt.% PALF loading. Concerning the effect of CH on impact strength result was shown in Figure 4.14. the maximum impact strength was 13.42J at 5wt.% CH this is due to addition of filler increases impact energy. Further addition of filler reduced impact

energy due to agglomeration of filler together by weak force. Regarding fiber orientation maximum impact energy was 13.5J at 90/45 fiber angle.

Table 4.10 Impact energy result

Expt. No	PALF	CH	Fiber angle	Average Impact energy (MPa)	S/N ratio
1	10	0	0/90	10.75	20.62
2	10	5	0/45	11.75	21.40
3	10	10	90/45	13.5	22.60
4	20	0	0/45	11.75	21.40
5	20	5	90/45	16.25	24.21
6	20	10	0/90	11.25	21.02
7	30	0	90/45	10.75	20.62
8	30	5	0/90	12.25	21.76
9	30	10	0/45	11.5	21.21

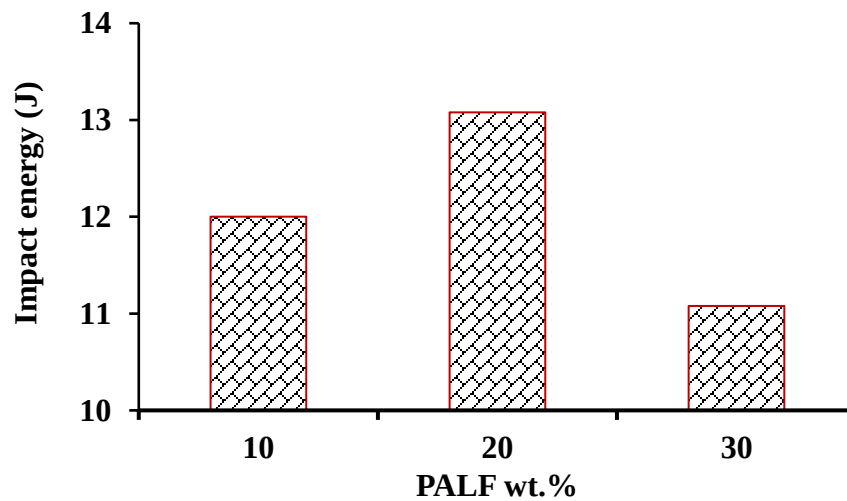


Figure 4.13 Impact energy Vs PALF wt. %

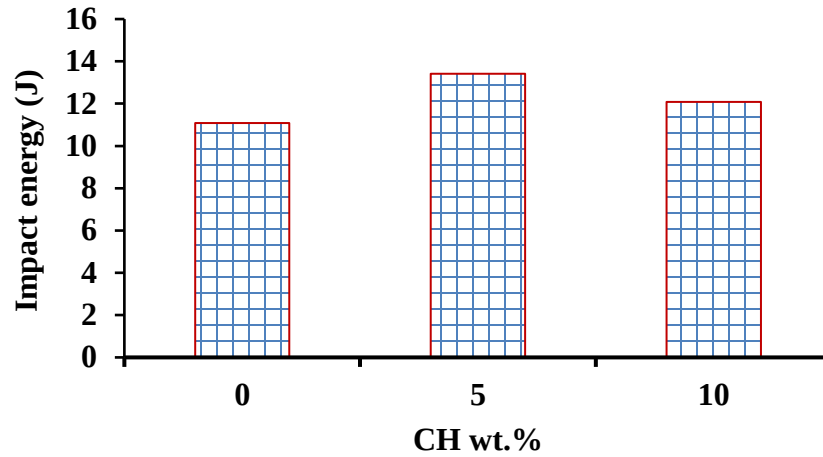


Figure 4.14 Impact energy Vs CH wt. %

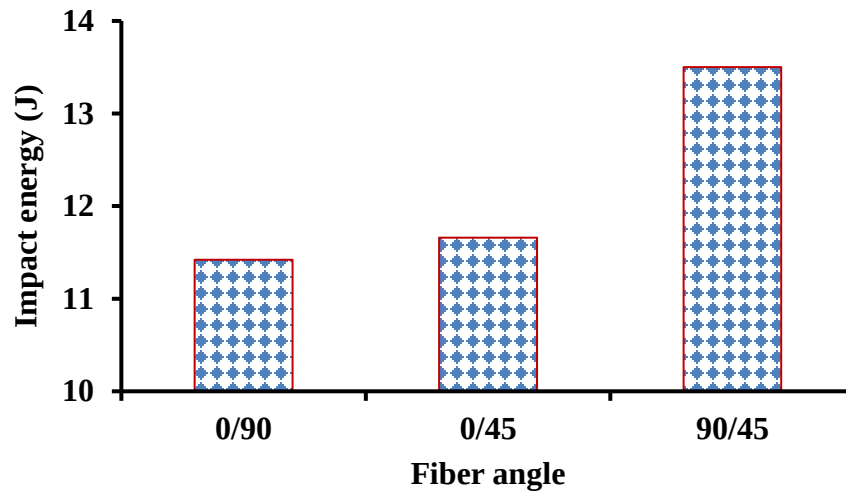


Figure 4.15 Impact strength Vs fiber angle

Analysis of main effect, response table and ANOVA table for impact strength.

The main effect plot for S/N ratios of impact strength was shown in Figure 4.16. the graph implies that the optimum condition for the impact strength was 20 wt.% PALF, 5 wt.% CH, and 90/45 fiber orientation.

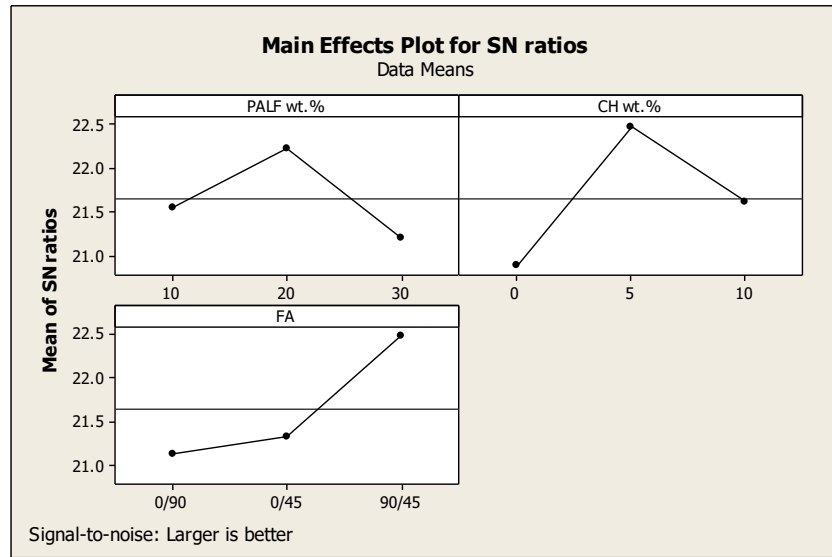


Figure 4.16 Main effect plot for S/N ratio of impact energy

Response table for S/N ratio of impact strength shown in Table 4.11 shows that cardamom husk filler had the highest contribution in increasing the impact strength with delta number of 1.57. while fiber orientation angle was the second contributed factor with delta number of 1.35. The third contributed factor was pineapple fiber loading with delta number of 1.01.

Table 4.11 Response table for S/N ratio of impact energy

Level	PALF wt. %	CH wt. %	FA
1	21.55	20.89	21.14
2	22.21	22.46	21.34
3	21.20	21.61	22.48
Delta	1.01	1.57	1.35
Rank	3	1	2

Table 4.12 ANOVA table foe impact energy

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	3.931	3.931	1.965	0.94	0.515	16.31%
CH wt. %	2	8.222	8.222	4.111	1.97	0.337	34.12%
FA	2	7.764	7.764	3.882	1.86	0.350	32.22%
Error	2	4.181	4.181	2.090			17.35%
Total	8	24.097					100%

The ANOVA table for impact strength was shown in Table 4.12. It shows that cardamom husk wt.% had the highest effect for the increase in impact strength with percentage contribution of 34.12%. The second influencing parameter was fiber angle with percentage contribution of 32.22%. The third contributed factor was pineapple fiber wt.% with percentage contribution of 16.31%. P-value shows that cardamom husk wt.% was more significant factor and the rest were less significant.

4.6 Hardness Test

Hardness is considered as one of the most important factors that govern the wear resistance of any material. The aim of the hardness test was to compute the resistance of the material to plastic deformation. A higher value of hardness indicates that the material is harder. As shown in Table 4.13 the maximum hardness was 54.35HV for sample 6, which was fiber angle 0/90, 20wt.% PALF, and 10wt.% CH. The minimum hardness was 38.98HV for sample 1, which was fiber angle 0/90, 10wt.% PALF, and 0wt.% CH.

Table 4.13 Hardness test result

Expt. No	PALF	CH	Fiber angle	Hardness			S/N ratio
				Trial 1	Trial 2	Average	
1	10	0	0/90	39.15	38.8	38.98	31.816
2	10	5	0/45	43.4	40.8	42.1	32.485
3	10	10	90/45	39.15	40.15	39.65	31.964
4	20	0	0/45	45.05	47.95	46.5	33.349
5	20	5	90/45	48.1	42.15	45.13	33.089
6	20	10	0/90	54.9	53.8	54.35	34.704
7	30	0	90/45	39.15	38.9	39.03	31.828
8	30	5	0/90	45.95	45.3	45.63	33.185
9	30	10	0/45	36	36.6	24.2	27.676

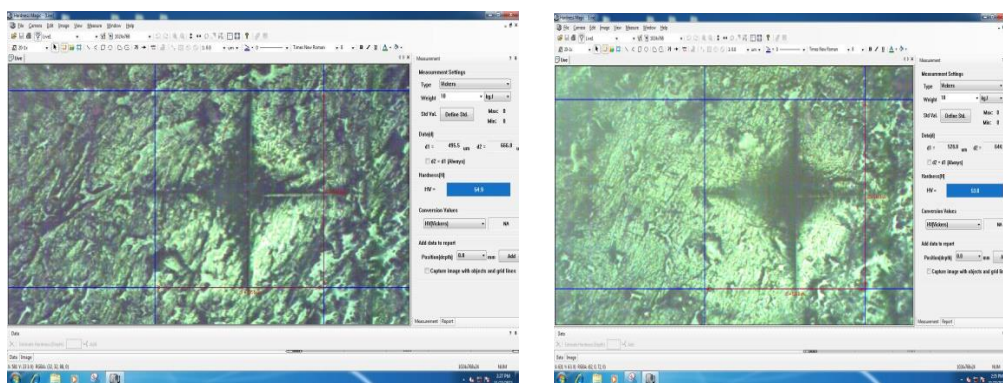


Figure 4.17 Test result of sample 6

Effect of pineapple fiber wt.% on hardness was shown in Figure 4.18. the hardness of the composites increases with fiber content and reached its maximum value 54.3 HV at 20wt.% fiber loading. Figure 4.19 illustrated the influence of CH wt.% on hardness value. Addition of filler increases the hardness of the composite but further addition of filler reduced the hardness.

