Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite with Silicon Carbide and Coffee Husk

Melkamu Mekonnen Regassa

A Thesis Submitted to the department of Mechanical Engineering,

School of Mechanical, Chemical and Material 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-2023
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis, entitled **"Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite with Silicon Carbide and Coffee Husk** ," is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Name of student	Signature	Date

RECOMMENDATION OF ADVISORS

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "**Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite with Silicon Carbide and Coffee Husk,**" prepared under our guidance by **Melkamu Mekonnen Regassa** submitted in partial fulfillment of the requirements for the degree of Mater‘s of Science in Manufacturing Engineering.

Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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Major Advisor	Signature	Date
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Co-Advisor	Signature	Date

APPROVAL PAGE

We, the advisors of the thesis entitled "**Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite with Silicon Carbide and Coffee Husk**," and developed by **Melkamu Mekonnen Regassa**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Melkamu Mekonnen Regassa** have read and evaluated the thesis entitled "**Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite with Silicon Carbide and Coffee Husk**," and examined the candidate during an 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.

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LIST OF ACRONYMS

Al_2O_3	Aluminum oxide
AMMC	Aluminum Metal Matrix Composite
ANOVA	Analysis of variance
ASTM	American society for testing and materials
ASTU	Adama Science and Technology University
BM	Bending modulus
BS	Bending strength
CHFW	Coffee husk fiber waste
CM	Composite Materials
CMC	Ceramic Matrix Composites
DOE	Design of Experiment
DOF	Degree of Freedom
DUEC	Defense University of Engineering College
EP	Epoxy polymer
FC	Flexural compressive
FRP	Fiber Reinforced Polymer
FTIR	Fourier Transform Infrared radiation
GF	Glass fiber
GFRP	Glass Fiber Reinforced Polymer
GRA	Grey Relation Analysis
GRG	Grey Relation Grade
H	Hardness
HDF	High Density Fiberboard
HNTs	Halloysite nanotubes
HRC	Rockwell Hardness
IM	Impact modulus
IS	Impact strength
ISO	International Organization for Standardization
KPa	Kilopascal
MEKP	Methyl ethyl ketone peroxide
MMCs	Metal matrix composites
MPa	Mega pascal

MTL	Material Testing Lab
NFs	Natural fibers
NAOH	Sodium hydroxide
NF	Nettle fiber
NFRPC	Natural Fiber-Reinforced Polymer Composite
OA	Orthogonal Array
OPEFB	Oil Palm Empty Fruit Bunch
PALF	Pineapple leaf fiber
PE	Polyethylene
PLA	Polylactide
PMCs	Polymer Matrix Composites
PP	Polypropylene
PRP	Particle Reinforced Polymer Composites
PVC	Poly-Vinyl-Chloride
RPM	Revolution per minute
RSM	Response surface methodology
S/N	Signal to Noise ratio
S1	Sample one
SEM	Scanning electron microscopy
SF	Sisal fiber
SHS	Superheated steam
TCHF	Torrefied coffee husk flour
TGA	Thermogravimetric analyzer
TM	Tensile modulus
TS	Tensile strength
UP	Unsaturated Polyester Resin
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
XRD	X-ray Diffractometry
YS	Yield Strength

LIST OF ABBREVIATIONS

𝒫a	Actual density (g/cm3)
𝒫	Density (g/cm3)
𝒫c	Density of composite (g/cm3)
𝒫f	Density of fiber (g/cm3)
𝒫m	Density of matrix (g/cm3)
𝒫p	Density of particle (g/cm3
𝒫t	Theoretical density (g/cm3)
𝒫W	Density of water (g/cm3)
Mc	Mass of composite (g)
Mf	Mass of fiber (g)
Mm	Mass of matrix (g)
Mp	Mass of particle (g)
VF	Volume fraction of fiber
VP	Volume fraction of particle
VM	Volume fraction of matrix
Vc	Volume of composite (mm3)
Vf	Volume of fiber (mm3)
Vp	Volume of particle (mm3)
Vm	Volume of matrix (mm3)
Vv	Volume fraction of voids
S1	Specimens 1
S1, S2, ..., S9	Sample (one, two, ..., nine)
L'	Diagonal of square impression (mm)
P'	Number of factors
VOL.%	Volume percentage
W1	Weight of the dry specimen
W2	Weight of the wet specimen
Wa	Weight of composite in air
Ww	Weight of composite in water
%EB	Percentage of elongation
wt.%	Weight percentage

ABSTRACT

Natural fiber composites are attractive materials for engineering and industrial applications because of their, light weight, high hardness, high strength-to-weight ratio, biodegradability and high tensile strength. The weaker fire resistance and high moisture absorption rate are the drawbacks of natural fibers. However, chemically treating the fiber and adding filler to the composite were utilized to reduce water absorption and change the surface characteristics of the fiber. The goal of this thesis work is to use hand layup techniques to fabricate a light weight, hard, and strong composite of pineapple leaf fiber reinforced polyester matrix composite with silicon carbide and coffee husk at different weight compositions and fiber orientations. The mechanical properties like tensile strength, flexural strength, hardness, impact strength, and physical properties like water absorption, actual density, void content with morphological analysis of the composite were studied. Minitab software, Taguchi L9 and grey relational analysis was used to analyze the statistical study of the response versus parameter and determine the relevance of each parameter. The hybrid composite fabrication was used meticulously prepared for physical, mechanical, and morphological tests in accordance with ASTM standards. The results revealed that maximum average tensile, flexural strength, hardness and impact strength were 34.8 MPa, 174.88 MPa,40.6 HV and 6J respectively. The was a minimum value of 0.235%. The minimum values of water absorption, actual density and void content of composite were 0.235%, 1.169 g/cm3 and 0.59% respectively. The results indicate that coffee husk and silicon carbide powder used as filler materials and pineapple leaf fiber as reinforcements in this study improved the mechanical properties of the developed composite. From Grey Relational Analysis, the optimum values for multi-response characteristics has been obtained at A2B1C3D2. Fabricated composite used in automotive application such as bicycle mud guard and engine under cover.

Keywords: Composites, Pineapple leaf fiber, Coffee husk fiber , Hand lay-up, Polyester, silicon carbide.

CHAPTER ONE

INTRODUCTION

1.1 Introduction to Composite Materials

Composite materials are heterogeneous mixtures of two or more homogeneous phases to create a new material with superior properties to the parent components. Consider a matrix made of fibers, fillers, and polymers. In many industrial uses, such as automotive and aerospace applications, modern engineering applications ask for lightweight materials with a high strength-to-weight ratio that are also more affordable, stronger, and replace conventional engineering materials (metals and wood). (Saha et al., 2021).

These days, natural fiber-reinforced polymer composites are preferred over synthetic fiber-reinforced polymer composites because they are more environmentally friendly, readily available, long-term renewable, biodegradable, safe for human health, highly flexible, require younger plants, are more affordable, are simpler to collect, and are accessible in more places (Mittal et al., 2016). Natural fibers like wood, bamboo, oil palm, cotton, wheat straw, coffee husk, date palm, peanut shell, and bagasse are frequently utilized with polymer matrix composites (Yan et al., 2016); (Jiru et al., 2022). Due to its widespread availability, biodegradability, high mechanical strength, and high cellulose concentration, pineapple leaf fiber (PALF), one of these, is most frequently utilized as a natural fiber. Additionally, they demonstrate increased strength, modulus, durability, ease of production, low density, and affordability (Senthilkumar et al., 2019). These fibers are lignocellulosic and multicellular. They are obtained through retting from the leaves of the Bromeliaceae species Ananus cosomus. Ash (1.1%), cellulose (70-80%), and lignin (5%–12%) are all present in PALF (Nugraha and Juwono, 2019).

The use of discontinuous or randomly dispersed PALF-based micro- and nanoparticles has the potential to improve biological devices, building materials, and vehicle parts. In-depth research was done on the mechanical properties of PALF reinforced composites made with various resins, such as polyester, vinyl ester, and epoxy, as well as with different fiber loading and fiber orientations (Hoque et al., 2021) These benefits have made PALF the best choice for making composite materials, which has led to its use in construction and a variety of other applications (Jiru, 2021). However, there are drawbacks to using natural fibers as composite reinforcement, such as adhesion issues with the most hydrophobic polymer matrices and high moisture absorption.

Researchers and scientists use a range of methods, such as adding filler, treating the fiber surface, and others, to improve the mechanical properties. Chemical treatments using sodium hydroxide (NaOH), which removes impurities like pectin, facts, and lignin from the fiber, are consequently taken into account for changing the fiber surface characteristics (Girisha et al., 2012). As a result, mechanical qualities including tensile, flexural, and compression strength are improved (Ramesh et al., 2013). It also strengthens the link between the fiber and the matrix.

The second phase of composite materials is matrix can be polymers, metals, or ceramics. Polymers were selected from the aforementioned matrix because of their excellent mechanical and physical properties, simplicity in production, low cost, and simplicity in use (Hoque et al., 2021). Unsaturated polyester resin (UPR), epoxy resin, polypropylene (PP), and polyethylene (PE) are a few examples of commonly used polymer matrices for fiber-reinforced composite materials (Hoque et al., 2021).

1.2 Problem statement

Lightweight materials that are strong for their weight, affordable, robust, and lightweight are required for modern engineering applications. Composite materials are now replacing conventional engineering materials (metals and wood) with natural fiber-reinforced polymer composites for use in several industrial applications, automotive, and aerospace applications due to their better mechanical and physical properties or high strength to weight ratio. With the help of various petroleum-based polymer matrices, synthetic fibers including carbon, glass, and Kevlar have been used as reinforcement in the production of composites for a variety of technical applications. However, because of serious drawbacks like non-renewability, non-biodegradability, non-recyclability, high processing energy needs, and restricted availability. Natural fiber/filler based composites are attracting more and more attention from scientists and engineers (Gurunathan et al., 2015); (Väisänen et al., 2017).

PALF-reinforced polyester composites have demonstrated a considerable improvement in mechanical, thermal, and physical qualities among natural fibers. Artificial fibers make environmental pollution and are hazardous to human health. However, natural fiber (PALF) composites have a number of disadvantages over synthetic composites, such as higher moisture absorption, poorer fire resistance, and weaker mechanical qualities (Hamritha et al., 2020). Coffee husk filler (CHF) can be wasted if it is kept for an extended period of time or is trimmed to fit the design when making parts, among other reasons. There are few works that used coffee husk as a filler material with another natural fiber-reinforced polymer matrix composite. Utilizing leftover coffee husks in place of pricey fillers in polyester reinforced with pineapple leaf fiber to improve the material's mechanical and physical qualities. It is necessary to analyze mechanical and physical qualities while considering various factors.

Reusable waste material: the coffee industry produces wastes such as coffee husk that are usually dumped in the open. Also, pineapple leaf thrown as waste material. Generally, to use solid wastes generated by industrial and agricultural activities.

Exploitation of natural resources: huge amount of natural resources used in composite fabrication for industrial applications.

Sustainable material for environment: It means having the least destructive impact on environment and least wasting of energy. Efforts to conserve environment and to reduce resource consumption require the use of sustainable or recycled materials.

1.3 Objective

The general objective of the study is to fabricate and characterize pineapple leaf fiber reinforced polyester matrix composite with silicon carbide and coffee husk.

1.3.1 Specific objective

1. To fabricate hybrid composite using different composition ratio and fiber orientation via hand layup technique.
2. To investigate mechanical properties such as tensile strength, impact strength, flexural strength and hardness.
3. To investigate the physical properties like water absorption, density and void contents.
4. To study the effect of fillers, fiber orientation and weight percentage composition on physical and mechanical properties.
5. To optimize its parameters using single and multi-response characteristics.

1.4 Significance of the study

The goal of the proposed study is to fabricate pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk used coffee grounds and pineapple leaves in place of more expensive fillers and fibers. This will also lessen the impact on the environment and water absorption while improving the mechanical and thermal properties of the pineapple leaf fiber-reinforced polyester. As a result, it offers significant advantages for people and other stakeholders at the national and international levels both academically and practically. The pineapple leaf fiber (PALF) is the most underutilized agronomic waste in terms of value additions from natural fiber. As a result, this waste can be used to create composites for a variety of applications such as infrastructure, furniture, packaging, automotive, biomedical, and so on, which can benefit both the environment and farmers by allowing them to earn money while contributing to the ecological balance system (Todkar and Patil, 2019). It will improve my theoretical and practical understanding of the research field, students who are studying it, future researchers as well as aerospace and auto manufacturing companies, which use this composite material.

1.5 Expected outcome of the study

This study primarily focused on the fabrication and characterization of pineapple leaf fiber reinforced polyester matrix composite filled with coffee husk and silicon carbide. Light and tougher composites to be fabricated. Several results are anticipated from this research work, including improved mechanical and physical properties fabricated composites, morphological property evaluation, and statistical analysis using (Taguchi and GRA).

1.6 Scope of the study

In order to improve mechanical and physical qualities, the research primarily focused on the fabrication and characterization of PALF/CHF/SiC polyester reinforced composite's mechanical and physical properties as well as the investigation of morphological properties. The fabrication of PALF/CHF/SiC polyester-reinforced composites with 0°/90°, 45° fiber orientation and chopped of pineapple leaf fiber with alkali treatment and using different weight percentage ratio of compositions was covered in this research work, as is the study's preparation of specimens for examination of physical properties (water absorption, density and void contents), mechanical properties (tensile strength, hardness, impact strength, and flexural strength) and morphological property, using Taguchi (S/N ratio and GRA) for optimization parameter. Composite testing was done on the locally available testing facilities as per the standards of different ASTM.

1.7 Limitation of the study

The major limitation of this thesis study was non-availability of epoxy matrix supply in our country, Ethiopia. This was due to its flammable properties not allowed to import to this country. Due to this case, an epoxy matrix was replaced by a polyester matrix. There are also some limitations;

- The non-availability of a pineapple leaf decortication and waving machine for fiber extraction and waving of the fiber.
- Non-availability of compression molding machine which is better than hand layup molding composite fabrication for better mechanical properties.

- The laboratories used in this work are found in different corners of the country causing time waste and the environment may affect the result.
- The malfunction of testing machines causes an unwanted reputation of the experiment in another machine and the unwillingness of different authorities for allowing machines to be used by the researcher.
- Non-availability of operator that work on testing machine properly.

1.8 Beneficiary of the study

The beneficiaries of this study were people, manufacturing industries, and automotive industries. The pineapple leaf fibers were applicable to automotive seatbacks, engine under cover, bicycle mud guard, parcel shelves, door panels, spare tire covers, boot liners, and cargo floor trays. Pineapple leaf fibers can be used for applications such as insulating boards, food containers, thermos flasks, refrigeration industry, building materials, interiors of aircraft and automobiles.

1.9 Research Motivation

Due to the growing use of natural in various industries, many researchers have been working on the fabrication and characterization of natural reinforced polymer matrix composite. The enduring issue with pineapple leaf fiber-based composites. however, water absorption has resulted in a low improvement in mechanical and morphological performance.

1.10 Thesis organizations

This thesis entitled “Fabrication and Characterization of Pineapple Leaf Fiber Reinforced Polyester Matrix Composite filled Silicon Carbide and Coffee Husk” consists of five chapters that were organized as follows.

Chapter One: provides the introduction, problem of the statement, objectives, research questions, significance of the study, scope of the study, limitations of the study and beneficiaries of the study were undertaken.

Chapter Two: presents the literature review on Composite materials, classification of composite materials and fibers, manufacturing methods of composite materials, Mechanical properties of PALF reinforced polymer composites, Effect of treated and untreated PALF on polymer composites, Effect of CH filled natural fiber on composites ,Effect of Sic filled natural fibers on composites ,Effect of fiber orientation and weight percentage on composite and Taguchi method optimization techniques.

Chapter Three: deals with the materials and methodology used for the study. This includes materials used, materials preparation, equipment used for the study; experimental procedures, types of tests performed, and design of the experiment by using the Taguchi method and Grey relational analysis were explained.

Chapter 4: In here results and discussion of the characterization of composite material, mechanical and physical properties are performed well and discussed in detail.

Chapter 5: This chapter contains the conclusion, recommendation, future work and appendix of this thesis.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter contains the literature review, summary of the literature, and research gaps. The objective of the literature review was to give the basic knowledge of the present investigation. The literature reviews were prepared on the following points:

- Composite materials
- Classification of composite materials
- Classification of fibers
- Manufacturing methods of composite materials
- Composite materials reinforced with natural fibers
- Mechanical properties of PALF reinforced polymer composites
- Effect of treated and untreated PALF on polymer composites
- Effect of CH filled natural fiber on composites
- Effect of Sic filled natural fibers on composites
- Effect of fiber orientation and weight percentage on composite
- Taguchi method optimization techniques
- Summary of literature review
- Research gap

2.2 Composite materials

A composite is a substance created by mixing two or more substances. The resulting substance has qualities that can surpass those of either of its parents. In the past two decades, composites have attracted a lot of attention, and numerous researchers are engaged in this topic. Discussing major studies pertaining to polymer composites and their properties becomes crucial at this point. The goal of the literature review is to highlight the applicability of the current study and to provide background knowledge on the topics that will be considered in this investigation. Regarding the creation and characterization of polymer composites, various features of polymer composites have been considered. The physical and mechanical characteristics of composites have been discussed in the literature that has already been published. To clarify the necessity for and goals of the current effort, a knowledge gap in the past investigations has been revealed (Gebre and Raj, 2016).

2.3 Classification of composite materials

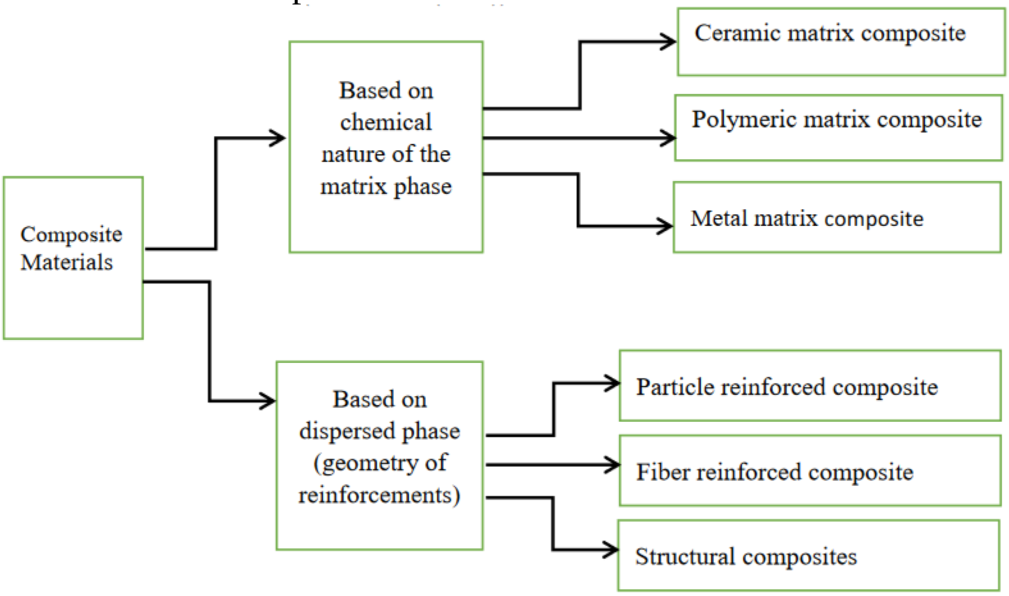

Figure 2. 1 Classification of composites (Kala et al. (2014)).

2.3.1 Metal matrix composite

Metal matrix composites (MMCs) are substances created by incorporating reinforcement in the form of ceramic or metal particles, fibers, whiskers, or even a sheet of metal into a metal or alloy matrix. More than their polymer counterparts, metal matrices provide high strength, fracture toughness, and stiffness. The majority of metals and alloys can be utilized as matrices, and they need reinforcement materials that are both non-reactive and stable across a wide temperature range. However, the decision's guiding factor mostly depends on the matrix material (Sharma et al., 2020). Almost all metals and alloys make effective matrices. Only lightweight metals are able to respond, with their low density serving as a benefit. The current fad matrix metals include titanium, aluminum, and magnesium, which are very beneficial for airplane applications. Alumina and silicon carbide are the two main reinforcing materials used. Continuous or discontinuous fiber reinforcement can be found in metal matrix composites (Kala et al., 2014).

2.3.2 Ceramic matrix composite

The third important kind is ceramic-matrix composites, with silicon carbide fibers fixed in a matrix constructed of borosilicate glass as an example. Because of their ceramic matrix, they are especially well suited for usage in thin, high-temperature components, including those for jet engine parts. The main benefits of ceramic materials over other types of materials include their resistance to oxidation and degradation at high temperatures, as well as their high melting points and compressive strengths. Ceramics unfortunately have relatively low ratings for fracture toughness because they are brittle and susceptible to fracture. Reinforcing ceramic using fibers, whiskers, or other small particles is one way to increase its fracture toughness.

2.3.3 Polymer matrix composite

Common matrix materials for polymer matrix composites is polymers. There are two reasons for this. The mechanical characteristics of polymers are typically insufficient for structural purposes. Their stiffness and strength, in particular, are inferior to those of metals and ceramics. By using polymers to reinforce other materials, these challenges are overcome. Second, processing PMC doesn't necessarily require high pressure or high temperature. The equipment needed to make PMC is also less complicated. Thermosetting and thermoplastic polymer matrix composites are the polymer composites that are used the most frequently in more industries (Sharma et al., 2020).

2.3.3.1 Thermoset Polymer matrix

A cross-link holds the molecules of thermoset polymers, commonly known as resin, chemically together. It is not possible to use them once a cross link has been created. They are used mostly because of how simple it is to manufacture them thanks to their low viscosity. The drawbacks that thermoset polymers face include a short room temperature storage life, a lengthy production process in the mold, and a low strain-to-failure.

The thermoset polymer matrix materials have overall, better economics and high temperature, good mechanical, wetting, and adhesion properties, and easiness for disposal. The most commonly used thermoset resin materials are epoxy, polyester, vinyl ester, and phenolic. Among these polyester properties are strongly depending on the cross-link density. Some of the advantages of the polyester resin are low cost, low specific gravity, easy to handle, low viscous, ability to be made translucent. The disadvantages are high shrinkage, strength and modulus is less than epoxy.

Table 2. 1 Comparison of thermoplastic and thermosetting resin (Nguyen et al., 2017)

Characteristic	Thermoplastics	Thermosets
Tensile properties	Excellent	Excellent
Stiffness properties	Excellent	Excellent
Compression properties	Good	Excellent
strength after impact	Good to excellent	Fair to excellent
Bolted joint properties	Fair	Good
Fatigue resistance	Good	Excellent
Damage Tolerance	Excellent	Fair to excellent
Durability	Excellent	Good to excellent
Maintainability	Fair to poor	Good
Service temperature	Good	Good
Environmental weakness	None of the hydraulic fluid	Moisture
Manufacturing scrap rates	Low	Low
Prepare shelf life and out time	Excellent	Good
Health/safety	Excellent	Excellent

Table 2. 2 Properties of thermoset polymers (Chaudhary and Ahmad,2020)

Name of polymers	Density (gm/cm^3)	Tensile Strength (MPa)	Compression Strength (MPa)	Young's modulus (GPa)	Elongation (%)
Epoxy resin	1.1-1.4	35-100	100-200	3-6	1-6
Polyester resin	1.2-1.5	33	90-250	1-1.3	1.5-1.8
Vinyl ester	1.2-1.4	69-83	100	3.1-3.8	4-7

2.3.4 Short Fiber-Reinforced Composites

Short fibers are utilized in an arbitrary and aligned manner since a composite is an isotropic component, meaning that its strength varies depending on the direction of applied force. The fibers are cut into the necessary lengths and utilized as reinforcement. Prior to employing composites, the qualities of the fibers should be examined because reinforcing affects every aspect of composites' properties. Additionally, utilized as reinforcement are stone or mineral particles. The performance of the composite will be significantly influenced by the adhesion and compatibility between the matrix and reinforcement (USG, 2000).

2.3.5 Continuous Fiber-Reinforced Composites

A layered or laminated construction is frequently made of continuously reinforced materials. Due to the continuous nature of the fibers, the application of matrices and fibers as slurry during the molding process is challenging due to work ability issues. When an impact force is applied, the structure generates a layer or laminate structure that has a propensity to separate from the mother composite; as a result, the application of continuous fibers is restricted to particular items (USG, 2000).

2.4 Classification of the Fiber

2.4.1 Natural fibers

These fibers are naturally available As a result, they are of lower quality than synthetic materials, yet they offer many benefits and have characteristics similar to those of glass fiber composites (John and Thomas, 2008). Natural fiber gives better properties in cost effectiveness, low density, light weight, water resistance, high impact strength, environmentally friendly and biodegradable (Aditya et al., 2017). As natural fiber grows naturally, there is non-homogeneity in their property (Shahinur and Hasan, 2020). The main components of the fiber cell walls are cellulose, hemicellulose, and lignin, with pectin typically regarded as the principal binder. The most important structural component, from which fibers are often made, is cellulose (John and Thomas, 2008). Due to their distinctiveness and availability, natural fiber composites have a promising characteristic to replace synthetic fiber (Norhidayah et al., 2014). The advantage and limitations of natural fiber were explained in Table 2.3.

Table 2. 3 Natural fibers advantage and their short-comes (Mochane et al., 2019)

Advantages	Disadvantages
Recyclable	High moisture absorption
Low density i.e., lightweight	Dimensional instability
Zero fingerprint CO2	Flammable
High specific mechanical properties than glass fibers	Low strength and thermal resistance than glass fibers
Non- abrasive to processing equipment	Anisotropic behavior
Processing should not produce any hazardous fumes or irritate the skin.	Odor generation during degradation

Regarding the development of ecologically friendly materials, natural fiber reinforced polymer composites have attracted a lot of attention and interest from scientists and engineers in recent years. They are inexpensive, readily available, and have excellent specific strength and modulus. Natural fibers are noted for their uneven cross sections and lack of uniformity, which gives them a structure that is extremely distinct from synthetic fibers like glass or carbon. Researchers from several fields have studied natural fibers made of polyvinyl, polystyrene, and polyester resins. These composites' distinguishing features include low cost, light weight, high specific strength, and no health hazards. Although the weak inter-facial interaction between the fibers and the hydrophobic polymers is caused by the presence of hydroxyl and other polar groups in natural fibers, these properties can be greatly improved by inter-facial treatment (Gebre and Raj, 2016).

Natural fiber-reinforced polymer composite materials are gaining popularity quickly in both fundamental research and practical applications. They are inexpensive, renewable, and fully or partially recyclable. As a source of lignocellulose fibers since the dawn of time, plants including flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, false banana (enset), etc., as well as wood, are increasingly used as the reinforcement of composites. They offer a compelling ecological substitute for glass, carbon, and other man-made fibers used in the production of composites due to their accessibility, renewability, low density, affordability, and good mechanical qualities. The natural fiber-containing composites are utilized in packaging, consumer goods, military applications, building and construction (ceiling panels, partition boards), and transportation (automobiles, railroad coaches, aircraft) (Sisay, 2011); (Kalus Emmanuel et al., 2018)

Natural fibers have the disadvantage of having poor compressive and transverse strengths. The environment's elements, such as moisture and temperature, can affect natural fibers negatively. A composite's mechanical characteristics often decline as moisture content increases. Consequently, various studies have been done to improve fiber matrix adherence using various techniques, such as chemically modifying the fiber surface (Sisay, 2011**)**; Kalus Emmanuel et al., 2018).

2.4.2 Synthetic / Man-made fibers

These fibers are named as man-made fibers and they show better mechanical properties than the natural fibers. But synthetic fibers are not bio-degradable and so a threat to the environment pollution as well as they require high cost compared to natural fibers.

