CHARACTERIZATION AND OPTIMIZATION OF HYBRID COMPOSITE REINFORCED WITH Al_2O_3/SiC, BAGASSE FIBERS AND POLYESTER

Yobsan Alemu Heyi

A Thesis Submitted to

Department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Office of Graduate Studies

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

November, 2021

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "Characterization and Optimization of Hybrid Composite Reinforced with Al_2O_3/SiC, Bagasse Fibers and Polyester**"** 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.

Yobsan Alemu Heyi _____ _____

Name of the student Signature Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Characterization and Optimization of Hybrid Composite Reinforced with Al_2O_3/SiC, Bagasse Fibers and Polyester" prepared under my guidance by Yobsan Alemu Heyi submitted in partial fulfillment of the requirements for the degree of Masters of Science Manufacturing Engineering. Therefore, I recommend the submission of the revised version of the thesis to the Department following the applicable procedures.

Dr. Moera Gutu Jiru _____ _____

Advisor Signature Date

APPROVAL SHEET

I, the advisor of the thesis entitled "Characterization and Optimization of Hybrid Composite Reinforced with Al_2O_3/SiC, Bagasse Fibers and Polyester" and developed by Yobsan Alemu Heyi hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Moera Gutu Jiru	_____	_____
Advisor	Signature	Date

I, the undersigned, members of the board of examiners of the thesis by Yobsan Alemu Heyi have read and evaluated the thesis entitled "Characterization and Optimization of Hybrid Composite Reinforced with Al_2O_3/SiC, Bagasse Fibers and Polyester" and examined the candidate during the 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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Finally, approval and acceptance of the thesis is contingent upon submission of its final Copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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ACRONYMS

AMMC	Aluminium Metal Matrix Composite
ANOVA	Analysis of Variance
ASTM	America Society for Testing and Material
ASTU	Adama Science and Technology University
BHN	Brinell Hardness Number
CM	Composite Materials
CMC	Ceramic Matrix Composites
DUEC	Defence University of Engineering College
DOE	Design of Experiment
DOF	Degree of Freedom
ECAE	Ethiopian Conformity Assessment Enterprise
ESCB	Ethiopian Sugarcane Bagasse
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
GRA	Grey Relation Analysis
GRG	Grey Relation Grade
HDF	High Density Fiberboard
HRC	Rockwell Hardness
ISO	International Organization for Standardization
MEKP	Methyl ethyl ketone peroxide
MMCs	Metal Matrix Composites
MTL	Material Testing Lab
NFs	Natural fibers
NFRPC	Natural Fiber-Reinforced Polymer Composite
OA	Orthogonal Array
OPEFB	Oil Palm Empty Fruit Bunch
PC	Percentage Contribution
PMCs	Polymer Matrix Composites
PP	Polypropylene
PRP	Particle Reinforced Polymer Composites
PVC	Poly-Vinyl-Chloride
S/N	Signal to Noise ratio

UP	Unsaturated Polyester Resin
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
YS	Yield Strength

ABBREVIATIONS

$\mathcal{P}_a$	Actual density (g/cm^3)
$\mathcal{P}$	Density (g/cm^3)
$\mathcal{P}_c$	Density of composite (g/cm^3)
$\mathcal{P}_f$	Density of fiber (g/cm^3)
$\mathcal{P}_m$	Density of matrix (g/cm^3)
$\mathcal{P}_p$	Density of particle (g/cm^3
$\mathcal{P}_t$	Theoretical density (g/cm^3)
$\mathcal{P}_W$	Density of water (g/cm^3)
M_c	mass of composite (g)
M_f	mass of fiber (g)
M_m	mass of matrix (g)
M_p	mass of particle (g)
V_F	Volume fraction of fiber
V_P	Volume fraction of particle
V_M	Volume fraction of matrix
V_c	Volume of composite (mm^3)
V_f	Volume of fiber (mm^3)
V_p	Volume of particle (mm^3)
V_m	Volume of matrix (mm^3)
V_v	Volume fraction of voids
S1	Specimens 1
L'	Diagonal of square impression (mm)
P'	Number of factor
W_1	Weight of the dry specimen
W_2	Weight of the wet specimen
W_a	Weight of composite in air
W_w	Weight of composite in water
wt.%	Weight percentage

NOMENCLATURE

Al_2O_3	Alumina
$Mg(OH)_2$	Magnesium hydroxide
NaOH	Sodium hydroxide
SiC	Silicon Carbide
L	length (mm)
P	load applied (N)
t	thickness (mm)
w	width (mm)

ABSTRACT

In the present study, hybrid composite materials are replacing heavy materials such as metals due to their lightweight advantages. The primary purpose of this study was to characterize a hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester for light weight applications. Hand lay-up technique was used for sample preparation of the composite. Taguchi L9 orthogonal array was utilized for the design of the experiment. This experiment was conducted using a mass balance, specimen cutter, UTM, Vicker hardness testing machine, impact testing machine, drilling machine, and scanning electron microscope. The specimens were prepared according to the ASTM standard for each test. The properties like tensile strength, flexural strength, hardness, impact strength, and water absorption test were studied. Actual density, void content, morphological analysis and machinability tests of the composite were also studied. Optimizations of parameters were done by using the taguchi method and grey relational analysis. The results revealed that maximum tensile and flexural strength were 39.9 and 56.1 MPa respectively. Hardness and impact strength were 75.05 HV and 14 J respectively. The water absorption was a minimum value of 0.250%. The minimum values of actual density and void content of composite were 1.252 g/cm^3 and 0.8% respectively. The results indicate that Al_2O_3 and SiC powder used as filler materials in this study improved the mechanical properties of the developed hybrid composite. Water absorption, actual density, and void content of the composite were increased as Al_2O_3, bagasse fibers and SiC wt.% increased. From grey relational analysis, the optimum levels were A1B1C2 which means 6 wt.% of alumina, 10 wt.% of bagasse fibers and 8 wt.% of silicon carbide. At these levels, all the mechanical and physical properties of the hybrid composite were optimum. Smooth surface finishing was observed for drilled surface and less amount of cracking was observed at the opposite side of the drilled surface. The results help higher institutes for research, automotive companies, manufacturing companies, construction sectors and government to conduct on how to utilize this abundant waste of bagasse fibers resource.

Keywords: *Hybrid composite. alumina, silicon carbide, bagasse fibers, polyester, Taguchi method, hand lay-up technique, Grey relational analysis*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Materials were very important in the development of human civilization. Materials were used for transportation, housing, clothing, communication, recreation, and food production for human life. Humans discover new materials with time. The engineering materials were classified as metals, ceramics, polymers and composites. Composite materials are formed when two or more materials with different properties are combined by different methods and their properties are superior to individual constituents. As a result of these properties, researchers were motivated to new composite materials for different light weight application was studied (Kawade and Narve, 2017). The composites were compound materials that differ from alloys by the fact that the individual components retain their characteristics but were so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings to obtain improved materials.

Composites materials are heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They were also considered homogeneous materials on a microscopic scale in the sense that any portion of them was the same physical property was studied (Verma et al., 2012). Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase was usually harder and stronger than the continuous phase and was called the 'reinforcement' or 'reinforcing material', whereas the continuous phase was termed the 'matrix'. The properties of composites are strongly dependent on the properties of their constituent materials, their distribution, and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents, or the constituents may interact in a synergistic way, resulting in improved or better properties.

The advantages of composites over their conventional counterparts were the ability to meet diverse design requirements with significant weight savings, as well as the strength-to-weight ratio was studied (Chandramohan and Marimuthu, 2011). They were, lower embedded energy compared to other structural metallic materials like steel, aluminum, etc,

less noisy while in operation and providing lower vibration transmission than metals, long-life composites enjoy a reduced life cycle cost compared to metals, and composites exhibit excellent corrosion resistance and fire retardancy. Natural fibers were well suited for making automobile parts and they were used as wood substitutes in the construction sectors as studied (Mochane et al., 2019). Ethiopia currently produces an average of 893,270 tons of Ethiopian sugarcane bagasse annually. Though some portion of it was burnt to provide energy and some used as livestock feed, on average nearly 123,011 tons of surplus was to spare without any considerable application was reviewed (Ayele et al., 2014).

Tadasse, (2017) reviewed on new area for research development in Ethiopia in which bagasse can be converted to nitrocellulose and used for different applications, including reinforcing in the polymer matrix that was addresses issues regarding bagasse. Due to its superior characteristics such as nanoscale dimension, high surface area, high availability, high crystalline, stiffness, biodegradability, and renewability, it was used for different applications including in construction, packaging, automobile, transportation, and biomedical fields. Hybrid composites are made of a combination of two or more fibers or fillers reinforced with the matrix. The interest in hybrid composite is materials increased in the last few years over composite materials because it had better properties as compared to non-hybrid composite. The hybridization of composites was one of the most efficient ways of enhancing the mechanical properties of composite material laminates. This new methodology was known as hybridization in which one or more fibers and filler particles are added into a composite was studied (Chavhan and Wankhade, 2020). The natural fiber composites were very cost-effective materials for the following applications. Building and construction industry such as panels for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which was used in times of natural calamities such as floods, cyclones, and earthquakes was studied (Chandramohan and Marimuthu, 2011).

In this study, the characterization and optimization of a hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester were investigated. Sample preparation of a hybrid composite was performed based on the Taguchi method and hand layup technique. After

preparation of samples, the mechanical and physical properties of the hybrid composite were performed based on ASTM standard method.

1.2. Problem Statement

In the modern world, research works indicates that more interest has been given in utilizing natural fiber materials for light weight applications. More of the content world's automotive and transportation industries' composite parts are manufactured based on Glass fibers. Glass fibers have high density, twice that of natural fibers, high purchasing cost, nonrenewable, high energy consumption, not CO_2 neutral, abrasion effect on machines, and high risk when inhaled, and are difficult to dispose of that means not biodegradable. The materials used for light weight applications was low density, low cost, renewable, consumed less amount of energy, and biodegradable. A solution for this problem was hybridization of composite materials from two or more natural fibers and fillers. This study aimed at characterization and optimization of the hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester had a great opportunity for research development in our country by solving this problem.

1.3. Objectives

1.3.1. General Objective

The general objective of this study was to characterize and analyze a hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester for light weight applications.

1.3.2. Specific Objectives

- To prepare sample of hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester with various weight fractions
- To conduct tensile strength, flexural strength, hardness, and impact strength tests on composite specimens
- To determine the actual density and void content of composite specimens
- To determine the water absorption behavior of composite specimens
- To study the influences of each process parameters on the mechanical and physical properties of composites using Taguchi method and Grey relational analysis
- To study the morphological analysis and machinability tests of the composite specimens

1.4. Research Questions

The research questions were raised concerning characterization and optimization of hybrid composites reinforced with Al_2O_3/SiC, bagasse fibers, and polyester.

- What were the process parameters and levels for preparing the sample of the composite?
- What were the mechanical and physical properties of the composite being studied?
- What was the problem this study solves?
- What was the contribution of this study?
- What motivates you did on this area?
- What do you recommend for future work?
- What were the difficulties during the preparing the sample of composite?

1.5. Significance of the Study

This study was helpful for the manufacturing industry and society to better use for different manufacturing equipment's: -

- Manufacturing of automotive components
- Reduce your energy consumption
- Reduce the amount of cost
- Reduce the environmental hazard during bagasse formation in a sugar factory
- Reduce waste products like bagasse in a sugar factory
- Option for new production technologies and materials

1.6. Scope of the Study

This study involves the characterization and optimization of hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester by using the hand lay-up technique. The prepared samples were tested by several testing techniques such as tensile testing, flexural testing, vickers hardness testing, impact testing, machinability testing, density, void content, water absorption measuring and morphological analysis of samples were performed. Finally, the response of all mechanical and physical properties of hybrid composites materials were optimized by using the Taguchi method and Grey relational analysis.

1.7. Limitation of the Study

The major limitation of this thesis study was non-availability of epoxy matrix supply in 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. Another limitation was the lack of a compressive moulding machine for sample preparation of composites with the required accuracy. In this case, the compression moulding method was replaced by the hand lay-up method. But the hand lay-up method was not as accurate as the compression moulding method.

1.8. Beneficiary of Study

The beneficiaries of this study were people, sugar industries, manufacturing industries, and automotive industries. The bagasse fibers were applicable to automotive seatbacks, parcel shelves, door panels, spare tire covers, boot liners, and cargo floor trays. Bagasse 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. Structure of the Thesis

This thesis entitled "Characterization and Optimization of Hybrid Composite Reinforced with Al_2O_3/SiC, Bagasse Fibers and Polyester" 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 was undertaken. Chapter Two: presents the literature review on classification of composite materials, manufacturing methods of composite materials, composite materials prepared from natural fiber, mechanical properties of bagasse fiber reinforced polymer composites, alumina and silicon carbide material filled natural fiber, and the Taguchi method. Finally, a summary of the literature and research gaps were described. 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 Four: elaborates on the experimental results of mechanical and physical properties of the composites under study, such as tensile strength, flexural strength, hardness, impact strength, actual density, void content, water absorption, optimization of all tests with the Taguchi method and grey relational analysis, machinability tests, and morphological analysis on specimens were discussed. Chapter Five: contains specific conclusions drawn from the experimental and analytical results, recommendations, and future research directions.

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:

- Classification of composite materials
- Manufacturing methods of composite materials
- Composite materials fabricated from natural fibers
- Mechanical properties of bagasse fibers reinforced polymer composites
- Alumina and silicon carbide material filled with natural fiber and
- Taguchi method

2.2. Classification of Composite Materials

A. Based-on Matrix Materials

Composite materials are classified into three groups on the based-on matrix materials investigated (Verma et al., 2012). They were: metal, ceramic and polymer matrix composites

1. Metal Matrix Composites

Metal matrix composites possess some attractive properties when compared with organic matrices. These include good strength at higher temperatures, higher transverse strength, excellent electrical conductivity, superior thermal conductivity and higher erosion resistance. However, the major disadvantage of metal matrix composites was their higher densities and consequently lower specific mechanical properties compared to polymer matrix composites. Another notable difficulty was the high energy requirement for the fabrication of such composites was studied (Dhibar et al., 2018).

2. Ceramic Matrix Composites

Ceramic materials are inorganic, non-metallic materials made from compounds of metal and non-metal. Ceramic materials were crystalline or partly crystalline. They were formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics, but many different ceramic materials were used in domestic, industrial,

and building products. Ceramic matrix composites were used in very high-temperature environments, these materials used a ceramic as the matrix and reinforce it with short fibers, or whiskers such as those made from silicon carbide and boron nitride was studied (Verma et al., 2012).

3. Polymer Matrix Composites

The most commonly used matrix materials are polymeric. The mechanical properties of polymers were inadequate for many structural purposes. In particular, their strength and stiffness were low compared to metals and ceramics. These difficulties were overcome by reinforcing other materials with polymers. Secondly, the processing of polymer matrix composites need not involve high pressure and didn't require high temperature. Composites had greater modulus than the polymer component but weren't as brittle as ceramics was studied (Chandramohan and Marimuthu, 2011).

B. Based on Reinforcement

The composites materials are classified into two based on reinforcement. These were: - particulate and fibrous composites.

1. Particulate Composites

As the name itself indicates, the reinforcement was of particle nature. It was spherical, cubic, tetragonal, a platelet, or of other regular or irregular shapes, but it was approximately equiaxed. In general, particles were not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particle filters were widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, improve machinability, increase surface hardness and reduce shrinkage was studied (Verma et al., 2012)**.**

2. Fibrous Composites

A fiber was characterized by its length was much greater compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibers were very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices**.** Fibers were three types: - plant fibers, mineral fibers, and animal fibers. Plant fibers contain cotton, flax, jute, ramie, sisal, hemp, and bagasse.

Asbestos was a mineral fiber. Animal fiber for the most part contains proteins; portrayals mohair, wool, silk, alpaca. Animal hairs were the strands got from animals e.g., horsehair, sheep's fleece, goat hair, alpaca hair, and so forth was studied (David and Naidu, 2017). Natural fibers were well suited for making automobile parts and they were used as wood substitutes in the construction sectors were studied (Mochane et al., 2019) .

2.3. Manufacturing Methods of Composite Materials

Fiber-reinforced plastics were fabricated by several methods depending upon the shape of the component to be manufactured. All those methods fall under a principle called polymerization. Polymerization was the process of joining a large number of synthetic molecules together to form a rigid structure was reviewed (Srinivas et al., 2017). The natural fiber composites were manufactured by the following methods.