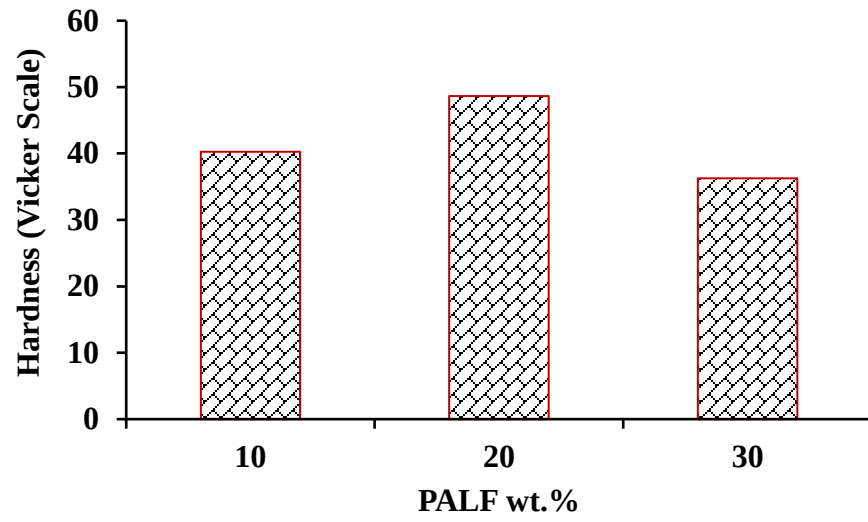


Figure 4.18 Hardness Vs PALF wt. %

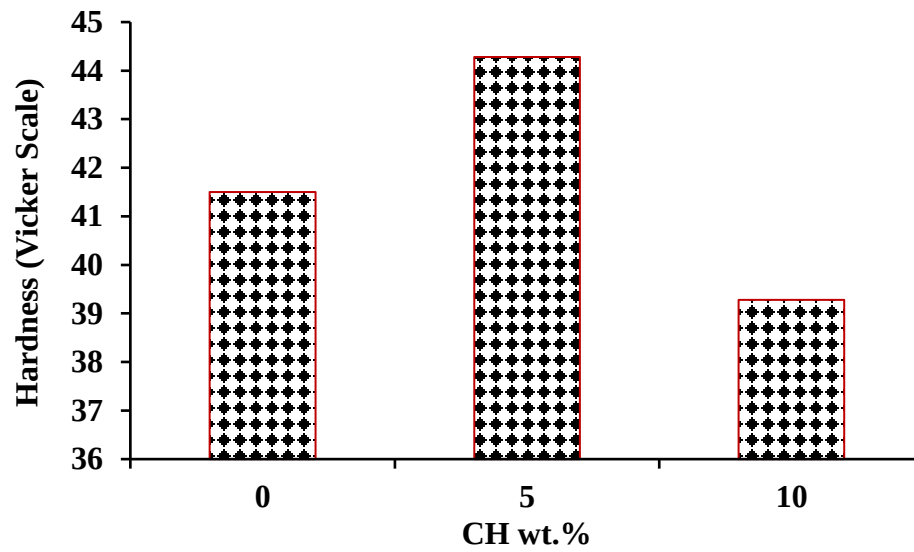


Figure 4.19 Hardness Vs CH wt. %

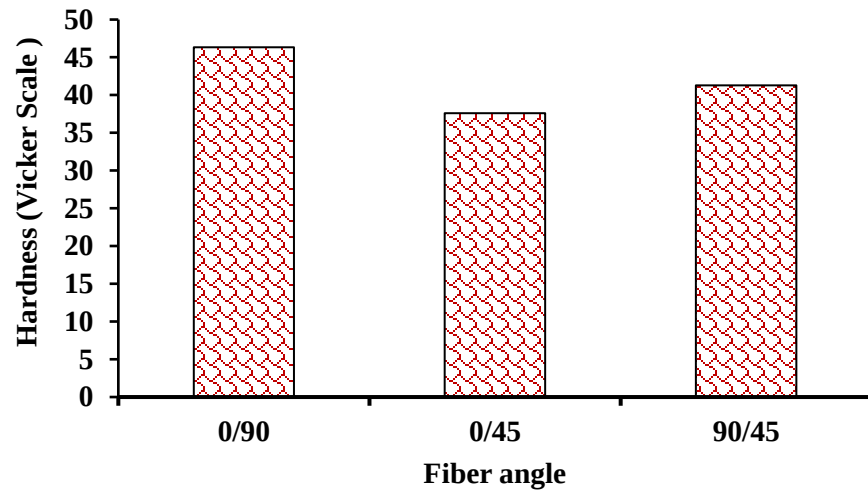


Figure 4.20 Hardness Vs fiber angle

Analysis of main effect plot, response table and ANOVA table for hardness

The main effect plot for S/N ratios of hardness was shown in Figure 4.21. the graph implies that the optimum condition for the hardness strength was 20 wt.% PALF, 5 wt.% CH, and 0/90 fiber orientation.

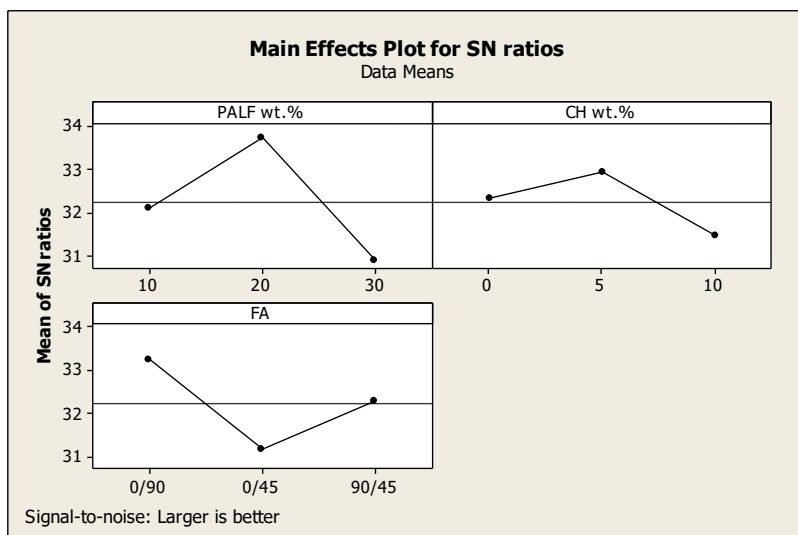


Figure 4.21 Main effect plot for S/N ratio of hardness

Response table for S/N ratio of hardness strength shown in Table 4.14 shows that pineapple fiber loading had the highest contribution in increasing the hardness strength with delta number of 2.82. while fiber orientation angle was the second contributed factor with delta number of 2.06. The third contributed factor was cardamom husk filler with delta number of 1.47.

Table 4. 14 Response table for S/N ratio of hardness

Level	PALF wt. %	CH wt. %	FA
1	32.09	32.33	33.24
2	33.71	32.92	31.17
3	30.90	31.45	32.29
Delta	2.82	1.47	2.06
Rank	1	3	2

Table 4.15 ANOVA table for hardness

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	239.59	239.59	119.80	1.66	0.377	44.75%
CH wt. %	2	36.05	36.05	18.03	0.25	0.801	6.73%
FA	2	115.01	115.01	57.50	0.79	0.557	21.48%
Error	2	144.75	144.75	72.37			27.04%
Total	8	535.4					100%

The ANOVA table for hardness was shown in Table 4.15. It shows that pineapple fiber wt.% had the highest effect for the increase in hardness with percentage contribution of 44.75%. The second influencing parameter was fiber angle with percentage contribution of 21.48%. The third contributed factor was cardamom husk wt.% with percentage contribution of 6.73%. P-value shows that pineapple fiber wt.% was more significant factor and the rest were less significant.

4.7 Water Absorption Test

The impact of moisture absorption on the mechanical and physical properties of composites has to be taken into account in order to encourage their extended use in high performance applications. Increased water absorption in a composite can lead to fiber swelling, microcracks, and void development at the fiber-matrix interface. Higher water absorption of a composite can result in a reduction in the mechanical properties and dimensional stability of composites. A water absorption test was carried out to determine the percentage of water absorbed under specified conditions. The weight of the samples that were measured before immersion is shown in Table 4.16.

Table 4.16 Weight of the sample before immersion

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9
Average Weight before immersion (gm)	2.68	2.84	3.02	4.34	4.85	5.12	5.45	5.68	5.82

Table 4.17 Water absorption result and S/N ratios

S. No	Immersion period in (hr)									S/N ratio
	24	48	72	96	120	144	168	192	Average	
S1	2.26	2.53	2.71	2.98	3.22	3.61	3.77	3.88	3.12%	9.883
S2	2.87	2.98	3.11	3.37	3.52	3.81	4.1	4.18	3.5%	10.881
S3	3.56	3.96	4.32	4.58	4.79	5.02	5.22	5.4	3.95%	11.931
S4	2.52	2.84	3.16	3.43	3.74	3.98	4.13	4.23	3.53%	10.955
S5	2.76	3.18	3.53	3.87	4.25	4.67	4.73	4.82	3.97%	11.975
S6	3.05	3.48	3.97	4.42	4.78	4.97	5.11	5.26	4.38%	12.829
S7	2.85	3.28	3.63	3.93	4.2	4.78	4.92	4.99	4.07%	12.191
S8	3.18	3.42	3.78	3.97	4.47	4.62	4.81	4.93	4.15%	12.361
S9	3.72	4.13	4.57	4.93	5.24	5.67	5.87	5.96	5.01%	13.996

The water absorption percentage of each sample soaked in the water was weighted by the interval of 24hrs as shown in Table 4.3, and water absorption increases with immersion time, although the rate of absorption decreases with increased time. The rate of water absorption increases with increased fiber loading this is due to fiber absorbed more water than the matrix and filler. The minimum water absorption percentage was 3.12% at 10wt.% PALF loading, as shown in Figure 4.22. This result is well agreed with (Daraloma *et al.*, 2017). The addition of particulate results in an increment of water absorption, as shown in Figure 4.23. Increasing the amount of CH filler wt.% increases the water absorption rate. 10wt.% CH was the maximum water absorption. This is due to hydrophilic nature of lingo-cellulose particulates. The result was agreed with (Saha *et al.*, 2021). Regarding fiber orientation the minimum water adsorption was 3.88% at 0/90 degree, as shown in Figure 4.24.