Artificial fibers include synthetic fibers. Glass, carbon, aramid, and boron fibers are the most widely used synthetic reinforcements. The typical range of fiber sizes is 5 m (0.0002 in) to 20 m (0.0008 in). Glass fibers range in diameter from 5 to 25 m, carbon fibers are 5 to 8 m, aramid fibers are 12.5 m, and boron fibers are 100 m. The fiber is flexible and easily adapts to varied shapes due to its small diameter. In fiber-reinforced polymers (FRP), glass, carbon, aramid, and boron are the most often used fiber materials. Glass is found in abundance; so, glass fibers are the cheapest among all other types of fibers. There are three major types of glass fibers: E-glass, S-glass, and S2-glass. Some of the common types of reinforcements include:

- Continuous carbon tow, glass roving, aramid yarn
- Discontinuous chopped fibers
- Woven fabric
- Multidirectional fabric (stitch bonded for three-dimensional properties)
- Stapled
- Woven or knitted three-dimensional performs

Continuous fibers are employed in applications such as filament winding, braiding, and weaving. The majority of thermoset and thermoplastic resin systems employ continuous fibers. Compounds for injection molding and compression molding are made from chopped fibers. The continuous fibers are severed to create the chopped fibers. Continuous fibers are utilized in spray-up and other operations, but they are first machine-chopped into tiny pieces before being applied. Prepares and laminates for a number of purposes (such as boating, marine, and sporting) are made from woven textiles. Braiding and other techniques are used to create preforms, which are then used as reinforcement for resin transfer molding (RTM) and other molding processes (Frank, 2002); (Edition, 2007).

2.5 Manufacturing methods of composite materials

A composite construction can be cast using a variety of techniques, whether it is straightforward or intricate, single or many. Each technique has advantages and disadvantages of its own. The kind of matrix and fibers, pressure requirements for high viscous resin to flow through the fibers, temperature requirements for matrix production and curing, end product geometry, and cost savings all affect the choice of a particular manufacturing process. Among the frequently utilized manufacturing methods are:

1. Hand lay-up
2. spray up
3. Vacuum molding
4, Compression molding
5. Resin transfer molding (RTM)

2.5.1 Hand layup

An open forming technique used to create composite materials is called hand lay-up. It is the simplest and most traditional type of composite production procedures, and can be seen as being especially appropriate for large components in lamination techniques (Leonelli and Romagnoli, 2015). Hand-applied resins are incorporated into chopped or mat-shaped fibers. In most cases, resin is applied to the fiber and voids or impurities are removed using rollers or brushes. The composite is allowed to cure in a typical atmosphere. The main flaw in hand layup is its inconsistent quality; the worker's skill greatly affects the final product. For the laminator, resins must have a low viscosity in order to be handled by hand.

2.5.2 Spray up

One of the hand mounding techniques, which was a development of the hand layup technique, was spray lay-up. Pressurized resin and reinforcement in the form of chopped fibers were sprayed using a spray cannon. Matrix material and reinforcement were sprayed simultaneously or sequentially. To release the air that had been trapped in the layups, a roller was gently pushed over the surface that had been sprayed. The material was removed from the mold after the substance had been sprayed up to the necessary 10 thicknesses and had been allowed to cure at room temperature. Because these mechanical qualities were impacted, this approach also utilized low viscosity resins. For smaller volumes, this procedure worked well. This just provides a good surface finish on the side. It was investigated how to produce the material at a lower cost. The benefits of this technology include a continuous process, the use of any material as a mold, and the ability to correct errors by re-spraying; nevertheless, the drawbacks include a low volume fraction and the ability to produce only boards as studied (Srinivas et al., 2017).

2.5.3 Vacuum bagging

The primary composite fabrication method for creating laminated composite structures is vacuum bag molding, which is particularly well-liked in the aerospace sector. Its limited application in the automobile industry is a result of the labor-intensive process's potential for lengthy cycle times (Mallick, 2010). One of the procedures within the prepreg moulding and autoclave moulding categories is vacuum bagging. The difference between these two techniques is that one involves curing in a vacuum bag (oven), while the other involves curing in an autoclave. In this technique, the laminate is strengthened by applying compaction pressure using a bag. An expanded form of the hand or wet lay-up method is vacuum bag moulding. Epoxy, phenolic, and polyimide are examples of polymer materials that can be utilized in this method (Sapuan and Yusoff, 2015). Vacuum bag method enables very good and lightweight composite materials to be obtained with a Constant and high mechanical characteristic of the composite plates can be achieved.

2.5.4 Compression molding

One of the closed-mold composite manufacturing processes that uses paired metal molds and external pressure is compression molding. It is typically employed in the production of high-volume composite parts, such as those seen in automobiles. Compression molding procedures can be divided into two categories: cold and hot. While the hot press method requires both temperature and pressure, the cold press technique just uses pressure. While the hot press technique needs a temperature to transmit heat to the composite and start the curing process, the cold pressure method can cure at ambient temperature (Sapuan and Yusoff, 2015). Compression molding is one of the most common types of production methods, which utilizes fibers and matrices, prepregs, sheet molding compounds (SMC), and bulk molding compounds (BMC) as raw materials (Srinivas et al., 2017).

2.5.5 Resin transfer molding (RTM)

This type of closed-mode manufacturing involves packing dry fiber reinforcements into a mold tool that will eventually form the composite product. To inject resin into the cavity, a second mold tool is clamped over the first. An adhesive release agent is adhered to the mold's exterior for simple removal of the molded composite. The main disadvantage of this strategy is the expensive cost of matched instruments, which are typically limited to smaller parts that can tolerate high pressures. RTM manufacturing is employed in the production of hollow forms, intricate constructions, auto body pieces, big containers, and bathtubs (Devaraju and Alagar, 2019).

2.6 Composite materials reinforced with natural fibers

Natural fibers were extracted from different renewable resources, namely animals, vegetable plants, and minerals. There are many polymer matrices that can be reinforced with natural composites to obtain better composites.

Daramola and Adediran, (2017) examined how treated pineapple leaf fiber reinforced polyester matrix composites behave when it comes to water absorption and mechanical qualities. In order to improve the fiber and matrix's good adherence, PALF was chemically treated after being extracted by the wet retting method from the pineapple plant. For the production of the composite, they employed room-temperature manual layup procedures, and samples were made for tensile, flexural, hardness, and water absorption tests. According to the study's findings, the ultimate tensile strength and young's modulus of elasticity both rise in proportion to an increase in the fiber weight fraction content while the elongation at break decreases. The ideal flexural strength and flexural modulus were attained at 20 weight percent PALF, and the ideal hardness value was at 30 weight percent PALF. The results of the water absorption test showed that the amount of water absorbed by the composite increased with increase in fiber loading and weight fraction.

Jeyapragash et al., (2020) reviewed of the mechanical characteristics of epoxy composites reinforced with natural fiber and particulates. One of the many resources that may be found in nature are natural fibers. They are inexpensive, readily renewable, biodegradable, and easily broken down. It is extracted from a variety of plant and animal resources. The numerous natural fibers utilized in polymer composites were enumerated, their scientific names were evaluated, as well as their mechanical and chemical qualities. The natural composites were divided into four categories: hybrid fiber composites, fiber-particulate composites, fiber composites with fibers, and particulate composites with particulates. For the development of natural-fiber composites, they are used as reinforcing materials in polymers. The current study compares the mechanical properties of epoxy resin reinforced with various natural fiber materials and agricultural by-product particles. In the current survey, mechanical properties for all types of natural composites were listed, including tensile strength, flexural strength, and impact strength. The potential for developing new natural fiber-impregnated polymer composites in place of synthetic fiber composites as well as the depletion of wood resources were both discussed. This review aims to provide fundamental and background knowledge on natural fibers and their composites in order to stimulate fresh research efforts and aid in the creation of new types of polymer composites.

Hoque et al., (2021) reviewed a number of academic papers on pineapple leaf fiber-reinforced epoxy resin-based composites' mechanical characteristics. After reading a wide variety of literature, they have concluded that adding pineapple leaf fiber to composites made with epoxy resin enhanced the mechanical qualities of the composites. Because pineapple leaf fiber has a smaller microfibrillar angle and contains 70–82% cellulose, it gives composites a high degree of strength. Finally, it can be said that epoxy resin-based composites reinforced with pineapple leaf fibers have a bright future in the field of fibrous composites.

Krishna et al., (2017) It is important to assess the mechanical properties of a hybrid reinforced polymer composite. Composites are made up of two or more separate constituent materials that work better together than they do separately. Because they are cost-effective, renewable, non-abrasive, eco-friendly, corrosion-resistant, and biodegradable, natural fibers can be utilized as reinforcement in composites, increasing their strength, stiffness, and resistance to temperature creep. Pineapple is one of the natural fibers with the greatest cellulose concentration (almost 80%). Although PALF has the strongest tensile strength among related natural fibers and a very high Young's modulus, its density is on par with that of other natural fibers. Borassus fiber is used to create low-cost natural fiber composites with good thermal insulation qualities by changing the volume proportion in polyester resin. In this study, hybrid composite materials were made using fibers from the Borassus fruit and PALF. These two components combine with epoxy and resin to create novel hybrid composite materials in various proportions. Thus, laminate composites made from pineapple leaf fiber and borassus fruit fiber exhibit greater flexural strength and impact resistance than do separate laminate materials. These filled natural fiber composites have many uses, including front and rear door liners, seat backs, interior sun roof shields, valence panels below front and rear bumpers, electronic packages, cabin and cargo hold furnishings for aircraft, artificial limbs for the physically challenged, the oil industry, and air conditioning ducts.

Santosh Kumar et al., (2015) investigated the hand lay-up approach with fiber volume ratios of 10%, 20%, and 30% to develop the pineapple leaf fiber-reinforced epoxy resin composite. They created composites to evaluate their mechanical properties, such as tensile, flexural, and hardness tests, and they concluded that the highest tensile, flexural, and hardness attained were 65.95 MPa, 121.83 MPa, and 80B, respectively, when viewed in a 30% volume ratio. Based on their research, they suggested using pineapple leaf fiber-reinforced epoxy resin composite as a substitute for wood.

Sathish et al., (2018) the mechanical characteristics of several natural fiber-reinforced epoxy hybrid composites were tested experimentally. By employing a compression molding technique with a weight ratio of 40:60 for the fiber to resin, they investigated the mechanical qualities (tensile, flexural, and impact strength) and morphological traits of epoxy hybrid composites reinforced with flax, kenaf, pineapple, and sisal fibers. They concluded that the hybrid of flax/kenaf/epoxy showed no porosity producing the fracture surface, homogenous distribution of fibers, and matrix with improved bonding. higher mechanical qualities for composites as a side effect.

2.7 Mechanical properties of PALF reinforced polymer composite

Challabi et al., (2019) investigated how PALF/PLA Bio composite's mechanical properties and dimensional stability were affected by superheated steam treatment. They looked into how well superheated steam (SHS), a different, environmentally friendly treatment method, worked to alter the surface of pineapple leaf fiber (PALF) for bio composite. Enhancing the interfacial adhesion between the fiber and the polymer was the goal of this treatment. The treatment was conducted at various times and temperatures (190-230℃) in a SHS oven (30-120 minutes). Utilizing melt-blending procedures, bio composites made of polylactic acid (PLA) and SHS-treated PALFs at a weight ratio of 30:70 were created. For the bio composites, the mechanical characteristics, dimensional stability, scanning electron microscopy (SEM), and X-ray diffraction (XRD) were assessed. In comparison to other treatment temperatures, the results showed that treatment at a temperature of 220 C for 60 min offered the best tensile qualities. The addition of PALF that had undergone SHS treatment improved the bio composites' tensile, flexural, and impact capabilities as well as their dimensional stability. The increase in tensile strength, tensile modulus, and elongation at break, respectively, were determined to be 24%, 16%, and 14%. The SEM examination revealed an improvement in the SHS-PALF/PLA bio composite's interfacial adhesion, and the XRD graph revealed that the bio composite's crystallinity had increased as a result of the SHS treatment. Additionally, the SHS-PALF/PLA bio composite's flexural strength, flexural modulus, and impact were all improved by 12%, 7%, and 16%, respectively. Improvements of 42% and 60% in water uptake and thickness swelling were also seen in dimensional stability. Therefore, this work demonstrates the viability of SHS. The findings imply that SHS can be utilized as an environmentally beneficial PALF modification technique when making bio composite materials.

Motaleb et al., (2018) improvements to the pineapple leaf fiber reinforced composite's physical and mechanical properties have been studied. Compression molding was used to create the composites after the fiber contents of 25, 30, 35, 40, and 45 wt.% PALF/PP composite were treated with 3,5 and 7 (w/v) % NaOH solution for 1 hour at room temperature. They came to the conclusion that adding more fiber significantly raises all of the mechanical properties; for example, a composite made of PP and PALF at a content of 45 wt.% showed increases in TS, 412% TM, 155% BS, 265% BM, and 140% IS when compared to PP matrix, while an alkali treatment with 7 (w/v)% NaOH showed increases in TS, 43.45% TM, 15.78% BS, and 52% BM The tensile strength of the composite did, however, marginally decline at above 7% NaOH concentration as a result of the fibers' excessive exposure to NaOH.

Senthilkumar et al., (2019) studied improvement of pineapple leaf fiber reinforced composite's physical and mechanical properties. They use 1 N NaOH and KOH for 1 h for fiber treatments, 25 wt.%, 35 wt.%, and 45 wt.% fiber loadings for untreated and treated PALF/PE composites, and FTIR to understand the effects of chemical and compression molding techniques for composite fabrication. Their goal is to analyze the influence of fiber treatments and different fiber loading on the mechanical, physical, and chemical properties of pineapple leaf fiber-reinforced polyester composites (PALF/PE). The strongest flexural strength (83 MPa) and maximum flexural modulus (6 GPa) for composites with untreated fibers were obtained at 35% and 45% fiber loading, respectively. Alkali-treated fiber, however, has inferior flexural and modulus properties. Finally, they draw the conclusion that treating PALF/PE composites with 1 N NaOH, 45 wt.% successfully and satisfactorily enhanced both the mechanical and morphological qualities. Due to their better strength and modulus with increased fiber loading, the obtained composites hold promise for use in building materials, furniture, and automotive components.

Hamritha et al., (2020) pineapple leaf fiber bonded with epoxy resin and composites made using the hand lay-up method were studied for their mechanical characteristics, extraction, and manufacture. 10% to 30% of the weight is made up of fibers. They employed Epoxy resin of grade LY556 and hardener HY951 to extract and chemically modify the fibers so they would bond with the resins. The epoxy used has strong mechanical characteristics, a low shrinkage rate, good adhesion, and improved performance at high temperatures. The fibers are removed from the leaf using a quick two-roll machine. The fiber is extracted, cut to the necessary length (2 to 6 feet), rinsed at 70 degrees Celsius in a solution containing 2% detergent, combined with the epoxy, and then left to cure. The standard specimen is produced in accordance with ASTM D 570 and has the following measurements: 50mm in length, 15mm in breadth, and 5mm in thickness. With the volume fraction rising at 10%, 20%, and 30%, the amount of moisture absorption, hardness, tensile, and ultimate strength was tested and increased. This clearly shows that as the percentage of fiber increases, the amount of water absorption also increases (i.e., its weight gradually increases). However, the strong performance of the composite was determined by the results, which showed that the composite performed better as the volume fraction increased. This leads to the conclusion that a high cellulose content and a low microfibrillar angle are related to the fiber's mechanical properties.

Suresha and Hemanth, (2021) studied how alkali-treated pineapple fiber reinforced epoxy composites with halloysite nanotubes affected the form and mechanical properties. In the present study, the surface morphology and mechanical properties of an epoxy composite produced from alkali-treated pineapple fiber, both with and without halloysite nanotubes (HNTs), are investigated. 1, 3, and 5% of the PF/Ep composite's weight is loaded with HNT. We assessed the morphological, tensile, flexural, density, and other properties of PF/Ep and HNTs filled PF/Ep composites. The results of the mechanical testing demonstrated that the tensile and flexural properties were improved by the addition of the HNTs Alkali treated PF/Ep composites with 3 weight percent HNTs shown increases in tensile strength and Young's modulus of 16% and 22%, respectively, as well as flexural strength and flexural modulus of 23.01% and 29.96% as compared to unfilled alkali treated PF/Ep composites. The failure surface morphology of the composites is determined by the matrix and any reinforcements used in the material system. Overall, they concluded that epoxy's morphological and mechanical properties had been greatly improved by PF that had undergone an alkali treatment and contained 3 weight percent HNTs for a number of designed and futuristic applications.

Saha et al., (2021) examined influence of pineapple leaf particulate on mechanical, thermal and biodegradation characteristics of pineapple leaf fiber reinforced polymer composite. They use five different weight fractions of pineapple microparticulate (2.5%, 5%, 7.5%, and 10%), a 5% NaOH solution, and a constant weight fraction (30%) of PALF to examine the thermo-mechanical characteristics, water absorption behavior, and biodegradability (XRD, FTIR, and TGA for characterization). Composites with increased mechanical and thermal characteristics, water absorption behavior, and biodegradability were produced by adding 7.5% of particles to PALF-reinforced epoxy. However, the addition of too many particles reduces the mechanical characteristics of the material by cauterizing and agglomerating it.

Anand et al., (2022) experimented the investigation of effect of fiber length on mechanical, wear, and morphological behavior of silane-treated pineapple leaf fiber reinforced polymer composites. They examine mechanical properties (impact, flexural, tensile strength, and wear rate), coefficient of friction, and wear based on the fiber length (5,10,15,20, and 25) and loads (10, 20, and 30N) by using the hand layup method and fiber treated with silane. The results showed that the 20 mm length of PALF resulted in better mechanical properties like flexural, tensile, impact, Young's modulus, elongation at break and wear resistance, and silane treatment for 15–20 mm fiber length resulted in better surface topography or better fiber–matrix bonding. These properties ensure the developed polymer composites can be applied to walls, building insulation, and artificial ceilings.

Hossain et al., (2022) the effects of gamma radiation on the fabrication and characterization of pineapple leaf fiber-reinforced epoxy composites were investigated. They looked at the mechanical properties of composites with 10%, 15%, 20%, 25%, and 30% PALF and treated fiber in a 2% NaOH solution, such as tensile strength (TS), percentage of elongation at break (%Eb), and impact strength (IM). The highest TS, 5% EB, and IM values for a 30% PALF-based epoxy composite were later determined to be 51.6 MPa, 15.88%, and 14.189 Kg/cm, respectively. Furthermore, as gamma radiation levels increased, these qualities improved. However, as the fiber content increased, the tensile modulus decreases.

2.8 Effect of treated and untreated fibers on composite

Amena et al., (2022) for the production of composite materials, a study was conducted on the physical and chemical characteristics of 10% NaOH-treated and untreated Ethiopian Arabica coffee husk fiber. They looked analyzed the material's density, porosity, moisture content, lignin, cellulose, hemicellulose, and ash content, among other physical and chemical traits. The experimental findings demonstrated that 10% NaOH treatment of coffee husk lowered the amounts of lignin, hemicellulose, and wax while increasing the amounts of cellulose and ash. The FTIR data and regression analysis for the treated coffee husk indicated, respectively, a reduction in lignin/hemicellulose and water absorption.

2.9 Effect of CH filled natural fibers

Ortiz-Barajas et al., (2020) studied torrefaction of coffee husk flour for the development of high sustainability green composite polylactide injection-molded pieces. To make coffee husk more thermally stable and compatible with biopolymers, it is milled into flour with fine particles (90 m) and torrefied at 250 C. Torrefied coffee husk flour (TCHF), 20–50% by weight, melt-composes with polylactide (PLA), lowering PLA's ductility and hardness. They concluded that balanced mechanical qualities may be efficiently attained at filler levels of 20 weight percent (tensile, flexural conditions, and improved hardness). Additionally, the PLA/TCHF pieces showed improved thermomechanical resistance and had a higher softening point of over 60 C. By valuing a lot of torrefied coffee garbage, incredibly sustainable items were subsequently produced. These innovative green composites can be utilized to create compostable rigid packaging and disposables for use with food under the circular bioeconomic framework.

Gonçalves et al., (2021) studied surface modifications of coffee husk fiber waste (CHFW) for polymer biocomposites for effective incorporation. Three surface treatments (chemical, physical, and biological) were applied to coffee husk wastes, and it was found that the hydrothermal treatment (at 121℃ temperature and 98.06 KPa for 30 minutes), which markedly increased the fiber/matrix interfacial bond, increased the tensile strength by as much as 60%. The CHFW treatments and the first tensile results suggest that castor oil-based polyurethane may be combined with inexpensive agricultural waste to produce sustainable biocomposites that may be utilized as plastic wood for household and automotive parts.

Jaramillo et al., (2021) eco-composites made of polyethylene and coffee husk for the manufacture of consumer goods with added value. The morphological, thermal, and mechanical properties of the 20 and 40 wt.% of coffee husks added as fillers with low-density polyethylene and high-density polyethylene were characterized. The gap between the polymer and the filler was seen using SEM. This is a result of the lack of usage of a compatibilizer agent. The high particle size of the filler, a large amount of filler added, the differences in chemical structure and polarity between the filler and the polymer matrix, and the lack of a compatibilizer agent led to a decrease in tensile strength and elongation at break but an increase in young's modulus and hardness.

2.10 Effect of SiC fillers on composite

Raj et al., (2022) investigated how graphene fillers affected the mechanical characteristics and water absorption of NaOH-treated kenaf fiber-reinforced epoxy composites. They developed composite materials using 5% NaOH, kenaf fibers as reinforcement, epoxy polymer (60 wt.%) as matrix, integration of graphene (0%, 2%, 4%, 6%, and 8%) as fillers, and compression molding process. The samples are prepared in accordance with the ASTM D3039, D790, D256, D2240, and D572 standards, respectively, for the tensile, flexural, impact, hardness, and water absorption tests. The sample with 6% graphene addition in the epoxy matrix reinforced with 5% treated kenaf fiber had the lowest water absorption of 5.13% and the maximum tensile strength of 63 MPa, flexural strength of 97 MPa, impact strength of 9.56 kJ/m2, and hardness value of 97. This is because the matrix's graphene fillers were properly distributed, improving the interfacial adhesion between the fiber and matrix. The attributes including tensile, flexural, and impact strength start to deteriorate in treated kenaf/epoxy composites with reinforcement of more than 6 weight percent gr, whereas an 8-weight percent gr filler sample achieves a maximum hardness value of 97. Beyond a graphene addition of 6 weight percent, the composite becomes embrittle, resulting in matrix aggregation and a loss of mechanical characteristics. Since the graphene fillers prevent water from penetrating the fibers, sample S5 had the lowest value in the water absorption test. To analyze the morphological surface of different graphene concentrations reinforced in treated kenaf/epoxy composites, SEM examination is performed on the prepared samples. The ideal 6 weight percent Gr filler sample showed no fiber pull-out and superior bonding in the SEM measurement.

Aynalem and Sirahbizu, (2021) study of Al2O3's impact and tensile effects on flax/unsaturated polyester composites with a focus on car body applications. The composite was made using a typical hand-lay-up approach, followed by compression molding, using Al2O3-filled chopped flax with loadings of 0, 5, 10, and 15 weight percent, along with 15 and 25 weight percent, of unsaturated polyester resin. Using the ASTM standard as a guide, the tensile and impact strengths were investigated. They concluded that the addition of 15 weight percent filler for the 15-weight percent fiber loading instance had improved the ultimate tensile strength of the base flax/UPR composite from 26.45 to 32.87 MPa. As a result, the addition of 5 weight percent Al2O3 filler has raised the basic 25/UPR composite's ultimate tensile strength from 26.65 to 32.07 MPa. Due to the addition of Al2O3 filler, the flax/UPR composite's energy absorption capacity and impact strength were significantly reduced.

Kiran et al., (2018) evaluated the mechanical property of glass fiber reinforced epoxy polymer with addition of filler material like aluminum, titanium dioxide and silicon carbide. In his work glass fabric/epoxy composites with alumina, titanium and mixture with silicon carbide hybrid fillers are prepared using hand layup method. Their mechanical properties like tensile strength, flexural strength and impact strength are investigated. These filler particles are spherical in shape (particle diameter: submicron-50µm) and have good property. According to the investigation, 2% TiO_2 + SiC filler added glass fiber/epoxy composites exhibited a 14% improvement in ultimate tensile strength whereas 2% Al_2O_3 + SiC filler added composites showed a 22% improvement. Glass fiber/epoxy composites with 6% TiO_2 filler added showed 76% improvement in flexural strength while those with 6% TiO_2 + SiC filler added showed 84% improvement in flexural strength. The composite with 6% Al_2O_3 + SiC showed 87% improvement in flexural strength and 84% improvement in impact strength. Due to SiC's high fracture toughness and high hardness, the combination of SiC with Al_2O_3 fillers has greatly improved the flexural strength, impact strength, and tensile strength of E-Glass epoxy composites.

Mishra et al., (2021) studied the influence of Coir Fiber Geometry on Mechanical Properties of SiC Filled Epoxy Composites to attempt the possibility to employ eco-friendly fiber in composite material for engineering applications and evaluate its mechanical properties like tensile strength, shear strength, flexure strength, and compressive strength with various fibers geometry (unidirectional, woven at ±45° orientation and chopped fiber) by using hand layup technique. Silicon carbide particles are used as filler material in the epoxy matrix. Further, the worn surfaces are studied using scanning electron microscopy (SEM) to understand the microstructure and mechanism of failure. The results of the investigation reveal that the unidirectional fiber reinforced composite has relatively higher magnitudes of the mechanical properties except shear strength in coir fabricated composite i.e. maximum magnitude of tensile, compressive and flexural strength 21 MPa, 84.29 MPa and 44MPa associated with unidirectional oriented fiber respectively. However maximum shear strength is 84 MPa with woven fibers. The fabricated composite might find application to develop various accessories used in automotive and public transports like dashboard, trays, cases for rear mirror etc. This is offering a future scope of research for commercialization of the developed materials.

Teja et al., (2016) Sisal fiber reinforced composite's mechanical and thermal properties, the impact of SiC filler material, and fabrication using the hand lay-up method were studied. According to the experimental results, a composite with 10% SiC has a 2.53 times stronger tensile strength than a composite without SiC. When compared to plain polyester composite without SiC, which has an impact strength of 14.25 J/m2, the 10% SiC composite has a 1.73 times higher impact strength. Thermodynamic parameters such as thermal conductivity, specific heat capacity, thermal diffusivity, thermal deterioration, and stability are examined. 0%, 5%, and 10% SiC powder are used in three different samples. Thermal conductivity rises with the addition of SiC filler powder; specific heat capacity progressively rises then falls; thermal diffusivity rises; and thermal stability rises with SiC filler powder.

2.11 Effect of fiber orientation and weight percentage on composite

Jiru, (2021) examined the impact of fiber orientation and weight percentage on the mechanical characteristics of a natural hybrid composite made of nettle, sisal, and glass fibers. To further eliminate lignin, hemicellulose, and other fiber remnants, 5% NaOH was applied to both fibers, and various weight percentages of nettle and sisal fiber were utilized with 0°/90° and 45° orientations. The fiber's overall volume percentage was 40% by weight. By maintaining the same weight percentage of glass, nettle and sisal fibers were hybridized from this wt.% to produce 20NF:10SF, 15NF:15SF, and 10NF:20SF through 0°/90° orientation in general, the 20NF, 10SF, and 10GF (S1) composition and 90/0-degree orientation were found to have higher maximum tensile strength (99MPa), minimal water absorption (1.25%), and greater impact strength than the 45-degree orientation for the same composition. The tensile strength decreased when the applied load's direction changed. The sample that had equal amounts of fiber in a 0°/90° orientation had a better surface quality. In general, the interaction between the fiber and matrix was better when the sisal and nettle fiber compositions were more than or equal.

2.12 Taguchi method optimization techniques

The Taguchi Method is a method for developing and carrying out experiments to explore processes where the outcome depends on numerous parameters (variables; inputs) without having to laboriously and economically run the process using all possible combinations of values for those variables. In an effort to raise the caliber of manufactured items, Japanese scientist Genichi Taguchi created the Taguchi Method in the 1950s. This approach is based on the idea that running the fewest amount of trials possible will save costs (Sirvanc et al. (2011)). The Taguchi technique is a tool for enhancing the performance, process, design, and system of the most beneficial products while significantly reducing experimental time and expense. By methodically selecting particular combinations of variables, it is possible to distinguish between their individual impacts and use them to create the experiment's combination of parameters, such as those used in composite fabrication and for machining. A task that tries to characterize and explain the variance of information under circumstances that are hypothesized to reflect the variation is known as a design of experiments (DOE).

2.12.1 Signal-Noise Ratio Analysis

The signal-to-noise ratio (S/N) of each level of the Taguchi method's machining parameters must be evaluated for each output function in order to determine the best machining settings. An ideal level is one with the highest S/N among the best parameter levels. Taguchi employs three kinds of signal-to-noise ratios to measure the quality attributes deviating from the ideal value (Yadav, 2012).

Nominal is the best characteristics,

$$\frac{S}{N} = 10log[\frac{Y^2}{S^2}] \tag{2.1}$$

Smaller is the better characteristic,

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} {Y_i}^2] \tag{2.2}$$

Larger is the better characteristics,

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{{Y_i}^2}] \tag{2.3}$$

Here Y = observation n = total number of observations, Y = the average of observed data, S^2 = the variation of Y and Yi = ith response.