1. Hand Lay-up

Hand lay-up was one of manufacturing method when the fiber reinforcements were positioned by way of hand then polymer resin was poured at the fiber reinforcement. The second layer of the fiber reinforcements was located on the polymer resin surface and a roller was moved with a little strain on reinforced fiber to avoid the air between the layers. This process was repeated for every polymer resin and fiber till the appropriate layers were stacked. This was kept under a pressure at room temperature around 24-48 hrs. This process was suitable for lower volumes. Resins need to be low in viscosity to be workable by hand this reduces the mechanical properties of the material due to the need for high diluent/styrene levels. This gives a good surface finish on the side only. It had more flexibility in material design and takes more cycles for producing the material was studied (Srinivas et al., 2017). The advantages of hand lay-up method were low cost tools, wide range of products. Disadvantages of this method were time consuming, easy to form air bubbles and disorientation of fibers and inconsistency process was investigated (David and Naidu, 2017).

2. Spray Lay-up

Spray lay-up was also one of the hand mounding techniques which was an extension of the hand layup method. Spray gun was used to spray pressurized resin and reinforcement that was within the shape of chopped fibers. Matrix material and reinforcement was sprayed concurrently or simultaneously one after one. A roller was rolled with a little strain over the sprayed surface to remove the air trapped into the layups. After spraying up to the

required thickness curing process was done at room temperature after this process the material was taken out from the mold. In this method, also low viscosities resins were used due to these mechanical properties were affected. This process was suitable for lower volumes. This gives a good surface finish on the side only. Lower cost for producing the material was studied (Srinivas et al., 2017). The advantages this method gives continuous process, any materials was utilized as mold and error can be adjusted by re-spraying and the disadvantages of low volume fraction and only board can be made as studied (David and Naidu, 2017)

3. Compression Moulding

Compression molding was a technique of molding wherein the molding material, generally preheated, first located in an open, heated mildew hollow space as studied (Srinivas et al., 2017). Compression molding was usually used for thermoplastic matrices with unfastened chopped fiber or mats of short or long fiber randomly oriented or aligned, however were used with thermoset matrices. The fibers were commonly stacked alternately with thermoplastic matrix sheets earlier than stress and warmth were implemented. David and Naidu, (2017) reviewed the advantages compression molding were low tool cost, low cost of manufacturing mold tool and easy to mold large parts. Disadvantages weren't handle high pressure and skilled lab our must be needed.

4. Filament Winding

Filament winding was the manufacturing process that mainly produces open or closed-end structures. The system entails winding filaments underneath tension over a rotating mandrel. The mandrel rotates around the spindle even as a shipping eye on a carriage traverses horizontally in step with the axis of the rotating mandrel, laying down fibers inside the preferred sample or perspective. This process was limited to convex shapes only. Low viscosity resins typically want to be used with their attendant decrease mechanical and health and safety properties as studied (Srinivas et al., 2017).

5. Injection Moulding

Injection moulding was one of the manufacturing processes when the material granules for the element were fed through a hopper into a heated barrel, melted using heater bands, and the frictional movement of a reciprocating screw barrel. The plastic was then injected through a nozzle right into a mold hollow space in which it cools and hardens to the configuration of the cavity. The mildew tool was set up on a moveable platen – when the

part has solidified, the platen opens and the component was ejected out the use of ejector pins. This process gives a good surface finish. This was suitable for higher volumes. It gave lower tensile strength than most thermoset systems was investigated (Srinivas et al., 2017).

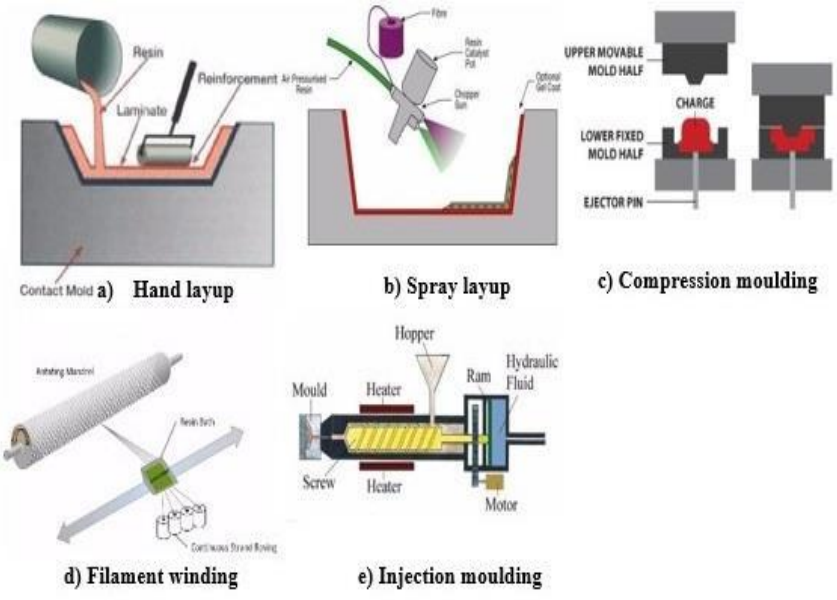


Figure 2. 1 Types of manufacturing process (Srinivas et al., 2017)

2.4. Composite Materials Reinforced with Natural Fibers

Natural fibers were extracted from different renewable resources, namely animals, vegetable plants, and minerals. The advantage and limitations of natural fiber were explained in shown Table 2.1.

Table 2. 1 Natural fibers advantages and their short-comes (Mochane et al., 2019)

Advantage	Disadvantages
Recyclable	High moisture absorption
Low density i.e., lightweight	Dimensional instability
Zero fingerprint CO_2	Flammable
High specific mechanical properties than glass	Low strength and thermal resistance than glass fibers
Non- abrasive to processing equipment	Anisotropic behavior
Generate non-harmful gases during processing and no skin irritation	Odor generation during degradation

Srinivas et al., (2017) examined the chemical and mechanical properties of natural fibers reinforced polymer-bonded composites and the processing techniques were compared for the reinforced composite materials. Natural fibers were classified into three types. They were plant, animal, and mineral fiber. The chemical and mechanical properties of the different natural fiber composites were compared. They concluded that the tensile strength of the natural fibers was low compared to the synthetic fibers. The strength of the fiber depended on the fiber loading. Some of the natural fibers were close to synthetic fibers like hemp, flax, kenaf, abaca, etc. The flexural strength of the fiber was depending on the fiber loading. If, fiber load was increased flexural strength also increased up to the optimal level then decreased.

Swain and Biswas, (2017) studied on influence of fiber surface treatments on physicomechanical behavior of jute/epoxy composites impregnated with aluminum oxide filler. An analysis has been carried out to make pre-treated jute fiber with 10, 20, 30, and 40 wt.% and different filler content 5 and 10 wt.% with epoxy-based composites. A comparative study of all the untreated jute/aluminum oxide-based hybrid composites with chemically treated jute/aluminum oxide-based hybrid composites was carried out. The investigated result shows that chemically treated composites considerably improved the mechanical properties of the composite. The maximum water absorption resistance and strength properties were found with benzoyl chloride-treated fiber-reinforced composite. The successful fabrication of pre-treated hybrid composite consisting of jute-epoxy resin impregnated with Al_2O_3 particulate filler was developed by simple hand-lay-up technique. Concerning the effects of filler content on mechanical properties of the jute/epoxy composites, it was found that the tensile strength, flexural strength, and impact strength were increased with an increased in the filler contents of Al_2O_3. The addition of 10 wt.% of Al_2O_3 filler reached the maximum mechanical strength of the composites. The tensile modulus, micro-hardness, and density of the composites were also greatly influenced by the content of Al_2O_3 filler.

Mittal et al., (2016) studied the natural fiber-mediated epoxy composites. The influence of the fiber content, fiber geometry, fiber size, surface treatment technique, and coupling agent on different properties like mechanical, thermal, and water absorption were

presented. The epoxy resin was a feasible polymer, which was effective strength, good toughness, and appreciable resilience. Vegetable, animal, and mineral fibers were part of the natural fiber. These fibers give superior strength to a composite when reinforced with the polymer matrix. They concluded that natural fibers filled with epoxy composites had great potential for engineering applications due to their environmental suitability, technical feasibility, and economic viability. Various researchers used different treatments like alkaline, silane, ultrasonic, and coupling agent (zinc oxide, alumina, nano-clays, tourmaline, and cloisite) to improve the performance of natural fiber-epoxy composites however, alkaline treatment was the most widely used technique for enhancing the mechanical, thermal and water absorption properties of the natural fiber-based epoxy composites due to economy and high efficiency.

Naidu and Rao, (2016) studied a review of the chemical behavior of natural fibers composites. Chemical treatment of the natural fibers was clean the fiber surface, chemically modify the surface, stopped the moisture absorption process and increased the surface roughness. The experiment was performed on alkali treatment, acetylation, silane treatment, and chemical properties, which play a significant role in applications and long-life behavior of the materials, were chemical resistance, water absorption, swelling, moisture absorption, void content, and density. From the conclusion, the chemical modification of natural fibers was necessary for increased adhesion between the hydrophilic fibers and hydrophobic matrix. The most common and efficient method of chemical modification was the alkali treatment of fibers.

Rao et al., (2020) studied on the mechanical properties of hybrid goat hair and banana fiber reinforced polymer composites. The composites were fabricated by hand lay-up and the mechanical properties tensile, flexural, and impact test were performed. From these studies, the addition of banana fiber in goat/ epoxy composite of up to 50 and 50% by weight increased mechanical properties. Tensile, flexural and impact strength were 15.4, 18.5 and 24 MPa respectively. From the result, they concluded that as wt.% of fiber increased its mechanical properties were increased and the hybrid composite was good replacement for traditional using synthetic fibers. Gairola et al., (2020) investigated fabrication and mechanical property evaluation of non-woven banana fiber epoxy-based

polymer composite. The non-woven banana fiber reinforced epoxy composite was fabricated with different weight percentages of fiber content with 10, 20, 30, 40, and 50%. The tensile, flexural, impact and hardeners were performed. From the result the maximum value of tensile and flexural strength were 65.6 38 MPa respectively at 30% of fiber. Whereas the maximum values impact strength was 2.8 joule and hardness was 45.6 HV at 40% of fiber.

2.5. Mechanical Properties of Bagasse Fibers Reinforced Polymer Composites

Bagasse fibers were founded from sugar cane industries for different application of the study. The composition of bagasse fiber was given in Table 2.2.

Table 2. 2 Composition bagasse fibers (Devadiga et al., 2020)

No	Composition of bagasse fiber	References
1	Cellulose 35.46%, hemicellulose 31.25%, lignin 23.7%, ash 9.5%	Kordkheili et al., (2012)
2	Cellulose 40–45% , 25-30% hemicellulose, and 20-25% lignin,	Balaji et al., (2015)
3	Cellulose 50.4%, hemicellulose 28.5%, lignin 14.9%, and ash 2%	Xiong, (2018)
4	Cellulose 49.44%, hemicellulose 23.19%, Lignin 12.56%, ash and extractives 14.8%	Ramlee et al., (2019)
5	Cellulose 43%, hemicellulose 10.1%, Lignin 33.23%, ash 1%, moisture 6.45%	Ibrahim et al., (2020)

Pradhan, (2016) studied epoxy composite filled with bagasse fibers by one of the oldest and simplest methods was hand lay-up in the composite making process. Bagasse fiber with particle size 3 mm was mixed with epoxy resin in various proportions. Bagasse fiber with 0, 4.68, 7.03, and 10.54 volume % were used. They concluded that the bagasse fiber-

filled epoxy polymer composite was used for food containers, insulating board, refrigeration industry, flasks, the interior of aircraft, etc as it was very lights weight and good insulating material. Tripathi and Kumar, (2016) investigated on mechanical behaviour of sugarcane bagasse fiber reinforced polymer matrix composites. The wooden molds of dimension 150 x 150 x 3.5 mm^3 were used for preparing the samples for tensile strength and 130 x 80 x 3 mm^3 was used to prepare the samples for flexural testing. The first group of samples was manufactured with 5, 10, 20, 25, and 30% volume fractions of fibers. The usual hand lay-up technique was used for the preparation of the samples. For different volume fractions of fibers, a calculated amount of epoxy resin and hardener ratio of 10:1 by weight was thoroughly mixed in a glass jar and placed in a vacuum chamber to remove air bubbles that got introduced. Composite tensile strength, flexural and macro hardness to the effect of content of the fiber was done. They concluded that tensile and flexural strength increased slowly to 20 percentages then starts decreasing. The study demonstrated the optimum for select performance for tensile, flexural, and macro hardness testing at 20% of fiber content.

Dhibar et al., (2018) studied tensile strength, bending strength, and water absorption with 10, 20, and 30 wt.% of bagasse fiber and with 90, 80, and 70 wt.% of polyester respectively. They concluded that the tensile strength and bending strength decrease as the percentage of fiber increases. 10% bagasse fiber composite has the highest tensile and bending strength compared to 20% and 30%. If the percentage of fiber increased, the water absorption increased, and 30% bagasse fiber composite was the highest water absorption. Srivastava and Dwivedi, (2019) investigated to observe the bagasse as reinforcement in the development of composites. From the literature, it was notified that bagasse can be used in the development of composite. They concluded that bagasse was a waste product that was utilized in the development of aluminum-based composite. By utilizing bagasse as reinforcement material, mechanical properties could be improved. By utilizing bagasse as reinforcement material, corrosion loss could be reduced.

Cao et al., (2006) studied the mechanical properties of biodegradable composites reinforced with bagasse fiber before and after alkali treatments. A steel mold was designed to produce the composites with a diameter of 30 mm. The composites reinforced with five

different bagasse fiber of 20, 35, 50, 65, and 75 wt.% were prepared for the investigation. Bagasse fibers were soaked in each 1, 3, and 5% NaOH solution at 25^0C for 2 hr, maintaining a liquor ratio of 20:1. The tensile test, flexural test, and impact test were performed. The geometry of the specimen was 30 × 10 × 2 mm^3 for the tensile test and 30 × 20 × 2 mm^3 for the flexural test. The span length was 10 mm for the tensile test and 18 mm for the flexural test, and both cross-head speeds were 1 mm/min. The unnotched specimens 30 × 10 × 2 mm^3 were mounted on the span of 20 mm and subjected to normal impact testing. The morphology of the fibers and the fracture surface of the composites were observed by SEM. They concluded that the tensile and impact strength of the untreated bagasse fiber composites increased with an increased in fiber content to the optimum fiber content of 65% only. The NaOH with 1% treated fiber composites showed maximum improvement in tensile, flexural, and impact strengths, compared with the NaOH 3 and 5% treated fiber composites. After 1% NaOH treatment an average improvement of 13% in tensile strength, 14% in flexural strength, and 30% in impact strength were observed.

Ramlee et al., (2019) studied on tensile, physical, and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fiber-reinforced phenolic hybrid composites. The pure and hybrid composites were fabricated using the hand lay-up technique with a size mold of 300 mm × 300 mm × 10 mm stainless steel plate. The tensile test was carried out according to ASTM C209 using a universal testing machine model INSTRON 3365 with a specimen dimension of 254 mm × 51 mm × 10 mm. Water absorption tests were conducted according to ASTM D1037 with a dimension of 152 mm × 152 mm × 10 mm. Void content of composites was carried out by ASTM D 2734-94 method. They concluded that hybrid composites 7OPEFB:3SCB show better performance as compared to others composites. The OPEFB fiber-based composite shows good mechanical strength due to higher cellulosic content, while SCB fiber help to reduce the water content and void in fiber composites. Studies on the treatment of fiber such as chemical and alkaline treatments were required for prospects to improve the performance of hybrid composites.

Ramlee et al., (2021) investigated the effect of surface treatment on mechanical, physical, and morphological properties of oil palm/bagasse fiber-reinforced phenolic hybrid

composites for wall thermal insulation application. For composite preparation, 300 mm × 300 mm ×10 mm mold by hand lay-up method was used. The treated pure and hybrid composites of OPEFB and SCB fiber were compressed and prepared by using a hot press molding machine. The tensile, flexural, compression test and water absorption behavior were performed. The tensile was with dimension size of 254 mm × 51 mm × 10 mm. The flexural with ASTM D790-15 of sample 280 mm × 52 mm × 10 mm was prepared. The compression tests were with a dimension of specimen 101 mm × 25 mm × 10 mm prepared. ASTM D1037 was used for water absorption test with size 152 mm × 152 mm ×10 mm. From the conclusion treated OPEFB and SCB fiber with 2 volume % silane solution increased the performance of hybrid composites reinforced bio-phenolic resin in comprised with hydrogen peroxide treatment. Among the hybrid composite ST 7OPEFB:3SCB and 5OPEFB:5SCB treated composites improved in tensile, flexural, and compressive strength, respectively whereas ST 3OPEFB:7SCB treated hybrid composites were better performance in water absorption and thickness swelling. The hybridization of silane treated (ST 5OPEFB:5SCB) fiber showed the best properties.