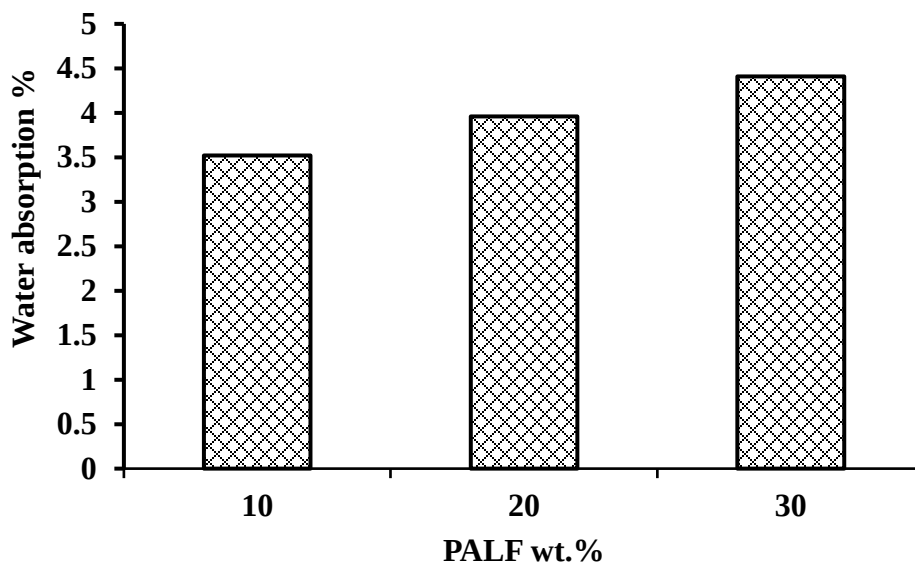


Figure 4.22 Water absorption Vs PALF wt. %

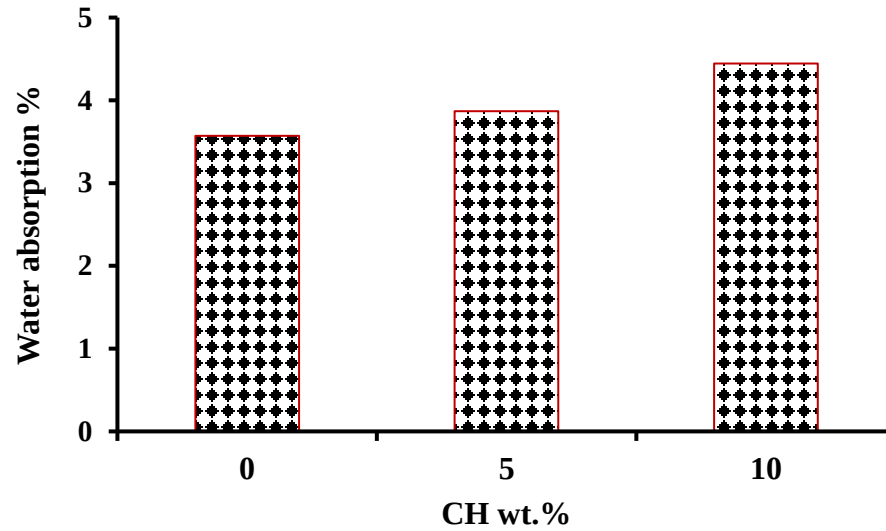


Figure 4.23 Water absorption Vs CH wt. %

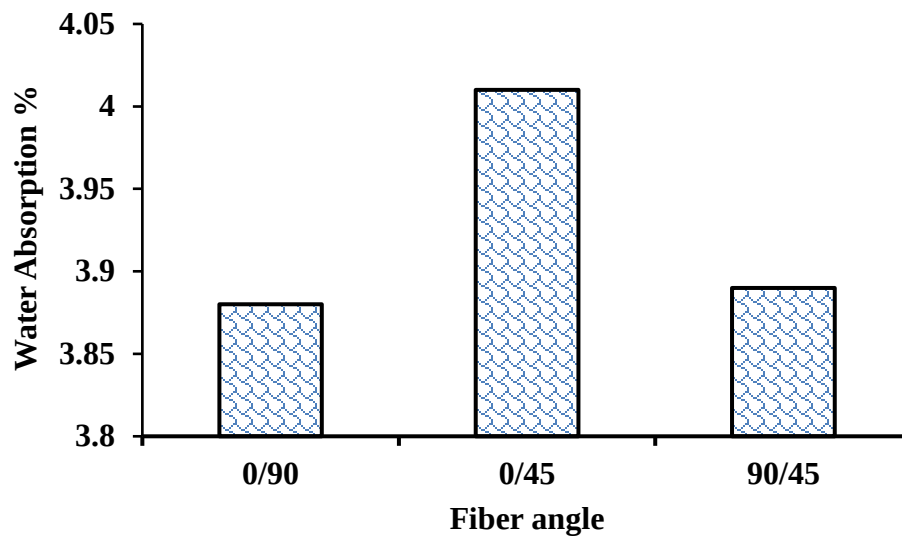


Figure 4.24 Water absorption Vs Fiber angle

Analysis of main effect plot, response table and ANOVA table for water absorption rate

The main effect plot for S/N ratios of water absorption rate was shown in Figure 4.25. the graph implies that the optimum condition minimum water absorption rate was 10 wt.% PALF, 0 wt.% CH, and 0/90 fiber orientation.

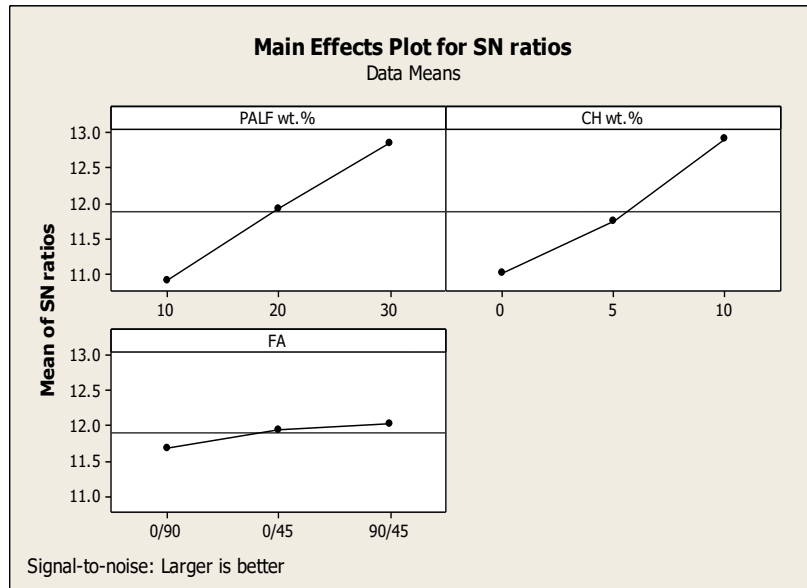


Figure 4.25 Main effect plot for S/N ratio of water absorption

Response table for S/N ratio of water absorption rate shown in Table 4.18 shows that pineapple fiber loading had the highest contribution in increasing the water absorption rate with delta number of 1.95. While cardamom husk filler was the second contributed factor with delta number of 1.91. The third contributed factor was fiber orientation angle with delta number of 0.34.

Table 4.18 Response table for S/N ratio of water absorption rate

Level	PALF wt. %	CH wt. %	FA
1	10.90	11.01	11.69
2	11.92	11.74	11.94
3	12.85	12.92	12.03
Delta	1.95	1.91	0.34
Rank	1	2	3

Table 4.19 ANOVA table for water absorption rate

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	0.000118	0.000118	0.000059	30.69	0.032	48.55%
CH wt. %	2	0.000118	0.000118	0.000059	30.75	0.031	48.63%
FA	2	0.000003	0.000003	0.000002	0.78	0.561	1.24%
Error	2	0.000004	0.000004	0.000002			1.58%
Total	8	0.000243					100%

The ANOVA table for water absorption rate was shown in Table 4.19. It shows that both pineapple fiber wt.% and cardamom husk wt.% had the highest effect with percentage contribution of 48.55% and 48.63, respectively. The second influencing parameter was fiber angle with percentage contribution of 21.48%. The third contributed factor was cardamom husk wt.% with percentage contribution of 6.73%. P-value shows that pineapple fiber wt.% was more significant factor and the rest were less significant.

4.8 Density and Void fraction

The density of the composites is one of the most essential factors in determining their properties, and it depended on the relative proportion of reinforcing and matrix materials. Void is unavoidable in composites fabrication through the hand-lay-up method, which estimates the quality of composites. The theoretical density, actual density, and void fraction of the composites were calculated by using equation (3.12), equation (3.11), and equation (3.14) respectively. The weight of the sample measured in the air and water is shown in Table 4.20

Table 4.20 Weight of sample in the air and in the water

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9
Wt. of sample in the air (g)	2.42	2.62	2.88	3.02	3.21	3.39	3.51	3.63	3.78
Wt. of sample in the water (g)	0.34	0.35	0.37	0.44	0.45	0.44	0.55	0.55	0.53

Table 4.21 Theoretical density, measured density, and void fraction of the composites.

Sample	Theoretical density (g/cm^3)	Measured density (g/cm^3)	Void fraction %	S/N ratios
S1	1.174	1.163	0.998	-0.0174
S2	1.162	1.153	0.775	-2.2139
S3	1.158	1.147	0.949	-0.4547
S4	1.183	1.171	1.102	0.8436
S5	1.177	1.165	1.019	0.1634
S6	1.164	1.151	1.054	0.4568
S7	1.198	1.186	1.157	1.2666
S8	1.186	1.174	1.012	0.1036
S9	1.172	1.16	1.124	1.0153

From Table 4.21 the theoretical density was larger in all samples than measured density due to the presence of voids in the composite. Density of the composite increased with increase in fiber and filler loading. For lower levels of fiber and filler the density was smaller than that of a higher level. For 10wt.% PALF loading light weight composites were made, since density is directly proportional to mass. Increased density of the composite because of increases the weight percentage of PALF. Increase CH wt.%. Also increased density and result high void content in the composite.