2.12.2 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to find which parameters significantly affect the quality characteristic. ANOVA is the statistical technique used to find the influence of all control parameters. In the analysis of variance, the percentage contributions of each control factor are used to measure the corresponding effects on the performance characteristics. The significance level of 5 %, i.e. for a 95 % level of confidence was considered in this analysis. ANOVA results indicate whether there is a statistical significance in difference or not in output characteristics. ANOVA analysis involves when α values are below 0.05 is significant and above 0.05 is not significant. Percent contribution measures the percentage contribution of each model term relative to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. From the analysis of variance percentage contribution of each influential parameter was calculated by the following formula,

$$P = \frac{SS}{SST} * 100 \tag{2.4}$$

where, P: Percentage contribution of individual factor,

SS: Sum of squares or treatment sum of squares,

SST: Total sum of squares

2.12.3 Grey Relational Analysis Optimization Techniques

Grey relational analysis is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis has been applied by several researchers to optimize the control parameters having multi-responses through grey relational grade. In this approach, a grey relational grade is obtained for analyzing the relational degree of the multiple responses have attempted a grey relational-based approach to solve multi-response problems in the Taguchi methods. The Grey relational analysis is widely used to combine all the considered performance characteristics into a single value that can be used as the single characteristic in optimization problems.

2.12.4 Optimization Steps Used in Grey Relational Analysis

Step 1: Transform the original response data into S/N ratio (Y_{ij}) using the appropriate formula depending on the type of quality characteristic using Eq.2.1, Eq.2.2, and Eq. 2.3.
Step 2: Normalize Y_{ij}as Z_{ij} (0 _ Z_{ij} _ 1) by the following formula to avoid the effect of using different units and to reduce variability. Normalization is a transformation performed on a single input to distribute the data evenly and scale into an acceptable range. Z_{ij} = Normalized value for ith experiment/trial for jth dependent variable/response.

$$Z_{ij} = \frac{Y_{ij} - \min(Y_{ij}, i=1,2,3,...n)}{\max(Y_{ij}, i=1,2,3,...n) - \min(Y_{ij}, i=1,2,3,...n)} \tag{2.5}$$

(To be used for S/N ratio with larger-the better case)

$$Z_{ij} = \frac{\min(Y_{ij}, i=1,2,3,...n) - Y_{ij}}{\max(Y_{ij}, i=1,2,3,...n) - \min(Y_{ij}, i=1,2,3,...n)} \tag{2.6}$$

(To be used for S/N ratio with smaller-the better case)

$$Z_{ij} = \frac{Y_{ij} - \mathrm{T} - \min(Y_{ij} - T, i=1,2,3,...n) - Y_{ij}}{\max(Y_{ij} - T, i=1,2,3,...n) - \min(Y_{ij} - T, i=1,2,3,...n)} \tag{2.7}$$

(To be used for S/N ratio with nominal-the best case)

Step 3: Compute the grey relational coefficient (GRC) for the normalized S/N ratio values.

$$GRCij = \frac{\Delta min + \partial \Delta max}{(\Delta ij + \partial \Delta \mathrm{max})} \quad (2.8)$$

Where, i= 1, 2, ..., n-experiments and j= 1, 2, ..., m-responses

GRCij = GRC for the ith experiment/trial and Δ= absolute difference between $Y_{oj}$and Y_{ij}

Y_{oj} = optimum performance value or the ideal normalized value of jth response

Y_{ij} = the ith normalized value of the jth response/dependent variable

2.13 Literature summary

Numerous studies have been done on the fabrication and characterization of polymer matrix composites with various types of reinforcement, different reinforcement particle sizes, different fabrication procedures, different fillers and also varied testing circumstances. The aforementioned literature analysis amply demonstrates the extensive research done on a variety of fabrication processes, primarily hand layup techniques, as well as the impact of processing conditions, fillers, and reinforcement. The main benefits of pineapple leaf fiber reinforced polymer composite materials with fillers are their increased mechanical properties, especially in the areas of hardness, flexural, tensile, and impact strength, as well as morphological qualities. The effects of weight composition and fiber orientation on the mechanical and morphological behavior of the generated composite have been explored in PALF, which are reinforced polymer composites with a variety of particle fillers. In the creation of natural reinforced polyester matrix composites, PALF were frequently used as reinforcements. According to the aforementioned research, adding various particle fillers considerably enhances the physical, mechanical, and morphological characteristics of natural reinforced polyester matrix composites.

2.14 Research gap

Several researchers were done on experimental investigation of pineapple leaf fibers reinforced polyester composite. From literature reviews there was no experimental investigation done on pineapple leaf fibers reinforced polyester matrix with addition of filler material (silicon carbide and coffee husk). The most of experiments didn’t depend or consider how could we use waste material (solid wastes generated by agricultural activities) such as pineapple leaf fiber and coffee husk flakes. In addition to this the improvement of mechanical and physical properties of composites with the addition of filler material (coffee husk fiber) was not done. In previous works researchers used single response optimization rather than multi response optimization method. In this study for enhancing its mechanical property, a filler material (coffee husk fiber) and silicon carbide used to a broad its application. Also, it conducted properties like physical, morphological in addition to tensile strength test, flexural strength test, impact strength test and hardness.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

It is necessary to understand the composite qualities needed for industrial and construction applications. These characteristics must encompass all evaluations of the physical, mechanical, morphological, and statistical features. The raw materials used in this work were pineapple leaf fiber as reinforcements, polyester resin as matrix with its hardener material are utilized directly for composite preparation. Silicon carbide and coffee husk fiber will all be employed in this research project as filler materials to produce the desired qualities. Composites were produced by compounding bidirectional, unidirectional and chopped pineapple leaf fiber with polyester resin by hand lay-up. Cost, properties, and availability all need will be considered when making this decision. Finally, the tests were performed at Material Science Engineering Department, in Adama Science and Technology University.

3.2 Materials

3.2.1 Pineapple leaf fiber reinforcements

Three-year-old PALF plants were collected from Aleta Chuko Werada, Sidama region, Ethiopia, which is a land location, and were then cut in a longitudinal orientation. The stands are soaked in water for three days to facilitate the separation of the cellulose from the lignin component (Mishra et al., 2001). It is utilized to make it simpler to separate the fiber from the lignin portion of the plant. The extraction yields 5 kg of fiber. Using a mechanical method of fiber extraction is frequently useful for acquiring high-quality fibers rapidly. From the excised pineapple leaf sheath, the fiber bundles are taken from the plant's pseudo-stem. The remaining water content in the fibers is removed through a process of sun drying.

Table 3. 1 Properties of PALF (Aynalem and Sirahbizu, 2021)

Properties	Units	PALF
Density	g/cm^3	0.8-1.6
Elongation	%	1.6-14.5
Elastic modulus	GPa	1.44-82.5
Tensile strength	MPa	180-1627
Length	mm	900-1500
Moisture contents	Wt.%	11.8

3.2.1.1 Extraction and treatment of pineapple leaf fiber

The four main components of plant fibers are cellulose, hemicellulose, lignin, and pectin. The distribution of cellulose fibers in the form of a natural composite in a lignin matrix. The crystallinity and shape of cellulose determine how well plant fiber reinforcing works. The lignin and pectin components of fibers, respectively, give them their stiffness and flexibility. Three fundamental techniques exist for extracting fibers: mechanical, chemical, and combination. The most popular types of retting are mechanical, and studies demonstrate that they offer greater properties than other types. Pineapple leaf fiber is extracted from the leaves type.

Figure 3. 1 Pineapple leaf fiber (a) harvesting plant (b) extraction process (c) extracted fiber (d) treated fiber

Alkaline treatment was found to be most effective method to improve interfacial bonding between fiber and matrix, while other treatment methods shows either reduction on the strength of fiber (Seisa et al., 2022). A 2-hour chemical treatment with 5% NaOH is used to increase the adhesive characteristic, followed by a water wash to neutralize the fiber. In May, the fiber is allowed to dry during clear sky days. Chemical processing reduces the porosity and water absorption of fibers while increasing the surface roughness at the fiber-matrix contact. Higher alkali concentrations have been found to cause excessive delignification of natural fiber, which makes the fiber weaker or damaged (Bisanda, 2000).

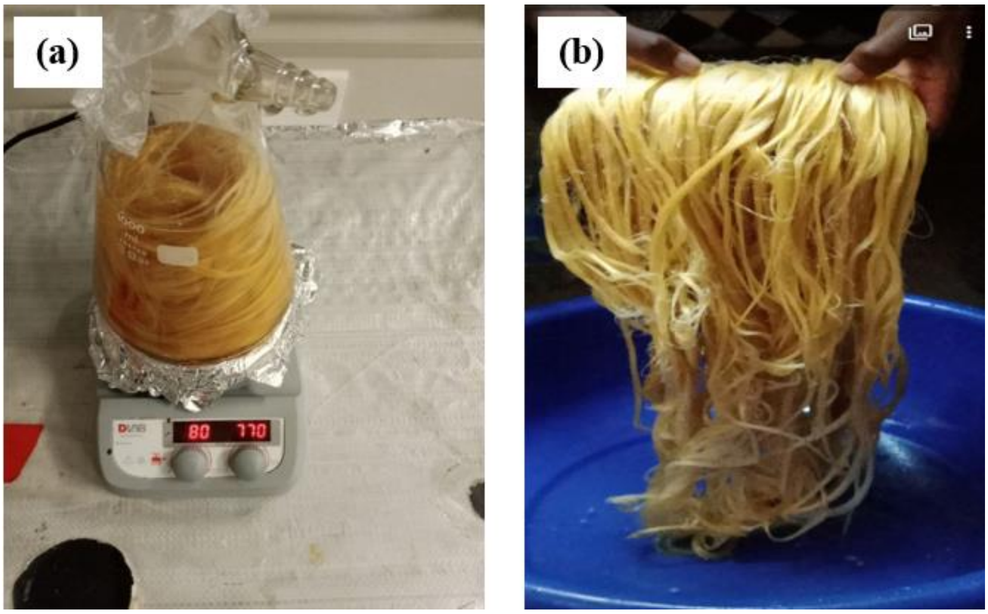

Figure 3. 2 Pineapple leaf fiber (a) treating (b) washing

3.2.1.2 Orientation of composite

The orientation of fiber gives strength and stiffness at different loading conditions such as: 0^{o} orientation Provide axial, $\pm 45^{o}$ orientation Provide shear and torsional, 90^{o} orientation Provide transverse strength. quasi-isotropic layup gives the property of composite material in all direction to resist axial, shear and transverse loads. Composite performance is greatly influenced by the direction of the fibers. To increase the strength of the composite it should be oriented in all direction for resisting shear, longitudinal and transverse loading. The ply orientation is given as [0°/90°, ±45° and chopped (Jiru, 2021).

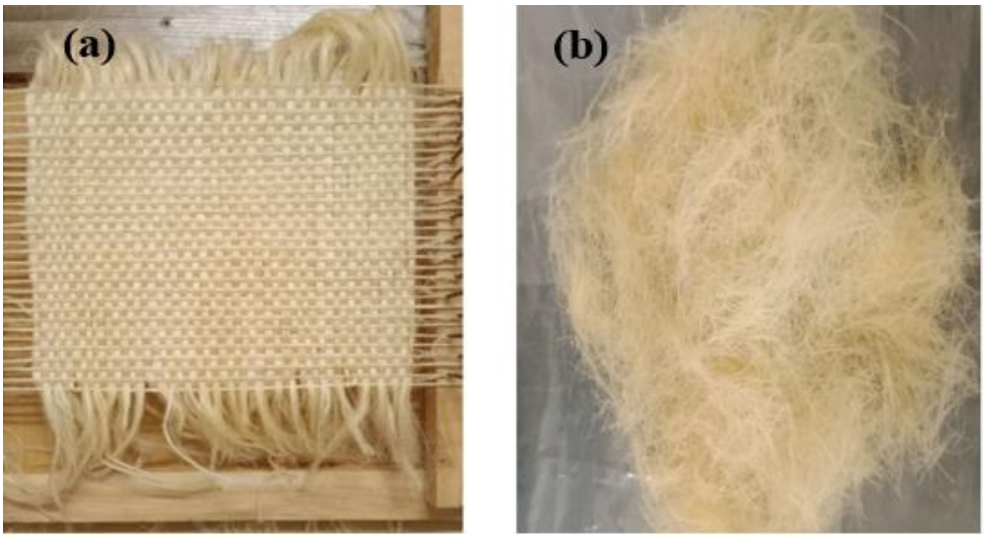

Figure 3. 3 Pineapple leaf fiber (a) mat (b) chopped

3.2.2 Coffee husk flakes

The coffee husk used in this project was collected from Aleta Chuko werada, Sidama region, Ethiopia which is dry processed and fresh. coffee is harvested from leaves. Coffee husk were separated from natural dried grains by a threshing process and obtained from a coffee crop by dried in sunlight. The CHF was washed correctly, and the composite was prepared using the hand layup method. Composites of the coffee husk fibers (CHF) were prepared using the following process. The CHF was dried under vacuum at 103 ◦C for 24 h to reduce the water content. The CH has a thickness of 3–5 mm and a length of 0.20 m. They underwent a 24-hour oven drying process after being cleaned with clean water up till the dirty of husk was removed. The fiber was submerged in a 5% NaOH solution for 12 hours. The husks were periodically rinsed with regular water and then with clean water, followed by a 24-hour period of drying at room temperature to remove contaminants from the surface of the fiber. 5% NaOH alkali has been used to treat the CH fiber. Finally, to create the powder, the treated CH was processed in a 0.18 mm mill. The dried husks were ground and then sieved to a final product of 100-150 mesh. To enhance the physical and mechanical properties of polymer composites, this coffee husk powder will be chosen as a filler ingredient.

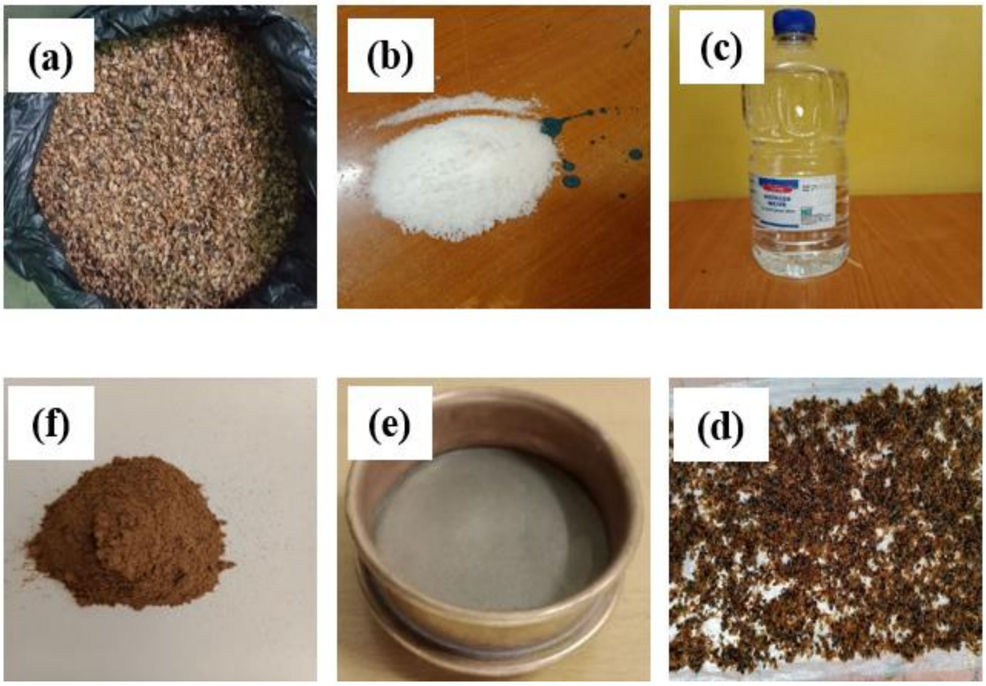

Figure 3. 4 (a) coffee husk flakes (b) sodium hydroxide (c) distilled water (d) treated coffee husk (e) sieve (f) sieved coffee husk

3.2.3 General purpose polyester resin

The resin utilized for this research work is Unsaturated Polyester (TOPAZ-1110 Phthalic Anhydride) which used for general-purpose applications. When exposed to the proper circumstances, unsaturated polyester resin thermoset might be cured from a liquid to a solid form. Unsaturated polyester has advantages over other thermosetting resins that have been studied, including low viscosity for quick wet-out, ease of use for hand layup applications, low cost, low density, good mechanical and chemical resistance, low-pressure molding capabilities, and the ability to cure at room temperature. (Aynalem and Sirahbizu, 2021)The ratio of catalyst is 1.5 % to the total volume of resin to be used. Generally, it is mixed with polyester resin at normal atmospheric temperature. It's supplied by World Fiber Glass and Water Proofing Engineering, Addis Ababa, Ethiopia.

Table 3. 2 Properties of general-purpose polyester resin

Descriptions	Units	UPR
Density	g/cm^3	1.2-1.5
Elastic modulus	GPa	2-4.5
Tensile strength	MPa	40-90
Compressive strength	MPa	90-250
Elongation	%	2
Cure shrinkage	%	4-8
Water absorption	(24 hr. @ 20℃)	0.1-0.3
Izod Impact Notched	J/cm	0.15-3.2

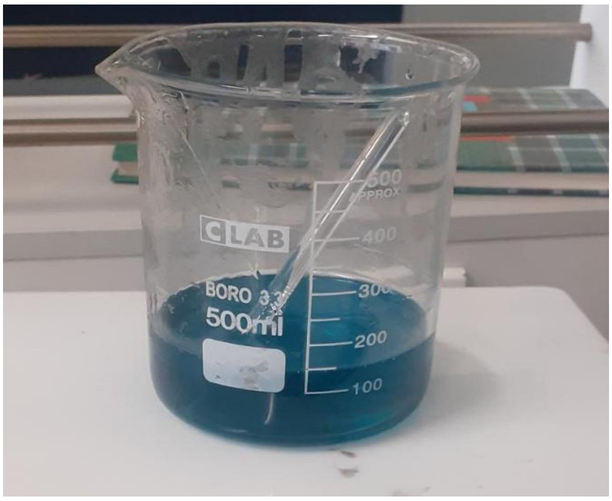

Figure 3. 5 Unsaturated polyester resin

3.2.4 Hardener

A hardener or catalyst was applied to the unsaturated polyester resin to cure it, beginning a chemical reaction. The liquid polyester resin and monomer component are converted into a solid through a chemical process that the catalyst initiates. As a result, the curing agent for this study was a hardener with the brand name "methyl ethyl ketone peroxide hardener." It is supplied from World Fiber Glass and Water Proofing Engineering in Addis Ababa, Ethiopia.

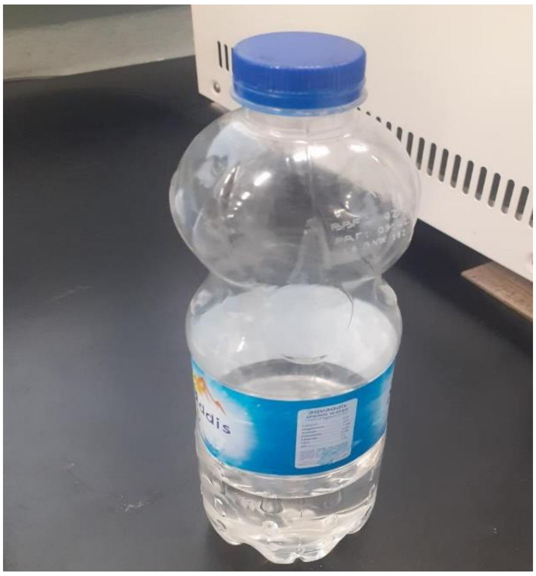

Figure 3. 6 Hardener

3.2.5 Mold release

Using release wax as a chemical agent, it was possible to prevent the molding material from sticking to the mold. When the composite was being disassembled, it was essential to use mold release to prevent the polyester from sticking to the mold. However, several mold releases were used depending on the kind of mold and the required characteristics of the finished product. The most popular kind, honey wax 250, will be used for this thesis project and will be acquired from the local supplier, World Fiber Glass and Waterproofing Engineering in Addis Ababa, Ethiopia.

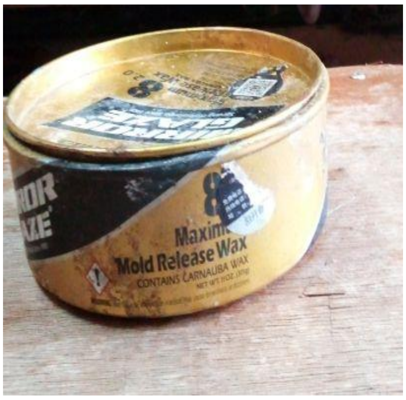

Figure 3. 7 Mold release

3.2.6 Sodium hydroxide

Sodium hydroxide, also known as lye or caustic soda, has the chemical formula NaOH and is a very caustic metallic base and alkali salt. Pure sodium hydroxide was a yellowish solid that was available in pellet, flakes, granule, and 50% saturated solution forms, as was previously mentioned. It is analytical reagent grade, 99.8% pure, and has a molecular weight of 39.99971 g/mol (Aynalem and Sirahbizu, 2021). This alkali was deliquescent and quickly absorbed carbon dioxide from the atmosphere in addition to moisture. Sodium hydroxide was used in a wide range of sectors, primarily as a robust chemical base in the manufacturing of pulp and paper, textiles, drinking water, soaps, and detergents. NaOH was used in this investigation to treat PALF in the form of fibers and CH in the form of flakes, which will be purchased from local vendors.

Figure 3. 8 (a) sodium hydroxide (b) powder form

3.2.7 Silicon Carbide

To develop the characteristics of the composite, silicon carbide is employed as fillers in the form of particles. For several polymer matrix composites, silicon carbide particles have emerged as a popular filler ingredient. They are strong ceramic particles that are brittle and rigid, and they have great elasticity, thermal, and electrical resistance. SiC has several uses because of its high hardness, including in abrasives, refractories, ceramics, cutting tools, aerospace components, vehicle components, etc. In the research work, the malleable, odorless and black powder of silicon carbide with an average particle size of 50-150 micron has a density of 3.21 gm/cm3 was purchased from the (Chengdu Huarui Industrial Co., Ltd.

A-1203, Guanghua center, qngyang district,610015, P. R China). Other Properties of silicon carbide particle is shown in table 3.3.

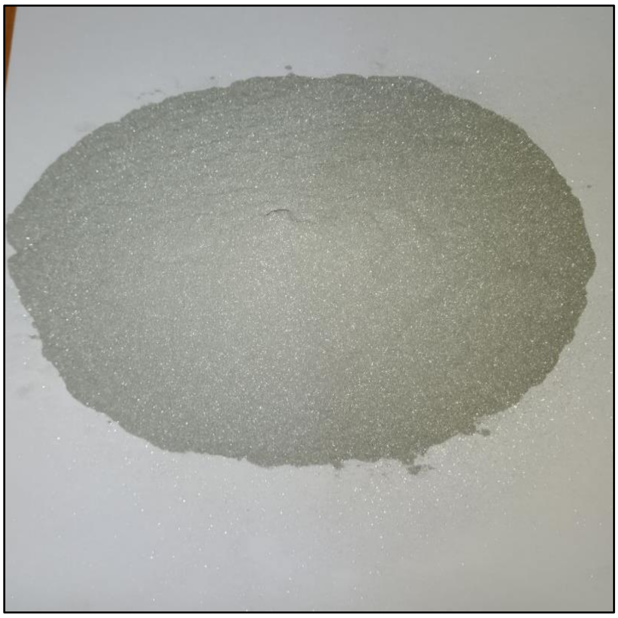

Figure 3. 9 Silicon carbide

Table 3. 3 Properties of Silicon Carbide (SiC) (Subramanya Reddy et al., 2017)

property	Value
Density	3.21 g/cm^3
Melting point	2730℃
Modulus of elasticity	410 GPa
Tensile strength (σt)	3900 MPa
Poisson's ratio (v)	0.14
Form	Powder
Particle size	270 mesh
Hardness	2800 Kg/mm^2

3.3 Methods

3.3.1 Design variable selection

The weight fractions of PALF, SiC, CHF, and the orientation of PALF fibers will be chosen as variables that affect the produced composite. These three factors, whose weight percentages range from 0% to 25% and which are combined with polyester matrix percentages of 55%, 70%, and 85%, are employed to enhance the mechanical qualities of the composite that has been created.

3.3.2 Design of Experiment for Composite Fabrication

By using the hand layup method, a composite was created using a Taguchi experimental design that was created based on the basic input parameters (Angle/Orientation and Weight Percentage of Reinforcement) for each fabrication. Taguchi L9 Orthogonal Array Experimental Design at Three Levels with Four Factors was used. Because it is a technique for problem-solving that can enhance the performance of the product, process design, and system. DOE is a method for designing and examining every scenario including several parameters, variables, and other aspects in an experiment. The three levels of particle content, pineapple leaf fiber content, and fiber direction were taken into consideration in order to observe the most significant process variables in the fabrication of SiC/CHF/pineapple leaf fire reinforced polyester composite. The selected parameters, levels, and values at different levels are given in Tables 3.4.

Table 3. 4 Experimental Parameters and Their Levels

S. No	parameters	levels			units
1	Angle	0/90	45	chopped	degree
2	Wt.% of PALF	15	20	25	%
3	Wt. % of Sic	0	5	10	%
4	Wt.% of CH	0	5	10	%

The selection of a particular orthogonal array was based on the number of levels of various factors, Here, to conduct the experimental 4 factors each at 3 levels were selected. Now the Degree of Freedom (DOE) can be calculated by the formula as given below:

$$DOE = P^* (L - 1) \tag{3.1}$$

$$DOE = 4 * (3 - 1) = 8$$

where, P= number of factors

L = number of levels

However, the total number of the experiment of the orthogonal array (OA) should be greater than or equal to the DOE required for the experiment. Therefore, L9 orthogonal array was selected to make the further experiments are shown in Table 3.5.

Table 3. 5 Experimental Design for Fabrication

S. No	Fiber direction	PALF	SiC	CHF	UPR	Designation
1	0/90	15	0	0	85	S_1
2	0/90	20	5	5	70	S_2
3	0/90	25	10	10	55	S_3
4	45	15	5	10	70	S_4
5	45	20	10	0	70	S_5
6	45	25	0	5	70	S_6
7	Chopped	15	10	5	70	S_7
8	Chopped	20	0	10	70	S_8
9	chopped	25	5	0	70	S_9

3.3.3 Fiber and Matrix Volume Content

Fiber and matrix weight fraction (WF, WM)

Experience can be used to calculate the resin to fiber ratio. It might be based on a weight or volume ratio. The ratio was created using their weight as a starting point, and it was then transformed into a volume ratio. The next section discusses the formula used to determine the weight fraction and volume fraction of fiber and matrix.