Acharya, (2008) investigated on weathering behavior of bagasse fiber reinforced polymer composite. A wooden mold dimension with 120 × 100 × 6 mm^3 was used for casting the composite sheet. Composite samples were treated in various environmental conditions like subzero, steam, and saline water. The three-point bend test was carried out in a UTM 201 machine by ASTM D2344-84 to measure the flexural strength of the composites. All the specimens having length varied from 100-125 mm, breadth of 100-110 mm, and thickness of 4-6 mm. They concluded that bagasse fiber was used to manufacture composite by providing increased profitability for the sugar industry. The shear stress of the composite was very sensitive to the treatments. The shear stress decreased with an increased in fiber volume fraction. Devadiga et al., (2020) investigated sugarcane bagasse fiber-reinforced composites. They concluded that fiber loading up to 20% in most of the studies resulted in improvement in mechanical properties such as tensile strength, elastic modulus, flexural modulus, flexural strength, and impact strength and fiber treatment methods such as alkali treatment, acrylic acid, and silane treatment had shown improvement in adhesion between the matrix systems and the bagasse fibers.

Hoque et al., (2019) studied on the tensile, bending, and water uptake properties of sugarcane bagasse fiber reinforced polypropylene based composite. The composites were prepared by a compression molding process. Composites were made from 30% by weight and treated by using 3, 5, and 7% solution of sodium hydroxide. They concluded that fiber composites achieved a 51% increased in tensile strength, 151% in tensile modulus, 109% in bending strength, and 68% in bending modulus over that of polypropylene, and 7% solution of sodium hydroxide demonstrated the lowest tensile and bending properties. Zakaria et al., (2020) investigated on the effects of fiber surface treatment and fiber loading on tensile and flexural properties of sugarcane bagasse reinforced polyester composites. Under these, the tensile strength was performed by ASTM D638 and flexural strength was performed with ASTM D790. Sugarcane bagasse fibers were alkalized with 1, 3, and 5% concentrations of sodium hydroxide solution. The different fiber loading formulations with 0, 20, 30, and 40 wt.% and hot-pressed to form natural fibers composite were prepared. A hollow rectangular mold was used in the compression molding, which had a size of 170 mm × 135 mm × 3mm. The results indicated that 3% of sodium hydroxide solution improved the tensile strength and modulus and untreated bagasse gave the lowest value.

Mathur et al., (2018) studied the experimentation and optimization of sugar cane bagasse dust reinforced epoxy based composite. The composite was prepared with four different percentage of the filler weight as 100 wt.% epoxy + 0 wt.% SCBF, 100 wt. % epoxy + 6 wt.% SCBF, 100 wt.% epoxy + 12 wt.% SCBF, and 100 wt.% epoxy + 18 wt. % SCBF. The hand lay-up method was used to fabricate the polymer composite sheet, and as per ASTM standard sample be cut and mechanical behavior of tensile and flexural strength was studied. Optimization of mechanical properties was also executed using the Taguchi method to find out the optimal combination of design constraints that maximizes the load and stresses values. The result shows that maximum load, tensile stress and strain, and flexural stress, and strain values were found to be maximum and minimum at the filler weight of 18 percent and 0 percent respectively with the speed of 2 mm/min.

Athijayamani et al., (2016) investigated the parametric analysis of mechanical properties of bagasse fiber-reinforced vinyl ester composites. Mechanical properties such as tensile and flexural strength of the composite were conducted and the fabrication process

parameters were optimized by using taguchi and analysis of variance techniques. The composites were fabricated by using the hand lay-up technique. Composites plates were fabricated by taguchi's L18 experimental design as the function of process parameters such as fiber length, fiber content, fiber diameter, sodium hydroxide concentration, and sodium hydroxide treatment duration. The results show that the fiber content at 40 wt.% was the most significant factor influencing the tensile and flexural strength. Subramonian et al., (2016) studied the effect of fiber loading on the mechanical properties of bagasse fiber-reinforced polypropylene composites. Bagasse was treated with alkali and then reinforced in polypropylene using hot pressing. Fiber loading was set to be varied from 10 to 20 wt.%. The fabricating specimens according to the standard size of the tensile testing specimen prepared as ASTM D3039, hardness testing specimen prepared as D785, and flexural testing specimen prepared as ASTM 7264.The result shows that composites with 30 wt.% of bagasse fibers have the highest tensile strength than the others, but it was lesser than that of standalone PP. Rockwell hardness value of the composites increased with increased fiber content. The highest flexural strength obtained was 57 MPa which was PP with 1 wt.% of the filler or bagasse fiber.

Oladele, (2014) investigated the effect of bagasse fibre reinforcement on the mechanical properties of polyester composites. The bagasse fiber particle of 5, 10, 15, and 20 wt.% for the production of the composites were taken by added polyester matrix. The mechanical properties such as tensile and hardness were carried out according to ASTM standards. Samples were prepared according to ASTM D412 1983 for tensile test and hardness tester following ASTM procedure No. D2240. The result shows that there was an enhancement in the mechanical properties of the reinforced polyester composites up to threshold point of 10 wt.% bagasse fibers loading and bagasse particulate fiber in the range of 5-10 wt.% gave the optimum results which show that low fiber weight content was good for better enhancement of properties.

2.6. Alumina and Silicon Carbide Material Filled Natural Fibers

Rajesh et al., (2014) investigated the analysis of mechanical behavior of glass fibre/ Al_2O_3 - SiC reinforced polymer composites. The composite was fabricated by using epoxy and polyester resin with 2 and 3% of SiC and Al_2O_3 with 2 and 3% with the glass fiber. Resin transfer molding was used for the preparation of the sample. Mechanical testing such as

tensile, impact, hardness, shear, and biaxial stress testing were conducted. They concluded that the composite with epoxy resin was higher in tensile strength of 36.53 MPa. The composite with polyester higher in biaxial stresses was 40.7 MPa and the shear strength more with the polyester resin of value 6.45 kN.

Mishra et al., (2021) studied the influence of coir fiber geometry on mechanical properties of SiC filled epoxy composites. Tensile strength, shear strength, flexure strength, and compressive strength with various fibers geometry were performed by using the hand layup technique. Fibers oriented at unidirectional, woven at ± 45° orientation, and chopped fiber. Silicon carbide particles were used as filler material in the epoxy matrix. Composite fabricated by adding 10 wt.% of coir fiber with 7-8 wt.% of silicon carbide, with balanced epoxy resin. They concluded that the fiber geometry plays an important role in providing good strength to the composite. Suresh et al., (2020) investigated the simulation and mechanical characterization of kevlar epoxy reinforced composite with silicon carbide filler. Kevlar epoxy sample was prepared with three different micro-scale weight percentages of 2, 4, and 6% silicon carbide using the hand lay-up technique. Tensile, flexural test performed and software simulations were conducted by autodesk fusion 360. The result showed an improvement in tensile strength up to 298.22 MPa and flexural strength of 232.39 MPa with the addition of a 6% weight percentage of silicon carbide.

Kopur, (2019) studied the modal analysis of silicon carbide-banana fiber epoxy composites using an experimental set-up. The composite was fabricated with banana fiber composition with 25, 30, and 35% and silicon carbides at 4, 8, and 12%. Mechanical properties of the composite material such as tensile, hardness, bending, and modal tests were performed by using finite element analysis using ansys. They concluded that fiber ratio had a major effect on the mechanical properties of the composites and better mechanical properties were found for composites having banana fiber at 35%. Kiran et al., (2018) investigated the evaluation of mechanical properties of glass fiber reinforced epoxy polymer composites with alumina, titanium dioxide, and silicon carbide fillers. The polymer composites were manufactured by reinforcing silicon carbide and titanium dioxide as fillers along with glass fibers and consist of alumina and titanium carbide with 0, 2, 4, and 6% volume. The tensile, flexural, and impact test were performed according to ASTM

test standards. The tensile test samples were prepared based on the ASTM D638 standard of dimensions 165 mm x 19 mm x 4 mm. Specimens were prepared as per the ASTM D5943-96 standards of dimension 150 mm x 15 mm x 3 mm for flexural and izod impact tests were conducted specimens of size 63.5 mm x 12.7 mm x 3.2 mm as per ASTM D256 standard. The experimental results show that tensile and flexural strengths were 77 and 118 MPa respectively. SEM morphology was used to check the bonding and filler distribution in the matrix. As a result alumina and silicon carbide fillers reinforced composites exhibited enhanced mechanical properties.

Chethanbabu and Ramachandra, (2019) studied on the evaluation of mechanical properties of polypropylene fiber reinforced epoxy composite filled with silicon carbide particulates. Composite material laminates were fabricated by the vacuum bag molding technique. Poly propylene fiber with 40, 45, and 50%, epoxy with 40, 50, and 60%, and filler with 5 and 10 % weight were prepared. Tensile test was performed with the ASTM D638, flexural test was conducted according to the ASTM D790, and water absorption was performed according to the ASTM D570. Water absorption was performed using distilled water. In conclusion, the tensile and fracture strength were increased as the percentage of epoxy increased and fiber % decreased, along with 5% silicon carbide as a filler material with tensile strength was 32.55 MPa, and after 45% of fiber loading the tensile strength decreased because excess of fibers made the absence of appropriate holding between the matrix and fiber around their interface and better mechanical behaviors were found in the composite specimen with 5% fiber and 40% of epoxy filled with 10% of filler material. Good water resistance property by adding silicon carbide particulate as the filler material to the matrix which helps the material to suitable for outdoor application.

Swain and Biswas, (2017) studied the physical and mechanical behavior of Al_2O_3 filled jute fiber reinforced epoxy composites. Composites with five different fiber loading with 0, 10, 20, 30, and 40 wt.% with four different filler loading with 0, 5, 10 and 15 wt.% were fabricated by using a simple hand layup technique. The micro hardness test, tensile strength, flexural strength, and density of composite were undertaken according to ASTM standards. The result shows that the void content of composites was increased with an increase in fiber and filler loading. The composite with 10 wt.% jute fiber shows minimum

void content. The hardness of the composites increased with the increase in fiber and filler loading. It was observed that composite with 40 wt.% fiber and 15 wt.% filler exhibits maximum hardness value. Devendra and Rangaswamy, (2012) investigated the determination of mechanical properties of Al_2O_3, Mg (OH) $_2$, and SiC filled E-glass/ epoxy composites. Composites were fabricated by the standard method. The tensile strength, impact strength, flexural strength, and hardness of the fabricated composites were studied. The E-glass /epoxy-based composites filled with varying concentrations of 0, 10 and 15% volume of aluminum oxide, magnesium hydroxide, and silicon carbide were prepared by using hand layup techniques. The results show that composites filled by 10 vol.% of $Mg(OH)_2$ exhibited maximum tensile strength 375.36 MPa and SiC filled composites exhibited maximum impact strength, flexural strength were 291.55 MPa, and hardness at 15 vol.% was 91.73 MPa.

Singh, (2013) studied the optimization of process parameters for stir-casted aluminum metal matrix composite using the taguchi method. Particle sizes of alumina 75, 105 and 150 wt.% of micron, reinforcement with 3, 6, and 9%, stirring time with 15, 20, and 25 minute was used to fabricate different samples of AMMCs by using the stir casting technique. Each parameter had three different levels. L9 orthogonal array used to make different specimens. The result shows that the hardness of composites increased with increasing the weight percentage of Al_2O_3 particles, stirring time but decrease with an increase in particle size. The tensile strength of the manufactured composite was higher in the composite. All these mechanical properties show an increasing trend with an increase in wt.%, stirring time, and decrease in particle size of the reinforcement.

Aynalem and Sirahbizu, (2021) studied the effect of Al_2O_3 on the tensile and impact strength of flax/unsaturated polyester composite with emphasis on automobile body applications. The composite prepared with the 0, 5, 10 and 15 wt.%, Al_2O_3-filled chopped flax with 15 and 25 wt.% loading unsaturated polyester resin composite and conventional hand-lay-up method followed by a compression molding process. The tensile and impact strength were studied based on the ASTM standard. They concluded that the ultimate tensile strength of the base flax/UPR composite had improved from 26.45 to 32.87 MPa due to the addition of 15 wt.% filler for the 15 wt.% fiber loading case. Accordingly, the

ultimate tensile strength of the base 25/UPR composite had increased from 26.65 to 32.07 MPa due to the inclusion of 5 wt.% Al_2O_3 filler. Energy absorbance capacity and impact strength of flax/UPR composite were highly affected due to the incorporation of Al_2O_3 filler.

2.7. Review on the Taguchi Method

Mathur et al., (2018) investigated the experimental and optimization of sugar cane bagasse dust reinforced epoxy-based composite. The different four percentages of bagasse with 0, 6, 12, and 18 wt.% and 100% of epoxy were used for fabrication of composite. The fabricated samples were tested at two different speeds respectively 2 mm/minute and 4 mm/minute. The composites were fabricated by using the hand lay-up method according to ASTM standard samples. The tensile and flexural tests were studied. The optimizations of mechanical properties were performed by using the taguchi method of L8 design to find out the optimal combination of design. The result shows that the maximum load, tensile stress and strain, and flexural stress, and strain values were found to be maximum and minimum at the filler wt. of 18 percent and 0 percent respectively with the speed of 2 mm/min.

Athijayamani et al., (2016) studied the parametric analysis of mechanical properties of bagasse fiber-reinforced vinyl ester composites. The composites were fabricated by hand lay-up and taguchi's L18 experimental design as the function of process parameters such as fiber length with 3, 9, and 15 mm, fiber content of 17.17, 35.6 and 55.43 wt.%, fiber diameter of 0.27, 0.88, and 1.49 mm, sodium hydroxide concentration with 3, 6, and 10% and sodium hydroxide treatment duration of 1, 3, and 5 hr. The tensile and flexural tests were performed according to ASTM standards. The result showed that the optimum fabrication process parameters on the tensile strength, bagasse fiber length was 15 mm, the fiber content was 35.6 wt.%, NaOH treatment duration was 1 hr, the fiber diameter was 0.27 mm, and NaOH concentration was 10%. The fiber length of 15 mm, the fiber content of 35.6 wt.%, NaOH treatment duration of 1 hr, the NaOH concentration of 6%, and the fiber diameter of 1.49 mm was found to be the optimum level for the flexural strength. They concluded that the fiber content, fiber length, and NaOH treatment duration were identified as the most significant fabrication process parameters.

Karuppusamy et al., (2015) investigated the mechanical properties of bagasse fiber-reinforced epoxy composite using taguchi and response surface methodology. Three bagasse fiber-resin volume percentages of 40, 50, and 60 with 1% fiber with resin were considered. For the combination of three factors with three levels, 27 trials were determined based on the taguchi L27 orthogonal array. A compression molding technique was used for the preparation of the samples. The flexural strength of the samples were studied based on the ASTMD790-10 standard. The result shows that the maximum flexural strength estimated from the response surface plot was 37.86 MPa for the best combination of fiber volume of 40%, and alkali concentration of 4.34, and a treatment time of 3hr. They concluded that fiber volume, alkali concentration, and treatment time were major factors in reaching maximum flexural strength. Statistical analysis indicates that fiber volume and alkali treatment had a significant effect on flexural strength.

2.8. Summary of Literature Review

From the literature the following summary was presented in Table 2.3.

Table 2. 3 Summary of literature review

No	Authors	Matrix type	Fibers and filler	Method	Results
1	Athijayamani et al.,(2016)	Vinyl ester	Bagasse fibers	Hand lay-up technique	Tensile and flexural strength were 63.2 and 62.6 MPa respectively
2	Aynalem and Sirahbizu, (2021)	Polyester	Flax fibers and Al_2O_3	Hand lay-up technique	Tensile strength was 37.06 MPa and impact strength 85.5 KJ/m^2
3	Cao et al., (2006)	Aliphatic polyester	Bagasse fibers	Hot mounting Press	Tensile and flexural strength were 26.77 and 50.86 MPa respectively. Impact strength was 11.27KJ/m^2
4	Dhibar et al., (2018)	Polyester	Bagasse fibers	Hand lay-up technique	Tensile and compression strength were 12.73 and 2.315 MPa respectively and water absorption was 27.66%
5	Mathur et al., (2018)	Epoxy	Bagasse fibers	Hand lay-up technique	Tensile and flexural strength were 22.085 and 36.62 MPa respectively.
6	Rajesh et al., (2014)		Al_2O_3 and SiC	Resin transfer	Tensile, shear and biaxial strength were 61.23,

				moulding	76.85and 53.52 MPa respectively. Impact was 4.38 J and hardness was 61.51 BHN.
7	Ramlee et al., (2019)	Phenolic	OPEFB and bagasse fibers	Hand lay-up technique	Tensile strength was 5.56 MPa, water absorption was 15.4% , density was 0.521g/cm^{3}and void content was 6.45%
8	Subramonian et al., (2016)	Polypropylene	Bagasse fibers	Hot pressing.	Tensile and flexural strength were 19.6 and 57MPa respectively. Hardness was 104.7 HRC
9	Swain and Biswas, (2017)	Epoxy	Jute fibers and Al_2O_3	Hand lay-up technique	Hardness value was 37.9HV, tensile strength was 98 MPa and void content was 4.23%
10	Zakaria et al., (2020)	Polyester	Bagasse fibers	Hot pressed	Tensile and flexural strength were 18 and 38 MPa respectively.