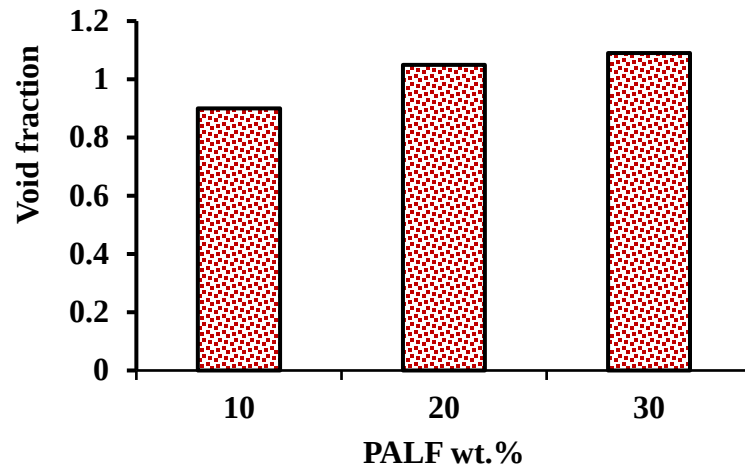


Figure 4.26 Void fraction Vs PALF wt. %

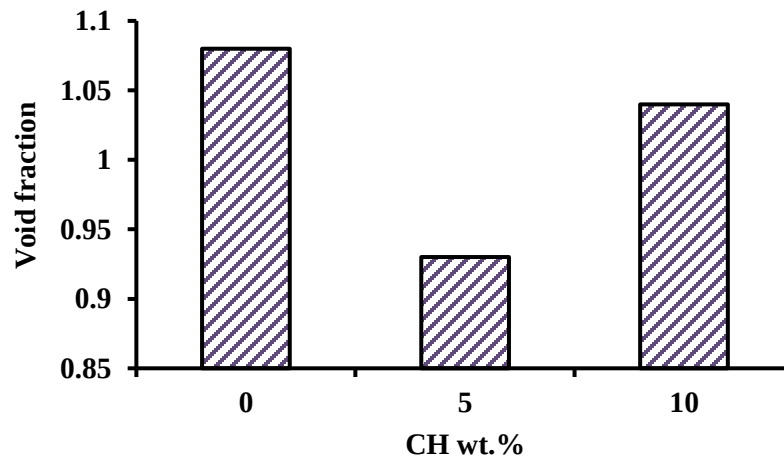


Figure 4.27 Void fraction Vs CH wt. %

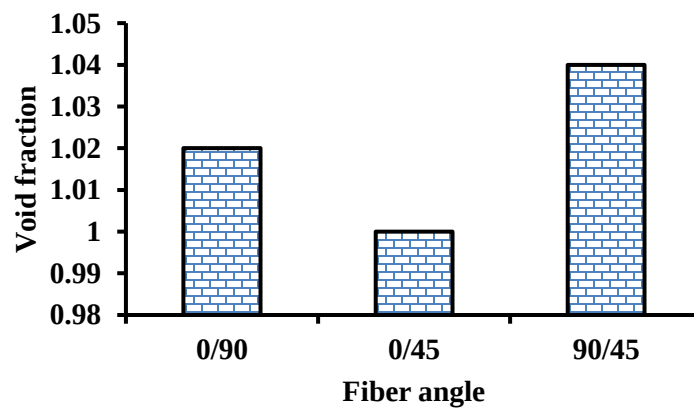


Figure 4.28 Void fraction Vs fiber angle

Figure 4.26 shown the variation of void content with fiber loading. Increase in fiber loading result increased the void content of the composite due to poor adhesion between matrix and reinforcement because of insufficient matrix. 10 wt.% PALF was minimum void content. Figure 4.27 shown Addition of filler above 5wt.% increased the void content of the composite because of agglomeration, air bubble and weak bond formation between the filler. Fiber orientation was minimum effect on the density of the composite. 0/45 fiber angle was minimum void content than other.

Analysis of main effect plot, response table and ANOVA table for void content

The main effect plot for S/N ratios of void fraction was shown in Figure 4.29. The graph implies that the optimum condition minimum void content was 10 wt.% PALF, 5 wt.% CH, and 0/45 fiber orientation.

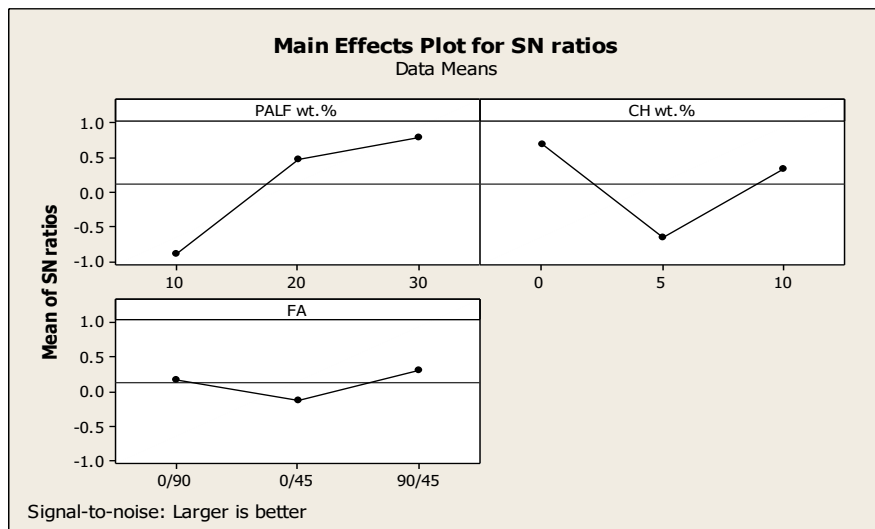


Figure 4.29 main effect plot for S/N ratio of void content

Response table for S/N ratio of void content shown in Table 4.22 shows that pineapple fiber loading had the highest contribution with delta number of 1.6905. While cardamom husk filler was the second contributed factor in void content with delta number of 1.3466. The third contributed factor was fiber orientation angle with delta number of 0.4435.

Table 4.22 Response table for S/N ratio of void content

Level	PALF wt. %	CH wt. %	FA
1	-0.8953	0.6976	0.1810
2	0.4880	-0.6490	-0.1183
3	0.7952	0.3392	0.3252
Delta	1.6905	1.3466	0.4435
Rank	1	2	3

Table 4.23 ANOVA table for void content

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	0.060575	0.060575	0.030287	15.13	0.062	58.77%
CH wt. %	2	0.035927	0.035927	0.017963	8.97	0.100	34.86%
FA	2	0.002563	0.002563	0.001281	0.64	0.610	2.49%
Error	2	0.004004	0.004004	0.002002			3.88%
Total	8	0.103069					100%

The percentage contribution of the factors was shown in Table 4.23. The ANOVA table illustrated that fiber loading had 58.77% contribution. Cardamom husk wt.% had percentage contribution of 34.86%. Fiber angle had percentage contribution of 2.49%. P-value shows that pineapple fiber wt.% was more significant factor and the rest were less significant.

4.9 Grey Relational Analysis of Mechanical and Physical properties

Table 4.24 shown the experimental results of tensile, flexural, compression, impact, hardness, water absorption, and void content were transformed into Signal to-Noise (S/N) ratio using Taguchi analysis. By using the S/N ratio value calculate normalizing sequence. The Deviation

sequence was calculated from the normalizing sequence. The Gray relational coefficients were calculated using the deviation sequence values. Finally, the GRG is calculated from the GRC and optimum parameter was selected.

Table 4.24 Summary of experimental results

Responses (results)							
Expt. No	Tensile (MPa)	Flexural (MPa)	Compression (MPa)	Impact (J)	Hardness (HV)	Water absorption (%)	Void fraction
1	21.4	70.25	40.24	10.75	38.98	3.12	0.998
2	35.95	57.25	54.08	11.75	42.1	3.5	0.775
3	42.3	79.75	60.08	13.5	39.65	3.95	0.949
4	39.5	57.25	63.12	11.75	46.5	3.53	1.102
5	54.11	102.25	95.84	16.25	45.13	3.97	1.019
6	45.96	68.5	63.52	11.25	54.35	4.38	1.054
7	22.3	57.25	40.64	10.75	39.03	4.07	1.157
8	30.35	52.75	49.92	12.25	45.63	4.15	1.012
9	20.4	50.5	53.04	11.5	24.2	5.01	1.124

The S/N ratios obtained from Taguchi were shown in Table 4.25 for all experiments. As discussed in chapter three the next step was normalization of S/N ratios using equation (2.4) for larger the better and equation (2.5) for smaller the better.

Table 4.25 S/N ratios result

S/N ratios							
Expt. No	Tensile	Flexural	Compression	Impact	Hardness	Water absorption	Void fraction
1	26.61	36.93	32.09	20.62	31.816	9.883	-0.0174
2	31.11	35.15	34.66	21.40	32.485	10.881	-2.2139
3	32.53	38.03	35.57	22.60	31.964	11.931	-0.4547
4	31.93	35.15	36.00	21.40	33.349	10.955	0.8436
5	34.66	40.19	39.63	24.21	33.089	11.975	0.1634
6	33.24	36.71	36.05	21.02	34.704	12.829	0.4568
7	26.96	35.15	32.17	20.62	31.828	12.191	1.2666
8	29.64	34.44	33.96	21.76	33.185	12.361	0.1036
9	26.19	34.06	34.49	21.21	27.676	13.996	1.0153

The normalization sequence was used to eliminate data repetition and duplicates data from the relation table. The values were normalized between 0 and 1.

Table 4.26 Normalizing sequence result

Normalizing sequence							
Expt. No	Tensile	Flexural	Compression	Impact	Hardness	Water absorption	Void fraction
1	0.049	0.468	0.000	0.000	0.589	0.000	0.631
2	0.581	0.177	0.341	0.217	0.684	0.242	0.000
3	0.748	0.647	0.461	0.551	0.611	0.497	0.505
4	0.677	0.177	0.518	0.217	0.807	0.261	0.878
5	1.000	1.000	1.000	1.000	0.771	0.508	0.683
6	0.832	0.432	0.525	0.111	1.000	0.716	0.767
7	0.091	0.177	0.011	0.001	0.591	0.561	1.000
8	0.407	0.062	0.248	0.317	0.783	0.602	0.665
9	0.000	0.000	0.318	0.164	0.000	1.000	0.927

By using the normalized data, the deviation sequence can be calculated as $1 - X_{ij}$. 1 is used because it is the highest value of quality. Where X_{ij} is the actual value of each experiment.

Table 4.27 Deviation sequence result

Deviation sequence							
Expt. No	Tensile	Flexural	Compression	Impact	Hardness	Water absorption	Void fraction
1	0.951	0.532	1.000	1.000	0.411	1.000	0.369
2	0.419	0.823	0.659	0.783	0.316	0.758	1.000
3	0.252	0.353	0.539	0.449	0.389	0.503	0.495
4	0.323	0.823	0.482	0.783	0.193	0.739	0.122
5	0.000	0.000	0.000	0.000	0.229	0.492	0.317
6	0.168	0.568	0.475	0.889	0.000	0.284	0.233
7	0.909	0.823	0.989	0.999	0.409	0.439	0.000
8	0.593	0.938	0.752	0.683	0.217	0.398	0.335
9	1.000	1.000	0.682	0.836	1.000	0.000	0.073

The calculated deviation sequence (quality loss) shown in Table 4.27 was used to find the grey relational coefficients. Then the grey relational coefficient was calculated by using equation (2.6). Finally, the grey relational grades were calculated by using equation (2.7).