Fiber of weight fraction $= \frac{\text{fiber weight}}{\text{Total weight}}$ (3.2)

$$W_p = \frac{\mathrm{W_p}}{\mathrm{W_p+W_s+W_{ch}+W_m}} \tag{3.3}$$

Filler $weight\ fraction = \frac{\text{filler weight}}{\text{Total weight}}$ (3.4)

$$W_s = \frac{\mathrm{W_s}}{\mathrm{W_p+W_s+W_{ch}+W_m}} \tag{3.5}$$

$$W_{ch} = \frac{\mathrm{W_{ch}}}{\mathrm{W_p+W_s+W_{ch}+W_m}} \tag{3.6}$$

$$Matrix\ weight\ fraction = \frac{weight\ of\ matrix}{Total\ weight} \tag{3.7}$$

$$W_m = \frac{\mathrm{W_m}}{\mathrm{W_p+W_s+W_{ch}+W_m}} \tag{3.8}$$

$$W_C = W_p + W_s + W_{ch} + W_m \tag{3.9}$$

$$W_p + W_s + W_{ch} + W_m = 1 \quad (3.10)$$

Fiber and matrix volume fraction (VF, VM)

Volume of fibers, matrix and composite is given by:

$$\mathrm{V_p} = \frac{\mathrm{W_p}}{\mathrm{\rho_p}} \quad (3.11)$$

$$\mathrm{V_s} = \frac{\mathrm{W_s}}{\mathrm{\rho_s}} \quad (3.12)$$

$$\mathrm{V_{ch}} = \frac{\mathrm{W_{ch}}}{\mathrm{\rho_{ch}}} \quad (3.13)$$

$$\mathrm{V}_m = \frac{\mathrm{W_m}}{\mathrm{\rho_m}} \quad (3.14)$$

$$\mathrm{V}_C = \mathrm{V_p} + \mathrm{V_s} + \mathrm{V_{ch}} + \mathrm{V}_m \quad (3.15)$$

$$Fiber\ of\ Volume\ fraction = \frac{Fiber\ Volume}{Total\ Volume} \quad (3.16)$$

$$V_p = \frac{\mathrm{V_p}}{\mathrm{V_p+V_s+V_{ch}+V_m}} \quad (3.17)$$

$$\text{Filler volume } fraction = \frac{filler\ volume}{Total\ volume} \quad (3.18)$$

$$V_s = \frac{\mathrm{V_s}}{\mathrm{V_p+V_s+V_{ch}+V_m}} \quad (3.19)$$

$$V_{ch} = \frac{\mathrm{V_{ch}}}{\mathrm{V_p+V_s+V_{ch}+V_m}} \quad (3.20)$$

$$Matrix\ \ fraction = \frac{volume\ of\ matrix}{Total\ volume} \quad (3.21)$$

$$V_m = \frac{\mathrm{V_m}}{\mathrm{V_p+V_s+V_{ch}+V_m}} \quad (3.22)$$

$$V_p + V_s + V_{ch} + V_m = 1 \quad (3.23)$$

The density of composite

$$\rho_C = \frac{1}{\left[\frac{\mathrm{W_p}}{\mathrm{\rho_p}}+\frac{\mathrm{W_s}}{\mathrm{\rho_s}}+\frac{\mathrm{W_{ch}}}{\mathrm{\rho_{ch}}}+\frac{\mathrm{W_m}}{\mathrm{\rho_m}}\right]} \quad (3.24)$$

The composite weight $\mathrm{W_C}$ is the multiplication of the composite volume $\mathrm{V_C}$ and composite density $\mathrm{\rho_C}$;

$$\mathrm{W_C} = \mathrm{V_C} * \mathrm{\rho_C} \quad (3.25)$$

Calculation of the Mass of Samples

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

Volume of the composites = $l \times w \times t$ (3.26)

Where, l = length, w = width and t = thickness l = 300 mm, w = 300 mm and t = 4 mm

Volume of the composite = $300mm \times 150mm \times 4mm = 180\ cm^3$

According to the density of bagasse fiber, polyester resin, aluminum oxide, silicon carbide was given bellow in g/cm3.

Table 3. 6 Density value of parameters

Parameters	value
Pineapple leaf fiber density (ρ_p)	1.35 g/cm^3
Silicon carbide density (ρ_s)	3.22 g/cm^3
Treated Coffee husk filler density (ρ_{ch})	5.26 g/cm^3
Matrix density (ρ_m)	1.15 g/cm^3

For sample - 1

Pineapple leaf fiber $= 15\ wt.\% = 0.15$ Coffee husk filler $= 0\ wt.\% = 0$

Silicon carbide $= 0\ wt.\% = 0$ Polyester resin $= 85\ wt.\% = 0.85$

The density of the composite was calculated by the rule of law of the mixture method and obtained first by adding the volume fraction of polyester resin, Pineapple leaf fiber, and ceramic particulate (coffee husk and silicon carbide) for each composite ratio was reviewed (Dhibar et al., 2018).

$$\rho_C = \frac{1}{[\frac{W_p}{\rho_p}+\frac{W_s}{\rho_s}+\frac{W_{ch}}{\rho_{ch}}+\frac{W_m}{\rho_m}]} \quad (3.27)$$

$$\rho_C = \frac{1}{[\frac{0.15}{1.35}+\frac{0}{3.22}+\frac{0}{5.26}+\frac{0.85}{1.15}]} = 1.176$$

$$M_C = \rho_C \times V_C \quad (3.28)$$

$$M_C = 1.18\frac{g}{cm^3} \times 180cm^3 = 211.8g$$

The mass of the composite was multiplied by each particulate /fiber/matrix ratio. Then the mass of each coffee husk, Sic, pineapple leaf fiber, and unsaturated polyester resin was obtained.

Mass of pineapple leaf fiber = $0.15 \times 212\ g = 31.8g$

Mass of silicon carbide = $0 \times 212\ g = 0g$

Mass of coffee husk filler = $0 \times 212\ g = 0g$

Mass of polyester resin = $0.85 \times 212\ g = 180g$

By calculating for other samples of the composites in similar ways the results were given in table below:

Table 3. 7 Mass of each sample of composites

		Composition (%)				Mass (g)				
S	Angle	PALF wt.%	SiC wt.%	CH wt.%	Polyester wt.%	PALF	SiC	CHF	Polyester	Total
S_1	0/90	15	0	0	85	31.8	0	0	180	211.8
S_2	0/90	20	5	5	70	46	11.5	11.5	161	230
S_3	0/90	25	10	10	55	63.1	25.24	25.24	138.82	252.4
S_4	45	15	5	10	70	35.74	11.92	23.83	166.81	238.3
S_5	45	20	10	0	70	45.6	22.8	0	159.6	228
S_6	45	25	0	5	70	55.9	0	11.2	156.6	223.7
S_7	Chopped	15	10	5	70	35.5	23.6	11.82	165.4	236.3
S_8	Chopped	20	0	10	70	47.3	0	23.7	165.6	231.6
S_9	Chopped	25	5	0	70	55.5	11.1	0	155.5	222.1

The mechanical properties of the composite were affected by the content of fibers, particulate fillers, and matrix materials. These were expressed either as volume fractions or as mass fractions. During sample preparation using mass fraction, volume fractions are easier. Volume fractions are used in the theoretical analysis of composites. According to the density of pineapple leaf fiber, unsaturated polyester resin, coffee husk and silicon carbide all their mass were calculated in the same way.

3.3.4 Tools and Equipment

Table 3. 8 List of equipment used in the study.

S.No	Tools	Function/task
1	Universal testing machine (UTM)	To determine the composite material's tensile strength or capacity to endure loads that causes it to enlarge in size.
2	Vickery hardness machine	To determine the composite's hardness
3	ImageJ software	ImageJ is an image analysis program extensively used for microstructural analysis
4	Minitab 17 software	Software package used for the analysis of data and optimization, Taguchi (S/N ratio, GRA)
5	Digital mass balance	Weighting the mass of materials
6	Specimen cutter machine	Cutting samples into specimens
7	Impact test machine	Give information of energy required to break specimens.
8	Scanning electron microscopy	Observe morphology of composite materials

3.4 Fabrication of composite using hand layup

Lay-up is the earliest but most fundamental method of manually producing composites. Each sample was created using a rectangular wood mold with dimensions of 300 mm × 300 mm, as illustrated in Figure 3.10. This method entails dotting a mold with fiber in an even layer and covering it with a resin matrix. The resin matrix is then distributed evenly by rolling it with a hand roller after that. Additionally, hand rolling makes it possible to roll to the desired thickness and increases contact between the reinforcement and matrix.

The fiber reinforcements were manually placed down in one of the manufacturing processes known as "hand lay-up," and after that, polymer resin was poured on top of them. To avoid the air between the reinforcements and matrix, a roller was moved very slightly while being pulled on the reinforced fiber. The same process was followed until the appropriate number of mixes were piled for each polymer resin and fiber. This was kept at room temperature and under pressure for around 24 to 48 hours. Smaller volumes responded nicely to this approach. For hand handling, resins must have a low viscosity. The material's mechanical properties are diminished as a result of the demand for high diluent/styrene ratios. This simply offers a fantastic side surface polish. The material under research has higher material design flexibility and required more cycles to create (Srinivas et al., 2017). The hand lay-up method had the benefit of many different items and inexpensive tools. Time-consuming, simple to create air bubbles, and fiber disorientation were some of this method's drawbacks.

Figure 3. 10 Fabrication process

3.4.1 Basic processing steps

The major processing steps in the hand lay-up process to prepare the short chopped and woven pineapple leaf fiber reinforced polyester with coffee husk and silicon carbide fillers:

1. The mold is disinfected and ready for use.
2. To facilitate the removal of the composite, the mold cavity was cleaned to eliminate debris and then covered with layers of releasing agent (wax).
3. This composite material's volume and mass fractions must be calculated.
4. After manually mixing the polyester and fillers for a few minutes at a moderate pace, 1.5 weight percent of hardener is added to the polyester resin ratio, and the mixture is again slowly mixed for two minutes.
5. Following that, the operator applies or lays the matrix layer and reinforcement to the mold.

6. After manually combining the reinforcement and resin in a mold, the resin-reinforcement mixture is then squeezed using a hand roller. Using brush, resin is uniformly distributed over the mold.
7. After that, the part is allowed to cure at room temperature overnight.
8. Finally, pineapple leaf fiber, coffee husk and silicon carbide filler reinforced polyester composite is fabricated.

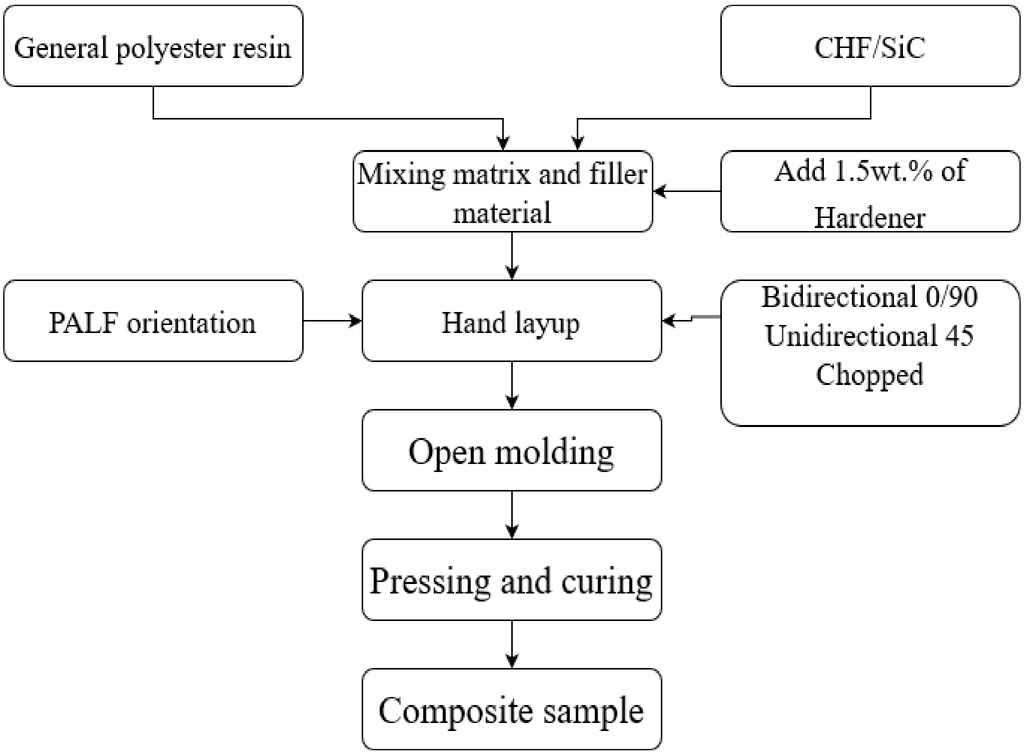

Figure 3. 11 Fabrication approach of composite

3.4.2 Advantage of hand layup

The wet lay-up process is one of the oldest composite manufacturing techniques with the following advantages:

- Very low capital investment is required for this process because there is a negligible equipment cost as compared to other processes.
- The process is very simple and versatile, any fiber type material can be selected with any fiber orientation.
- The cost of making a prototype part is low because a simple mold can be used to make the part. In addition, the raw material used for this process is resin, mat, and fabric material, which are less expensive.

3.4.3 Disadvantages of hand layup

The wet lay-up process has the following limitations:

- The process is labor intensive.
- The process is mostly suitable for prototyping as well as for making large structures.
- The quality of the part produced is not consistent from part to part.
- The process is not clean (Frank, 2002).

3.5 Sample Preparation for Characterization

Following the manufacture of the composite material, the composite was prepared for mechanical, physical, and micro structural testing. The specimen was cut to the proper shape and size for physical, mechanical, and tests in accordance with ASTM standards.

3.6 Research Methodology

Various steps followed in methodology of the thesis work were shown in the form of flow chart shown in Figure 3.12.

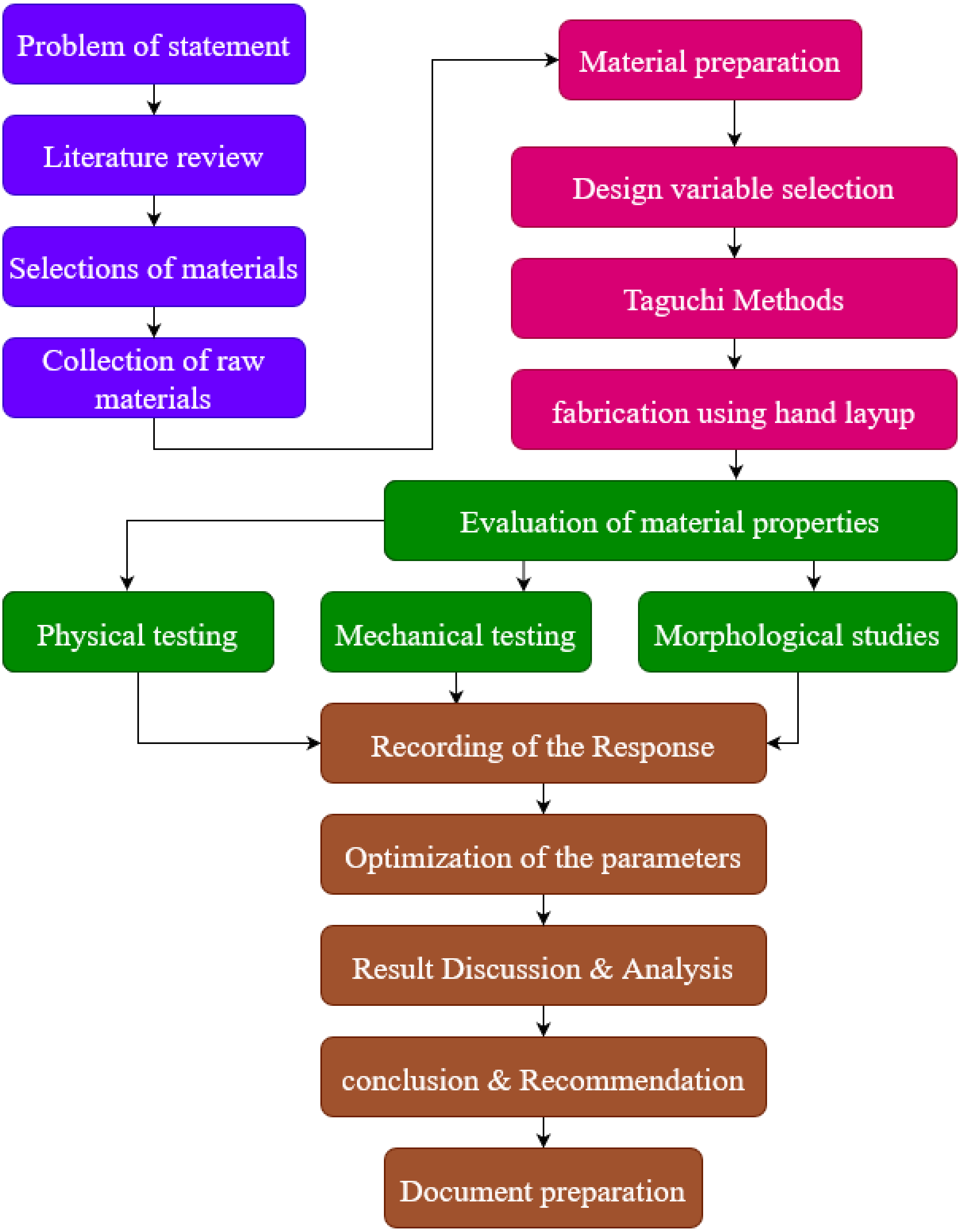

Figure 3. 12 Research methodology

3.7 Equipment's Used for Study

Equipment was used for performing tests as well as all tasks needed in these studies. These include an analytical (digital) mass balance, a specimen cutter, a universal testing machine, a Vickers hardness testing machine, a drilling machine, an impact test machine, and a scanning electron microscope.

3.7.1 Analytical (Digital) Mass Balance

The digital mass balance was used for weighting the amount of pineapple leaf fiber, Sic, coffee husk, and polyester resin used for sample preparation. The balancing equipment was used for the physical characterization of composite property. It was found in the material science Engineering laboratory at Adama Science and Technology University, Ethiopia.

Figure 3. 13 Digital mass balance

3.7.2 Specimen Cutter Machine

Specimen cutter machine was a grinder used for cutting samples into specimens according to ASTM standard test.

Figure 3. 14 Cutter machine

3.7.3 Universal Testing Machine

The universal testing machines were a computer equipped machines used to measure the mechanical properties of materials under different loading conditions. This measured the tensile, compressive and bending strength of the materials by simply by changing the jaws and modes of operations were reviewed (Jiru, 2021).

The main parts of the UTM were the main frame, the drive system, movable crosshead, load cell, and digital indicator. The main frame includes the rectangular base where the gearbox was placed, the fixed crosshead and the two vertical parallel columns. The drive system includes a stepper motor with variable speed. The gearbox was formed by a worm shaft, and two worm gears, which moved the two drive screws. The movable crosshead was integrated by the bottom grip, two conical fastener tools with internal thread and an adjustable conical ring. The conical fastener tools provide stabilization for the movable crosshead when moving along the drive screws. The load cell was used for tension or compression testing; it was located on the upper side of the frame and supports the upper grip. The digital indicator measures the crosshead displacement and consists of a digital micrometer from Starrer with 0.001 mm of resolution, which was connected with an RS232 interface to a computer to acquire data.

The UTM was connected with a computer display which allows us to print the test output (stress-strain curve). Specimen dimensions, speed of the machine, alignment and others were fixed before the machine startup. This UTM was found by the Ethiopian Defense University of Engineering College Bishoftu, Ethiopia. MTL/015 Universal Testing Machine with a 2000kN was used for performing the tensile test.

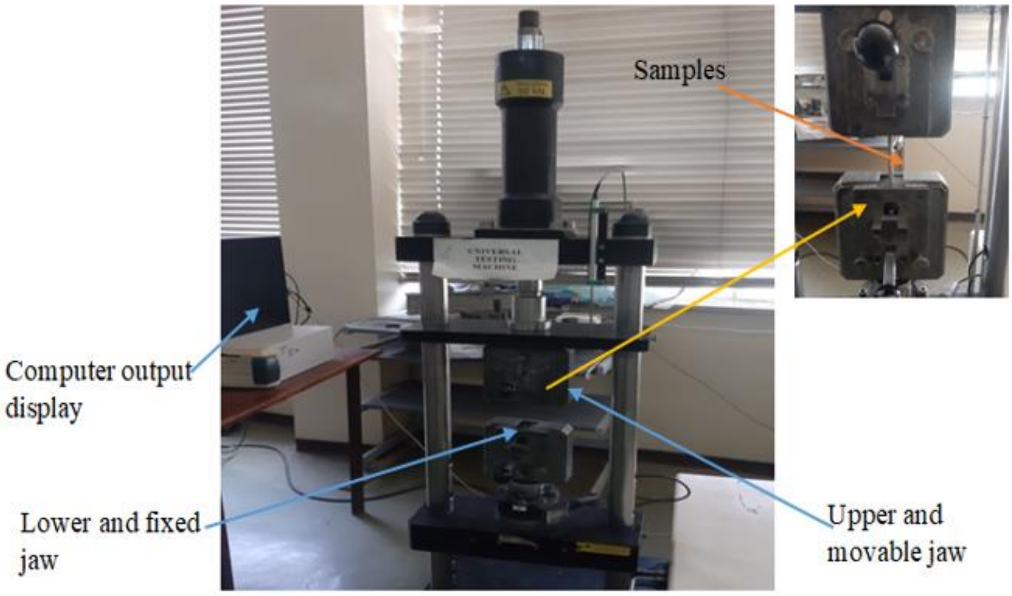

Figure 3. 15 Universal Testing Machine

3.7.4 Vickers Hardness Machine

The Vickers hardness machine was used HV50. It was used for surface hardness testing. This machine found in Adama Science and Technology University in Material Science Engineering laboratory.

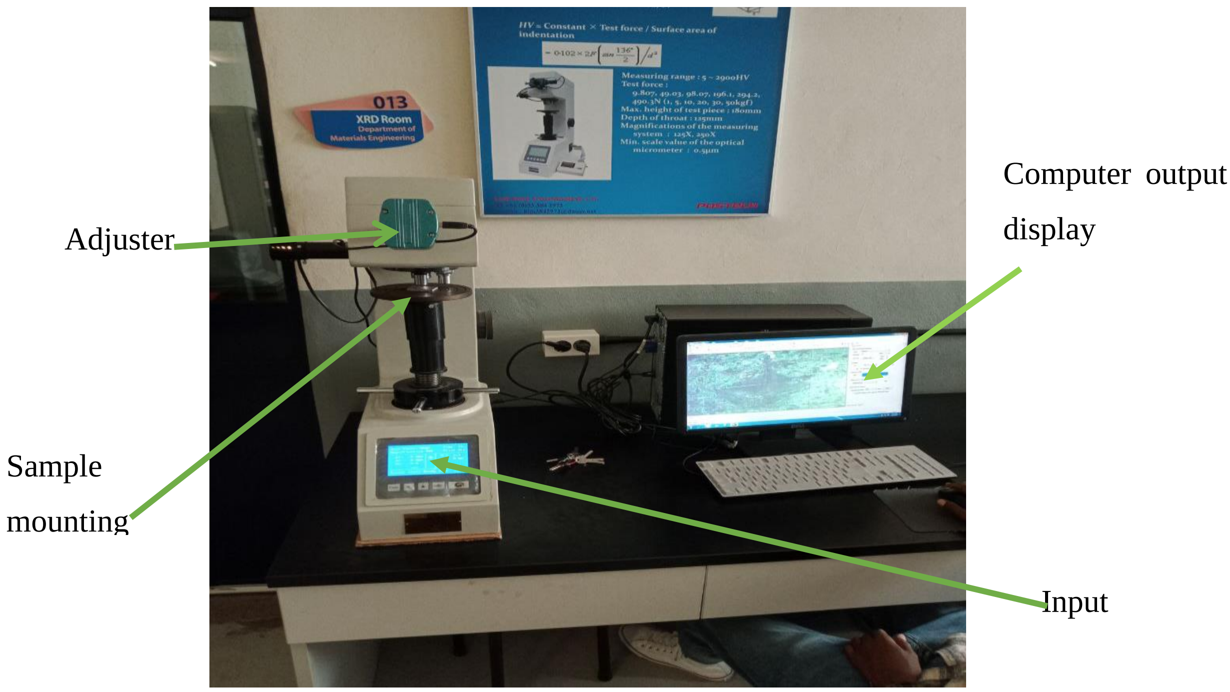

Figure 3. 16 Vickers Hardness Machine

3.7.5 Impact Test Machine

The impact strength of material provides information regarding the energy required to break a specimen of a given dimension, the magnitude of which reflects the material's ability to resist a sudden impact (Elanchezhian et al., 2018). The Charpy impact test was also known as the Charpy V- notch test. It was a standardized high strain-stress test that determines the amount of energy absorbed by a material during fracture. This absorbed energy was a measure of a given material's notch toughness and acts as a tool to study temperature dependent ductile-brittle transition. It was widely applied in the industry since it was easy to prepare and conduct, and results were obtained quickly and cheaply. This machine was found at Defense University of Engineering College, Bishoftu, Ethiopia.

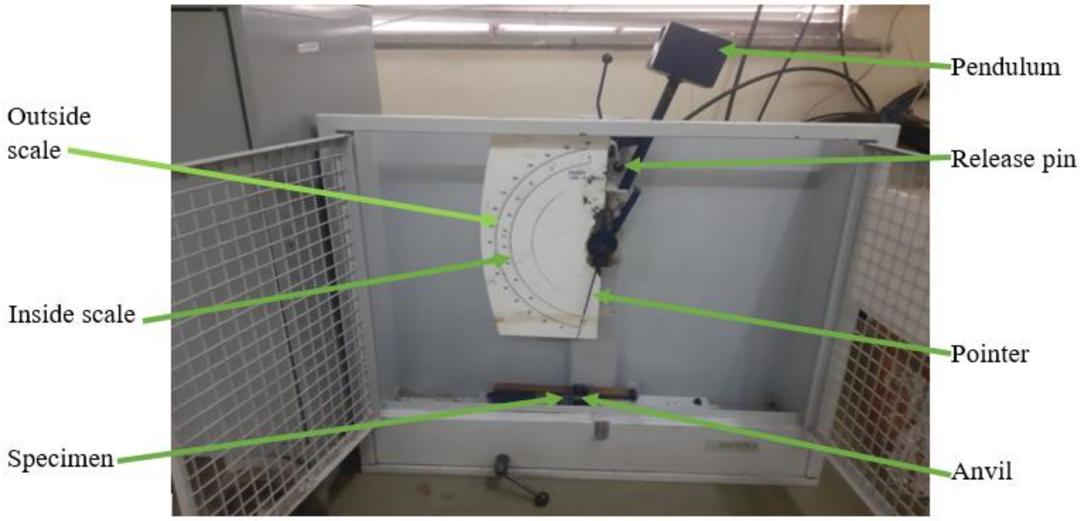

Figure 3. 17 Charpy Impact Test Machine

3.7.6 Scanning Electron Microscope

A JCM/6000Plus Japan desktop SEM model of a scanning electron microscope is used to observe the morphology of the composite surface. Specimens to be observed under the SEM were mounted on conductive adhesive tape, sputter-coated with gold, and observed in the SEM using a voltage of 15kV. This scanning electron microscope was found at Adama Science and University Technology, in the Biology Department laboratory.

Figure 3. 18 Scanning Electron Microscope

3.8 Composite Characterization

The composite characterization involves both mechanical and physical characterization of the prepared specimens. These characterizations were performed at room temperature and by using the ASTM standard for each test performed.

3.8.1 Mechanical Characterization

The mechanical characterization consists of the tensile strength, flexural strength, Vickers hardness, and impact tests of prepared composite specimens.

3.8.1.1 Tensile Strength Testing

The tensile test was a measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before fracture. The tensile strength of a material was the maximum amount of tensile stress obtained before failure. The tensile strength was calculated as force per unit area applied to the material. It was the maximum tensile stress, which was the limit of the materials to withstand exerted tension force without causing a failure. The specimen used for the tensile test was the flat type. During the tests, a uniaxial load was applied through both ends of the sample. The samples were positioned vertically in the grips of the testing machine. The grips were then tightened evenly and firmly to prevent any slippage. As the tensile test starts, the specimen elongates; the resistance of the specimen increases and was detected by a load cell. This load value was recorded until a rupture of the specimen occurred. Instrument software provided along with the equipment will calculate the tensile properties for yield strength and elongation at break. Tensile strength at yield = Maximum load recorded/Cross-section area was reviewed (Tripathi and

Kumar, 2016). Tensile test was conducted in Ethiopian Defense University of Engineering College Bishoftu, Ethiopia. Tensile strength test performed according to the ISO 6892-1 on the computerized USM. The specimen size tensile strength test was 165 mm × 19 mm × 5 mm based on machine standard requirement. MTL/015 Universal Testing Machine with a capacity of up to 2000 KN was used. The tensile Strength of the composite was investigated (Suresh et al., 2020) as follows:

$$\sigma_t = \frac{p}{wt} \tag{3.29}$$

Where, p = load applied (N); w = width (mm); t = thickness (mm)

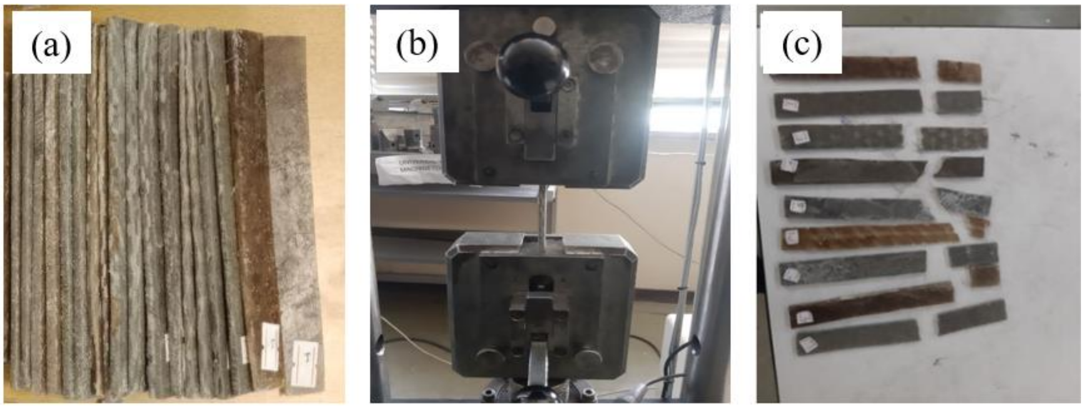

Figure 3. 19 Specimens for tensile strength test (a) before test (b) under test (c) after test

3.8.1.2 Flexural Strength Testing

Flexural strength was the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. Sometimes it was referred to as cross-breaking strength where maximum stress developed when a bar-shaped test piece, acting as a simple beam, was subjected to a bending force perpendicular to the bar. This stress decreased due to the flexural load was a combination of compressive and tensile stresses. Two methods cover the determination of flexural properties of the material such as three-point loading system and four-point loading system. The specimens for the flexural test are prepared according to the ASTM D790 standards (ASTM standard D790, 2002). The specimen was placed in the machine and tested by applying load with the help of the same UTM. The sample dimension was 127mm x 30mm x 5mm. The flexural strength was given (Suresh et al., 2020) as follows.

$$\sigma_f = \frac{3Pl}{2wt^2} \tag{3.30}$$

Where, p = Load applied (N), l = length (mm), w = width (mm), and t = thickness (mm) A flexural strength test was done in Defense University, of Engineering College in Bishoftu, Ethiopia by using computer controlled universal testing machine with WP 310 Universal Material tester model which had a capacity of up to 50 KN.