From the reviewed literature, the following conclusion was presented.

- Flexural strength and tensile strength of the fiber was depending on the fiber loading. If fiber loading was increased flexural strength and tensile strength also increased up to the optimal level then decreased
- The hardness of the composites increased with the increased in fiber and filler loading. After reaching the optimal level then decreased

2.9. Research Gaps

Several researchers were done on experimental investigation of bagasse fibers reinforced polyester composite. From literature reviews there was no experimental investigation done on alumina and silicon carbide reinforced bagasse fibers and polyester matrix. In addition to this the improvement of mechanical and physical properties of composites with the addition of alumina and silicon carbide was not done. From literature reviews there was no optimization method done by using grey relational analysis for bagasse fiber composite. In previous works researchers used single response optimization rather than multi response optimization method.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

In this chapter, the materials and methods used for preparing samples of composites were explained. For this study, materials such as alumina, silicon carbide, bagasse fibers, and unsaturated polyester resin with their corresponding hardeners, mold release, normal water, distilled water, and sodium hydroxide were utilized to manufacture the hybrid composite materials samples. The apparatus, such as plastic containers, plastic bowls, beakers, stirrers, sieves, C-clamps, and mold plates, were used for this work. The equipment such as digital mass balance, grinding machine, specimen cutter machine, universal testing machine, Vickers hardness testing machine, drilling machine, and Scanning electron microscope were used.

3.2. Materials

3.2.1. Alumina

Alumina was the most commonly used filler material for polymer matrix composites due to its relatively high hardness, good oxidation resistance, and chemical stability. It was the most widely used filler material. The limitation of the application of alumina was due to its low fracture toughness as studied (Kiran et al., 2018). Aluminum oxide is a chemical compound made from aluminum and oxygen with the chemical formula Al_2O_3. It was commonly called alumina. It has strong ionic interatomic bonding and commonly occurs in its crystalline polymorphic phase α-Al_2O_3 was investigated (Yohanes, 2019). The properties of alumina are explained in Table 3.1. Alumina was ceramic materials used as the filler in the present study were purchased from Bangaiere Fine chem- Bangalore; India. This alumina had an average particle size of 70-230 meshes ASTM with had a density of 3.94 g/cm^3.

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

Description	**Alumina**
Density (g/cm^3)	3.95
Tensile strength (MPa)	200 – 660
Young's modulus (GPa)	380
Bending strength (MPa)	200 – 600
Compressive strength (MPa)	1900 – 2000
Poison' s ratio	0.25 - 0.3
Coefficient of thermal expansion (^oC)	7.39×10^{-6}

(a) (b)

Figure 3. 1 Alumina powder (a) packed (b) powder

3.2.2. Silicon Carbide

Silicon carbide was an inorganic material produced from quarts by the carbothermal reaction. A mixture of pure quartz (SiO_2) sand and carbon in the form of finely ground coke was built up around a carbon conductor within a refractory kiln electrical resistance type furnace. The SiC was produced by the high temperature around 2700°C for 40hrs was investigated (Selvam et al., 2017). Silicon carbide exhibits favorable mechanical and chemical properties at high temperatures for many applications. The benefits of using SiC as reinforcement were improved stiffness, strength, thermal conductivity, wear resistance, fatigue resistance, reduced thermal expansion and dimensional stability was studied (Devendra and Rangaswamy, 2012). Silicon carbide was produced by combining silica sand and carbon in an acheson graphite electric resistance furnace at a high temperature. It was also prepared by the thermal decomposition of a polymer under an inert atmosphere at low temperatures. It has low density, high strength, high hardness, high thermal conductivity and also excellent thermal shock resistance. Silicon carbide was one of the

best filler material that used in composite as investigated (Rajesh et al., 2014). Silicon carbide was selected due to these properties. Silicon carbide powder ceramic materials used as the filler in this study were purchased from Bangaiere Fine chem- Bangalore, India. These powders have an average particle size of 220 meshes ASTM with a density of 3.22 g/cm^3.

(a) (b)

Figure 3. 2 Silicon carbide powder (a) packed (b) powder

3.2.3. Bagasse Fibers

Bagasse is a fibrous residue that remains after crushing the stalks of sugar cane and contains short fibers. It consists of water, fibers, and small amounts of soluble solids as studied (Dhibar et al., 2018). Bagasse fibers are agricultural waste or by-products of the sugar cane industry. The burning of large quantities of bagasse fibers is dangerous and harmful to the environment. This has caused the main source of air pollution in many countries. The target was maintained clean environment, produce cost-effective advanced composite materials, and enhance the character of the composite by using these bagasse fibers were investigated (Naguib, 2015). The properties of bagasse fiber were shown in Table 3.2.

Table 3. 2 Physical- mechanical properties of bagasse fibers (Balaji et al., 2015)

Properties	**Values**
Tensile strength (MPa)	180-290
Young's modulus (GPa)	17
Density (g/cm^3)	1.25

Bagasse fibers were selected due to lower thermal conductivity, low density, and environmentally friendly, renewable, cheap, good stability, no toxic and good strength. For this study, fresh bagasse fibers were taken from the wonji sugar factory found in Adama,

Ethiopia. Bagasse fiber is sieved with 2 mm opening diameter sieve and the length of bagasse fiber from particle size to 10 mm the maximum length.

(a) (b)

Figure 3. 3 (a) Untreated fresh bagasse fibers and (b) treated bagasse fibers

3.2.4. General Purpose Polyester Resin

General purpose polyester resin was an unsaturated polyester resin. Unsaturated polyester resin thermoset and was capable of being cured from a liquid to a solid state when subjected to the right conditions. Low viscosity for fast wet-out, convenient for hand lay-up applications, low cost, low density, exhibits good mechanical and good chemical resistance, low-pressure molding capabilities and the capability to cure at room temperature were the advantages of unsaturated polyester when compared to other thermosetting resins studied (Fasil, 2020). For this study, unsaturated polyester resin with the brand name TOPAZ-1110 Phthalic Anhydride was used. This unsaturated polyester resin was purchased from the local supplier World Fiber Glass and Waterproofing Engineering in Addis Ababa, Ethiopia. The characteristics of unsaturated polyester resin are given in Table 3.3.

Table 3. 3 Characteristics of UPR (Aynalem and Sirahbizu, 2021)

Description	**UPR**
Density (g/cm^3)	1.09-1.35
Tensile strength (MPa)	40
Young's modulus (GPa)	3.3
Flexural strength (MPa)	45
Poison's ratio	0.44
Maximum elongation (%)	1

3.2.5. Hardener

Unsaturated polyester resin was cured by adding a hardener or a catalyst, which causes a chemical reaction. The catalyst initiates the chemical reaction of the polyester resin and monomer ingredient from liquid to solid-state. Therefore, the hardener or curing agent used for this study was a hardener with the brand name methyl ethyl ketone peroxide hardener. GP polyester laminating resin ought to be combined with MEKP catalyst at a ratio of 1-3%, by weight as investigated (Bhaskaran, 2020). It was purchased from the local supplier, World Fiber Glass and Waterproofing Engineering in Addis Ababa, Ethiopia.

(a) (b)

Figure 3. 4 (a) Unsaturated polyester resin and (b) hardener

3.2.6. Mold Release

Release wax was a chemical agent used to stop the bonding of the molding material with the mold. Mold release was essential for preventing the polyester from sticking to the mold when the composite was taken apart. Even though, there were several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this thesis work was honey wax 250 purchased from the local Supplier, World Fiber Glass and Waterproofing Engineering in Addis Ababa, Ethiopia.

(a) (b)

Figure 3. 5 Honey wax 250 (a) closed (b) opened

3.2.7. Sodium Hydroxide

Sodium hydroxide, also known as lye or caustic soda has the molecular formula NaOH and was a highly caustic metallic base and alkali salt. Pure sodium hydroxide was a whitish solid, which was available in pellets, flakes, granules, and as a 50% saturated solution as reviewed (Yohanes, 2019). Sodium hydroxide was soluble in water, ethanol, and methanol. This alkali was deliquescent and readily absorbs moisture and carbon dioxide in the air. Sodium hydroxide was used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps, and detergents. In this work, NaOH in flakes form was used for the treatment of bagasse fiber and it was purchased from local suppliers.

Figure 3. 6 Sodium hydroxide

Alkali Treatment of Bagasse Fibers

NaOH treatment helps to remove lignin and hemicellulose from the surface of bagasse fibers and it has the advantages of activating the hydroxyl groups attached to cellulose and lignin.

$$\text{Fiber} - \text{OH} + \text{NaOH} \rightarrow \text{Fiber} - \text{O} - \text{Na}^{+} + \text{H}_2\text{O} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Bagasse fibers were hydrophilic and highly polar, whereas the polymer matrices were largely non-polar and hydrophobic. Therefore, both the natural fibers and polymer matrices have inherently incompatible surfaces, hindering the stress transfer at the interface. The incompatibility of the hydrophilic natural fibers and hydrophobic polymer matrix leads to poor interfacial adhesion, which then results in a composite material with poor physical and mechanical properties was studied (Vidyashri et al., 2019). To overcome the drawbacks of poor interfacial adhesion of natural fibers and polymer matrix improved properties by surface modification. Alkali treatment was one of the approaches to improve the inherent properties of natural reinforcements. Mercerization was a commercial

technology developed a long time ago which consists of the treatment of the fibers with a sodium hydroxide solution. The concentration of sodium hydroxide and the time of treatment vary in a very wide range, from 0.03 wt.% to 40 wt.% and from a few minutes to 48 hr. Alkali treatment of sodium hydroxide to maximize the efficiency of the bagasse fiber was reviewed (Bartos et al., 2020). Zakaria et al., (2020) studied sugarcane bagasse fiber reinforced polyester composites. Taking alkali treatment of fiber at 1, 3, and 5% concentration of NaOH solution, bagasse fibers were soaked at room temperature for 1hr. The fibers were then washed several times with distilled water to remove any NaOH solution that stuck to the fiber and the fibers were oven-dried for 72 hours at 70^{o}C. From this 3% concentration of NaOH resulted in improved tensile strength and flexural strength of composites.

For this study, the bagasse fiber were washed with normal water and dried in sunlight for 2 days. Then bagasse fibers were soaked to taking a chemical treatment of bagasse fiber at a 3% concentration of NaOH. That means the bagasse fibers were soaked in 150 grams of sodium hydroxide mixed in five liters of distilled water at room temperature for 1hr. after that washed with normal water several times. Finally, the fibers were allowed to dry in bright sunlight for 3 days.

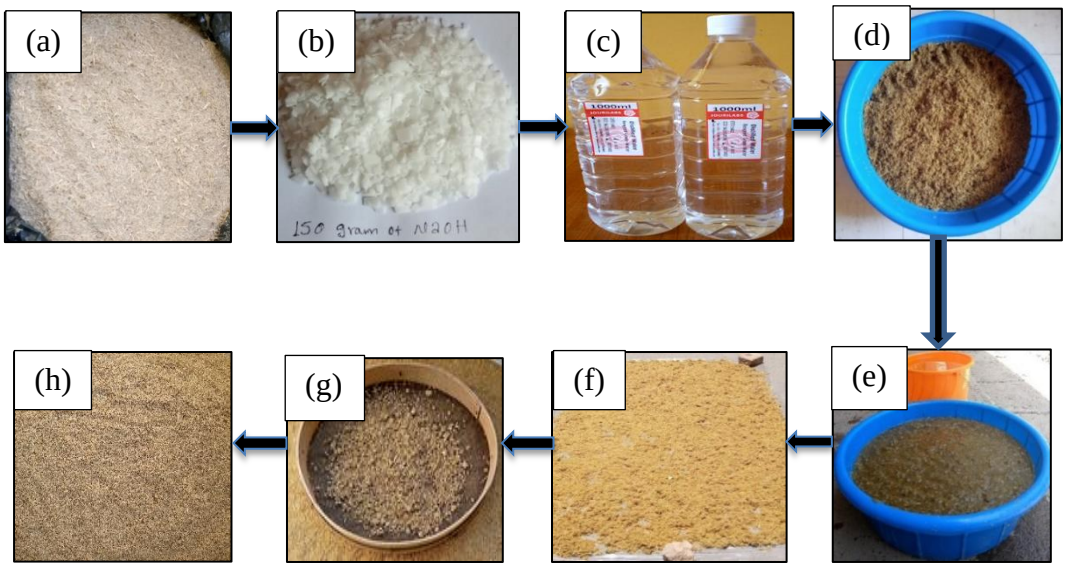


Figure 3. 7 Alkali treatments of bagasse fibers. (a) bagasse fiber (b) NaOH (c) distilled water (d) soaked bagasse fibers (e) washed (f) cured (g) sieved (h) treated bagasse fibers

3.3. Methods

3.3.1. Design of Experiment

In the design of the experiment, the Taguchi method was used because it was a problem - solving tool which improved the performance of the product, process design and system. This method combines the experimental and analytical concepts to determine the most influential parameter on the result response for the significant improvement in the overall performance that was investigated (Singh, 2013). The Taguchi method was described as an efficient design of experiment technique for a systematic approach and for optimizing parameters with a minimum number of experiments. The Taguchi design of the experiment consists of orthogonal arrays to study all the parameters of the project with a minimum number of experiments. The process of performing a taguchi experiment follows several distinct steps was reviewed (Mathur et al., 2018): -

Step1: Problem formulation

Step 2: Identify output and input parameters that affect the outcome of the problem.

Step 3: Identify the control factors, noise factors, and signal factors. The control factors were those, which was controlled under regular making conditions. The noise factors were those, which were either too difficult or too expensive to control under usual making conditions. The signal factors were those which affected the mean performance of the process.

Step 4: The selection of factor levels, possible interactions with the degrees of freedom related to each factor, and the interaction effects.

Step 5: Design an appropriate orthogonal array.

Step 6: Preparation of experiment.

Step 7: Run the experiment has appropriate data collection.

Step 8: Statistical analysis with the interpretation of the experimental results.

Step 9: Undertaking a confirmatory run of the experiment.

A. Orthogonal Array

The selection of a specific orthogonal array was based on the number of levels of various factors using the Taguchi method. The steps to go through were as follows:

- Selection of factors to be evaluated
- Selection of number of levels
- Selection of an appropriate orthogonal array

- Experiment and analyze the results

Characterization and optimization of the hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers, and polyester was carried out by hand using a lay-up technique with three levels and three factors. To observe the most influential process parameters in the prepared sample of Al_2O_3, SiC and bagasse fiber reinforced polyester matrix composites, namely particulate filler content and bagasse fiber content, at three levels were considered. In this, work to experiment with three factors and three levels by using the Taguchi method L9 orthogonal array with Minitab 16 software.

Table 3. 4 Process parameters and levels

Factors	**Parameter's designation**	**Level 1**	**Level 2**	**Level 3**
Al_2O_3 wt.%	A	6	8	10
Bagasse fiber wt.%	B	10	15	20
Silicon carbide wt.%	C	6	8	10

The degrees of freedom were defined as the number of comparisons between the process parameters that required determining which level was good and precisely how much better it was explained (Mathur et al., 2018). Taguchi supports the use of signal to noise ratio as essential to maximize the performance of a system or product by minimizing the effect of noise with maximizing the mean performance. The S/N treated as a response or output of the experiment. It was measured that the deviation when uncontrolled noise factors were present in the system was investigated (Mathur et al., 2018). The response values were transformed into a signal-to-noise ratio to measure the quality characteristics deviating from the desired value; a larger S/N ratio has higher-quality characteristics were reviewed (Karuppusamy, 2015). The degree of freedom was calculated by the formula given below.

$$\mathrm{DOF} = \mathrm{P}' \times (\mathrm{L} - 1) \quad \text{……...……..} \quad (3.2)$$

Where, P' = number of factors and L = number of levels

$$\mathrm{DOF} = 3 \times (3 - 1) = 6$$

However, the total number of experiments of the orthogonal array should be greater than or equal to the DOF required for the experiment. Thus, the L9 orthogonal array was selected to make the further experiments are shown below.