Table 4.28 Grey relational coefficients and Grey relational grade

Expt. No	Grey relational coefficients							GRG	Rank
	Tensile	Flexural	Compression	Impact	Hardness	Water absorption	Void fraction		
1	0.344	0.484	0.333	0.333	0.548	0.333	0.575	0.421	9
2	0.544	0.377	0.431	0.389	0.612	0.397	0.333	0.440	7
3	0.664	0.586	0.481	0.526	0.562	0.498	0.502	0.545	3
4	0.607	0.377	0.509	0.389	0.721	0.403	0.803	0.544	4
5	1.000	1.000	1.000	1.000	0.685	0.504	0.611	0.828	1
6	0.748	0.468	0.512	0.359	1.000	0.637	0.682	0.629	2
7	0.354	0.377	0.335	0.333	0.550	0.532	1.000	0.497	6
8	0.457	0.347	0.399	0.422	0.217	0.556	0.598	0.426	8
9	0.333	0.333	0.423	0.374	0.333	1.000	0.872	0.524	5

Analysis of main effect plot, response table, and ANOVA table for S/N ratios of GRG

The main effect plot for the S/N ratios depicted in Figure 4.30 shows that optimum condition for the experiment carried out was 20 wt.% pineapple fiber loading, 5 wt.% cardamom husks, and 90/45 fiber orientation (angle). Best result was achieved by using parameter levels at A2B2C3.

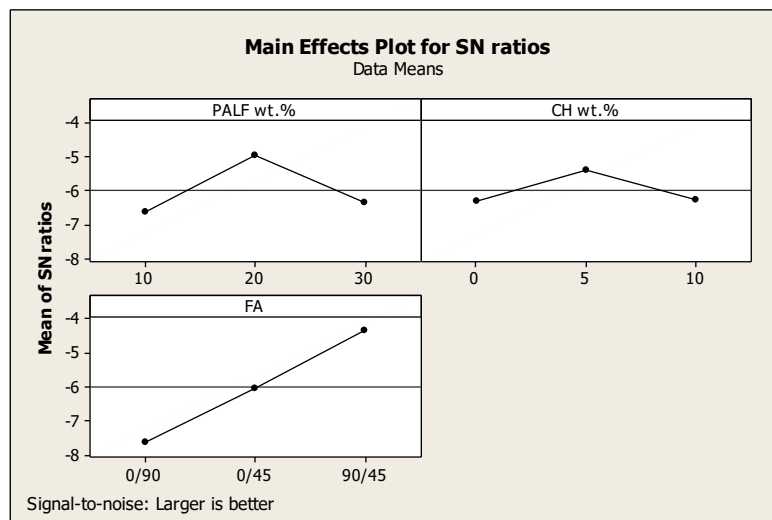


Figure 4.30 Main effect plots for S/N ratios of GRG

The GRG response Table 4.27 shows that fiber loading had the highest contribution in increasing the tensile, flexural, compression, impact strength, and hardness of the composite material with delta number of 2.988. The second contributed factor was cardamom husk filler weight percentage with delta number of 1.990. The third contributed factors were fiber orientation with delta number of 1.321. The optimal parameter set from the rank and grey relational analysis optimum combinations were similar.

Table 4.29 Response table for S/N ratios of GRG

Level	PALF wt. %	CH wt. %	FA
1	-6.639	-6.292	-6.318
2	-3.651	-5.394	-6.011
3	-6.366	-4.971	-4.328
Delta	2.988	1.990	1.321
Rank	1	2	3

Table 4.30 ANOVA table for GRG

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution
PALF wt. %	2	0.07362	0.07362	0.036812	5.92	0.145	56.56%
CH wt. %	2	0.03192	0.03192	0.015961	2.56	0.281	24.52%
FA	2	0.01217	0.01217	0.006085	0.98	0.506	9.56%
Error	2	0.01245	0.01245	0.006223			9.35%
Total	8	0.13016					100%

Analysis of variance for grey relational coefficient shows that pineapple weight percentage had the highest contribution of 54.56% for optimized experimental result. The second contributed factor was cardamom husk with percentage contribution of 24.52%. the third contributed factors was fiber angle with percentage contribution of 9.56%. Depending up on the P-value factor pineapple and cardamom husk were more significant factors and fiber angle was less significant.

4.10 Morphological Analysis

Figure 4.31 shown the distribution of particles, fiber matrix adhesion and morphology of S2 hybrid composites specimen. The morphology of the composite was affected by fabrication technique, since the scanning electron microscope result indicated that the composite with air bubbles, voids, internal crack and rough surfaces. Due to the reason that it was fabricated by hand layup technique, it was more exposed to formation of air bubbles on the surface, void space which are uncontrolled.

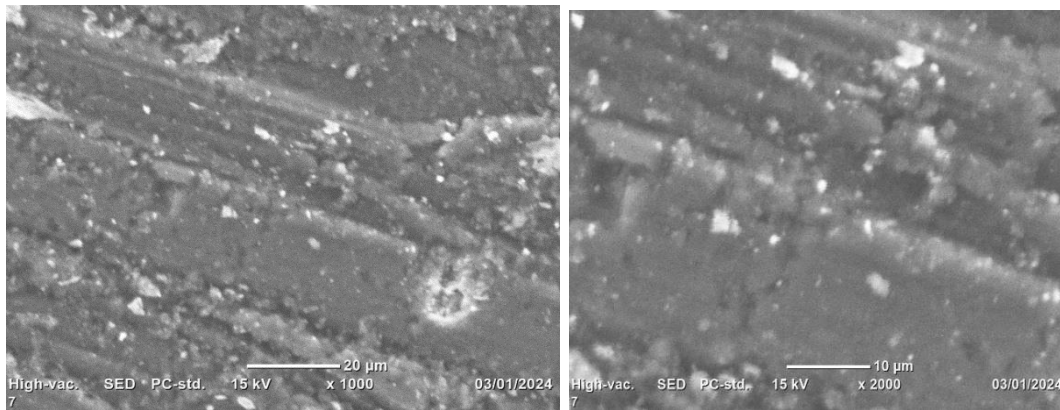


Figure 4.31 SEM analysis of S2

4.11 Comparison of Existing Interior Door Panel

The strength of the fabricated composite material was compared with the existing interior body panel material. From Table 4.31 the material has good strength and it can be applicable for interior automotive panel.

Table 4.31 Door panel strength of different car manufacturers.

Polymer/reinforcement	Tensile strength (MPa)	Automaker
Jute-epoxy	110	Mercedes-Benzes
Kenaf-PP	58	Ford
Flax/sisal-PUR	40-50	Audi
Flax/hemp/coconut-PP	30-60	Daimler Chrysler
Pineapple/cardamom/polyester	54.11	Present work

4.12 Comparison with Previous Work

Table 4.32 Effect of different processing factors on pineapple fiber reinforced composite

No	Authors	Matrix	Reinforcements	Method	Inference
1	Hossain <i>et al.</i> , (2022)	Epoxy	Pineapple fiber (10%, 15%, 20%, 25%, and 30%wt.%)	Hand-layup	The properties of composites increase with the addition of PALF. The maximum tensile strength was 51.6 Mpa
2	Senthilkumar <i>et al.</i> , (2019)	Polyester	Pineapple fiber (25%, 35%, and 45% wt.%)	Hand-layup	The mechanical properties of composites increase with increasing fiber content. The highest tensile strength was 33.13Mpa.
3	Omkumar & Selvakumar, (2018)	Epoxy	Pineapple fiber and corn husk powder (10:20, 15:15, and 20:70 ratios of PALF/CHP)	Hand-layup	The maximum tensile, flexural, impact strength is 13.39 MPa, 76.26 MPa, and 1.96J at 20% PALF and 10% CHP
4	Balaji., et al (2020)	Epoxy	Banana fiber	Compression molding	Maximum tensile, flexural and impact strength was 30.4Mpa, 56.3Mpa, and 2.7J
5	Present work	Polyester	Pineapple fiber (10%, 20%, 30%) cardamom husk (0%, 5%, 10%)	Hand-layup	The mechanical properties of the composites are maximum (54.11Mpa tensile, 102.25Mpa flexural, and 16.25J impact strength) for 20wt.% PALF loading, 5wt.% CH, and 90/45 fiber orientation angle

CHAPTER FIVE

CONCLUTION AND RECOMMENDATIONS

5.1 Conclusion

In this research fiber reinforced polymer matrix composite samples were made from pineapple fiber, cardamom husk filler and polyester resin using hand layup technique. Pineapple fiber reinforced polymer composites filled with cardamom husk exhibits excellent mechanical and physical properties. From the selection of process parameters to physical and mechanical characterization were discussed briefly. The physical and mechanical properties such as tensile, flexural, compression, impact, hardness, water absorption, density and void fraction were evaluated through the experimental requirements. Based on the experimental data obtained, the following conclusions were made.

- The effect of pineapple fiber and cardamom husk filler on the mechanical (tensile, compression, flexural, hardness and impact energy), physical (water absorption), and morphological properties were characterized.
- The maximum tensile, flexural, compression and impact strength was obtained at S5 (20wt.% PALF loading, 5wt.% CH, and 90/45 fiber orientation angle) 54.11MPa, 102.25MPa, 95.84MPa and 16.25J respectively.
- The maximum hardness was 54.35HV obtained at S6 (20wt.% PALF loading, 10wt.% CH, and 0/90 fiber orientation angle).
- Water absorption rate was highly influenced by fiber and filler wt.%. Minimum water absorption rate was 3.12% obtained for sample 1 (10wt.% PALF, 0wt.% CH and 0/90 fiber angle). For void content sample 2 (10wt.%, 5wt.% CH and 0/45 fiber angle) had the smallest void content of 0.775%.
- Statistical analysis of the response versus parameter and the significance of each parameter by ANOVA was determined. The p-values of tensile strength, flexural strength, compression strength, hardness, impact energy, void content, and water absorption are within an acceptable range. The PALF wt.% is more significant parameter compare to another parameter.

- The morphological behavior of the composite specimen at PALF to CHF (10:5) attributed to the proper bonding between the fiber, filler, and matrix that leads to enhance in energy absorbing capacity on fracture propagation, as well as a good result, was achieved from this interaction.
- The optimum condition using Taguchi based Grey relational analysis was 20wt.% PALF, 5wt.% CH and 90/45 fiber orientation angle. The multi response levels and the optimum process parameter condition showed the similar parameter levels.

5.2 Recommendations

- The recommendation from this thesis paper is that the composite made up of pineapple fiber reinforced polyester with cardamom husk filler can be used for automotive bodies, ceiling boards, partitions, furniture, drawing and art materials, and other structural application production
- During fabrication through hand layup method avoiding voids is difficult, therefore it is better to use any other fabrication method. So, the performance of the output may be improved by using more precise composite production techniques, such as the resin transfer method, vacuum bagging, vacuum-assisted hand layup, and others
- Epoxy resin should be used instead of polyester matrix to obtain more improved mechanical properties.
- Extraction of fibers should be performed with fiber extraction machine.
- Pineapple fiber and cardamom husk was waste product throughout the country so researcher conduct further experiment on their mechanical, chemical, thermal and physical properties.

5.3 Future Work

- Characterization and development of pineapple fiber reinforced polymer with other hybrid fiber and filler for improvement of mechanical and physical properties.
- Thermal and wear property of the composites can be studied

- Comparison of the characteristics of chemically treated and untreated pineapple fiber and cardamom husk filler and their influences.
- Screening other variables that affect the responses rather than reinforcement weight, filler weight, and orientation.