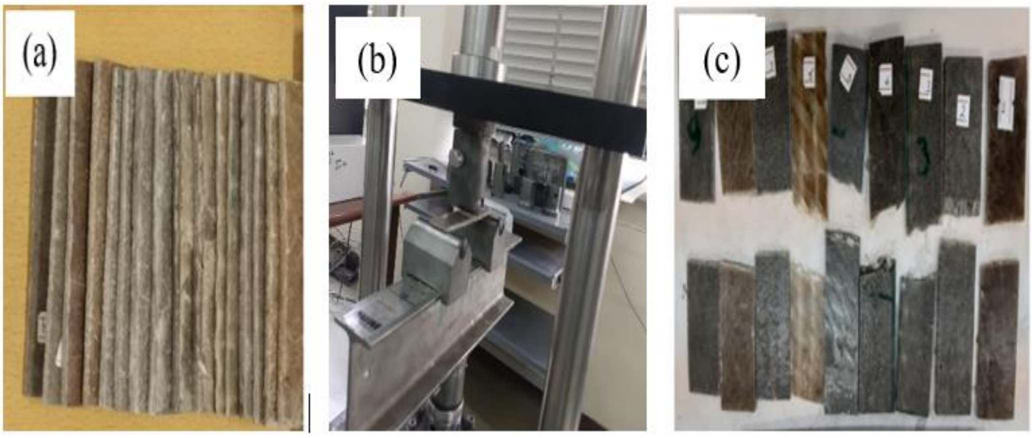

Figure 3. 20 Specimens for flexural strength test (a) before test (b) under test (c) after test

3.8.1.3 Vickers Hardness Testing

The Vickers hardness test involves measuring the amount of force required to implant a specified indentation on the surface of the specimen. Vickers hardness testing relies on the use of optical measurement. Microhardness test procedure, ASTM E-384, with the dimension of the specimen (20x20x5)mm^3 specifies different loads using a diamond indenter to make an indentation which is then measured and converted to a hardness value. This Study used a Vickers hardness testing machine (HVS-50 Buehler, USA). The indenter was a diamond pyramid shape with a square base having an included angle of 136^0 ±0.5. The indenter was forced into the sample's surface at a constant load of 10 Kgf with a dwell time of 10s. The surface-projected diagonal lengths of the resulting impression of each sample were then measured immediately after unloading using an upright optical. Two diagonals x and y of the indentation left on the surface of the material after removal of the load were measured and their arithmetic means was calculated. Vickers hardness number was calculated using the given (Biswas., 2014).

$$HV = 0.1889\frac{P}{L'^2} \quad (3.31)$$

$$L' = \frac{X+Y}{2} \quad (3.32)$$

Where, p is the applied load (N),

L' is the diagonal of square impression in mm.

x is the horizontal length (mm) and y is the vertical length (mm).

3.8.1.4 Impact Strength Testing

Impact strength was defined as the ability of a material to resist the fracture under stress applied at high speed. The impact properties of composite materials were directly related to overall toughness and composite fracture toughness was affected by inter laminar and interfacial strength parameters were investigated (Devendra and Rangaswamy, 2012). Impact strength test of the composite was prepared as per ASTM D256 standard with specimen's size of 55 ×13 mm × 5 mm. A notch was prepared with a depth of 2.5 mm at 45° inclination. Impact strength test performed in Defense University of Engineering College, Bishoftu, Ethiopia.

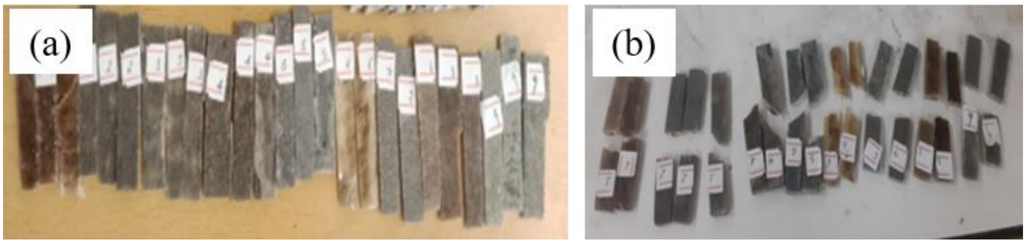

Figure 3. 21 Specimens for impact strength test (a) before test (b) after test

3.8.2 Physical Characterization

Physical characterization involved the characterization of physical properties of prepared composite specimens. These included the studies of water absorption, density, and void content.

3.8.2.1 Water Absorption Test

Water absorption of composites was one major concern in their outdoor applications. Water absorption of composites was performed as per ASTM D570 was reviewed (Yogesha, 2016). The water absorption tests of hybrid composites made from coffee husk, silicon carbide reinforced with pineapple leaf fiber and polyester were done with specimens' dimension was 30 mm x 28 mm x 4 mm by immersion in distilled water at room temperature. The specimens were taken out periodically and after wiping out the water from the surface of the specimens weighted immediately using a digital mass balance to find out the content of water absorbed. The specimens were weighed regularly at 12, 24, 36, 48, 60, 72 and 84 hours. The water absorption was calculated by the weight difference. The percentages weight gained of the specimens were measured at different time intervals by using the following equation (Biswas, 2016).

$$Water\ absorption\ (\%) = \frac{W_a - W_w}{W_w} \times 100 \quad (3.33)$$

Where, W_a and W_w are the weight of the dry and wet specimens.

3.8.2.2 Density and void content of composite

Density was the degree of compactness of a substance. Density was a measure of mass per volume of material. The density of composite was given (Ramlee et al., 2019).

$$\rho = \frac{m}{v} \quad (3.34)$$

Where ρ was the density of composite, m was mass of composite and v was volume of composite.

The reciprocal density of a substance was called its specific volume. The density of the material was directly related to the weight of the material. So as the density was reduced, the weight of the material will get reduced. The density of composite materials and their component were calculated by any of the three methods such as Archimedes method, the sink float method and the density gradient method. For this work, the actual density (ρa) of composite was determined by the Archimedes principle using rainwater as the medium. This method used the ASTM D792-13 standard investigated (Souza et al., 2020). The dimensions of the specimens were 30 mm length, 25 mm width, and 5 mm thickness of the materials. As per this principle when any object was immersed in the liquid the apparent loss in its weight was the same as the up thrust and equal to the weight of the liquid displaced was reviewed (Pradhan, 2016). The density actual of the composites fabricated can be calculated as below.

$$\rho_a = \frac{\rho_w W_a}{W_a - W_w} \quad (3.35)$$

The theoretical density of composite materials in terms of weight fraction is calculated using the following equation given (Biswas, 2017).

$$\rho_C = \frac{1}{\left[\frac{W_p}{\rho_p} + \frac{W_s}{\rho_s} + \frac{W_{ch}}{\rho_{ch}} + \frac{W_m}{\rho_m}\right]} \quad (3.36)$$

Where W and represent the weight fraction and density, respectively. The suffixes p, m, s, and ch stand for the pineapple leaf fiber, matrix, silicon carbide, coffee husk filler, and composite materials, respectively.

The volume fraction of voids (V_v) in the composites was calculated using the following equation reviewed (Ramlee et al., 2019).

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \quad (3.37)$$

Where, ρ_t and ρ_a are the theoretical and experimental densities of the composite, respectively. In all the composites, the volume fractions of voids were reasonably small that means less than 10%. However, the presence of void was unavoidable in composite fabricated particularly through hand-lay-up method was investigated (Swain and Biswas, 2017).

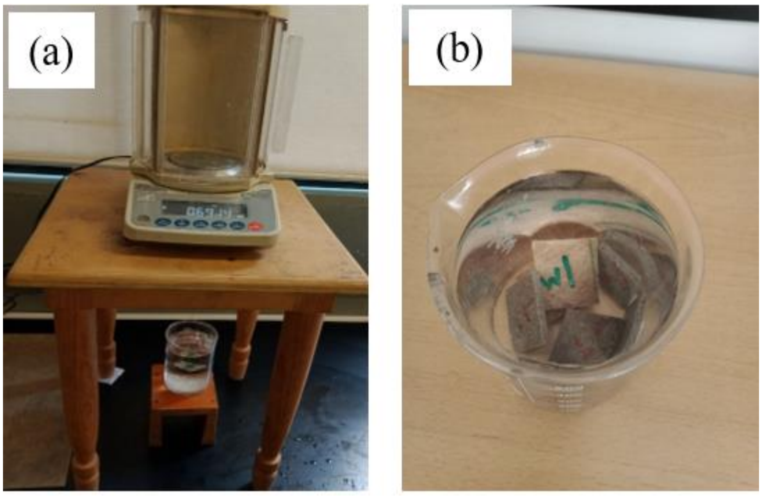

Figure 3. 22 (a) setup of density (b) specimens for density and void content

3.8.3 Morphological Analysis

Morphological analysis of specimens under SEM was carried out for S3, S4, S7 and S8. The reason to select these specimens shows good mechanical properties such as impact strength, flexural, tensile and hardness respectively when compared to the other specimens.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

The investigation includes morphological analysis as well as mechanical characteristics, such as flexural strength, tensile strength, impact strength, and hardness, as well as its physical characteristics, such as water absorption, density, and void contents. The composite was developed by maximizing the parameters according to the Taguchi technique for single response and Taguchi Grey Relational Analysis for multi-response characterization**.**

4.2 Analysis of Mechanical Properties

The qualities of composites are often influenced by a variety of elements, such as the properties of the resin and fiber, the quantity, length, and orientation of the fibers, the amount and type of fillers, and the bonding that occurs between the matrix and fiber. Due of their stronger influence on physical and mechanical qualities, fiber orientation and component weight percentages were chosen as the experiment's main considerations. Nine samples were used in each case for every experiment, and the average results have been selected for analysis. The best physical and mechanical properties of the created fiber composite were needed to further explain the strength of the interfacial bonding between the fibers and the matrix of composite samples.

4.2.1 Tensile Strength Test

Based on the results of the experimental work, tensile strength test results and S/N ratios from the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour were given in Table 4.1.

Table 4. 1 The tensile strength and S/N ratio of the experiment

Specimens	Angle (Orientation)	PALF wt.%	SiC wt.%	CH wt.%	Tensile Strength (MPa)	S/N ratio (dB)
S_1	0/90	15	0	0	8.60	18.69
S_2	0/90	20	5	5	22.37	26.99
S_3	0/90	25	10	10	21.71	26.73
S_4	45	15	5	10	26.01	28.30
S_5	45	20	10	0	30.00	29.54
S_6	45	25	0	5	11.89	21.50
S_7	Chopped	15	10	5	34.78	30.83
S_8	Chopped	20	0	10	33.73	30.56
S_9	Chopped	25	5	0	18.86	25.51

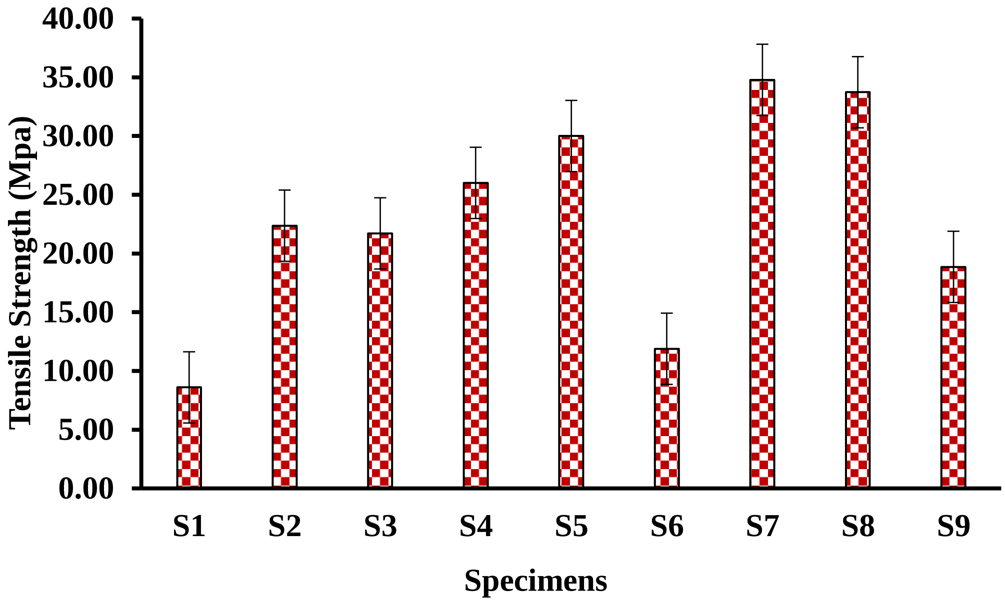

Figure 4. 1 Tensile strength test results

Figure 4.1 displays the outcomes of the tensile strength testing for each specimen. The maximum tensile strength of specimen 7 which was developed from 5 weight percent coffee husk, 10 weight percent silicon carbide, 15 weight percent pineapple leaf fiber and chopped fiber orientations was 34.78 MPa. The tensile strength from this reached its peak at 10 weight percent silicon carbide.

The minimal tensile strength was achieved at specimen 1 with 0/90 fiber orientation, 15% pineapple leaf fiber, and no fillers. This was because there was no weight percent of either Silicon carbide or coffee husk filler utilized, both of which had a greater effect on the tensile strength. Tensile strength increased at 20 weight percent, decreased at 15 weight percent, and drastically decreased at 25 weight percent of pineapple leaf fiber.

According to typical findings, the type of filler materials had a significant impact on the composite's tensile strength results, with silicon carbide having a bigger influence than coffee husk (Kiran et al., 2018). The tensile strength of the composite was also affected by variations in the weight percentage and fiber orientation of pineapple leaf fiber.

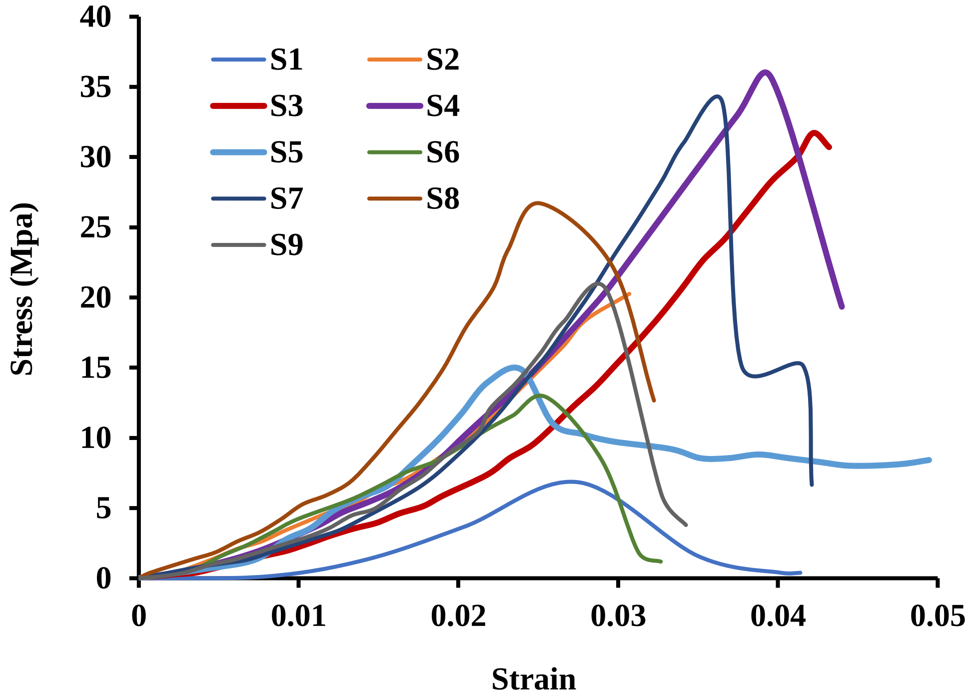

Figure 4. 2 Stress vs strain curve for tensile test

The stress-strain tests of each specimen showed a wide variety of strengths since specimen had a different filler type, fiber orientation, and weight percentage of pineapple leaf fiber. The stress-strain figure shows how the tensile strength increased until it reached its maximum and subsequently declined. The curves showed the typical brittle fracture behavior of composite specimens as they abruptly dropped after reaching their highest point. Natural fibers' stress-strain curves are nonlinear because celluloses respond to high stresses while hemicelluloses respond to low stresses. The specimens 4, 7, and 9 from this specimen were more brittle, whereas the other specimens had material that was more ductile and less brittle.

Table 4. 2 Tensile strength response for S/N ratios

Level	Fiber Angle	PALF	SiC	CHF
1	24.14	25.94	23.58	24.58
2	26.45	29.03	26.94	26.44
3	28.97	24.58	29.03	28.53
Delta	4.83	4.45	5.45	3.95
Rank	2	3	1	4

According to response Table 4.2 signal-to-noise ratios for tensile strength, silicon carbide weight percentage was the composite's first-ranking contributor to enhanced tensile strength, with a delta number of 5.45. The second most important component in increasing the tensile strength of the composite with a delta number of 4.83 was the weight % of the fiber orientation. The third-ranking component that increased the tensile strength of the composite was pineapple leaf fiber, with a delta number of 4.45; the fourth-ranking element was the weight percentage of coffee husk filler, with a delta value of 3.95. The best feasible parameter combination to increase the tensile strength of the hybrid composite on a larger, better-quality character was A3B2C3D3.

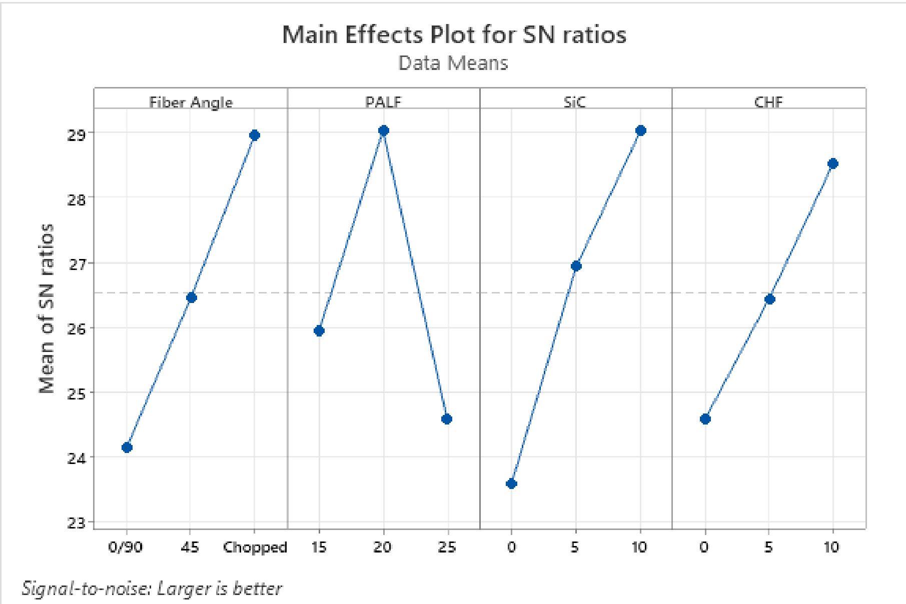

Figure 4. 3 Main effects of the S/N ratio plot for tensile strength

Figure 4.3 shows the S/N ratio's basic effect plot, with a greater ratio being better for tensile strength. The S/N ratio was optimum at level 3 fiber orientation content, level 2 pineapple leaf fiber, level 3 silicon carbide content, and level 3 coffee husk content. From among these potential variable configurations, A3B2C3D3 with chopped fiber orientation, 20 weight percent pineapple leaf fiber, 10 weight percent silicon carbide, and 10 weight percent coffee husks were chosen for the S/N ratios of the tensile strength, respectively. This result illustrates how a composite material's tensile strength can be increased by adding more filler.

4.2.2 Flexural Strength Test

Based on the results of the experimental work, flexural strength test results and S/N ratios from the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour were given in Table 4.3.

Table 4. 3 The flexural strength and S/N ratio of the experiment

specimens	Fiber direction	PALF wt.%	SiC wt.%	CH wt.%	Flexural Strength (MPa)	S/Ratio (dB)
S_1	0/90	15	0	0	60.77	35.67
S_2	0/90	20	5	5	43.42	32.75
S_3	0/90	25	10	10	53.42	34.55
S_4	45	15	5	10	174.88	44.85
S_5	45	20	10	0	77.39	37.77
S_6	45	25	0	5	42.96	32.66
S_7	Chopped	15	10	5	51.80	34.29
S_8	Chopped	20	0	10	98.78	39.89
S_9	Chopped	25	5	0	62.71	35.95

Based on Table 4.3, specimen 4's composite had a maximum flexural strength of 174.88 MPa and contained 15 weight percent pineapple leaf fiber, 5 weight percent silicon carbide, 10 weight percent coffee husk fiber and at 45 fiber orientation. Flexural strength in specimen 6 with 5 weight percent coffee husk, 0 weight percent silicon carbide, 25 weight percent pineapple leaf fiber, and 45 fiber orientation had a minimum value of 42.96 MPa. The flexural strength was greatly affected by the amount of coffee husk filler to the overall weight.

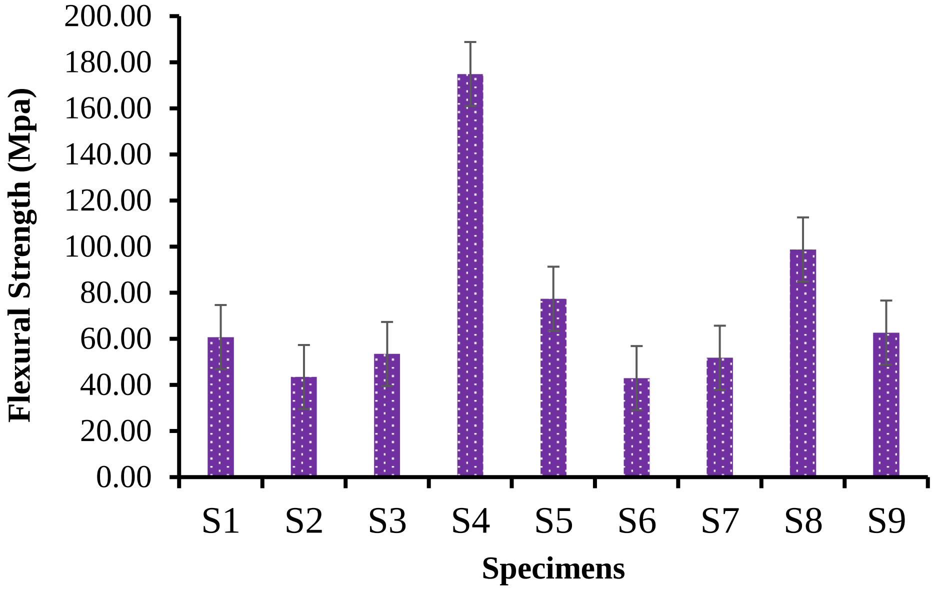

Figure 4. 4 Flexural strength test result

Table 4. 4 Flexural strength response for S/N ratios

Level	Fiber Angle	PALF	SiC	CHF
1	34.33	38.27	36.08	36.46
2	38.43	36.81	37.85	33.23
3	36.71	34.39	35.54	39.77
Delta	4.10	3.88	2.31	6.53
Rank	2	3	4	1

Table 4.4 displays the flexural strength signal-to-noise ratios. The first-ranking contributing element that raised the composite's flexural strength was the weight percentage of coffee husk, with a delta value of 6.53. The second most important element that contributed to the composite's was fiber orientation with a delta value of 4.10, weight %. of Pineapple leaf fiber, which came in third with a delta value of 3.88, and silicon carbide, which came in fourth with a delta value of 2.31. A2B1C2D3 was the ideal combination of parameters to raise the flexural strength of a hybrid composite on a larger, better-quality character .

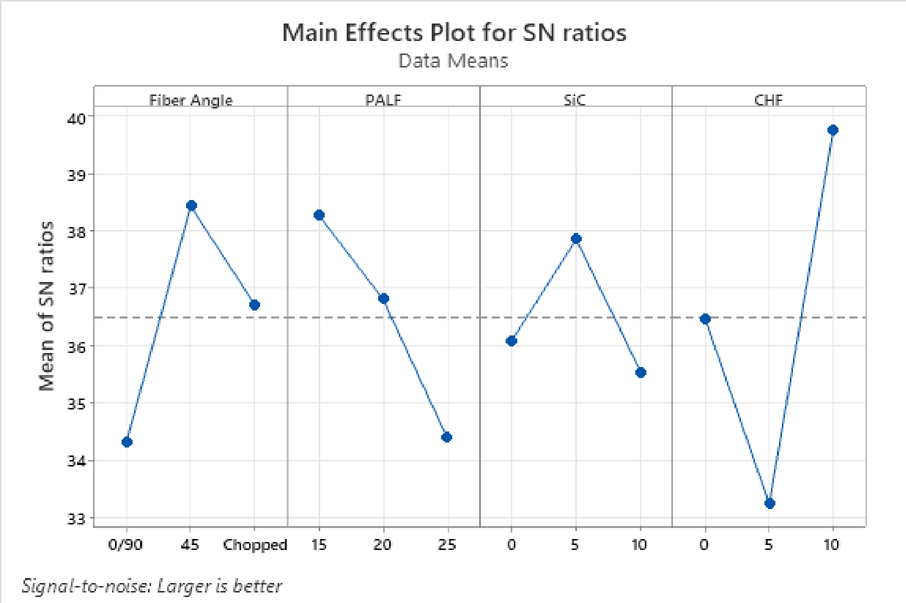

Figure 4. 5 Main effects plot for S/N ratio for flexural strength

Figure 4.5 shows the primary effect plot for the S/N ratio, with greater numbers indicating better for flexural strength. S/N ratio reached its maximum at level 2 fiber orientation content, level 1 pineapple leaf fiber content, level 2 silicon carbide content, and level 3 coffee husk content. For these S/N ratios of flexural strength, the parameter combinations that were useful were A2B1C2D3 with a 45-degree fiber orientation, 15 weight percent pineapple leaf fiber, 5 weight percent silicon carbide, and 10 weight percent coffee husks, respectively.

The findings show that flexural strength greatly increases at 5 to 10 weight percent of coffee husk and reduces at 0-5 weight percent. As the fiber content of pineapple leaves decreased, flexural strength increased. Additionally, with 45 unidirectional fiber orientations, flexural strength increased (Mishra et al., 2021).

4.2.3 Hardness Test

Based on the results of the experimental work, hardness test results and S/N ratios from the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour were given in Table 4.5.