Table 3. 5 L9 orthogonal array

Exp. No	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

For this study A represented an alumina wt.%, B represented the bagasse fiber wt.%, and C represented the silicon carbide wt.%. In this nine different composites were prepared with different parameters and at different levels.

B. Analysis of Variance

The statistical foundations for design of the experiments and the analysis of variance were first introduced by Sir Ronald A, Fisher, and the British biologist. ANOVA was a method of partitioning total variation into accountable sources of variation in an experiment. It is a statistical method used to interpret experimental data and make decisions about the parameters under study was investigated (Krishnaiah and Shahabudeen, 2012). The basic equation of ANOVA was given as below.

$$\text{Total sum of squares} = \text{sum of squares due to factors} + \text{sum of squares due to error}$$

$$SS_{Total} = SS_{Factors} + SS_{Error} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

Athijayamani, (2016) stated that Taguchi experimental design with signal-to-noise ratio and analysis of variance were used to prepare and analyze the composite. The S/N ratios help in data analysis and the prediction of the optimum results. ANOVA was employed to identify the important fabrication process parameters and to calculate the percentage contribution of each process parameter on the quality characteristics responses such as tensile strength, flexural strength, impact, hardness, water absorption, and density and void content. The larger the better characteristic was selected to determine the S/N ratio for

tensile strength, flexural strength and hardness tests were maximized. The smaller the better characteristic was selected to determine the S/N ratio for water absorption, actual density and void content were minimized. From the analysis of variance, the percentage contribution of each influential parameter was calculated by the following formula.

$$PC = \frac{\text{Sum of squares or treatment sum of squares}}{\text{Total sum of squares}} \times 100 \quad \text{..... (3.4)}$$

Where, PC: Percentage contribution of individual factor

In the analysis of variance, the percentage contributions of each control factor were used to measure the corresponding effects on the performance characteristics. The significance level of 5%, i.e., for 95% level of confidence was considered in this analysis. ANOVA results indicate whether there was statistical significance indifference or not in output characteristics. ANOVA analysis involves when α values are below 0.05, which is significant and above 0.05, which is not significant. Percent contribution measures the contribution of each model term relative to the total sum of squares. It was often a rough but effective guide to the relative importance of each model term. The variance of any factor/component was given by its sum of squares divided by its degrees of freedom. It was also referred to as mean square. It was individual variation divided by the degree of freedom of that factor.

$$V = \frac{\text{Sum of the square}}{\text{degree of freedom}} \quad \text{..... (3.5)}$$

F-test was used to test whether the effects due to the factors were significantly different or not. F-value was computed by dividing the factor variance/mean square with the error variance/mean square. However, in the case of multi-factor designs with random effects or mixed effects model, the denominator for computing F-value shall be determined by computing expected mean squares given (Krishnaiah and Shahabudeen, 2012). F-test was a qualitative analytical tool to observe which process parameters have a significant effect on the process.

$$F_A = \frac{S_A}{S_E} = \frac{V_A}{V_E} = \frac{\text{Sum of the square of factor}}{\text{sum of the square of the error}} \quad \text{..... (3.6)}$$

The weight fraction of the Composites

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, fractions are easier. Volume fractions are used in the theoretical analysis of composites.

Table 3. 6 Designation and Composition in weight percentage of the composite

Designation	**Composition in weight percentage of the composite**			
	Polyester	Alumina (wt.%)	Bagasse fiber (wt.%)	Silicon carbide (wt.%)
S1	78	6	10	6
S2	71	6	15	8
S3	64	6	20	10
S4	74	8	10	8
S5	67	8	15	10
S6	66	8	20	6
S7	70	10	10	10
S8	69	10	15	6
S9	62	10	20	8

Mass Fraction of the Composites

$$M_c = M_p + M_f + M_m \quad \text{..... (3.7)}$$

$$\text{Particle mass fraction} = \frac{\text{mass of particle}}{\text{total mass}} = M_P = \frac{M_P}{M_M}$$

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

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

$$M_P + M_F + M_M = 1$$

Volume Fraction of Particle, Fiber and Matrix (V_P, V_F, V_M) of Composites

$$\text{Volume of particle} = \frac{\text{mass of particle}}{\text{density of particle}} = V_p = \frac{M_p}{\mathcal{P}_p}$$

$$\text{Volume of fiber} = \frac{\text{mass of fiber}}{\text{density of fiber}} = V_f = \frac{M_f}{\mathcal{P}_f}$$

$$\text{Volume of matrix} = \frac{\text{mass of matrix}}{\text{density of matrix}} = V_f = \frac{M_m}{\mathcal{P}_m}$$

$$V_c = V_p + V_f + V_m$$

$$\text{Particle Volume fraction} = \frac{\text{volume of particle}}{\text{total volume}} = V_P = \frac{v_p}{v_p + v_f + v_m}$$

$$\text{Fiber Volume fraction} = \frac{\text{volume of fiber}}{\text{total volume}} = V_F = \frac{v_f}{v_p + v_f + v_m}$$

$$\text{Matrix Volume fraction} = \frac{\text{volume of matrix}}{\text{total volume}} = V_M = \frac{v_m}{v_p + v_f + v_m}$$

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 (Dhibar et al., 2018).

$$\text{volume of the composite} = l \times w \times t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.8)}$$

Where, l = length, w = width and t = thickness

l = 300 mm, w = 300 mm and t = 4 mm

$$\text{Volume of the composite} = 300\ \text{mm} \times 300\ \text{mm} \times 4\ \text{mm}$$

$$\text{Volume of the composite} = 360000\ \text{mm}^3 = 360\ \text{cm}^3$$

According to the density of bagasse fiber, polyester resin, aluminum oxide, silicon carbide was given bellow in g/cm^3.

- Bagasse fiber = 1.25 g/cm^3
- Polyester resin = 1.15 g/cm^3
- Aluminum oxide = 3.94g/cm^3
- Silicon carbide = 3.22 g/cm^3

$$V_c = V_{polyester} + V_{Bagasse} + V_{Particulate} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.9)}$$

For sample - 1

Alumina = 6 wt.% = 0.06 Bagasse fiber = 10 wt.% = 0.1

Polyester resin = 78 wt.% = 0.78 Silicon carbide = 6 wt.% = 0.06

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, bagasse fiber, and ceramic particulate for each composite ratio was reviewed (Dhibar et al., 2018).

$$\frac{M_c}{\mathcal{P}_c} = \frac{m_{polyester}}{\mathcal{P}_{polyester}} + \frac{m_{Alumina}}{\mathcal{P}_{Alumina}} + \frac{m_{Bagasse}}{\mathcal{P}_{Bagasse}} + \frac{m_{SiC}}{\mathcal{P}_{SiC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.10)}$$

The density of composite obtained from equation above.

$$\frac{1}{\mathcal{P}_c} = \frac{0.78}{1.15} + \frac{0.06}{3.94} + \frac{0.1}{1.25} + \frac{0.06}{3.22} = 0.792$$

$$\mathcal{P}_c = 1.26\,{}^{g}/_{cm^3}$$

Mass of composite was calculated by using equation of (Dhibar et al., 2018)

$$\text{Mass of composite} = \text{density of composite} \times \text{volume of composite} \quad \ldots (3.11)$$

$$m_c = \mathcal{P}_c \times V_C$$

After getting the density of the composite, it was multiplied by the volume of the composite the mass of composite obtained.

$$m_c = \mathcal{P}_c \times V_c$$

$$m_c = 1.26\,{}^{g}/_{cm^3} \times 360 cm^3$$

$$m_c = 453.6\ g$$

The mass of the composite was multiplied by each particulate /fiber/matrix ratio. Then the mass of each alumina, Sic, bagasse fiber, and unsaturated polyester resin was obtained.

$$\text{Mass of alumina} = 0.06 \times m_c$$

$$\text{Mass of alumina} = 0.06 \times 453.6\ g = 27.2\ g$$

$$\text{Mass of bagasse fiber} = 0.1 \times m_c$$

$$\text{Mass of bagasse fiber} = 0.1 \times 453.6\ g = 45.36\ g$$

$$\text{Mass of SiC} = 0.06 \times m_c$$

$$\text{Mass of SiC} = 0.06 \times 453.6\ g = 27.2\ g$$

$$\text{Mass of polyester} = 0.78 \times m_c$$

$$\text{Mass of polyester} = 0.78 \times 453.6\ g = 353.8\ g$$

$$\text{Mass of polyester} = 0.64 \times m_c$$

$$\text{Mass of polyester} = 0.64 \times 471.6\ g = 301.8\ g$$

By calculating for other samples of the composites in similar ways the results was given in Table3.7.

Table 3. 7 Mass of each sample of composites

	Composition (wt.%)				Mass (g)				
Samples	Polyester	Al_2O_3	SiC	Bagasse fiber	Polyester	Al_2O_3	SiC	Bagasse fiber	Total
S1	78	6	6	10	353.8	27.2	27.2	45.36	453.6
S2	71	6	8	15	328.73	27.78	37	69.45	463
S3	64	6	10	20	301.8	28.3	47.16	94.32	471.6
S4	74	8	8	10	345.78	37.4	37.4	46.73	467.28
S5	67	8	10	15	319.1	38.1	47.62	71.44	476.28
S6	66	8	6	20	306.5	37.15	27.86	92.88	464.4
S7	70	10	10	10	337.4	48.2	48.2	48.2	482
S8	69	10	6	15	323	46.8	28	70.2	486
S9	62	10	8	20	296.8	47.88	38.3	95.76	478.8
Total					2913	338.81	338.7	634.34	

3.3.2. Samples preparation by Hand lay-up Technique

Composites samples were prepared by hand lay-up technique. The composites with 10, 15, and 20 wt.% of bagasse fibers and alumina and silicon carbide with 6, 8, and 10 wt.% were used for composites fabrication. The polyester resin and its hardener were used as matrix materials. The fabrication process was conducted at room temperature. The mold plates with 300 mm x 300 mm were made from wood. The mold plates were covered with mold release wax and the mixture was poured into the mold plate. Then level the mixture had uniform thickness. Finally closed the mold plates by applying for the upper plate and fixed the two plates with four C-clamp at four corners. The curing process was took 24 hr and nine experimental runs were finished in the same ways.

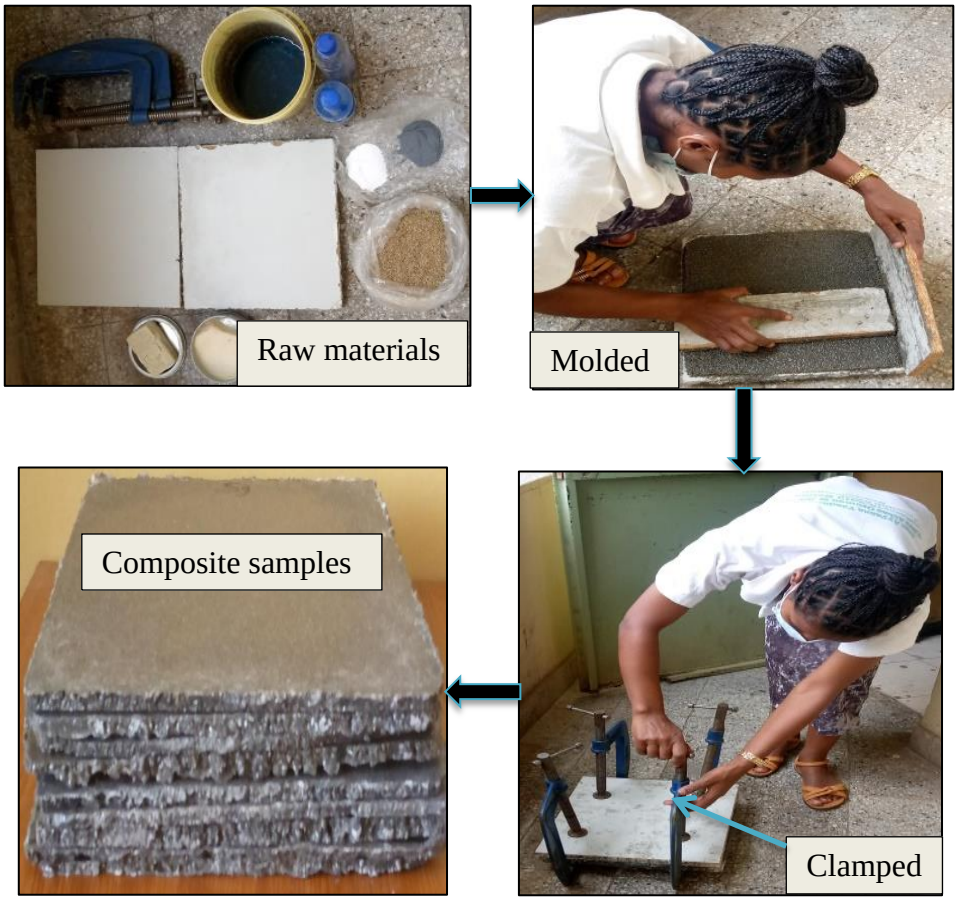


Figure 3. 8 Composites samples preparation process

3.3.3. Specimens Preparation Procedures

Characterization and optimization of a hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester were prepared based on Taguchi's L9 experimental design using the hand-layup method. The following steps were used for the prepared sample.

1. The masses of bagasse fibers, SiC, Al_2O_3, unsaturated polyester resin, and hardener were calculated according to the required weight fractions for each composite fabricated.
2. Applying honey wax 250 on the surface of mold plates for easy release of samples from plates.
3. Unsaturated polyester resin and hardener were mixed with a ratio of 10:2 by continuously using a simple stirrer for 2 minutes.
4. The mixture of Al_2O_3 and SiC were added into the mixture's polyester resin and the hardener was then stirred continuously and slowly to avoid bubbling for about 2 minutes.

5. Bagasse fibers were added again into the mixture and stirred continuously for about 2 minutes.
6. Pour a mixture of composite on the lower mold plate that was wax-lubricated wooden mold and manual labeling and impregnating.
7. The lower mold plate was closed with the upper mold plate after being wax-lubricated.
8. Fixed the two plates with C-clamp at 4 points and waited for 24 hrs for curing.
9. The samples are knocked and ejected from molds. Nine samples were fabricated at room temperature.
10. The samples were cut to specimens according to the standard dimensions for each test such as tensile, flexural, hardness, impact, water absorption, morphological analysis, density, and void content using the specimen's cutter or grinder machine. All tests were performed at room temperature. These procedures were more explained as flow chart on Figure 3.9.

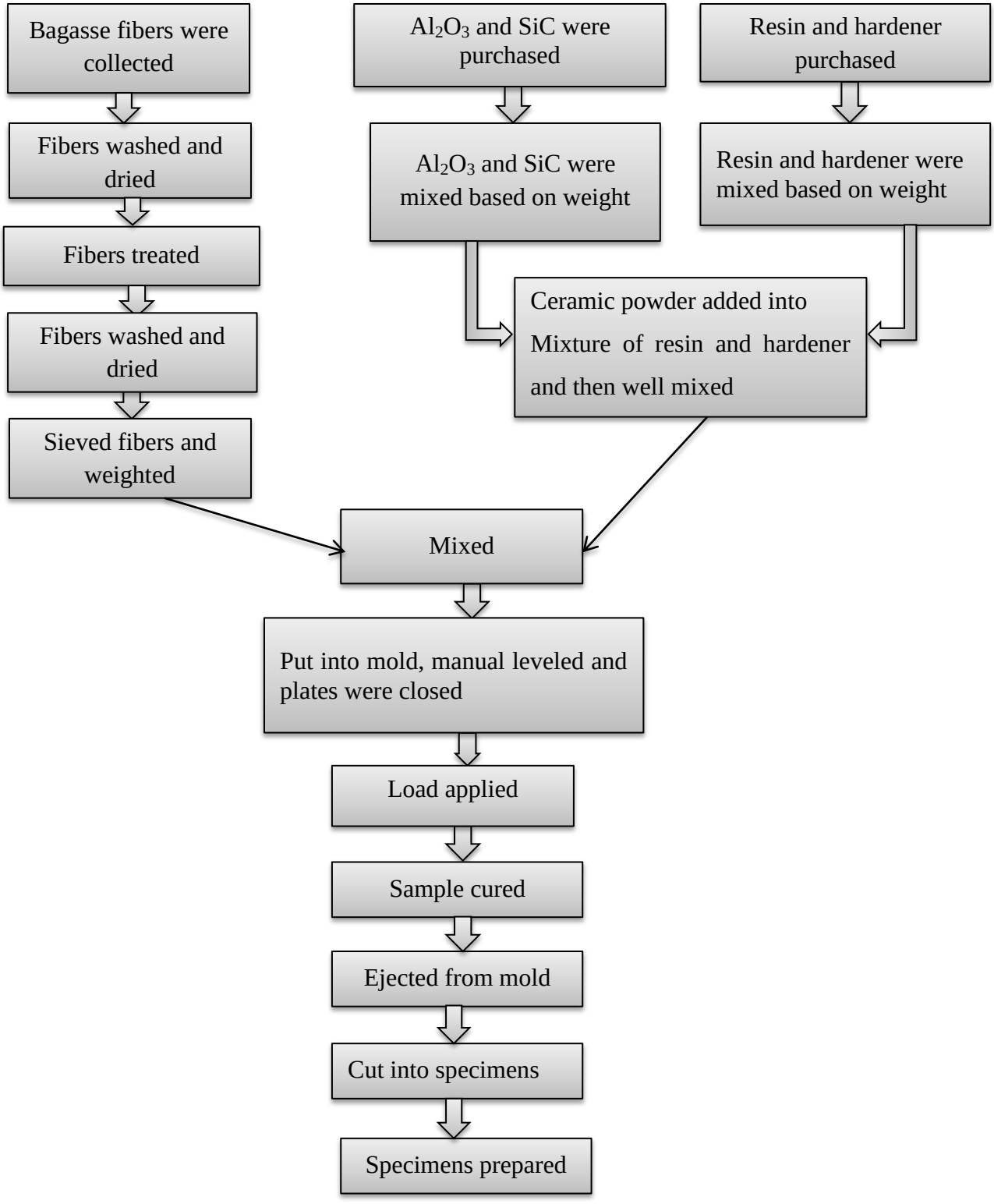


Figure 3. 9 Flow diagram of the specimen's preparation process

3.4. Research Methodology

Various steps followed in methodology of the thesis work were shown in the form of flow chart shown in Figure 3.10.