REFERENCES

- Alhijazi, M., Zeeshan, Q., Qin, Z., Safaei, B., & Asmael, M. (2020). Finite Element Analysis of Natural Fibers Composites: A Review. *Nanotechnology Reviews*, 9(1), 853–875.
<https://doi.org/10.1515/ntrev-2020-0069>
- Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M. R., Hoque, M. E., & Deng, Y. (2015). A review on pineapple leaves fibre and its composites. *International Journal of Polymer Science*, 2015. <https://doi.org/10.1155/2015/950567>
- B a, P., P Shetty, B., B, S., Singh Yadav, S. P., & L, A. (2022). Physical and mechanical properties, morphological behaviour of pineapple leaf fibre reinforced polyester resin composites. *Advances in Materials and Processing Technologies*, 8(1), 1147–1159.
<https://doi.org/10.1080/2374068X.2020.1853498>
- B A, P., P Shetty, B., N, V., H V, S., Singh Yadav, S. P., & L, A. (2022). Mechanical properties and water absorption behaviour of pineapple leaf fibre reinforced polymer composites. *Advances in Materials and Processing Technologies*, 8(2), 1336–1351.
<https://doi.org/10.1080/2374068X.2020.1860354>
- Balla, V. K., Kate, K. H., Satyavolu, J., Singh, P., & Tadimeti, J. G. D. (2019). Additive manufacturing of natural fiber reinforced polymer composites: Processing and prospects. *Composites Part B: Engineering*, 174(May), 106956.
<https://doi.org/10.1016/j.compositesb.2019.106956>
- Benin, S. R., Kannan, S., Bright, R. J., & Jacob Moses, A. (2020). A review on mechanical characterization of polymer matrix composites & its effects reinforced with various natural fibres. *Materials Today: Proceedings*, 33(xxxx), 798–805.
<https://doi.org/10.1016/j.matpr.2020.06.259>
- Bhutani, U., & Majumdar, S. (2017). Natural fibre envelope for cross-linked and non-cross-linked hydrogel-drug conjugates: Innovative design for oral drug delivery. *Materials Discovery*, 8, 1–8. <https://doi.org/10.1016/j.md.2017.10.001>
- Cabanac, G., Labbé, C., & Magazinov, A. (2021). Tortured phrases: A dubious writing style

emerging in science. Evidence of critical issues affecting established journals.
<http://arxiv.org/abs/2107.06751>

- Camlibel, N. O. (2018). Introductory Chapter: Introduction to “Polyester – Production, Characterization and Innovative Applications.” Polyester - Production, Characterization and Innovative Applications. <https://doi.org/10.5772/intechopen.74422>
- Cimbala, M. J. (2014). Taguchi Orthogonal Arrays. Instrumentation, Measurements, and Statistics, September, 4–6.
https://www.mne.psu.edu/me345/Lectures/Taguchi_orthogonal_arrays.pdf
- Daraloma, O. O., Adediran, A. A., Adewuyi, B. O., & AdewoleE, O. (2017). Mechanical properties and water absorption behaviour of treated pineapple leaf fibre reinforced polyester matrix composites. Leonardo Journal of Sciences, 16(30), 15–30.
- Das, G., & Biswas, S. (2016). Effect of fiber parameters on physical, mechanical and water absorption behaviour of coir fiber-epoxy composites. Journal of Reinforced Plastics and Composites, 35(8), 628–637. <https://doi.org/10.1177/0731684415626594>
- Das, S. C., Paul, D., Fahad, M. M., Das, M. K., Rahman, G. M. S., & Khan, M. A. (2018). Effect of Fiber Loading on the Dynamic Mechanical Properties of Jute Fiber Reinforced Polypropylene Composites. Advances in Chemical Engineering and Science, 08(04), 215–224. <https://doi.org/10.4236/aces.2018.84015>
- Egbo, M. K. (2021). A fundamental review on composite materials and some of their applications in biomedical engineering. Journal of King Saud University - Engineering Sciences, 33(8), 557–568. <https://doi.org/10.1016/j.jksues.2020.07.007>
- Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000-2010. Progress in Polymer Science, 37(11), 1552–1596.
<https://doi.org/10.1016/j.progpolymsci.2012.04.003>
- Faruque, A. Al, & Bilisik, K. (2020). Plant-Based Natural Fibre Reinforced Composites : A Review on Fabrication , Properties and Applications. 1–34.
- Feng, N. L., Malingam, S. D., Ping, C. W., & Razali, N. (2020). Mechanical properties and water

- absorption of kenaf/pineapple leaf fiber-reinforced polypropylene hybrid composites. *Polymer Composites*, 41(4), 1255–1264. <https://doi.org/10.1002/pc.25451>
- Gebino, G., & Muhammed, N. (2018). Extraction and characterization of ethiopian pineapple leaf fiber. *International Journal on Textile Engineering and Processes*, 4(3), 20–26.
- Groover, M. (2020). *Fundamentals of modern manufacturing: materials, processes, and systems*. <https://books.google.com/books?hl=en&lr=&id=mB7zDwAAQBAJ&oi=fnd&pg=PA1&dq=Groover+2020&ots=H1hgd97sEY&sig=qYhc1rUzTwj710v5Vn4fPsnxoO0>
- Hossain, M. A., Sahadat Hossain, M., Khan, R. A., Sarwaruddin Chowdhury, A. M., Hossain, R. A., Khan, A. M., & Sarwaruddin, C. (2022). Preparation and Characterization of Pineapple Leaf Fiber Reinforced Epoxy Composite: Effect of Gamma Radiation. *Advances in Applied Sciences*, 7(3), 65–72. <https://doi.org/10.11648/j.aas.20220703.15>
- Huang, L., Mu, B., Yi, X., Li, S., & Wang, Q. (2018). Sustainable Use of Coffee Husks For Reinforcing Polyethylene Composites. *Journal of Polymers and the Environment*, 26(1), 48–58. <https://doi.org/10.1007/s10924-016-0917-x>
- Hymete, A., Rohloff, J., & Iversen, T. H. (2006). Essential oil from seeds and husks of *Aframomum corrorima* from Ethiopia. *Flavour and Fragrance Journal*, 21(4), 642–644. <https://doi.org/10.1002/ffj.1634>
- Indra Reddy, M., Anil Kumar, M., & Rama Bhadri Raju, C. (2018). Tensile and Flexural properties of Jute, Pineapple leaf and Glass Fiber Reinforced Polymer Matrix Hybrid Composites. *Materials Today: Proceedings*, 5(1), 458–462. <https://doi.org/10.1016/j.matpr.2017.11.105>
- Ismail, M., Rejab, M. R. M., Siregar, J. P., Mohamad, Z., Quanjin, M., & Mohammed, A. A. (2020). Mechanical properties of hybrid glass fiber/rice husk reinforced polymer composite. *Materials Today: Proceedings*, 27(XXXX), 1749–1755. <https://doi.org/10.1016/j.matpr.2020.03.660>
- Jose, S., Salim, R., & Ammayappan, L. (2016). An Overview on Production, Properties, and Value Addition of Pineapple Leaf Fibers (PALF). *Journal of Natural Fibers*, 13(3), 362–

373. <https://doi.org/10.1080/15440478.2015.1029194>

- Karimah, A., Ridho, M. R., Munawar, S. S., Adi, D. S., Ismadi, Damayanti, R., Subiyanto, B., Fatriasari, W., & Fudholi, A. (2021). A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations. *Journal of Materials Research and Technology*, 13, 2442–2458. <https://doi.org/10.1016/j.jmrt.2021.06.014>
- Karthick, R., Adithya, K., Hariharaprasath, C., & Abhishek, V. (2018). Evaluation of mechanical behavior of banana fibre reinforced hybrid epoxy composites. *Materials Today: Proceedings*, 5(5), 12814–12820. <https://doi.org/10.1016/j.matpr.2018.02.265>
- Kerni, L., Singh, S., Patnaik, A., & Kumar, N. (2020). A review on natural fiber reinforced composites. *Materials Today: Proceedings*, 28(xxxx), 1616–1621. <https://doi.org/10.1016/j.matpr.2020.04.851>
- Khalid, M. Y., Imran, R., Arif, Z. U., Akram, N., Arshad, H., Rashid, A. Al, & Márquez, F. P. G. (2021). Developments in chemical treatments, manufacturing techniques and potential applications of natural-fibers-based biodegradable composites. *Coatings*, 11(3), 1–18. <https://doi.org/10.3390/coatings11030293>
- Kuan, H. T. N., Tan, M. Y., Shen, Y., & Yahya, M. Y. (2021). Mechanical properties of particulate organic natural filler-reinforced polymer composite: A review. *Composites and Advanced Materials*, 30, 263498332110075. <https://doi.org/10.1177/26349833211007502>
- Kumar, N., & Singh, A. (2020). Study the effect of fiber orientation on mechanical properties of bidirectional basalt fiber reinforced epoxy composites. *Materials Today: Proceedings*, 39(xxxx), 1581–1587. <https://doi.org/10.1016/j.matpr.2020.05.707>
- Kumar, S., Prasad, L., Patel, V. K., Kumar, V., Kumar, A., Yadav, A., & Winczek, J. (2021). Physical and mechanical properties of natural leaf fiber-reinforced epoxy polyester composites. *Polymers*, 13(9). <https://doi.org/10.3390/polym13091369>
- Kumar, S., Zindani, D., Bhoomani, R., & Kumar, K. S. (2019). Study the mechanical properties of corncob husk filler reinforced epoxy composite. *AIP Conference Proceedings*, 2200(December). <https://doi.org/10.1063/1.5141265>

- M, S. K., Raghul, R., Balaguru, I., & Ganesh, K. M. M. (2015). Development and Testing of Coir Fiber Reinforced Sandwich Panel. 209–215.
- Madhu, P., Sanjay, M. R., Senthamaraikannan, P., Pradeep, S., Saravanakumar, S. S., & Yogesha, B. (2019). A review on synthesis and characterization of commercially available natural fibers: Part-I. *Journal of Natural Fibers*, 16(8), 1132–1144.
<https://doi.org/10.1080/15440478.2018.1453433>
- Mehamud, I., Raj, J., & Zeleke, C. (2016). Fabrication and Mechanical Property Evaluation of Ethiopia Banana Fiber Reinforced Polymer Composites. *Advances in Research*, 7(5), 1–10.
<https://doi.org/10.9734/air/2016/26991>
- Mohankumar, D., Amarnath, V., Bhuvaneswari, V., Saran, S. P., Saravananaraj, K., Srinivasa Gogul, M., Sridhar, S., Kathiresan, G., & Rajeshkumar, L. (2021). Extraction of plant based natural fibers – A mini review. *IOP Conference Series: Materials Science and Engineering*, 1145(1), 012023. <https://doi.org/10.1088/1757-899x/1145/1/012023>
- Motaleb, K. Z. M. A., Islam, M. S., & Hoque, M. B. (2018). Improvement of Physicomechanical Properties of Pineapple Leaf Fiber Reinforced Composite. *International Journal of Biomaterials*, 2018. <https://doi.org/10.1155/2018/7384360>
- Noumi, E., Snoussi, M., Alreshidi, M. M., Rekha, P. D., Saptami, K., Caputo, L., De Martino, L., Souza, L. F., Msaada, K., Mancini, E., Flamini, G., Al-Sieni, A., & De Feo, V. (2018). Chemical and biological evaluation of essential oils from cardamom species. *Molecules*, 23(11). <https://doi.org/10.3390/molecules23112818>
- Omkumar, M., & Selvakumar, K. (2018). Mechanical Characterization of pineapple leaf fiber and corn husk powder reinforced epoxy composites. 1, 571–580.
<https://doi.org/10.21452/bccm4.2018.10.01>
- Onyekwere, O. S., Oladeinde, M. H., & Edokpia, R. O. (2021). Multi-Response Optimization of Bamboo Fiber Reinforced Unsaturated Polyester Composites using Hybrid Taguchi–Grey Relational Analysis Method. *Journal of Industrial and Production Engineering*, 38(2), 98–107. <https://doi.org/10.1080/21681015.2020.1848933>