Table 4. 5 The hardness and S/N ratio of the experiment

specimens	Angle (Orientation)	PALF Wt.%	SiC Wt.%	CH Wt.%	Hardness (HV)	S/N ratio (dB)
S_1	0/90	15	0	0	35.5	31.01
S_2	0/90	20	5	5	38.5	31.71
S_3	0/90	25	10	10	38.9	31.79
S_4	45	15	5	10	39.1	31.84
S_5	45	20	10	0	34.6	30.77
S_6	45	25	0	5	38.2	31.64
S_7	Chopped	15	10	5	40.3	32.11
S_8	Chopped	20	0	10	40.6	32.16
S_9	Chopped	25	5	0	35.5	31.00

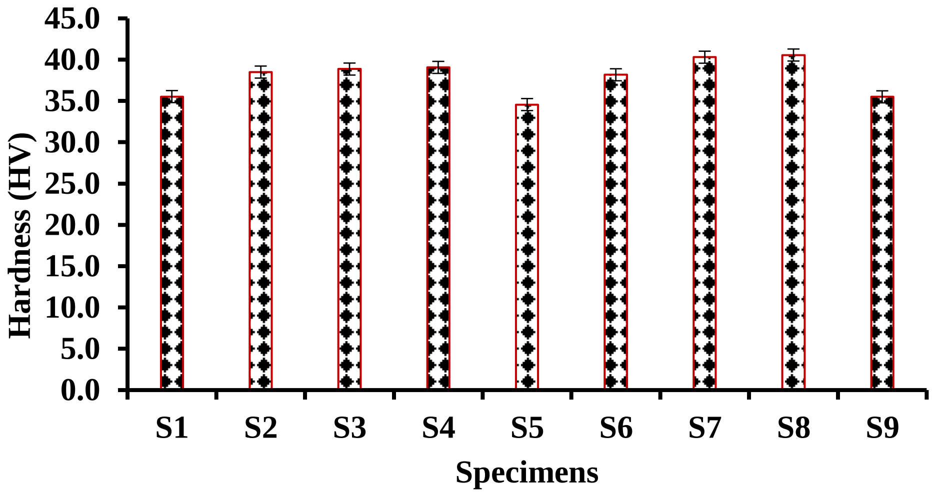

Figure 4. 6 Hardness test result

According to Figure 4.6, The Specimens 8 were produced at chopped fiber orientation, with a maximum hardness value of 40.6 HV, using 20 weight percent pineapple leaf fiber, 0 weight percent silicon carbide, and 10 weight percent coffee husks. The minimum hardness was for specimen 5 value of 34.6 HV with no coffee husk, 10 weight percent silicon carbide, 20 weight percent pineapple leaf fiber and at 45° fiber orientation . This showed that the hardness test findings for all specimens manufactured from the hybrid composite were different. Hardness of composite materials was affected by filler material types, filler weight percentages, fiber orientation, and pineapple leaf fiber weight percentages.

Coffee husk wt.% was more influence the hardness of composite materials. At 5-10 wt.% of CH increased hardness of composite materials and 0-5 wt.% of CH the hardness of composite materials was increased highly, this shows that up to 5% coffee husk was enough to increase hardness. Silicon carbide increased the hardness of composite material at 0-5 wt.% and decreased from 5-10 (Kiran et al., 2018). Figure 4.9 shows the hardness test values and deformation area of specimen 3 and 7 during the hardness test.

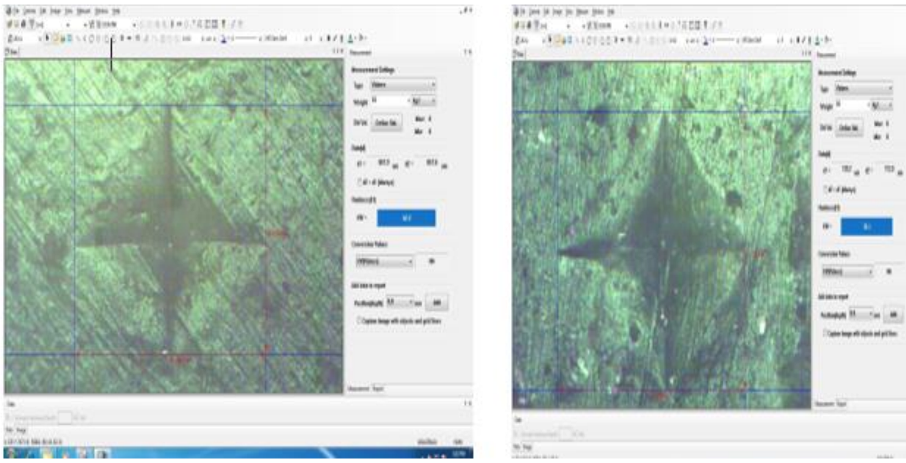

Figure 4. 7 Measurement of hardness for specimen 3 and 7

Table 4. 6 Hardness response for S/N ratios

Level	**Fiber Angle**	**PALF**	**SiC**	**CHF**
1	31.50	31.65	31.60	30.93
2	31.41	31.55	31.52	31.82
3	31.76	31.48	31.56	31.93
Delta	0.34	0.17	0.09	1.00
Rank	2	3	4	1

Table 4.6 shows Coffee husk weight percentage was the top contributor to enhanced the hardness of the composite, with a delta number of 1.00. Fiber angle orientation weight percentage was the second-ranking factor that increased the hardness of the composite. Pineapple leaf fiber, which came in third place, had a delta number of 0.17, while silicon

carbide weight percentage, which came in fourth place, had a delta number of 0.09. Coffee husk fill the gap between the fiber to increase the hardness.

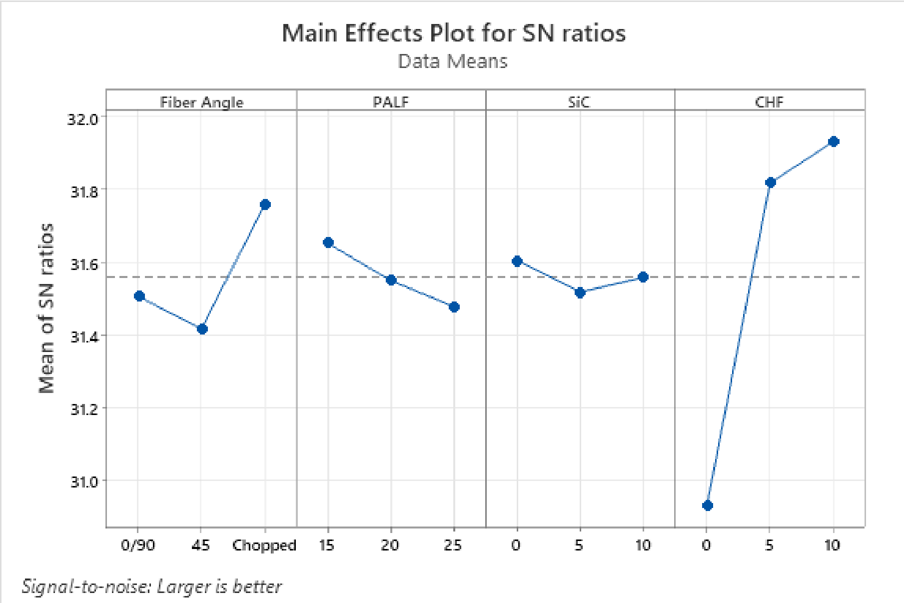

Figure 4. 8 Hardness main effects plot for S/N ratio

Figure 4.8 shows the main effect plot for S/N ratios, where bigger values were better for hardness. The S/N ratios were best at level 3 fiber orientation, level 1 silicon carbide content, level 1 pineapple leaf fiber and level 3 coffee husk content. A3B1C1D3 combination were at 0 weight percent silicon carbide, 10 weight percent coffee husks and 15 weight percent pineapple leaf fiber with chopped orientation, making it one of the possible best parameter combinations for the S/N ratio of hardness. According to the investigation, the process parameter combinations A3B1C1D3 produced the hardest material.

Coffee husk filler weight percentages of up to 5wt% dramatically improve hardness, and weight percentages of 5–10wt% steadily increase hardness. Chopped fiber orientation has been associated to high hardness, although pineapple leaf fiber and SiC weight percentage had no further impact on hardness.

4.2.4 Impact Strength Test

Based on the results of the experimental work, impact strength test results and S/N ratios from the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour were given in Table 4.7.

Table 4. 7 The impact strength and S/N ratio of the experiment

specimens	**Angle (Orientation)**	**PALF wt.%**	**SiC wt.%**	**CH wt.%**	**Impact (J)**	**S/Ratio (dB)**
S_1	0/90	15	0	0	3.25	10.24
S_2	0/90	20	5	5	4	12.04
S_3	0/90	25	10	10	5.25	14.40
S_4	45	15	5	10	6	15.56
S_5	45	20	10	0	5	13.98
S_6	45	25	0	5	3.75	11.48
S_7	Chopped	15	10	5	5.5	14.81
S_8	Chopped	20	0	10	4.5	13.06
S_9	Chopped	25	5	0	4.25	12.57

The specimen 4 had a maximum value of 6J and it had 15 weight percent pineapple leaf fiber, 5 weight percent silicon carbide, and 10 weight percent coffee husks, with a fiber orientation of 45 degrees. Specimen 1 had a minimum value of 3.25J, was 45 fiber orientated, contained no filler materials, and had a pineapple leaf fiber content of 15 weight percentages.

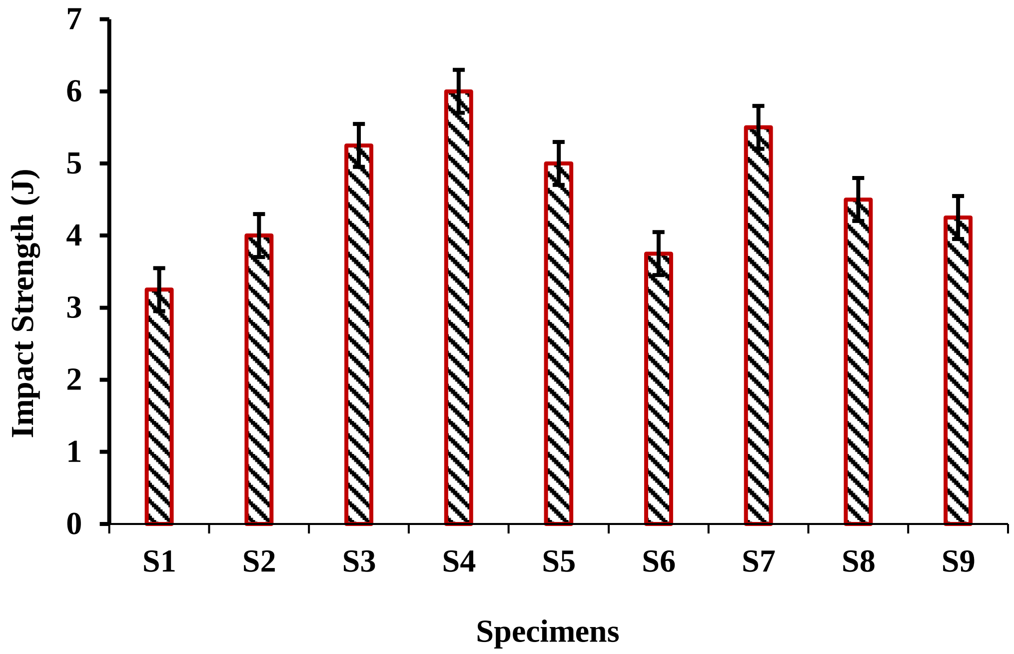

Figure 4. 9 Impact strength test result

Figure 4.9 shows the differences between each specimen's impact test results. The types of filler materials, their weight percentages, the orientation of the fibers, and the weight percentages of pineapple leaf fibers, according to a broad review of the data, changed the impact strength of composite materials. When coffee husk weight percentage had a greater impact on hardness than silicon carbide, the impact strength of composite materials improved more by silicon carbide (Kiran et al., 2018). When the weight percentage of pineapple leaf fiber increased from 15 to 25 weight percent, impact strength decreased.

Table 4. 8 Impact strength response for S/N ratios

Level	Fiber Angle	PALF	SiC	CHF
1	12.23	13.54	11.59	12.26
2	13.67	13.03	13.39	12.78
3	13.48	12.82	14.40	14.34
Delta	1.45	0.72	2.80	2.08
Rank	3	4	1	2

According to Table 4.8, the signal-to-noise ratio response table for the impact strength test, silicon carbide content was the primary factor that contributed to increase the impact strength with a delta value of 2.80. coffee husk content came in second in terms of increased impact strength with a delta value of 2.08. The third component for increased impact strength was fiber orientation content with a delta value of 1.45 and pineapple leaf fiber the fourth factor with a delta value of 0.72.

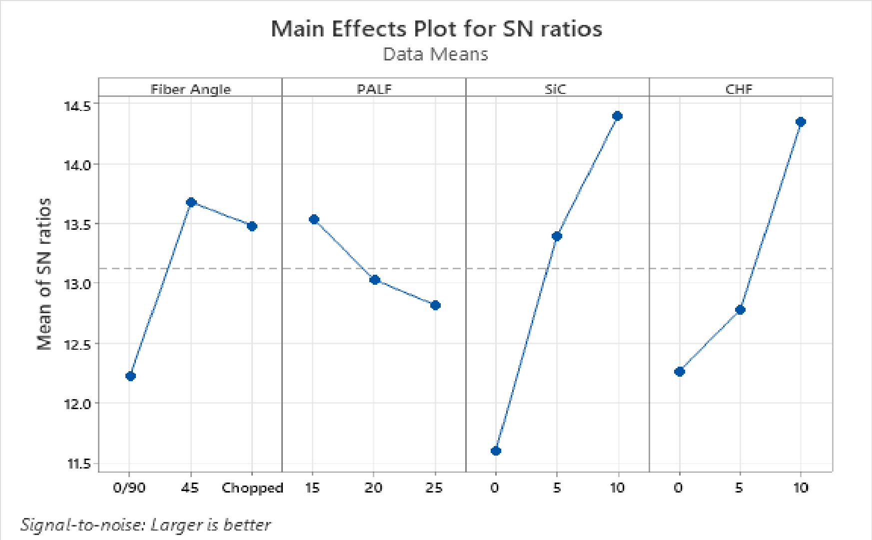

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Figure 4. 10 Main effect plot for S/N ratio for impact strength

The basic effect plot of the S/N ratio is shown in Figure 4.10, where a larger ratio is better for impact strength. The S/N ratios were optimum at level 2 fiber orientation, level 1 pineapple leaf fiber, level 3 silicon carbide, and level 3 coffee husk weight percentages. The A2B1C3D3 combination composite contained 15 weight percent pineapple leaf fiber, 10 weight percent silicon carbide, and 10 weight percent coffee husks, with a 45-degree fiber orientation. According to this study, the process parameter combinations that produced the strongest impact strength were A2B1C3D3.

As the composite's filler content increased, impact strength increased as well, and silicon carbide content greatly increased impact strength than coffee husk flour (Teja et al., 2016). Experimental results show that silicon carbide filled composites increase impact strength more than coffee husk flour filled composites. This is because the interface molecular chain is flexible and the filler, matrix, and fiber have strong bonding, allowing for more efficient energy absorption and dispersion as well as crack initiation prevention (Devendra and Rangaswamy, 2012).

However, when pineapple leaf fiber is increased from 15 to 25 weight percentages, impact strength decreased. More impact strength is provided by a unidirectional fiber arrangement at an angle of 45°.

4.3 Analysis of physical properties

4.3.1 Water Absorption Test

Based on the results of the experimental work, water absorption results as in Table 4.9.

Table 4. 9 The water absorption and S/N ratio of the experiment

specimens	Angle (Orientation)	PALF wt.%	SiC wt.%	CH wt.%	WA (%)	S/Ratio (dB)
S_1	0/90	15	0	0	0.392	8.13
S_2	0/90	20	5	5	0.361	8.85
S_3	0/90	25	10	10	0.311	10.14
S_4	45	15	5	10	0.263	11.60
S_5	45	20	10	0	0.235	12.58
S_6	45	25	0	5	0.476	6.45
S_7	Chopped	15	10	5	0.359	8.90
S_8	Chopped	20	0	10	0.249	12.08
S_9	Chopped	25	5	0	0.280	11.06

The ability of natural fiber polymer composite materials to absorb water was a crucial consideration when using them in diverse industrial applications under varying environmental circumstances. Due to fiber swelling, microcracks, and the formation of voids at the fiber-matrix interface region, water absorption reduced the mechanical characteristics and dimensional stability of composites. The process of absorbing water was done over the course of six days, and the average values of the outcomes were taken for examination. Table 4.10 provided the test's results on water absorption.

Table 4. 10 Water absorption test result

Samples	**Mass (g)**	**Measuring duration of water absorption test (hrs.)**						**Average**
		12	24	36	48	60	72	**WA%**
S_1	5.080	5.100	5.124	5.134	5.171	5.211	5.271	**0.392**
WA (%)		0.394	0.471	0.195	0.136	0.774	0.381	
S_2	5.806	5.816	5.829	5.862	5.869	5.898	5.933	**0.361**
WA (%)		0.172	0.223	0.566	0.119	0.494	0.593	
S_3	6.058	6.068	6.087	6.106	6.110	6.148	6.172	**0.311**
WA (%)		0.165	0.313	0.312	0.066	0.621	0.390	
S_4	7.683	7.701	7.716	7.755	7.761	7.792	7.805	**0.263**
WA (%)		0.234	0.195	0.505	0.077	0.399	0.167	
S_5	6.065	6.074	6.084	6.098	6.102	6.124	6.151	**0.235**
WA (%)		0.148	0.164	0.230	0.066	0.361	0.441	
S_6	3.320	3.334	3.364	3.441	3.450	3.465	3.485	**0.476**
WA (%)		0.422	0.598	0.564	0.261	0.435	0.577	
S_7	6.537	6.559	6.579	6.616	6.627	6.668	6.679	**0.359**
WA (%)		0.336	0.305	0.562	0.166	0.618	0.165	
S_8	6.641	6.657	6.672	6.703	6.711	6.732	6.741	**0.249**
WA (%)		0.241	0.225	0.464	0.119	0.313	0.134	
S_9	5.145	5.174	5.178	5.206	5.211	5.221	5.232	**0.280**
WA (%)		0.564	0.077	0.541	0.096	0.192	0.211	

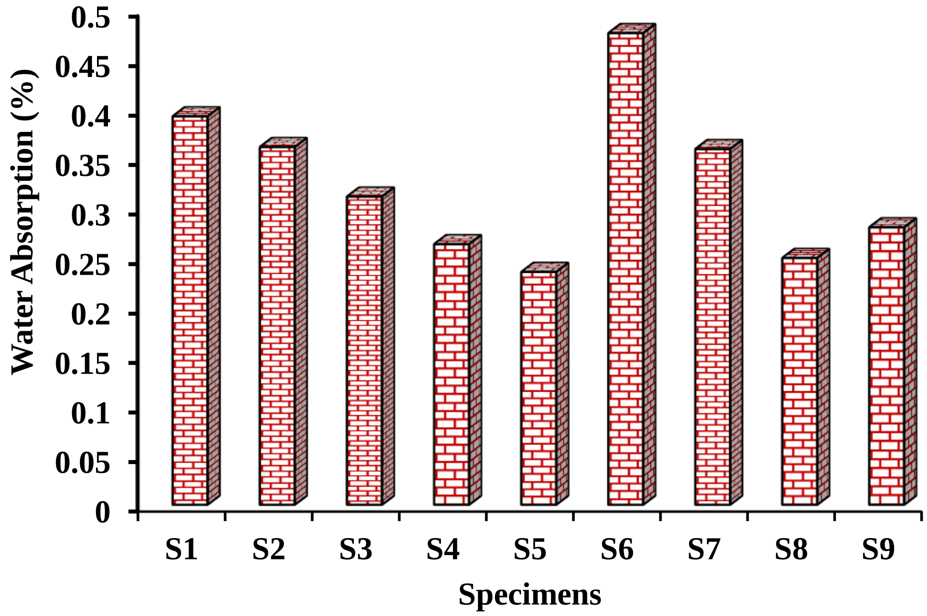

Figure 4. 11 Water absorption test results for 6 days

Table 4.10 and Figure 4.11 present the outcomes of a six-day water absorption test. This research revealed that specimens 5 and 8 absorbed water at rates of 0.235% and 0.249%, respectively. These two samples can absorb a very small amount of water. The fabrication of specimen 5 contained 45 fiber orientation, 20 weight percent pineapple leaf fiber, 10 weight percent silicon carbide, and 0 weight percent coffee husk. Chopped and 20 wt.% of pineapple leaf fiber, 0% silicon carbide, and 10% coffee husks were used to create specimen 8. This shows that the pineapple leaf fiber reinforcement and matrix had the best achievable bonding.

Table 4. 11 Water absorption response for S/N ratios

Level	**Fiber Angle**	**PALF**	**SiC**	**CHF**
1	9.043	9.544	8.886	10.590
2	10.209	11.168	10.503	8.065
3	10.677	9.216	10.541	11.274
Delta	1.634	1.952	1.654	3.209
Rank	4	2	3	1

Table 4.11 shows the response for the signal-to-noise ratios for the water absorption tests and the manufactured composite material had a very low water absorption rate. with a delta

value of 3.209, the weight percentage of coffee husks was the top contributor to the water absorption from this. With a delta value of 1.952, pineapple leaf fiber weight percentage came in second in the contribution to water absorption. With a delta value of 1.654, silicon carbide weight % placed third in the ranking of water absorption contributors, while fiber orientation weight percentage placed fourth with a delta value of 1.634.

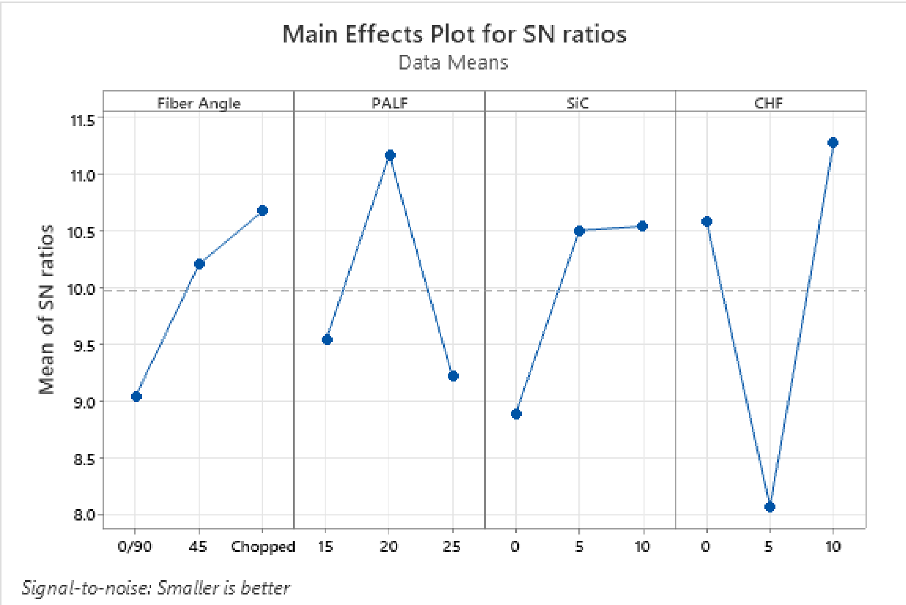

Figure 4. 12 Main effect plot for water absorption

The primary effect plot for the S/N ratio is shown in Figure 4.12, with a smaller value being better for water absorption. At level 1 fiber orientation, level 3 pineapple leaf fiber, level 1 silicon carbide, and level 2 coffee husk content, the S/N ratio was at its best. The A1B3C1D2 combination, with a 0/90 fiber angle orientation, had 25 weight percent pineapple leaf fiber, 0 weight percent silicon carbide, and 5 weight percent coffee husks. This was one of the possible best parameter combinations for the S/N ratio of the water absorption. This study contributed to the result that the process parameter combinations of A1B3C1D2 provided the hybrid composite with the least amount of water absorption.

The least amount absorption of water was absorbed at specimen 5 (0.235%). At least 20 weight percent of pineapple leaf fiber, 10 weight percent silicon carbide, 0 weight percent coffee husk, and 45 unidirectional fiber orientation were present.

4.3.2 Actual Density of Composite

One of the most important aspects in defining the qualities of composites was density, which is dependent on the relative amount of reinforcing and matrix components. Table 4.12 lists the composite materials' theoretical and experimental densities. It was found that theoretical densities of composite values that were derived from weight fractions did not match the values that were empirically tested. This distinction was brought about by the composites' void content. The weight percentage of composite materials was used to compute theoretical density.

One of three techniques the Archimedes approach, the sink-float method, or the density gradient technique is used to calculate the densities of composite materials. For this project, the Archimedes method is used to calculate the real density (a) of the composite using rainwater as the medium. ASTM standard D 570 covers this procedure. An item submerged entirely or partially in a fluid is buoyed up by a force proportional to the weight of the fluid it displaces, according to Archimedes' principle. (Kireš, 2007).

Table 4. 12 Actual density and signal to noise ratio results from experiments

specimens	**Angle (Orientation)**	**PALF Wt.%**	**SiC Wt.%**	**CH Wt.%**	**Theoretical Density (g/cm3)**	**Actual Density (g/cm3)**	**S/N ratio (dB)**
S_1	0/90	15	0	0	1.176	1.169	1.819
S_2	0/90	20	5	5	1.277	1.265	2.137
S_3	0/90	25	10	10	1.402	1.258	1.993
S_4	45	15	5	10	1.324	1.246	1.910
S_5	45	20	10	0	1.267	1.241	1.875
S_6	45	25	0	5	1.243	1.231	2.014
S_7	Chopped	15	10	5	1.313	1.276	2.117
S_8	Chopped	20	0	10	1.287	1.228	1.783
S_9	Chopped	25	5	0	1.234	1.224	1.755

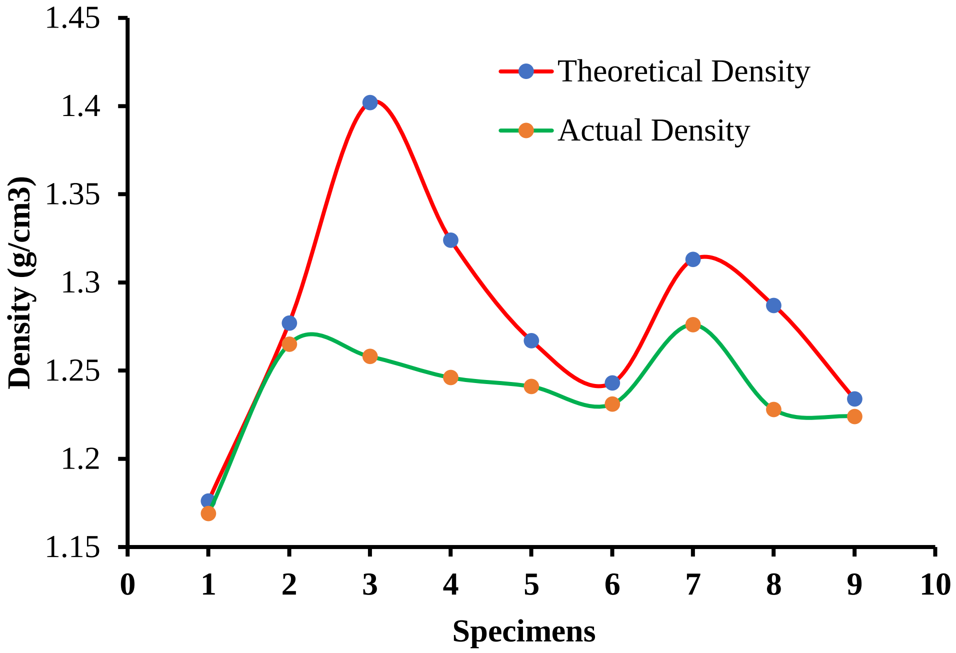

Figure 4. 13 Theoretical and actual densities of specimens

The composite material's actual density was 1.169 g/cm3 at specimen 1, which was the lowest value. At 15 weight percent pineapple leaf fiber, 0 weight percent silicon carbide, 0 weight percent coffee husk, and 0/90 bidirectional fiber orientation, the actual density was at a minimum. At sample 3, density decreases from 1.402 to 1.258. This is as a result of the increased silicon carbide content in composite materials.