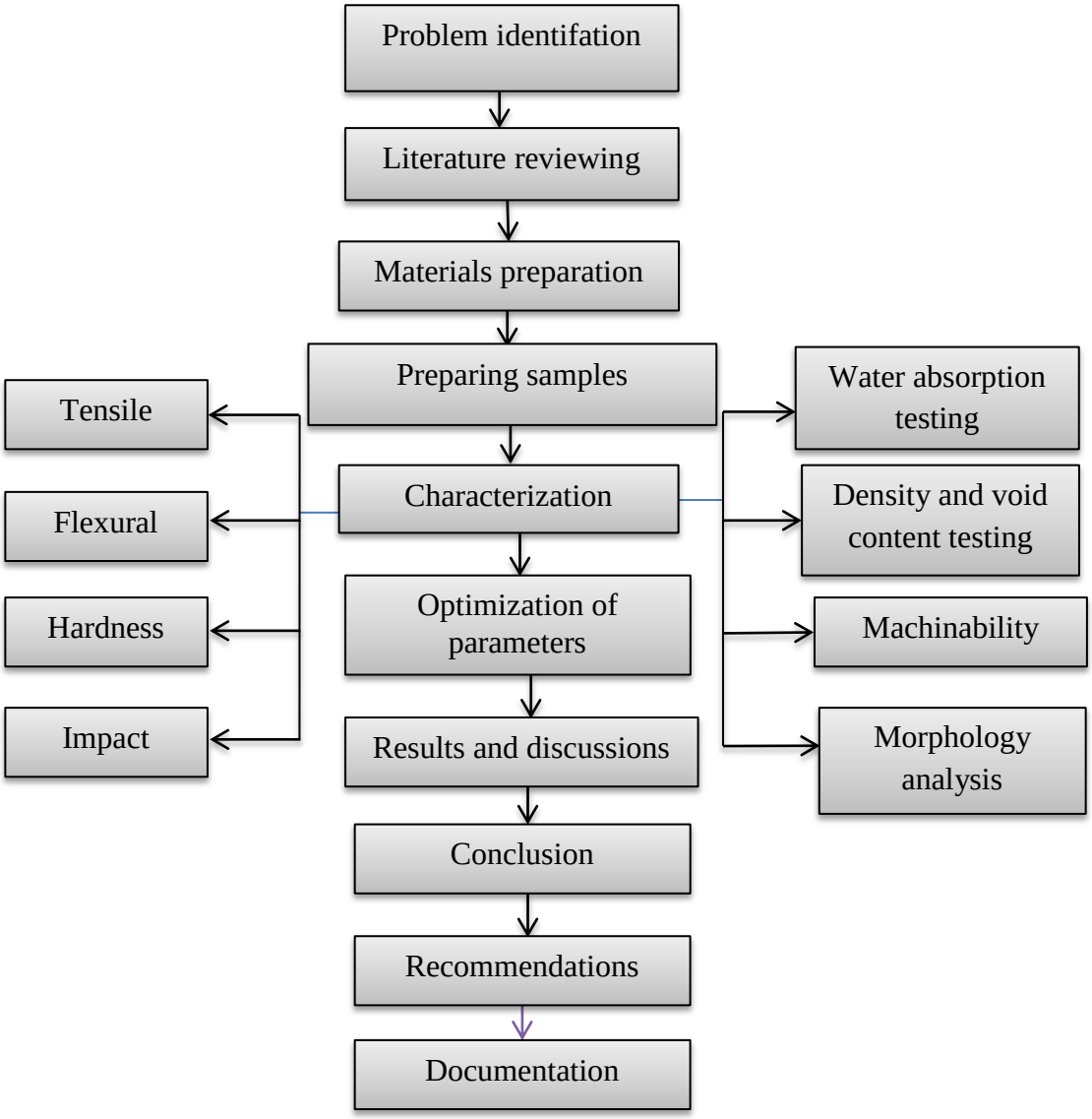


Figure 3. 10 Research methodology

3.5. 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.

3.5.1. Analytical (Digital) Mass Balance

The digital mass balance was used for weighting the amount of bagasse fiber, SiC, alumina, and polyester resin used for sample preparation. The balancing equipment was used for the physical characterization of composite property. It was found in the Chemical Engineering laboratory at Adama Science and Technology University, Ethiopia.

Figure 3. 11 Mass balance

3.5.2. Specimen Cutter Machine

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

Figure 3. 12 Specimen cutter machine

3.5.3. 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 (Adugna, 2018). 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 Starret with 0.001 mm of resolution, which was connected with an RS232 interface to a computer to acquire data (Huerta, 2010). 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 Conformity Assessment Enterprise (ECAE) in Addis Ababa, Ethiopia. MTL/015 Universal Testing Machine with a 2000kN was used for performing the tensile test.

Figure 3. 13 Universal testing machine

3.5.4. Vickers Hardness Machine

The vicker 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.

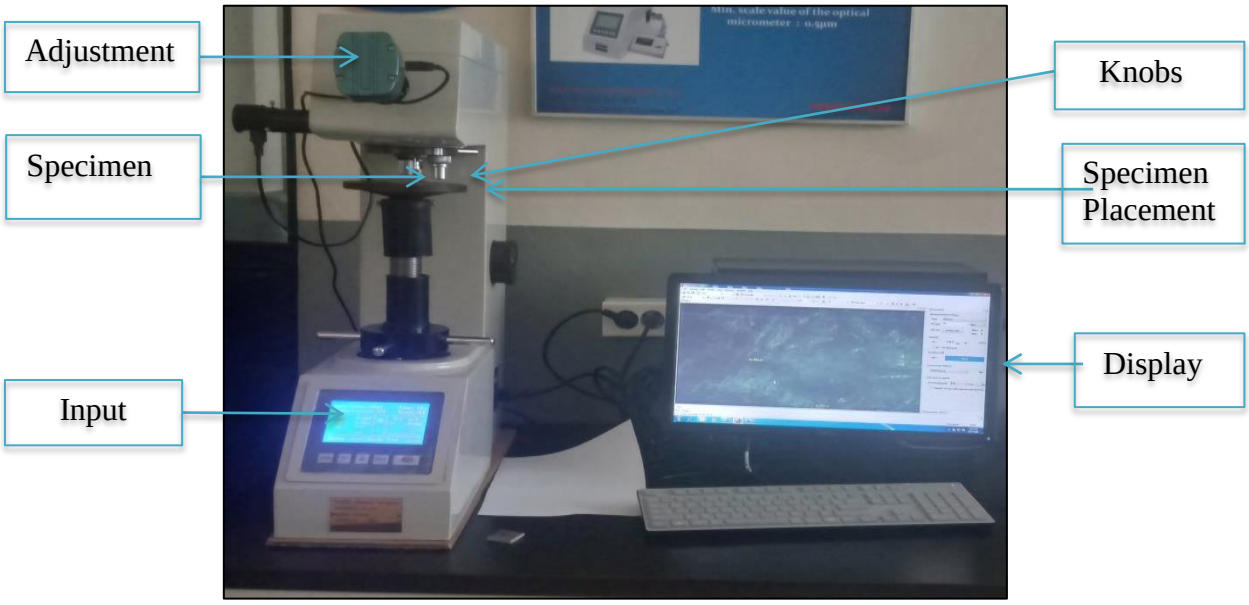


Figure 3. 14 Vickers hardness machine

3.5.5. 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 (Negash, 2021). This machine was found at Defence University of Engineering College, Bishoftu, Ethiopia.

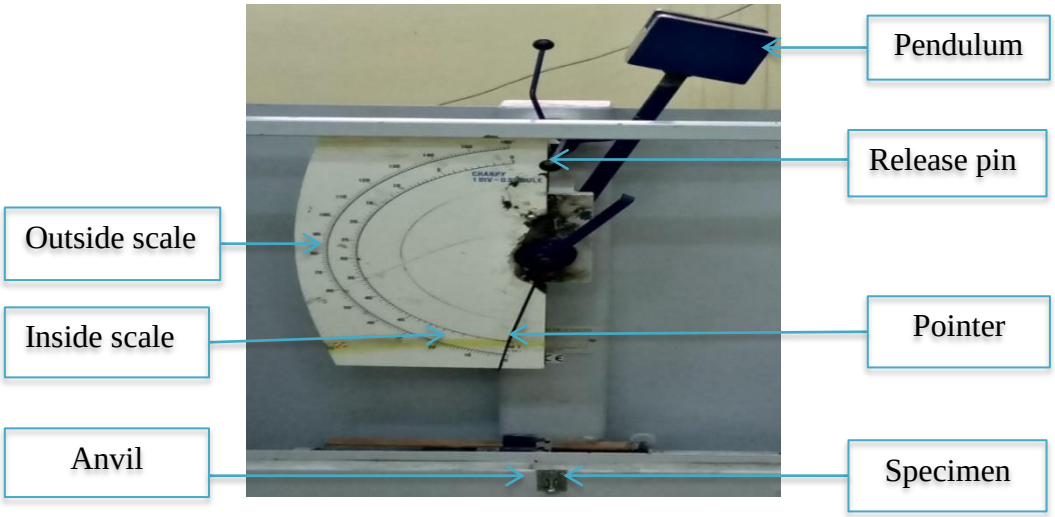


Figure 3. 15 Impact testing machine

3.5.6. Drilling Machine

A drilling machine, called a drill press, was used to cut holes into or through metal, wood, or other materials. Drilling machines used a drilling tool that had cutting edges at its point. This cutting tool was held in the drill press by a chuck or morse taper and was rotated and fed into the work at variable speeds. Drilling machines were used to perform other operations. They were performed by countersinking, boring, counterboring, spot facing, reaming, and tapping. All drilling machines had the following construction characteristics: a spindle, sleeve or quill, a column, a head, a worktable, and a base. This machine was found in Adama Science and Technology University in a mechanical workshop.

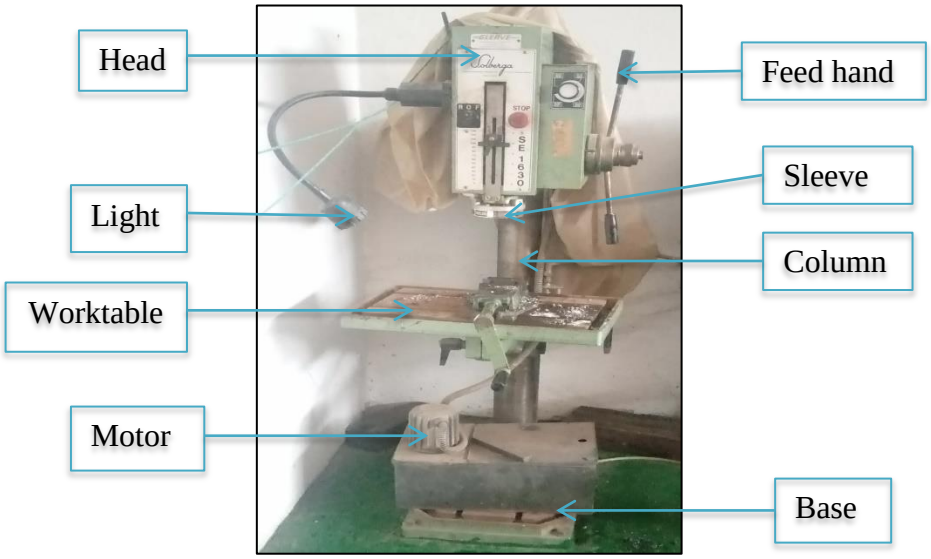


Figure 3. 16 Drilling machine

3.5.7. 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. 17 Scanning electron microscope

3.6. 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.

3.6.1. Mechanical Characterization

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

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 Conformity Assessment Enterprise (ECAE) in Addis Ababa, Ethiopia. Tensile strength test performed according to the ISO 6892-1 on the computerized USM. The specimen size tensile strength test was 300 mm × 30 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.

$$\sigma_t = \frac{p}{w \times t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.12)$$

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

(a) (b)

Figure 3. 18 Specimens tensile test (a) before test (b) after test

2. Flexural Strength Testing

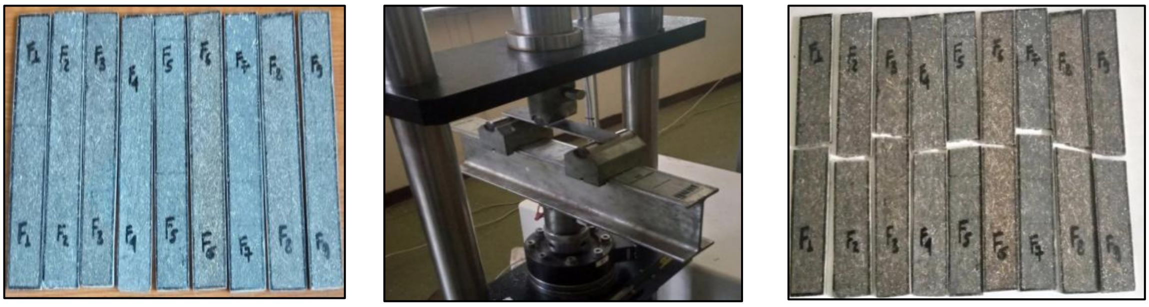
Flexural strength was the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. Sometimes it was referred to as cross-breaking strength where maximum stress developed when a bar-shaped test piece, acting as a simple beam, was subjected to a bending force 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. Flexural strength test performed with ASTM D790-2010 was studied (Bhaskaran, 2020). Specimens dimension of 170 mm × 25 mm × 5 mm. The flexural strength was given (Suresh et al., 2020) as follows.

$$\sigma_f = \frac{3pl}{2wt^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.13)$$

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.



(a) (b) (c)

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

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. A diamond indenter, in the form of a right pyramid with a quadrangular base and an angle of 136° among reverse faces was pressed into the material under a load p. 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).

$$H_v = 0.1889\frac{p}{L'^2} \text{ and } L' = \frac{x+y}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.14)$$

Where p is the applied load (N), L' is the diagonal of square impression (mm), x is the horizontal length (mm) and y is the vertical length (mm).