- Ouarhim, W., Zari, N., Bouhfid, R., & Qaiss, A. E. K. (2018). Mechanical performance of natural fibers-based thermosetting composites. *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*, 43–60. <https://doi.org/10.1016/B978-0-08-102292-4.00003-5>
- Pomy, S. J. (2023). Analysis of Cardamom (*Elettaria cardamomum*) Seed and Husk and its Flavor Extracted by Different Extraction Methods.
- Potluri, R. (2019). Mechanical Properties of Pineapple Leaf Fiber Reinforced Epoxy Infused with Silicon Carbide Micro Particles. *Journal of Natural Fibers*, 16(1), 137–151. <https://doi.org/10.1080/15440478.2017.1410511>
- Prabhakar, M. N., Shah, A. ur rehman, & Song, J.-I. (2015). Thermal and Mechanical Properties of Waste Ground Nut-shell Reinforced Polyester Composites. *Composites Research*, 28(3), 118–123. <https://doi.org/10.7234/composres.2015.28.3.118>
- Prasad, G. L. E., Megha, B. E., & Gowda, B. S. K. (2019). Study of Mechanical Characteristics of Banana and Jute Fiber Reinforced Polyester Composites. 5.
- Praveena, B. A., Shetty, B. P., Akshay, A. S., & Kalyan, B. (2020). Experimental study on mechanical properties of pineapple and banana leaf fiber reinforced hybrid composites. *AIP Conference Proceedings*, 2274(October). <https://doi.org/10.1063/5.0022381>
- Rahmawati, D., Mansur, D., Sulaswatty, A., & Diastuti, H. (2022). Conversion of Cardamom By-product into Liquid Smoke and Biochar by Pyrolysis. *Malaysian Journal of Chemistry*, 24(2), 293–301. <https://doi.org/10.55373/mjchem.v24i2.293>
- Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. *Polymers*, 11(10). <https://doi.org/10.3390/polym11101667>
- Saha, A., Kumar, S., & Kumar, A. (2021). Influence of pineapple leaf particulate on mechanical, thermal and biodegradation characteristics of pineapple leaf fiber reinforced polymer composite. *Journal of Polymer Research*, 28(2). <https://doi.org/10.1007/s10965-021-02435-y>

- Sahu, P., & Gupta, M. K. (2020). A review on the properties of natural fibres and its bio-composites: Effect of alkali treatment. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, 234(1), 198–217. <https://doi.org/10.1177/1464420719875163>
- Sajan, S., & Philip Selvaraj, D. (2021). A review on polymer matrix composite materials and their applications. *Materials Today: Proceedings*, 47(xxxx), 5493–5498. <https://doi.org/10.1016/j.matpr.2021.08.034>
- Sathish, S., Karthi, N., Prabhu, L., Gokulkumar, S., Balaji, D., Vigneshkumar, N., Ajeem Farhan, T. S., Akilkumar, A., & Dinesh, V. P. (2021). A review of natural fiber composites: Extraction methods, chemical treatments and applications. *Materials Today: Proceedings*, 45, 8017–8023. <https://doi.org/10.1016/j.matpr.2020.12.1105>
- Senthilkumar, K., Saba, N., Chandrasekar, M., Jawaid, M., Rajini, N., Alothman, O. Y., & Siengchin, S. (2019). Evaluation of mechanical and free vibration properties of the pineapple leaf fibre reinforced polyester composites. *Construction and Building Materials*, 195, 423–431. <https://doi.org/10.1016/j.conbuildmat.2018.11.081>
- Shaikh, N. T., Patil, Y. H., & Godse, S. P. (2019). Design and Development of Natural Composite Material. 2659–2667.
- Sharan Gupta, U., Dharkar, A., Dhamarikar, M., Choudhary, A., Wasnik, D., Chouhan, P., Tiwari, S., & Namdeo, R. (2021). Study on the effects of fiber orientation on the mechanical properties of natural fiber reinforced epoxy composite by finite element method. *Materials Today: Proceedings*, 45, 7885–7893. <https://doi.org/10.1016/j.matpr.2020.12.614>
- Sharma, A. K., Bhandari, R., Aherwar, A., & Rimašauskiene, R. (2020). Matrix materials used in composites: A comprehensive study. *Materials Today: Proceedings*, 21(xxxx), 1559–1562. <https://doi.org/10.1016/j.matpr.2019.11.086>
- Somaiah Chowdary, M., Raghavendra, G., Niranjana Kumar, M. S. R., Ojha, S., Anupama Ammulu, M., & Prasanthi, P. P. (2022). Evaluation of mechanical and tribological properties of nano clay reinforced Kevlar/Sisal polyester composites. *Polymer Composites*, 43(12), 8860–8868. <https://doi.org/10.1002/pc.27067>

- Sударsono, S., Hidayat, H., Othman, R., & Aminur, A. (2019). Mechanical Properties of Particulate Coconut Shell and Palm Fiber Reinforced Polymer Matrix Composites. 4(4), 141–147. <https://doi.org/10.4108/eai.1-4-2019.2287230>
- Sumesh, K. R., & Kanthavel, K. (2022). Grey relational optimization for factors influencing tensile, flexural, and impact properties of hybrid sisal banana fiber epoxy composites. *Journal of Industrial Textiles*, 51(3), 4441S-4459S. <https://doi.org/10.1177/1528083720928501>
- Thakur, P., Teli, S. N., & Lad, S. (2019). Multiobjective optimization in drilling of composites. *Lecture Notes in Mechanical Engineering*, January, 279–286. https://doi.org/10.1007/978-981-13-2490-1_25
- Todkar, S. S., & Patil, S. A. (2019). Review on mechanical properties evaluation of pineapple leaf fibre (PALF) reinforced polymer composites. In *Composites Part B: Engineering* (Vol. 174). Elsevier Ltd. <https://doi.org/10.1016/j.compositesb.2019.106927>
- Treilles, R., Cayla, A., Gaspéri, J., Strich, B., Ausset, P., & Tassin, B. (2020). Impacts of organic matter digestion protocols on synthetic, artificial and natural raw fibers. *Science of the Total Environment*, 748, 141230. <https://doi.org/10.1016/j.scitotenv.2020.141230>
- Van, H. T., Pham, T. V., Nguyen, H. T. D., Nguyen, N. A., & Truong, D. H. (2021). A review on chemical constituents of essential oils of *Aframomum* genus. *Journal of Phytology*, 13, 161–170. <https://doi.org/10.25081/jp.2021.v13.7249>
- Veerakumar, P., Rajkumar, C., Chen, S., & Lin, K. (2018). Activated porous carbon supported rhenium composites as electrode materials for electrocatalytic and supercapacitor applications. *Electrochimica Acta*. <https://doi.org/10.1016/j.electacta.2018.03.165>
- Vikas Sahu. (2015). Mechanical Properties Of Sisal And Pineapple Fiber Hybrid Composites Reinforced With Epoxy Resin. *Ijmer*, 5(1), 32–387. http://www.ijmer.com/papers/Vol5_Issue1/Version-1/E0501_01-3238.pdf
- Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., & Zainudin, E. S. (2016). Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner

application. Defence Technology, 12(1), 52–58. <https://doi.org/10.1016/j.dt.2015.08.005>

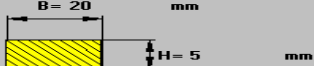
Zakir, M. (2018). Review on Korarima (*Aframomum Corrorima* (Braun) P.C.M. Jansen) Research Achievements, Challenges and Future Prospective in Ethiopia. International Journal of Research Studies in Agricultural Sciences, 4(1), 29–36. <https://doi.org/10.20431/2454-6224.0401005>

Flexural strength

Flectional strength

form of specimen

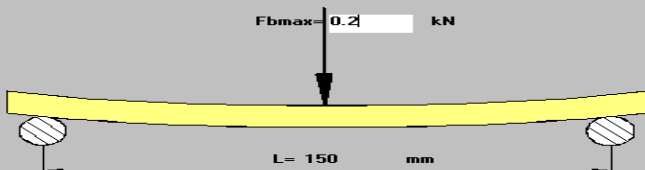
☒ Flat specimen



B = 20 mm
H = 5 mm

☐ Round specimen

Force F_{bmax} = 0.2 kN



L = 150 mm

Flectional strength

$$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 90.00 \text{ N/mm}^2$$

Calculate Test report Cancel

Flectional strength

form of specimen

☒ Flat specimen

☐ Round specimen

B = 20 mm
H = 5 mm

F_{bmax} = 0.21 kN

L = 150 mm

Flectional strength

$$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 94.50 \text{ N/mm}^2$$

Calculate

Test report

Cancel

Flectional strength

form of specimen

☒ Flat specimen

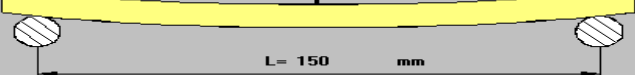


B = 20 mm
H = 5 mm

☐ Round specimen

$$W_b = \frac{B \cdot H^2}{6}$$

Fbmax = 0.16 kN



L = 150 mm

Flectional strength

$$\sigma_{b,B} = \frac{M_{b,max}}{W_b} = 72.00 \text{ N/mm}^2$$

Calculate

Test report

Cancel

Flectional strength

form of specimen

☒ Flat specimen

☐ Round specimen

$B = 20$ mm

$H = 5$ mm

$F_{bmax} = 0.14$ kN

$L = 150$ mm

$W_b = \frac{B \cdot H^2}{6}$

$M_{bmax} = \frac{F_{max} \cdot L}{4}$

Electional strength

$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 63.00 \text{ N/mm}^2$

Calculate

Test report

Cancel

Flectional strength

form of specimen

☒ Flat specimen

☐ Round specimen

$B = 20$ mm

$H = 5$ mm

$F_{bmax} = 0.15$ kN

$L = 150$ mm

$W_b = \frac{B \cdot H^2}{6}$

$M_{bmax} = \frac{F_{max} \cdot L}{4}$

Electional strength

$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 67.50 \text{ N/mm}^2$

Calculate

Test report

Cancel

Flectional strength

form of specimen

☒ Flat specimen

☐ Round specimen

$B = 20$ mm

$H = 5$ mm

$F_{bmax} = 0.12$ kN

$L = 150$ mm

$W_b = \frac{B \cdot H^2}{6}$

$M_{bmax} = \frac{F_{max} \cdot L}{4}$

Electional strength

$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 54.00 \text{ N/mm}^2$

Calculate

Test report

Cancel

Flectional strength

form of specimen

☒ Flat specimen

B= 20 mm

H= 5 mm

☐ Round specimen

Fbmax= 0.11 kN

L= 150 mm

Electional strength

$$\sigma_{b,B} = \frac{M_{bmax}}{W_b} = 49.50 \text{ N/mm}^2$$

$$W_b = \frac{B \cdot H^2}{6}$$

$$M_{bmax} = \frac{F_{max} \cdot L}{4}$$

Calculate

Test report

Cancel

Appendix B

Hardness test

Measurement Settings

Type: Vickers

Weight: 10 kg.f

Std Val. Define Std. Max: 0 Min: 0

Data[d]

d1 = 654.1 um d2 = 792.1 um

☐ d2 = d1 (Always)