Table 4. 13 Actual density response for signal to noise ratios

Level	Fiber direction	PALF	SiC	CHF
1	-1.797	-1.795	-1.648	-1.662
2	-1.864	-1.900	-1.903	-1.988
3	-1.886	-1.851	-1.995	-1.896
Delta	0.088	0.106	0.347	0.326
Rank	4	3	1	2

The signal to noise ratios for the actual density test are displayed in Table 4.13. The manufactured composite materials' actual densities were at a minimum for everyday use. With a delta value of 0.347, the silicon carbide weight percentage came in first place for its contribution to actual density. With a delta value of 0.326, coffee husk weight percentage came in second in the actual density contribution. With a delta value of 0.106, pineapple leaf fiber weight percentage came in third in the contribution to actual density, while fiber orientation weight percentage came in fourth with a delta value of 0.088.

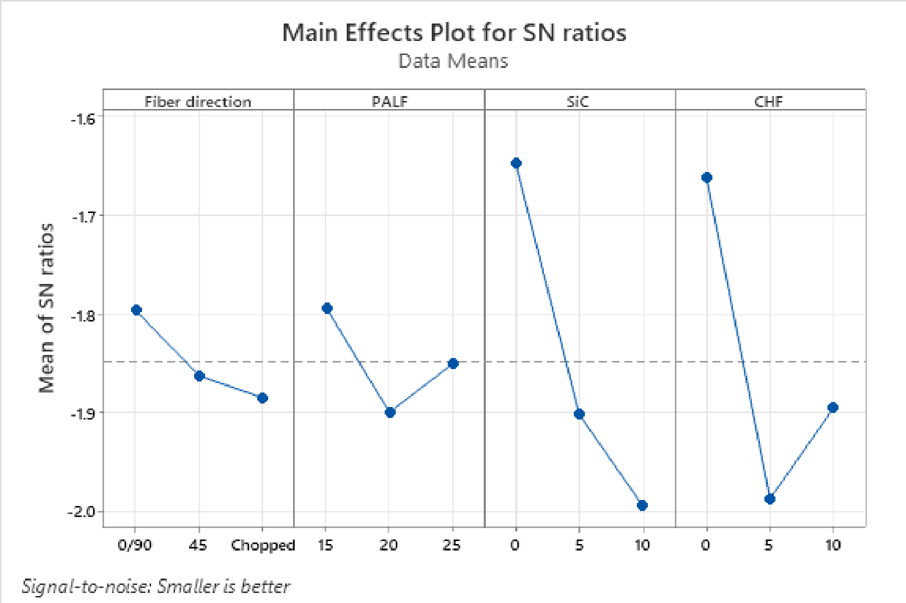

Figure 4. 14 Main effects plot for S/N ratio for actual density

Figure 4.14 shows that the S/N ratio main effect plot, with lower being better for real density. When, fiber orientation content was level 3,pineapple leaf fiber content of level 2, silicon carbide content was level 3coffee husk content was level 2, the S/N ratio of actual density was at its best. The possible best parameter combinations for the S/N ratio of the actual density from these were A3B2C3D2, which at chopped fiber orientation with 20% pineapple leaf fiber, 10% silicon carbide, and 5% coffee husks. Based on the results of the analysis, it can be said that the process parameter combinations A3B2C3D2 produced hybrid composites with the lowest actual density.

4.3.3 Testing of Void Content of Composite

Based on the results of the experimental work, void content test results and S/N ratios from the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour were given in Table 4.14.

Table 4. 14 Void content and signal to noise ratio results from experiments

specimens	Angle (Orientation)	PALF Wt.%	SiC Wt.%	CH Wt.%	Void Contents (%)	S/N ratio (dB)
S_1	0/90	15	0	0	0.59	-1.36
S_2	0/90	20	5	5	0.94	-2.04
S_3	0/90	25	10	10	10.27	-1.99
S_4	45	15	5	10	5.89	-1.91
S_5	45	20	10	0	2.05	-1.88
S_6	45	25	0	5	0.96	-1.81
S_7	Chopped	15	10	5	2.82	-2.12
S_8	Chopped	20	0	10	4.58	-1.78
S_9	Chopped	25	5	0	0.81	-1.76

The mechanical characteristics and even the performance of composites in the workplace have been significantly affected by the void content. It seemed obvious that a high-quality composite would contain fewer voids. The presence of empty content was unavoidable while creating composites, especially when using hand-lay-up techniques.

Table 4. 15 Void content response for signal to noise ratios

Level	Fiber Angle	PALF	SiC	CHF
1	-5.0370	-6.6081	-2.7599	0.0594
2	-7.0943	-6.3050	-4.3449	-2.7043
3	-6.7973	-6.0155	-11.8238	-16.2837
Delta	2.0573	0.5926	9.0639	16.3431
Rank	3	4	2	1

Table 4.15 displays the signal-to-noise ratios for the hybrid composite test's void content. For use in practical applications, the void content of the manufactured composite material was at a minimum. With a delta value of 16.3431, the weight percentage of coffee husks was the most significant contributor to void content from this group. The second-highest contributor to void content was silicon carbide weight percentage, with a delta value of

9.0639. Fiber orientation weight percentage came in third with a delta value of 2.0573 and pineapple leaf fiber weight percentage came in fourth in the contribution of void content with a delta value of 0.5926.

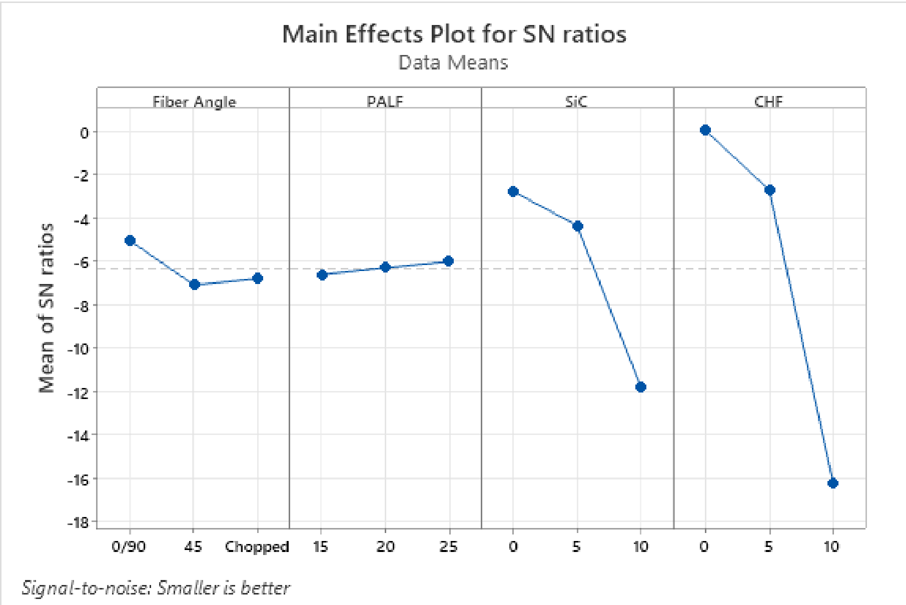

Figure 4. 15 Main effects plot for S/N ratio for void contents

Figure 4.15 shows the principal effect plot for the S/N ratio, where a lower value is preferred for the void content. The S/N ratio of void content was best at level 2 fiber orientation, level 1 pineapple leaf fiber, level 3 silicon carbide, and level 3 coffee husk content. One of the probable optimal parameter combinations for the S/N ratio of void content was found at 10 weight percent silicon carbide, 10 weight percent coffee husks, and 15 weight percent pineapple leaf fiber at 45 fiber orientation. This study found that hybrid composites with the lowest void content were created by the process parameter combinations A2B1C3D3, which also improved the mechanical properties of the composites.

At specimen 1, the composite material's void content was at its lowest0.59%. It had at least 15% pineapple leaf fiber, 0% silicon carbide, and 0% coffee husk, and the fibers were oriented 0/90 in a bidirectional fiber orientation. It has an impact on the composite's mechanical characteristics. The void decreased as both fillers increased. To reduce the voids, more filler material is added.

4.4 Grey Relational Analysis of Composite

Table 4.16 displays the findings of all experiments conducted on the fabrication of polyester composites reinforced with pineapple leaf fiber and filled with silicon carbide and coffee husk flour. The materials' mechanical and physical characteristics, such as their flexural strength, tensile strength, hardness, and impact strength, as well as their actual density, water absorption, and void content, were all measured during these tests.

Table 4. 16 Response for all the experiments

Samples	TS (MPa)	FS (MPa)	H (HV)	IS (J)	WA (%)	AD (g/cm3)	VC (%)
S1	8.60	60.77	35.5	3.25	0.392	1.169	0.59
S2	22.37	43.42	38.5	4	0.361	1.265	0.94
S3	21.71	53.42	38.9	5.25	0.311	1.258	10.27
S4	26.01	174.88	39.1	6	0.263	1.246	5.89
S5	30.00	77.39	34.6	5	0.235	1.241	2.05
S6	11.89	42.96	38.2	3.75	0.476	1.231	0.96
S7	34.78	51.80	40.3	5.5	0.359	1.276	2.82
S8	33.73	98.78	40.6	4.5	0.249	1.228	4.58
S9	18.86	62.71	35.5	4.25	0.280	1.224	0.81

Table 4. 17 Determination S/N ratio (dB) for responses

Samples	TS	FS	H	IS	WA	AD	Vc
S1	18.69	35.67	31.01	10.24	8.13	1.819	-1.36
S2	26.99	32.75	31.71	12.04	8.85	2.137	-2.04
S3	26.73	34.55	31.79	14.4	10.14	1.993	-1.99
S4	28.3	44.85	31.84	15.56	11.6	1.91	-1.91
S5	29.54	37.77	30.77	13.98	12.58	1.875	-1.88
S6	21.5	32.66	31.64	11.48	6.45	2.014	-1.81
S7	30.83	34.29	32.11	14.81	8.9	2.117	-2.12
S8	30.56	39.89	32.16	13.06	12.08	1.783	-1.78
S9	25.51	35.95	31	12.57	11.06	1.755	-1.76

Table 4. 18 Determination of normalized S/R ratio

Samples	TS	FS	H	IS	WA	AD	Vc
S1	0.000	0.247	0.173	0.000	0.726	0.832	0.000
S2	0.684	0.007	0.676	0.338	0.608	0.000	0.895
S3	0.662	0.155	0.734	0.782	0.398	0.377	0.829
S4	0.792	1.000	0.770	1.000	0.160	0.594	0.724
S5	0.894	0.419	0.000	0.703	0.000	0.686	0.684
S6	0.231	0.000	0.626	0.233	1.000	0.322	0.592
S7	1.000	0.134	0.964	0.859	0.600	0.052	1.000
S8	0.978	0.593	1.000	0.530	0.082	0.927	0.553
S9	0.562	0.270	0.165	0.438	0.248	1.000	0.526

Table 4. 19 Measurement of deviation of normalized S/N ratio

Samples	TS	FS	H	IS	WA	AD	Vc
S1	1.000	0.753	0.827	1.000	0.274	0.168	1.000
S2	0.316	0.993	0.324	0.662	0.392	1.000	0.105
S3	0.338	0.845	0.266	0.218	0.602	0.623	0.171
S4	0.208	0.000	0.230	0.000	0.840	0.406	0.276
S5	0.106	0.581	1.000	0.297	1.000	0.314	0.316
S6	0.769	1.000	0.374	0.767	0.000	0.678	0.408
S7	0.000	0.866	0.036	0.141	0.400	0.948	0.000
S8	0.022	0.407	0.000	0.470	0.918	0.073	0.447
S9	0.438	0.730	0.835	0.562	0.752	0.000	0.474

Table 4. 20 Determinations of GRC, GRG and rank

S	**TS**	**FS**	**H**	**IS**	WA	**AD**	**Vc**	**GRG**	**R**
S1	0.333	0.399	0.377	0.333	0.646	0.749	0.333	**0.453**	**9**
S2	0.613	0.335	0.607	0.430	0.561	0.333	0.826	**0.529**	**6**
S3	0.597	0.372	0.653	0.696	0.454	0.445	0.745	**0.566**	**4**
S4	0.706	1.000	0.685	1.000	0.373	0.552	0.644	**0.709**	**2**
S5	0.825	0.463	0.333	0.627	0.333	0.614	0.613	**0.544**	**5**
S6	0.394	0.333	0.572	0.395	1.000	0.424	0.551	**0.524**	**8**
S7	1.000	0.366	0.933	0.780	0.556	0.345	1.000	**0.711**	**1**
S8	0.957	0.551	1.000	0.516	0.353	0.872	0.528	**0.682**	**3**
S9	0.533	0.406	0.375	0.471	0.399	1.000	0.514	**0.528**	**7**

The main impact of S/N ratio is seen in Table 4.20, where greater is better for GRG. These represent potential combinations of the best parameters for the S/N ratio of GRG 0.711, which was produced at 45 fiber orientation, 15 weight percent pineapple leaf fiber, 10 weight percent silicon carbide, and 5 weight percent coffee husks. As a result, A2B1C3D2 has been found to be the best prediction condition for multi-response features. The ideal combinations of criteria for creating hybrid composite materials to increase their mechanical and physical properties are suggested by this thesis. Additionally, this data supports the idea that a hybrid composite's filler material is crucial.

4.5 Morphology Analysis

The distribution of the filler and bonding elements in the matrix may be seen using scanning electron microscopy. SEM images of the specimens were taken in order to analyze the microstructure. Images for the hybrid composite made of coffee husk, silicon carbide, and polyester fibers reinforced with pineapple leaf fiber were examined using a scanning electron microscope. Figure 4.16 illustrates how the polyester matrix and filler elements like coffee husk and silicon carbide were distributed throughout the pineapple fiber. The image was captured using a scanning electron microscope. There are no major defects in the composite that was produced.

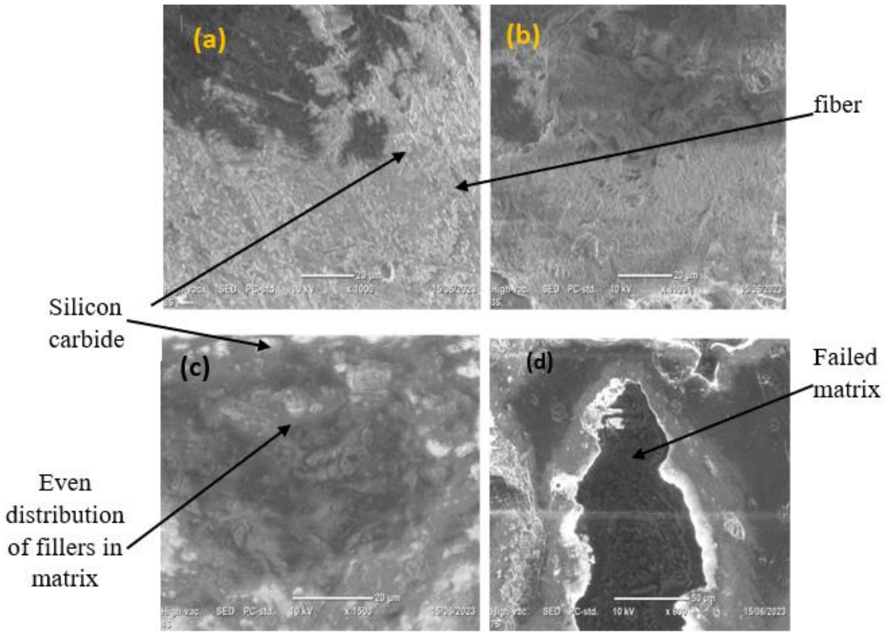

Figure 4. 16 Image of SEM (a) specimen 3 (b) specimen 8 (c)specimen 4 (d) specimen 7

The flow of polyester and the impregnation of pineapple leaf fiber with silicon carbide were visible in SEM micrographs. The outcomes showed that the resin was uniformly distributed throughout the fibers and that the bonding interaction between the polyester matrix, the pineapple leaf fiber, the coffee husk filler, and the sic ceramic filler was flawless. SEM images additionally showed brittle cracks in composite materials.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The hand lay-up approach was effective in producing the designed pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk and performing at three levels or three weight percentages. Based on the completed investigation, the following conclusions were drawn:

1. The tensile strength of specimen 7 was 34.8 MPa. From among these potential parameter combinations of S/N ratios of tensile strength, combination A3B2C3D3 was developed using chopped fiber orientation and contains 20% pineapple leaf fiber, 10% silicon carbide, and 10% coffee husks. This result shows that, when filler components are added, the tensile strength of composite materials improved.
2. The specimen 4 had a flexural strength of 174.88 MPa. The results show that flexural strength significantly increases at a coffee husk content of 10 wt.% and decreased at a coffee husk content of 5 wt.%. Flexural strength increased as pineapple leaf fiber content was lowered. At 45 unidirectional fiber orientations, flexural strength also increased. The maximum flexural strength occurred at 45° fiber orientation, 15 wt.% pineapple leaf fiber, 5 wt.% silicon carbide, and 10 wt.% coffee husks.
3. Specimen 8 had maximum hardness of value of 40.6 HV at 15 weight percent pineapple leaf fiber, 0 weight percent silicon carbide, and 10 weight percent coffee husks in the chopped fiber orientation. According to this investigation, the process parameter combinations that produced the greatest hardness were A3B1C1D3. Hardness of coffee husks increases significantly up to 5 weight percent and gradually from 5 to 10 weight percent as filler weight percentage increases. High hardness is associated with chopped fiber orientation, although SiC weight percentage and pineapple leaf fiber have little impact on hardness.
4. Specimen 4 had a maximum impact strength of 6 J. It was at its highest when there was a 45°-fiber orientation, 15% pineapple leaf fiber, 5% silicon carbide, and 10% coffee husks. Impact strength greatly improved along with the composite's filler content. However, dropped when pineapple leaf fiber added from 15 to 25 weight percentages. With the fibers oriented at an angle of 45°, impact strength was increased.

5. At specimen 5, a minimum of water absorption (0.235%) was absorbed. 2Minimum amount of water absorption was at 20 weight percent of pineapple leaf fiber, 10 weight percent silicon carbide, 0 weight percent coffee husk, and 45 unidirectional fiber orientation were present.
6. At specimen 1, the composite material's actual density was at its lowest, 1.169 g/cm3. At 0/90 bidirectional fiber orientation, the actual density was least at 15 weight percent pineapple leaf fiber, 0 weight percent silicon carbide, and 0 weight percent coffee husk. Density drops from 1.402 to 1.258 at sample 3. This is due to increasing high silicon carbide in composite.
7. At specimen 1, the composite material's void content was at its lowest value of 0.59%. It was minimum at 15% pineapple leaf fiber, 0% silicon carbide, and 0% coffee husk, and the fibers were oriented in a 0/90 bidirectional orientation. It has an impact on the composite's mechanical characteristics. The void decreased as both fillers added. To reduce the voids, more filler material is added.
8. From all the aforementioned potential ideal parameter combinations, the S/N ratio of Grey Relational Grade 0.711 was obtained at 45 fiber orientation, 15 weight percent pineapple leaf fiber, 10 weight percent silicon carbide, and 5 weight percent coffee husks.
9. Using SEM to analyze the morphology of the hybrid composite material, void content was discovered in a few localized locations of the composites. The characteristics of the created hybrid composites are significantly enhanced by using coffee husk and SiC powder as filler components.

5.2 Recommendations

The following suggestions were taken into consideration based on the fabrication of pineapple leaf fiber reinforced polyester composites filled with silicon carbide and coffee husk flour.

- This thesis suggests that research be done on how to use this plentiful waste resource of coffee husk and pineapple leaf fiber by higher educational institutions, automobile industries, manufacturing companies, the construction industry, and the government.
- Agriculturally dependent nations like Ethiopia should pay attention to the trend of replacing heavy metals with low density, biodegradable, renewable, environmentally friendly, and green composites.

- According to this concept, pineapple leaf fiber has a significant deal of potential to replace traditional reinforcing. This can transform coffee husk and leftover pineapple leaf fiber into highly valuable items.
- It will be better to use the coffee husk filler with pineapple leaf fiber reinforcement since we can get intermediate mechanical properties and also minimum cost relative to pure synthetic composites.

5.3 Future Works

In this study, pineapple leaf fiber concentrations of 15, 20, and 25% were mixed with fillers of 0, 5, and 10%. This can be extended to examine the effect of weight percentage and fiber orientation on the mechanical and physical properties of the composite.

- Examine pineapple leaf fiber's mechanical and physical characteristics in comparison to those of other natural fibers.
- Setting up decorticating equipment so that fiber can be easily removed from its life. Additionally, a waving device that can wave natural fiber in various fiber orientations is preferable.
- Only the hand lay-up approach was used to prepare the study samples. For next projects, various production techniques may be used.
- Adding nanoparticle fillers with the filler materials.
- Applying various methods to the treatment of coffee husk flakes and pineapple leaf fiber.
- Pineapple leaf fiber of different ages, climate conditions, and soil types should be disposed of throughout country as a waste should be utilized by conducting further researcher on its mechanical, physical, chemical, and thermal properties of composite.
- Compare and contrast the properties of chemically treated and untreated pineapple leaf fiber with filler materials composite.
- The work extended to study other properties such as creep, fatigue, compressive, shear strength, chemical resistance and electrical properties.

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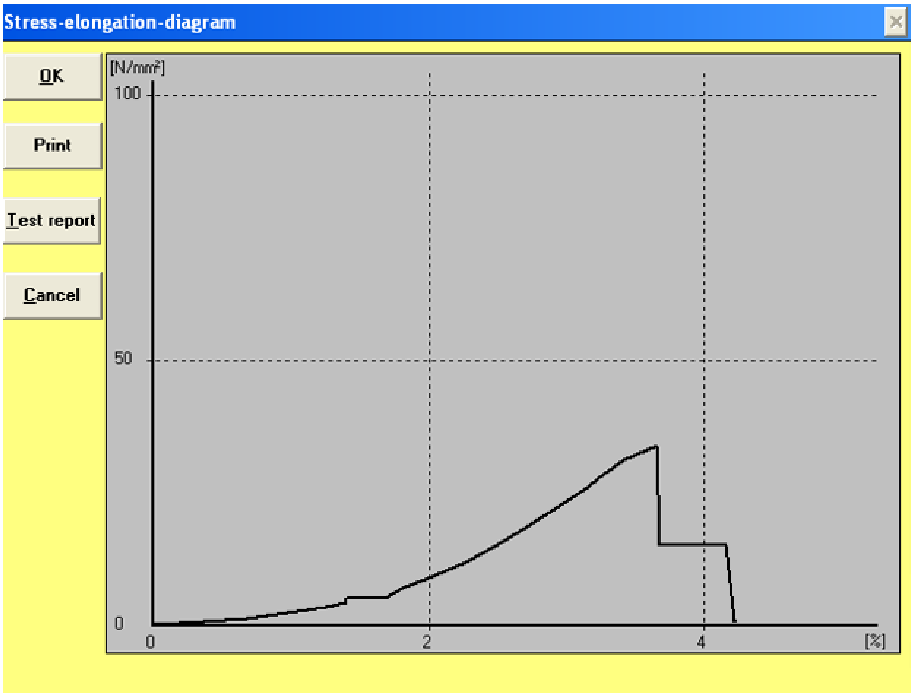
APPENDICES

Appendix A: Tensile test result

Specimens 7

Test report

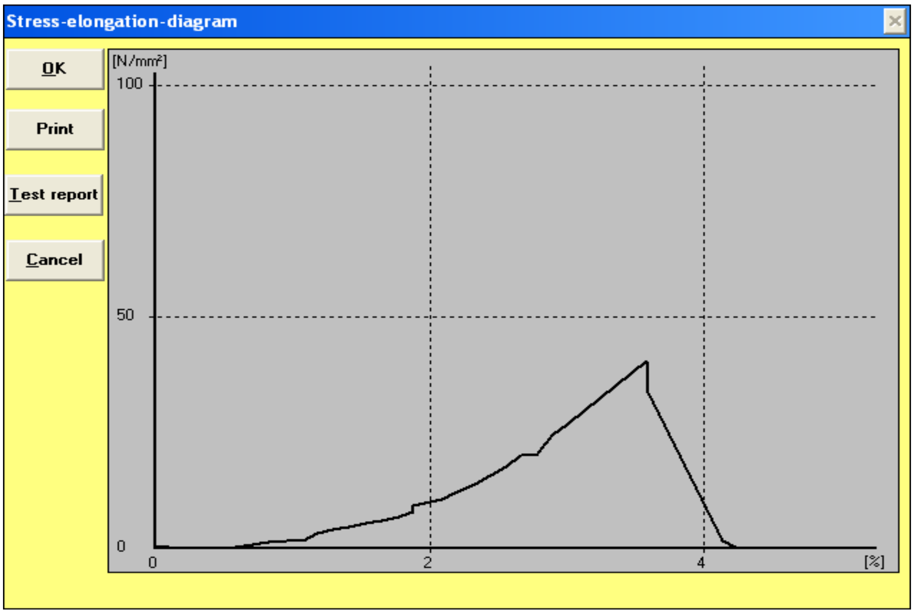
Kind of test:	Tensile test DIN 50106
Material of specimen:	composite
Dimensions of specimen:	Tension specimen B19 x 165 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	33.82 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	09.06.2023
Name of tester:	
Signature:	



Specimen 8

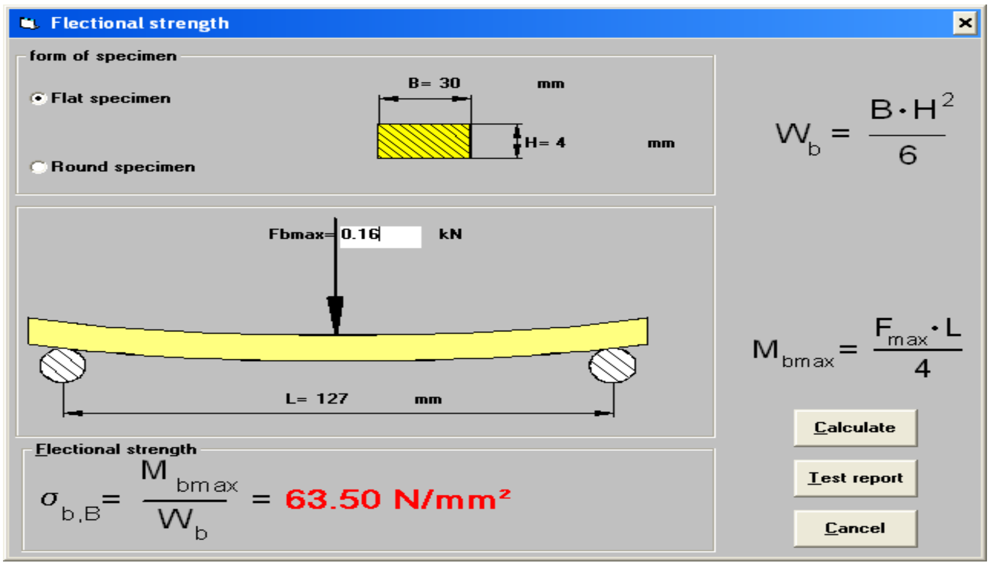
Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	composite
Dimensions of specimen:	Tension specimen B19 x 165 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	40.39 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	14.06.2023
Name of tester:	
Signature:	