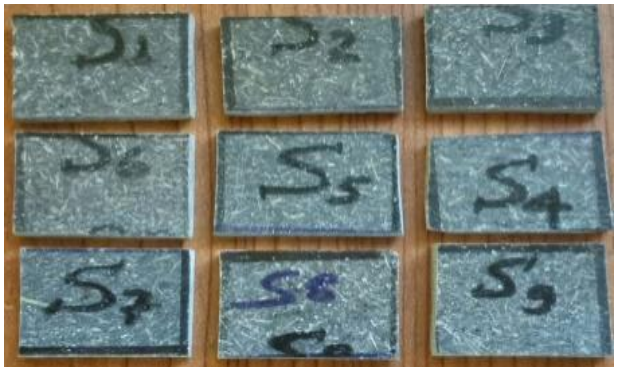
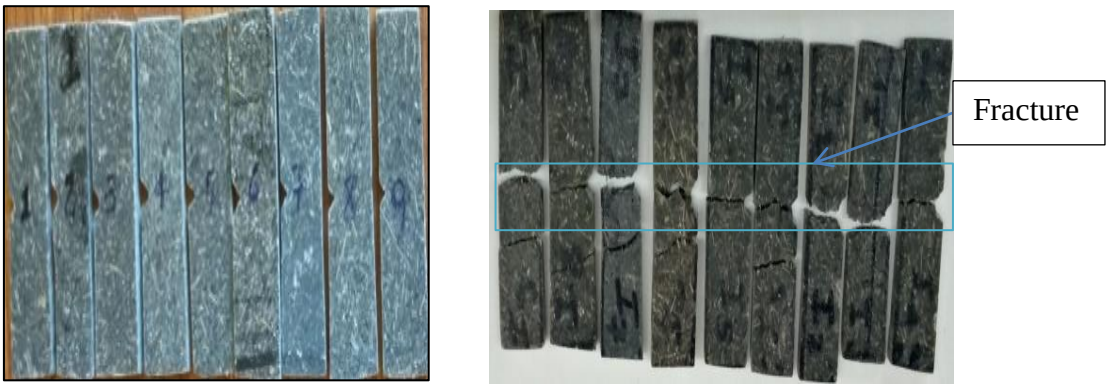


Figure 3. 20 Specimens for hardness test

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 was 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 Defence University of Engineering College, Bishoftu, Ethiopia.



(a) (b)

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

3.6.2. Physical Characterization

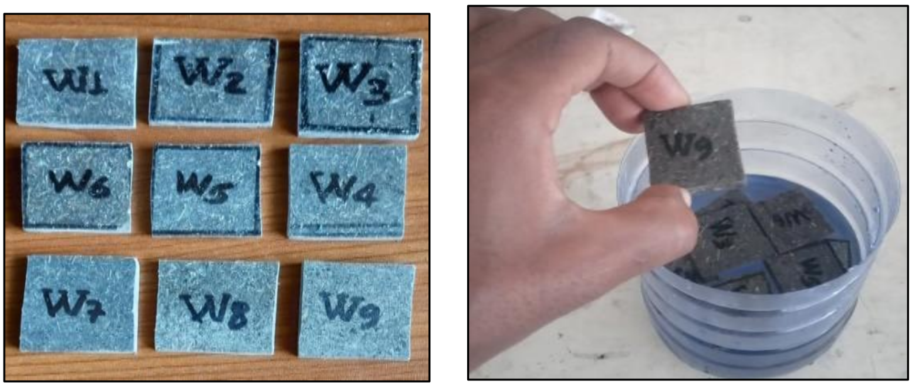
Physical characterization involved the characterization of physical properties of prepared composite specimens. These included the studies of water absorption, density, and void content.

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 alumina, silicon carbide reinforced with bagasse fiber and polyester were done with specimens dimension were 30 mm x 28 mm x 5 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 24, 48, 72, 96, 120, 144, 168, and 192 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).

$$\text{Water absorption } (\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3.15)$$

Where, W_1 and W_2 are the weight of the dry and wet specimens.



(a) (b)

Figure: 3. 22 (a) Specimens for water absorption test (b) in water

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).

$$\rho = \frac{m}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.16)$$

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 (ρ_a) 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 upthrust 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

$$\rho_a = \frac{\rho_w W_a}{W_a - W_w} \quad \text{..... (3.17)}$$

Where, ρ_a = actual density of composite or experimental density ρ_w = density of water

W_a = weight of the composite in air and Ww = Weight of composite in water

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

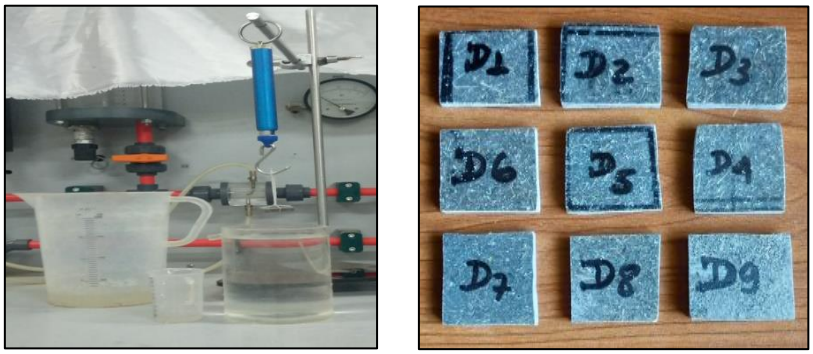
$$\rho_t = \frac{1}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} + \frac{W_p}{\rho_p}} \quad \text{..... (3.18)}$$

Where W and ρ represent the weight fraction and density, respectively. The suffixes f, m, p, and ct stand for the fiber, matrix, particulate filler, and composite materials, respectively.

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

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \quad \text{..... (3.19)}$$

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).



(a) (b)

Figure 3. 23 (a) Setup of density (b) specimens for density and void content

3. Machinability Testing

Performing machinability tests after preparation of the composite material was necessary. Drilling and cutting composite into different sizes was required for preparing composite parts for joining and assembly. The drilling operations were performed on the drilling machine. The drilling operations take place with a bench-type drill machine with a diameter of the drill bit 5 and 7 mm, 200 rpm, 2 mm per second speed, and 0.5 revolutions per minute feed rate of the drilling machines were operated. The purpose of drilling was to observe the surface finish through the hole. It helps to identify the material's surface finish. The other main purpose of drilling the fabricated composite was to check whether it shows good strength through-hole during riveting or tightening by the bolt.

4. Morphological Analysis

Morphological analysis of specimens under SEM was carried out for S1 and S9. The reason to select these specimens shows good mechanical properties such as flexural and tensile respectively when compared to the other specimens.

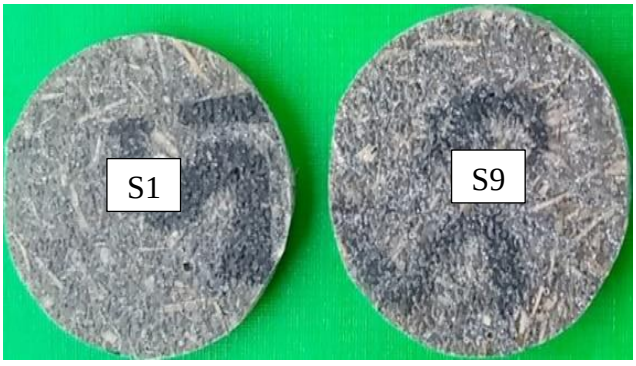


Figure 3. 24 Specimens for the SEM

3.9. Grey Relational Analysis

The grey relation analysis was used to analyze the multiple performances of characteristics. Complex problems having minimal information was solved by grey theory, it was an evaluation technique based on the random uncertainty of small samples. The 'white' systems means, the system which has complete information, whereas in a 'black' system has no known information. Any system lies between these two that was a 'grey' system with limited information reviewed (Robale, 2020). In this method the multiple performances of characteristics were converted as single equivalent grey relational grades. In first step the S/N ratio obtained from taguchi analysis was normalized in the range 0 to 1. Normalization was a transformation performed on a single data input to distribute the data evenly and scale it into an acceptable range for further analysis. The equal weight of 0.5 was used for all calculation. The grey relational grade indicates the relational degree between every sequence. The value of distinguishing coefficient (Ψ = 0.5) for all trials. Finally, the grey relational grade was calculated using the grey relational coefficients. Where m = number of response variables. Usually the higher value of grey relational grade could be considered as stronger relational grade. Moreover, the higher the grey relational grade indicates closer to the optimal value studied (Vasanthi and Selvan, 2020).

(a) Find S/N ratio was calculated as given in equation below.

For larger the better

$$\frac{S}{N}\ \text{ratio} = -10\log\left(\frac{1}{n}\right) + \left(\frac{1}{Y_{ij}^2}\right) \quad \text{..... (3.20)}$$

For smaller the better

$$\frac{S}{N}\ \text{ratio} = -10\log\left(\frac{1}{n}\right) + (Y_{ij}^2) \quad \text{..... (3.21)}$$

Where, n number of replication for each experiment and Yij response values

(b) Determination of Normalizing the S/N ratio

For larger the better

$$Xij = \frac{(Yij - \min(Yij))}{(\max(Yij) - \min(Yij))} \quad \text{..... (3.22)}$$

For smaller the better

$$Xij = \frac{(\max(Yij) - Yij))}{(\max(Yij) - \min(Yij))} \quad \text{..... (3.23)}$$

Where, Xij Normalized S/N ratio and Yij S/N ratio obtained from taguchi

(c) Determination of Deviation sequence or quality loss

$$\Delta = 1 - Xij \quad \text{………………………………………………} (3.24)$$

Where, 1 is highest value of quality loss and Δ is quality loss

(d) Determination of Grey Relational Coefficient

$$GCij = \frac{(\delta min + \psi\ \delta max)}{\delta ij + \psi\ \delta max} \quad \text{………………………………………………} (3.25)$$

Where, ψ is distinguishing coefficient

(e) Determination of Grey Relational Grade

$$Gi = \left(\frac{1}{m}\right) \Sigma GCij \quad \text{………………………………………………..} (3.26)$$

(f) Determination of optimal parameters

In this experiment the optimization of parameter was done by the taguchi optimization method on minitab16 statistical software and grey relational analysis method was used to change the responses into S/N ratio and the GRG value was used to optimize the parameters. This method enables as to optimize several parameters at a time. The GRG obtained was analyzed by analysis of variance and it provides the statistical significance of input process parameter over an output.

(g) Prediction of GRG under optimal parameters

Next step was to determine and confirm the development of quality characteristics by the optimal parametric combination was performed by minitab16 software. The predicted optimal condition can be calculated by software to get optimized parameters.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

Results of the experimental work of all tests were discussed in detail. The tests performed in this study were tensile strength, flexural strength, hardness, impact strength, water absorption, actual density, void content, machinability and morphological analysis of fabrication and characterization of hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester. Taguchi experimental design with signal-to-noise ratio and analysis of variance were used to prepare and for analysis of hybrid composite. Finally all test response was optimized by using Grey relational analysis.

4.2. Tensile Strength Test

From experimental work results for the tensile strength and S/N ratios of fabrication and characterization of hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester was given in Table 4.1.

Table 4. 1 Tensile strength and signal to noise ratio results from experiment

Specimens	Alumina wt.%	Bagasse fiber wt.%	Silicon carbide wt.%	Tensile strength (MPa)	S/N ratio (dB)
S1	6	10	6	35.3	30.956
S2	6	15	8	36.9	31.340
S3	6	20	10	33.5	30.500
S4	8	10	8	36.6	31.269
S5	8	15	10	35.6	31.029
S6	8	20	6	29.5	29.396
S7	10	10	10	37.2	31.410
S8	10	15	6	35.1	30.906
S9	10	20	8	39.9	32.019

Figure 4.1 shows the tensile strength tests were varies for all specimens. Specimen 1 had a tensile strength result of 35.3 MPa which was fabricated from 6 wt.% of alumina, 10 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. Specimen 2 had a tensile strength result of 36.9 MPa which was fabricated from 6 wt.% of alumina, 15 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. Specimen 3 had a tensile strength of 33.5 MPa. The specimen was fabricated with 6 wt.% of alumina, 20 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 4 had a tensile strength of 36.6 MPa which was fabricated from 8 wt.% of alumina, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. Specimen 5 had a tensile strength of 35.6 MPa which was fabricated from 8 wt.% of alumina, 15 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 6 had a tensile strength of 29.5 MPa which was fabricated from 8 wt.% of alumina, 20 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. Specimen 7 had a tensile strength of 37.2 MPa which was fabricated from 10 wt.% of alumina, 10 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 8 had a tensile strength of 35.1 MPa which was fabricated from 10 wt.% of alumina, 15 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. Specimen 9 had a tensile strength of 39.9 MPa which was fabricated from 10 wt.% of alumina, 20 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. From this, the specimen 9 shows maximum tensile strength.

From general of observation tensile strength the result of composite was highly affected by types of filler materials in which shows that all specimens with SiC had more strength than alumina. The other factor for change in tensile strength of composite was due to change in wt.% of filler materials and bagasse fiber. The maximum tensile strength was obtained at specimen 9 with 10 wt.% of alumina, 8 wt.% of SiC and 20 wt.% of bagasse fiber. From this tensile strength maximum at 8 wt.% of SiC and more than 8 wt.% decreased the tensile strength. The minimum tensile strength was obtained at specimen 6 with 8 wt.% of alumina, 6 wt.% of SiC and 20 wt.% of bagasse fiber. This was due to the SiC filler more affect the tensile strength and due to 6 wt.% was used. The tensile strength was increased for bagasse fiber with 10, 15 and 20 wt.%. For 6-8 wt.% of SiC tensile strength was increased and 8-10 wt.% of SiC tensile strength was decreased. Al_2O_3 with 6, 8, and 10 wt.% the tensile strength was increased.

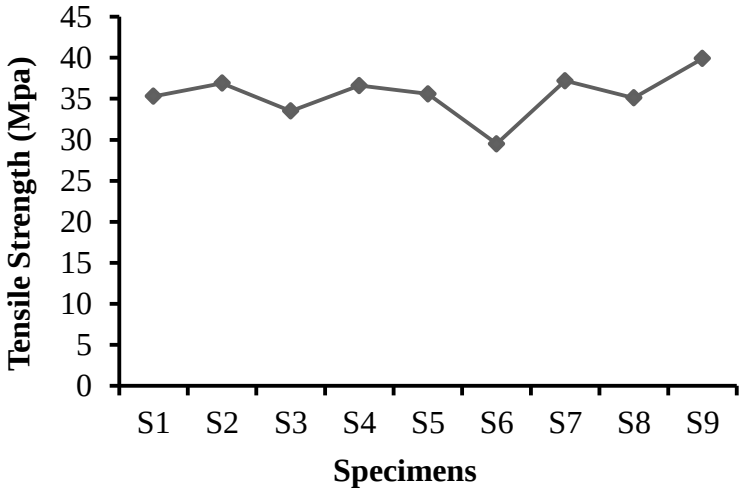


Figure 4. 1 Tensile strength test results

Figure 4.2 shows the stress-strain diagram of the tensile strength test. Specimen 1 had 1.6% strain at 35.3 MPa tensile stresses. Specimen 2 had 1.67% strain at 36.9 MPa tensile stresses. Specimen 3 had 1.7% strain at 33.5 MPa tensile stresses. Specimen 4 had 0.598% strain at 36.6 MPa tensile stresses. Specimen 5 had 0.82% strain at 35.6 MPa tensile stresses. Specimen 6 had 1% strain at 29.5 MPa tensile stresses. Specimen 7 had 0.977% strain at 37.2 MPa tensile stresses. Specimen 8 had 0.79% strain at 35.1 MPa tensile stresses. Specimen 9 had 1.2% strain at 39.9 MPa tensile stresses. From this stress-strain results of all specimens was different strength due to different types of filler materials and different wt.%. The stress- strain shows tensile strength was increased up to maximum strength and after reach maximum it dropped. The curves dropped steeply after maximum, exhibit typical brittle fracture behavior of composite specimens. From this specimen 4, 5 and 7 were more brittle and other specimens were less brittle means more ductile material. Stress versus strain diagram for tensile strength was given in figure 4.2.