Hardness[H]

HV = 35.5

Conversion Values

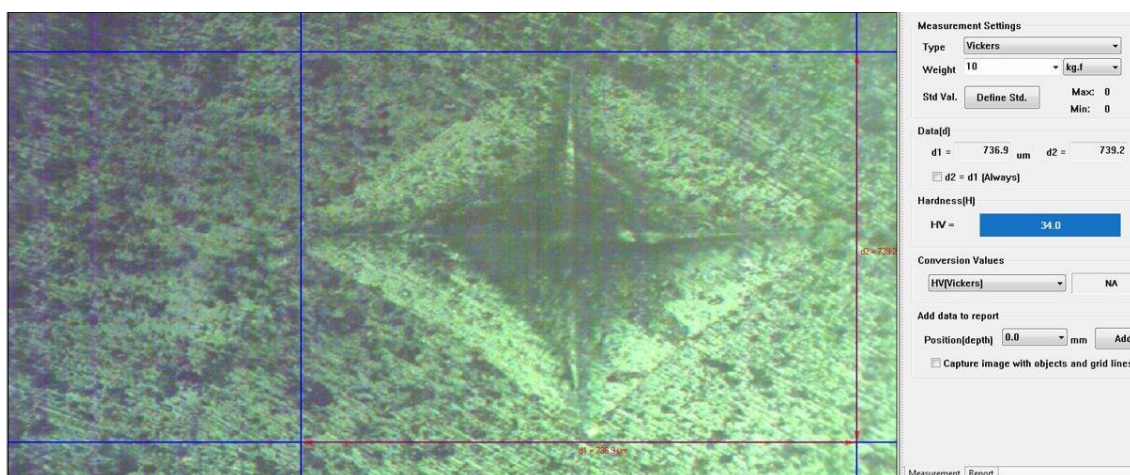
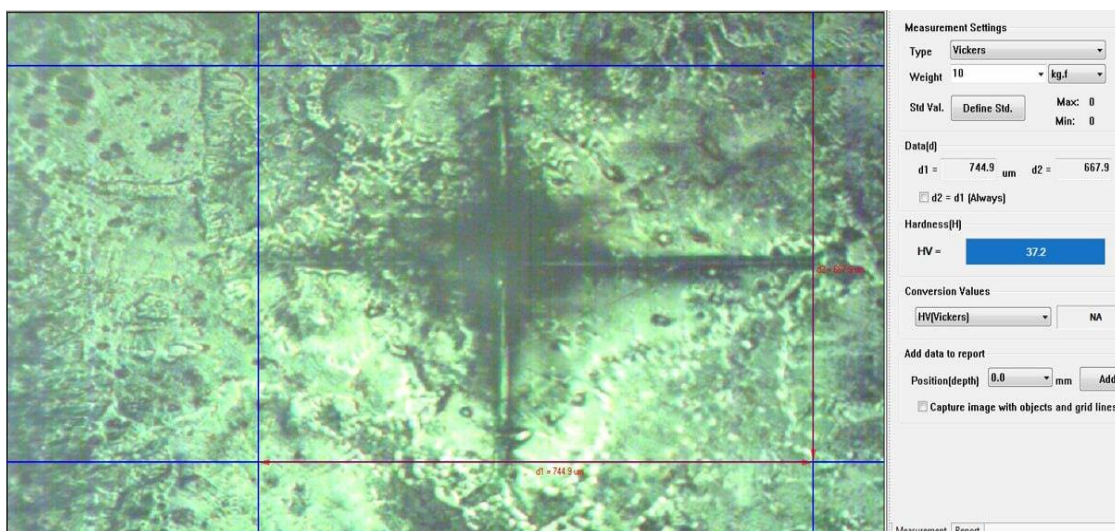
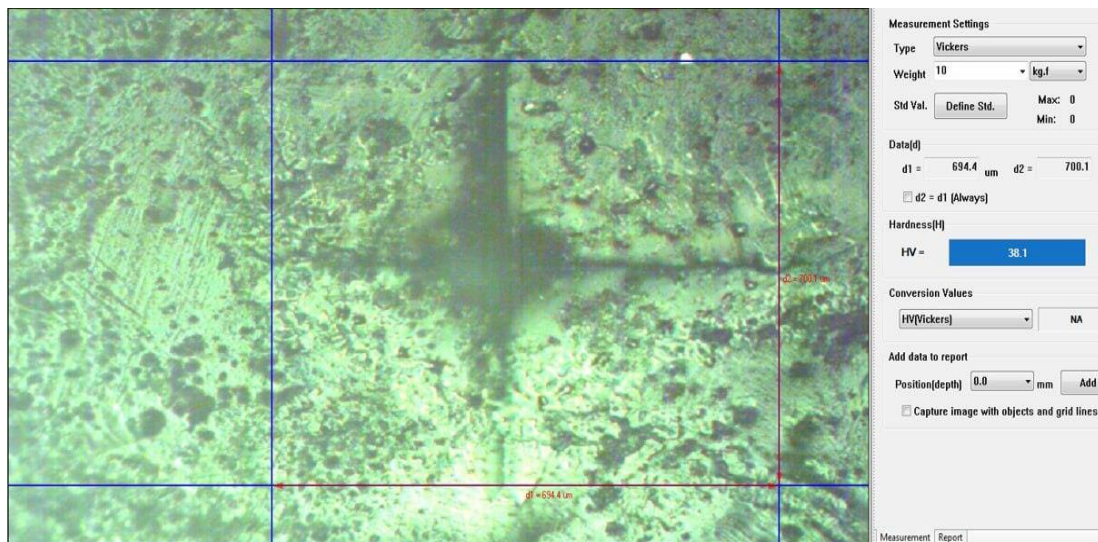
[HV(Vickers)] NA

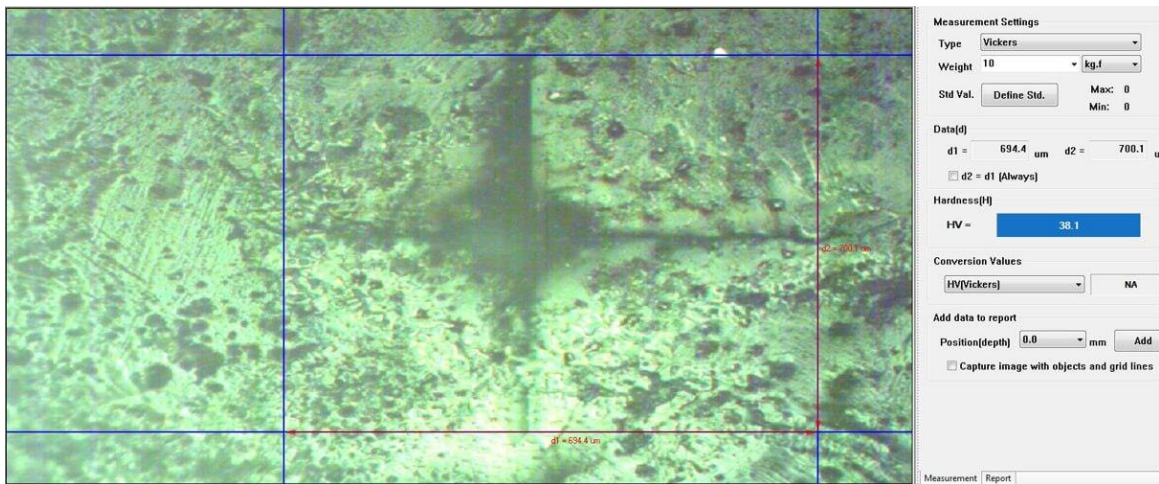
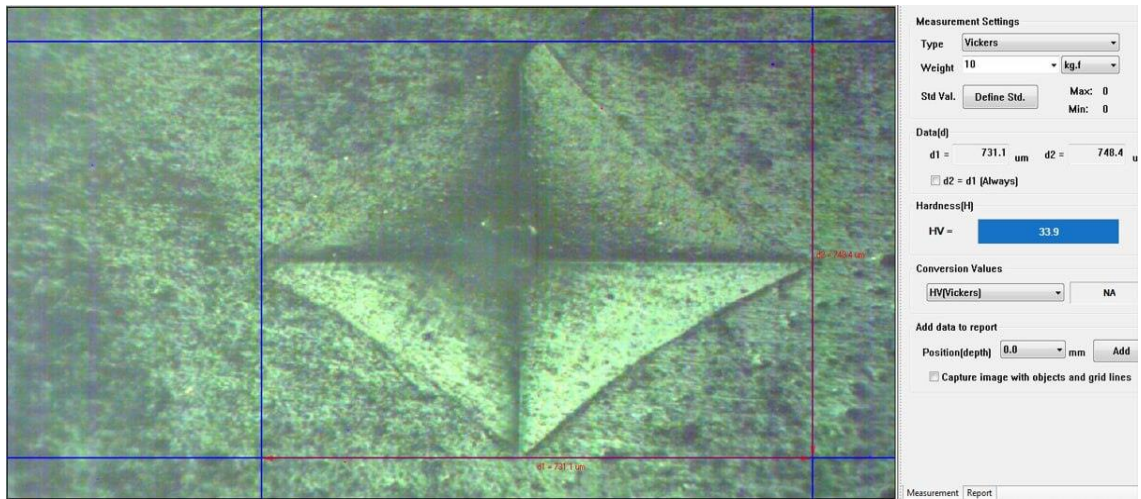
Add data to report

Position(depth) 0.0 mm Add

☐ Capture image with objects and grid lines

Measurement Report





Appendix C

Morphology