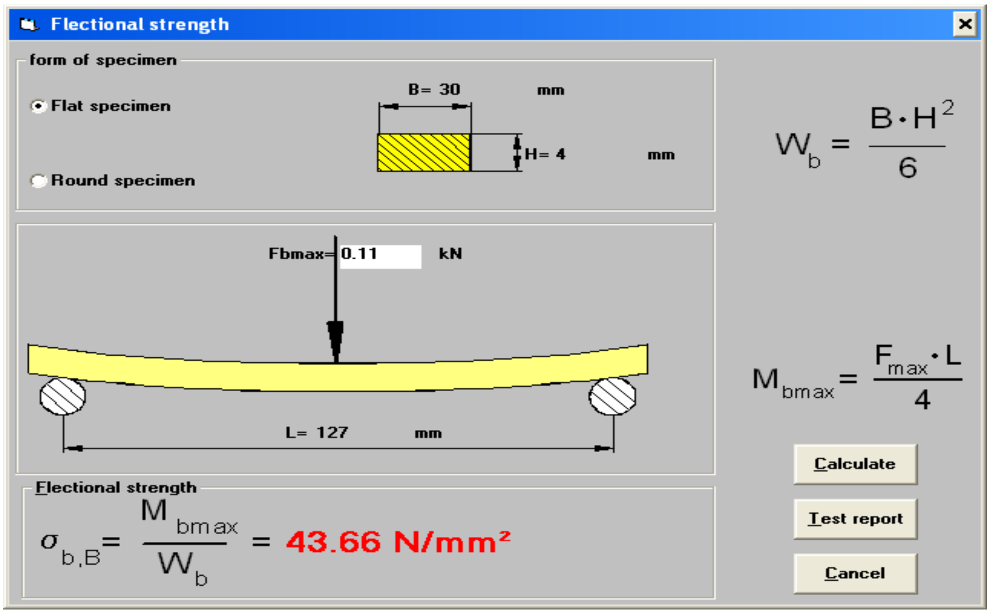


Appendix B: Flexural test result

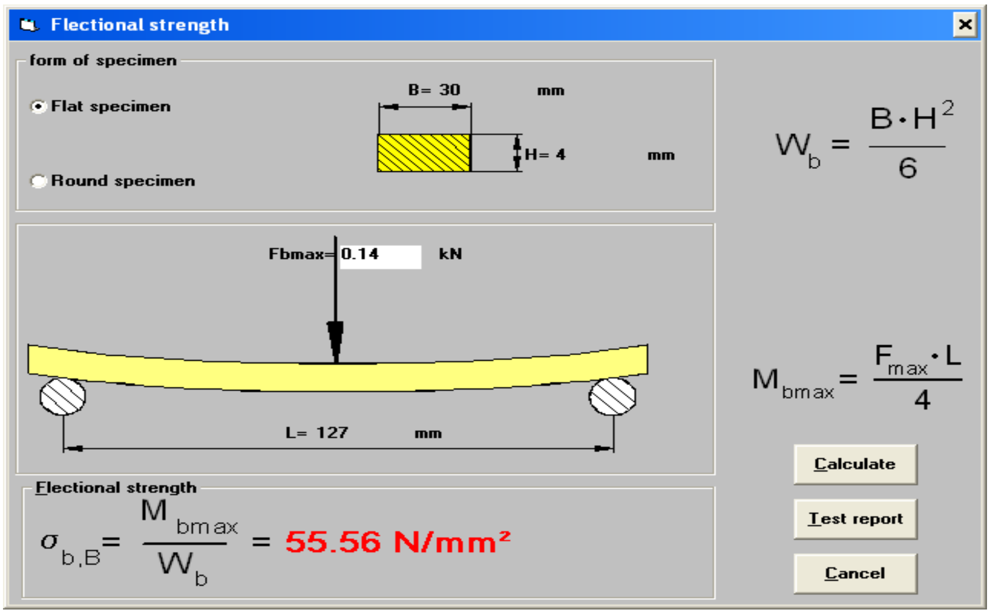
Specimen 1



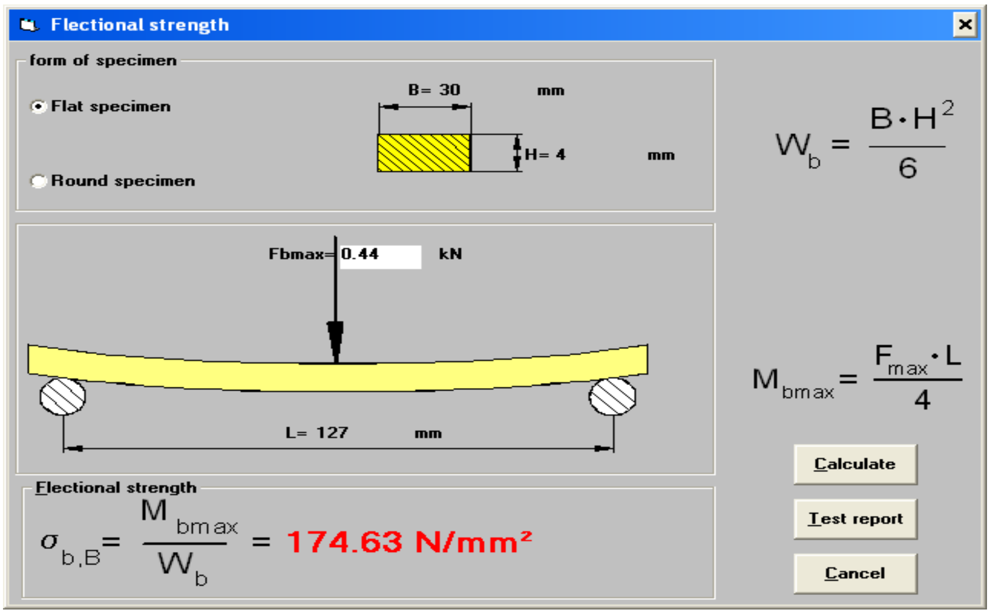
Specimen 2



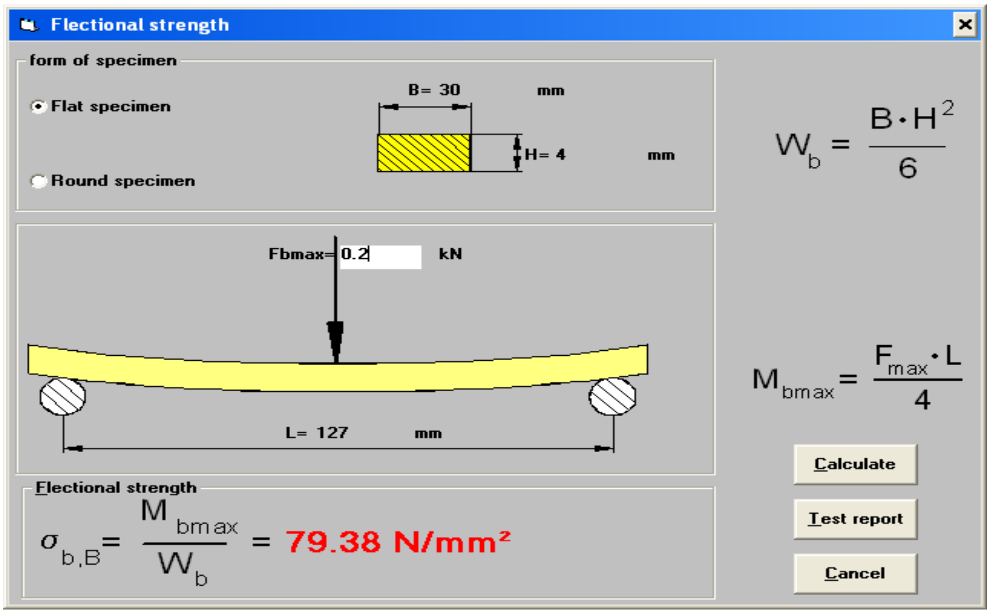
Specimen 3



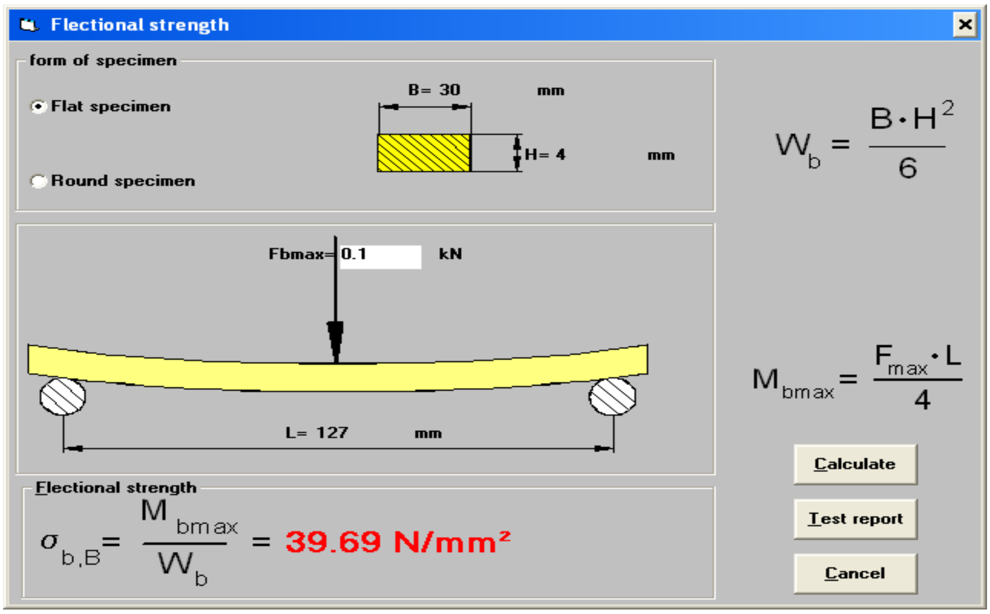
Specimen 4



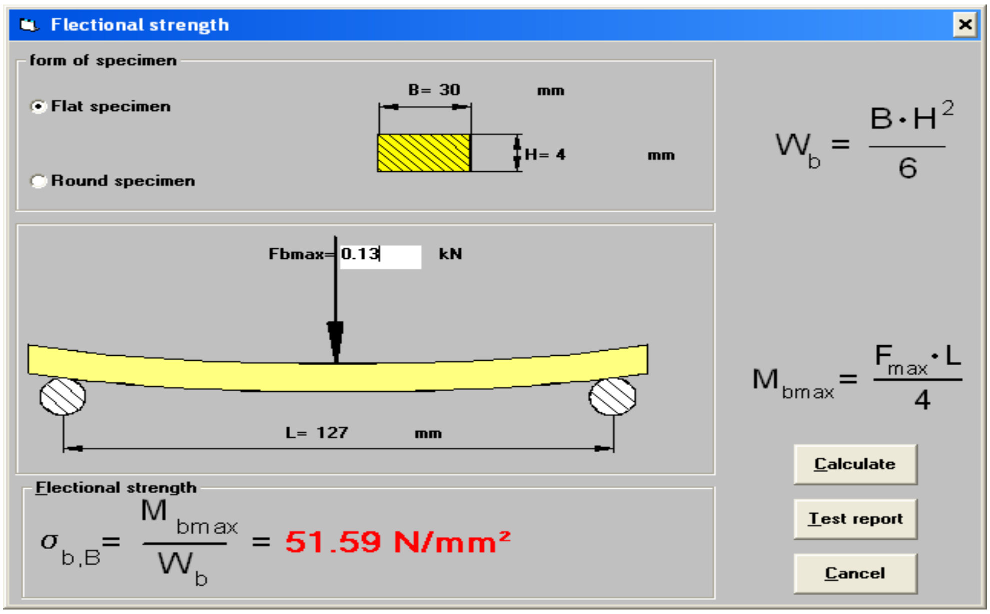
Specimen 5



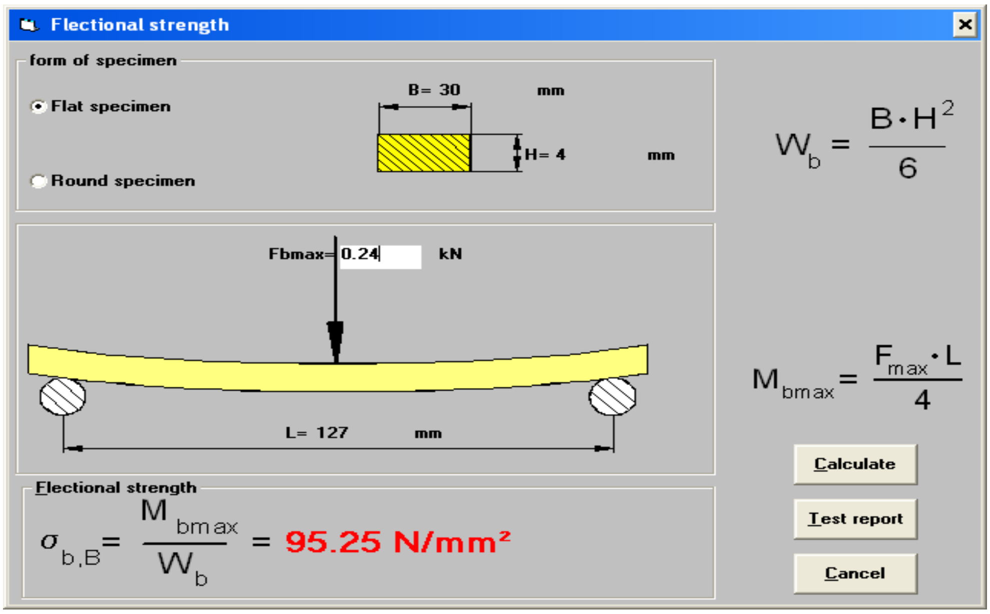
Specimen 6



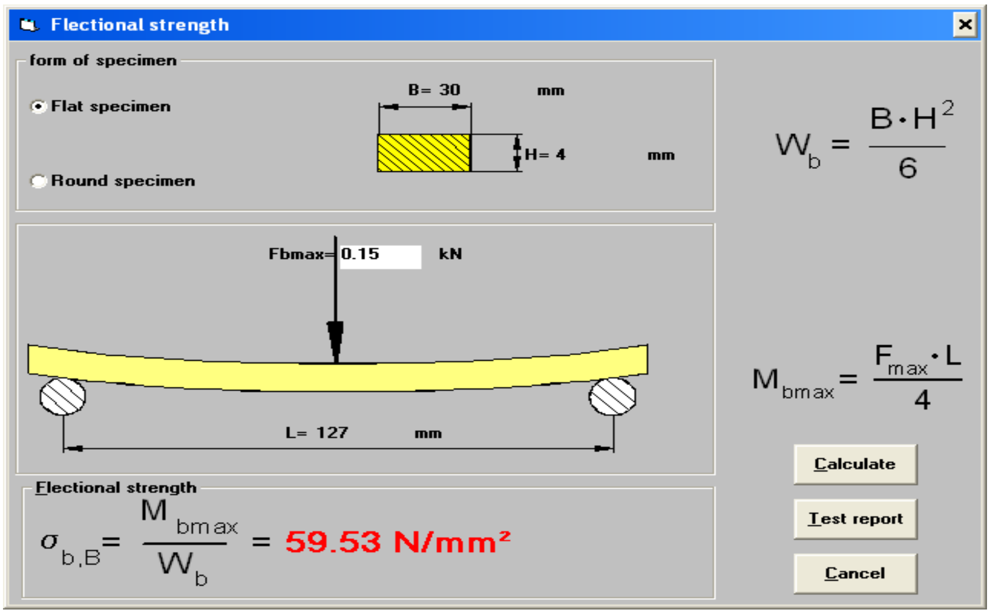
Specimen 7



Specimen 8

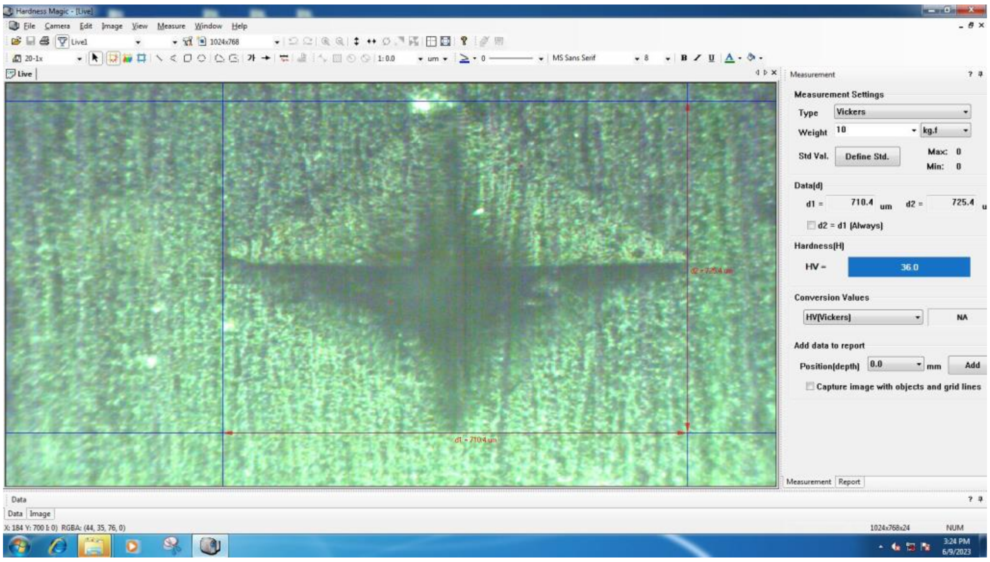


Specimen 9

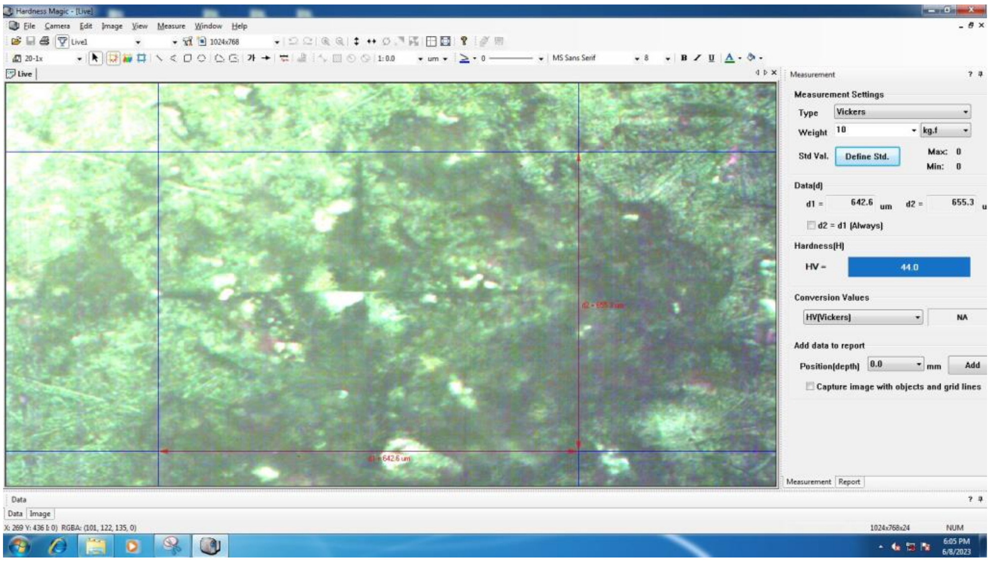


Appendix C: Hardness test result

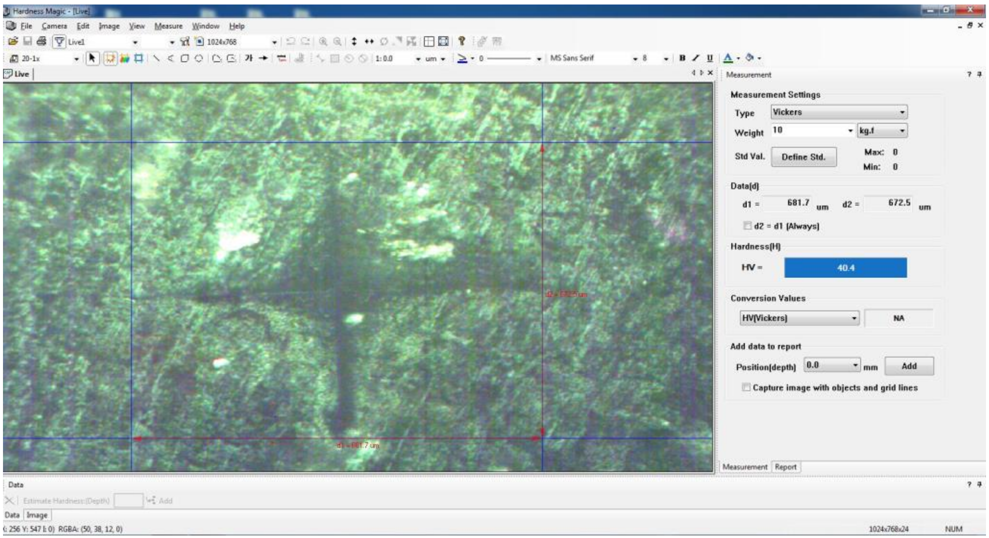
Specimen 1



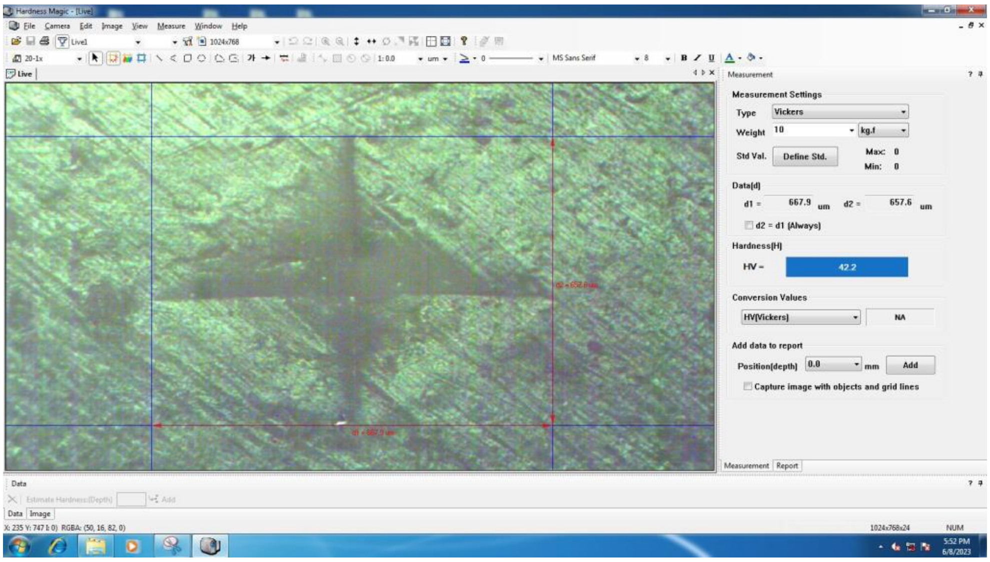
Specimen 2



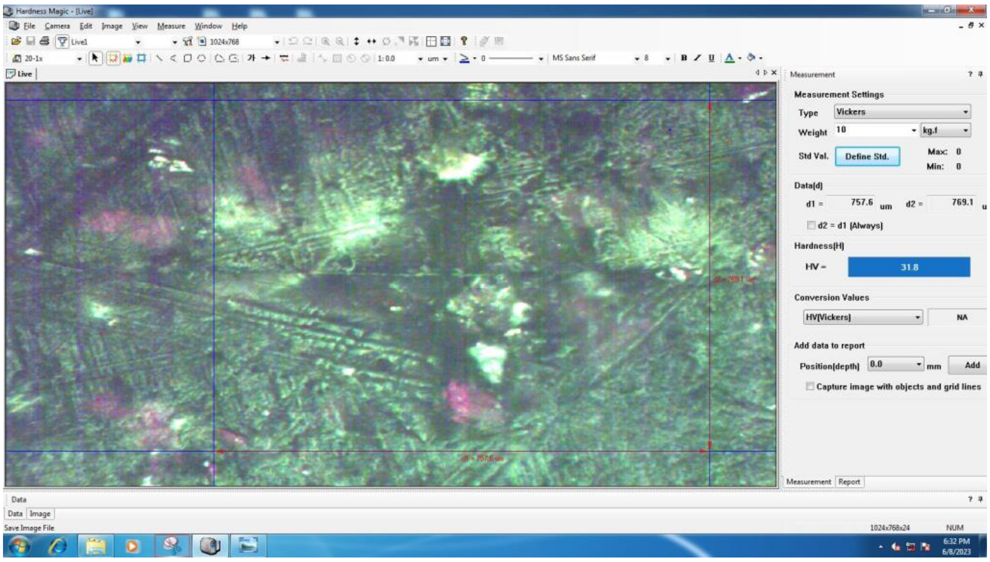
Specimen 3



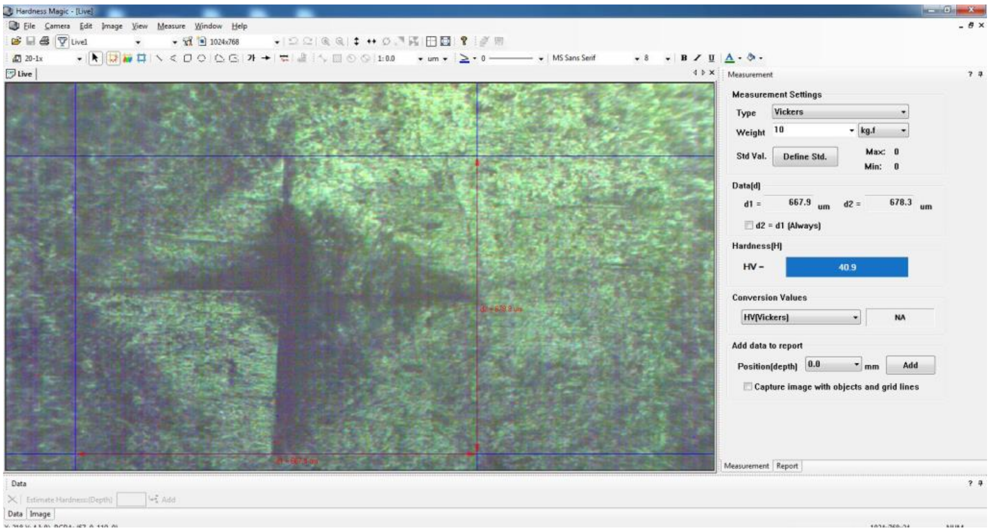
Specimen 4



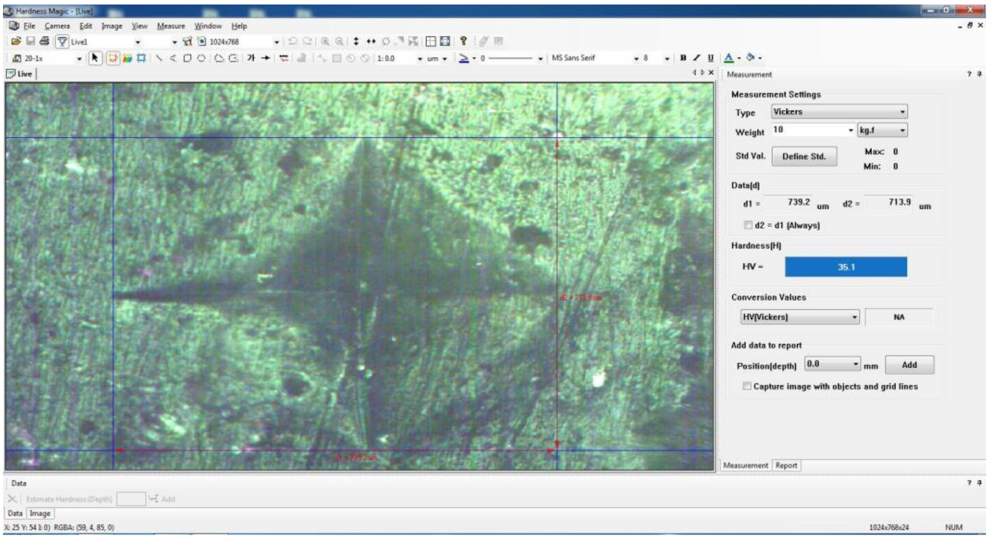
Specimen 5



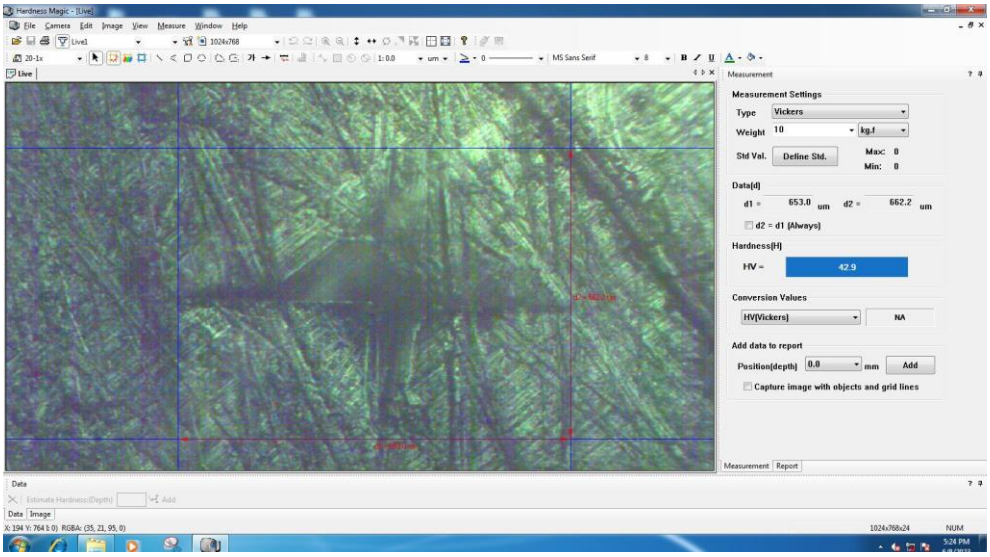
Specimen 6



Specimen 7



Specimen 8



Specimen 9