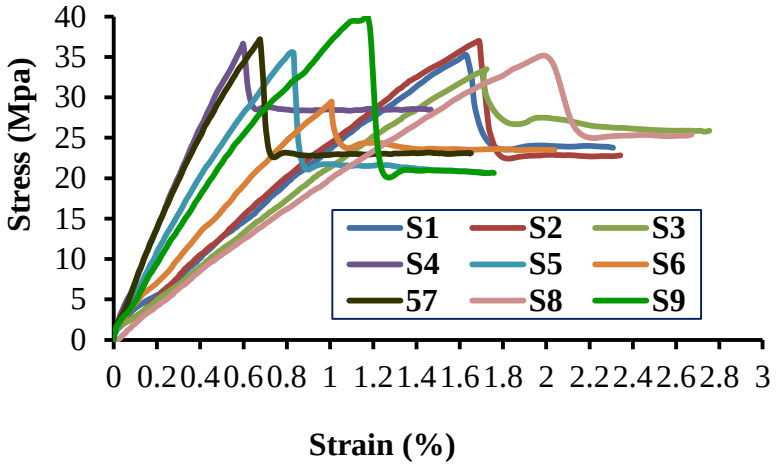


Figure 4. 2 Stress vs strain for tensile test

A. Taguchi Analysis using S/N Ratios for Tensile Strength

Table 4. 2 Response for signal to noise ratios of tensile strength

Level	Alumina content	Bagasse fiber content	Silicon carbide Content
1	30.93	31.21	30.42
2	30.57	31.09	31.54
3	31.45	30.64	30.98
Delta	0.88	0.57	1.12
Rank	2	3	1

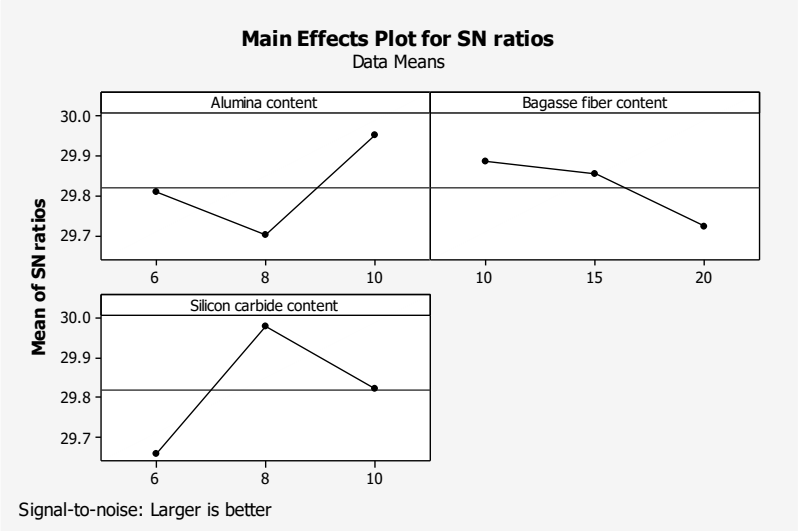
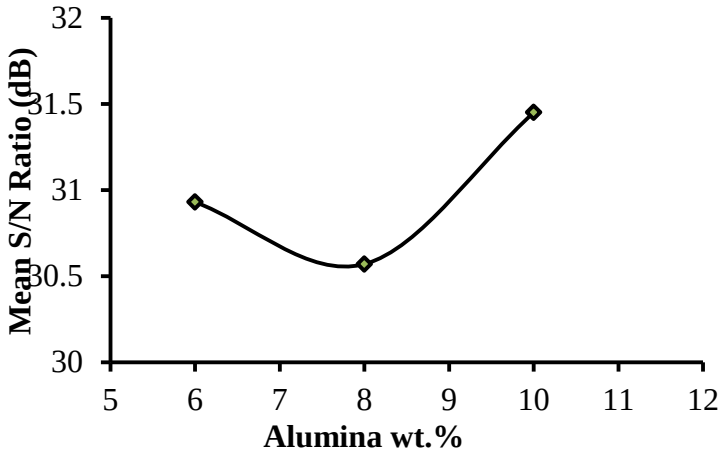


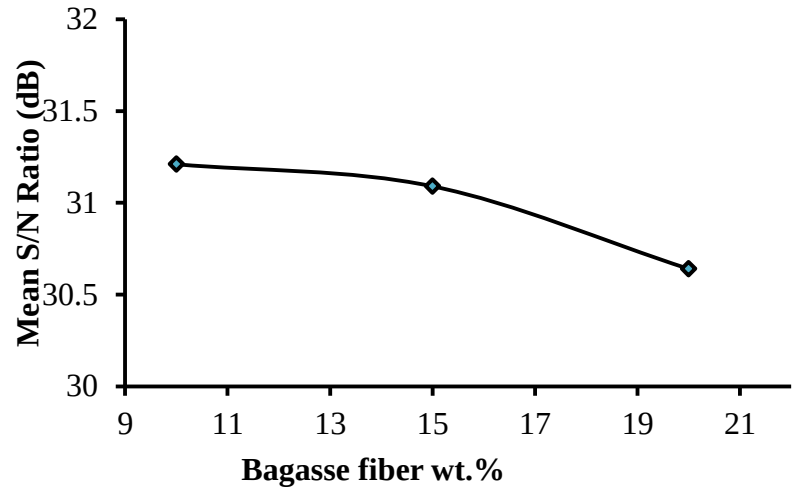
Figure 4. 3 Tensile strength main effects plot for S/N ratio

From the response Table 4.2 for the signal-to-noise ratios for tensile strength shows silicon carbide weight percentage was the first ranker contribution in increased the tensile strength of the composite with a delta number of 1.12. Alumina weight percentage was the second ranker contributing factor in increased the tensile strength of the composite with a delta number of 0.88 and third ranker contributing factor was bagasse fiber weight percentage with a delta number of 0.57. The optimal parameter combination on larger the better quality character with possible parameter combinations for increased the tensile strength of hybrid composite was A3B1C2. Figure 4.3 shown the main effect plot for S/N ratio with larger is better for the tensile strength. S/N ratio was optimum at alumina content of level 3, bagasse fiber content of level 1 and silicon carbide content of level 2. From this the possible parameter combinations of S/N ratios of tensile strength was A3B1C2 which contains 10 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide.

B. Effect of Each Parameter on Tensile Strength Using S/N Ratios



(a)



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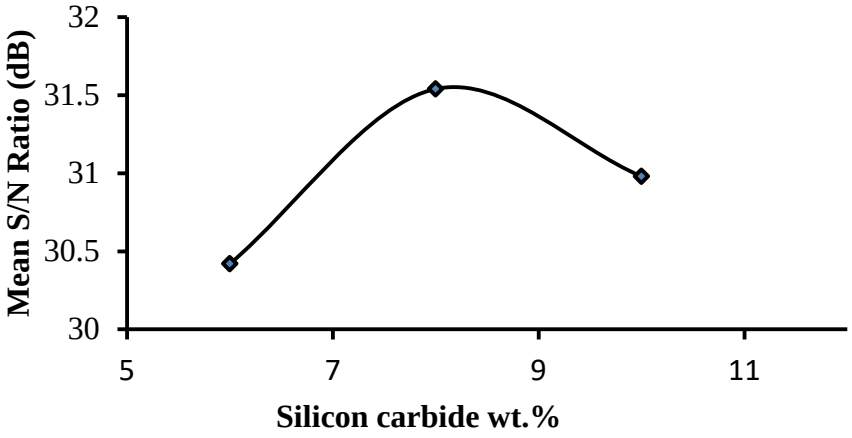


(c)

Figure 4. 4 (a) Al_2O_3 wt.% vs tensile strength (b) bagasse fiber wt.% vs tensile strength (c) SiC wt.% vs tensile strength

Figure 4.4 (a) shows tensile strength was decreased for 6-8 wt.% of alumina then it was increased from 8-10 wt.% of alumina and the tensile strength was a maximum at 10 wt.% of alumina. It was observed that the tensile strength of the Al_2O_3 filled composite was increased as the weight percentage of filler for compositions was increased. The reason for these improvements in the tensile strength composite was because the hard-ceramic filler increased the interfacial bonding among the reinforcement and the matrix which in turn leads to improved stiffness of the composite. It was also inferred due to the higher stiffness of the added ceramic filler which imparts its property to the weaker matrix and reinforcement. Similar test results were also observed with the incorporation of ceramic filler of alumina powder in natural fiber-reinforced polymer matrix composites was

investigated (Aynalem and Sirahbizu, 2021). The results indicate that as Al_2O_3 wt.% was increased the tensile strength was also increased and alumina was used as filler materials in the improvement of the tensile strength properties for hybrid composites.

Figure 4.4 (b) shows tensile strength was decreased slightly for 10-15 wt.% of bagasse fiber and also decreased for 15-20 wt.% of bagasse fiber. The tensile strength was decreased after 10 wt.% of bagasse fibers loading was due to increased interaction between the bagasse fibers inside the composites i.e. there was higher fiber to fiber contact which leads to poor interfacial bonding between the matrix and the fiber. Because of the poor interfacial bonding, effective load transfer was not taken place and lead to quick failure. If the percentage of fiber increased, the tensile strength was decreased. At 10 wt.% of bagasse fiber gives the highest tensile strength. This result was in good agreement with (Dhibar et al., 2018)

Figure 4.4 (c) shows tensile strength was increased for 6-8 wt.% of silicon carbide whereas it was decreased from 8-10 wt.%. At 8 wt.% of silicon carbide exhibited maximum tensile strength when compared with alumina. This was due to good particle dispersion and strong polymer/filler interface adhesion for effective stress transfer but further increased in filler content up to 10 wt.%. The tensile strength was found to be less this was due to more filler material distribution in the material. This result was in good agreement with (Devendra and Rangaswamy, 2012). From this silicon carbide was used to improve tensile strength of hybrid composite. Generally from taguchi optimization method the tensile strength maximum was at 10 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of SiC.

C. Analysis of Variance for S/N Ratios of Tensile Strength

The last column of the analysis of variance table shown in Table 4.3 was indicated the percentage of contribution of each parameter for tensile strength. Silicon carbide weight percentage was the highest level of percentage contribution of 44.38%. Alumina weight percentage was the second percentage contribution of 27.56% and bagasse fiber weight percentage was the third percentage contribution of 13.62%.

Table 4. 3 Analysis of variance for S/N ratios of tensile strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC

Alumina	2	0.09367	0.09367	0.04683	1.91	0.344	27.56%
Bagasse fiber	2	0.04631	0.04631	0.02316	0.94	0.514	13.62%
Silicon carbide	2	0.15084	0.15084	0.07542	3.08	0.245	44.38%
Residual Error	2	0.04902	0.04902	0.02451			
Total	8	0.33985					

4.3. Flexural Strength Test

From experimental work result for the flexural strength and S/N ratios of fabrication and characterization of hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester was given in Table 4.4.

Figure 4.5 shows the flexural strength result which varies for all specimens. Flexural strength of specimens 1, 2, and 3 were 56.1, 54.79, and 28.33 MPa respectively. Flexural strength of specimens 4, 5, and 6 were 51, 51, and 33.2 MPa respectively. Flexural strength of specimens 7, 8, and 9 were 45.27, 42.5, and 46.04 MPa respectively. From this flexural strength was changed due to type's filler materials and wt.% of filler materials and bagasse fiber used for fabrication of composite material.

Table 4. 4 Flexural strength and signal to noise ratio results from experiment

Specimens	**Alumina wt.%**	**Bagasse fiber wt.%**	**Silicon carbide wt.%**	**Flexural strength (MPa)**	**S/N ratio (dB)**
S1	6	10	6	56.1	34.979
S2	6	15	8	54.79	34.774
S3	6	20	10	28.33	29.045
S4	8	10	8	51	34.151
S5	8	15	10	51	34.151
S6	8	20	6	33.2	30.423
S7	10	10	10	45.27	33.116

S8	10	15	6	42.5	32.568
S9	10	20	8	46.04	33.263

Weight percentage of bagasse fiber was significant influence on the flexural strength. The flexural strength of composite was maximum value at specimen 1 which was fabricated from Al_2O_3 and SiC with 6 wt.% and 10 wt.% of bagasse fiber. Flexural strength of hybrid composite material was decreased with more than 10 wt.% of bagasse fibers was used. Flexural strength was minimum value at specimen 3 which was fabricated with 6 wt.% of Al_2O_3, 10 wt.% of SiC and 20 wt.% of bagasse fiber. Specimen 6 was fabricated from 8 wt.% of Al_2O_3, 6 wt.% of SiC and 20 wt.% of bagasse fiber.

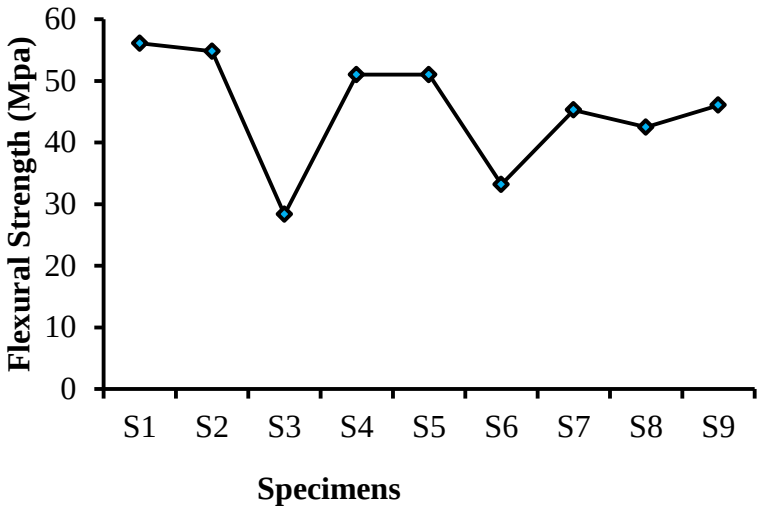


Figure 4. 5 Flexural strength test result

A. Taguchi Analysis Using S/N ratios for Flexural Strength

From the Table 4.5 shows the signal-to-noise ratios of flexural strength. Bagasse fiber weight percentage was first ranker contributed factor in increased the flexural strength of the composite with a delta number of 3.17. Silicon carbide weight percentage was the second ranker contributed factor in increased the flexural strength of the composite with a delta number of 1.96 and the third ranker contributed factor was alumina weight percentage with a delta number of 0.07. The optimal parameter combination on larger the better quality character with possible parameter combinations increased the flexural strength of hybrid composite was A3B1C2.

Figure 4.6 shows the main effect plot for S/N ratio with larger is better for the flexural strength. S/N ratio was optimum at alumina content of level 3, bagasse fiber content of

level 1 and silicon carbide content of level 2. From this the possible optimal parameter combinations of S/N ratio of flexural strength was A3B1C2 which contains 10 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide.

Table 4.5 Response for signal to noise ratios of flexural strength

Level	Alumina content	Bagasse fiber content	Silicon carbide Content
1	32.93	34.08	32.66
2	32.91	33.83	34.06
3	32.98	30.91	32.10
Delta	0.07	3.17	1.96
Rank	3	1	2

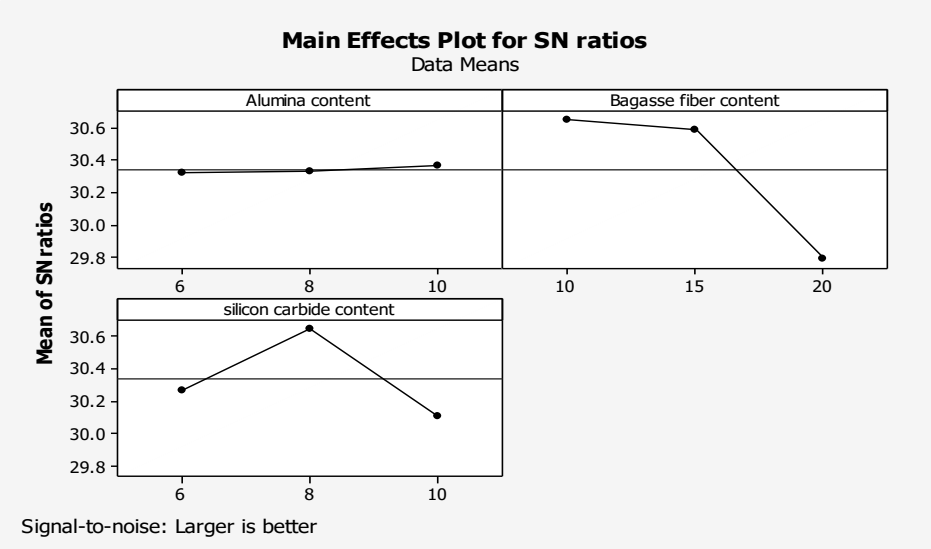
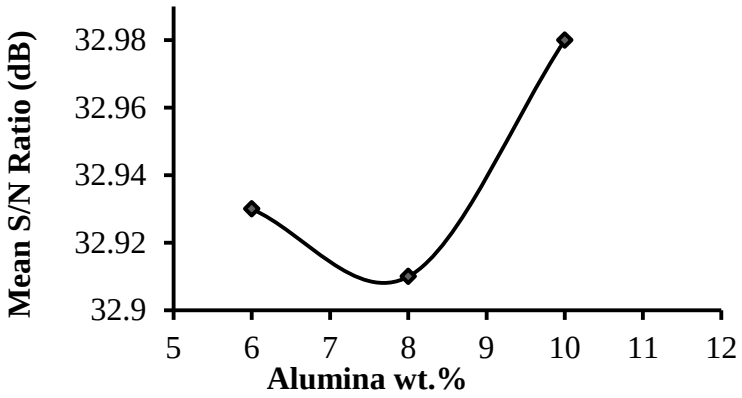
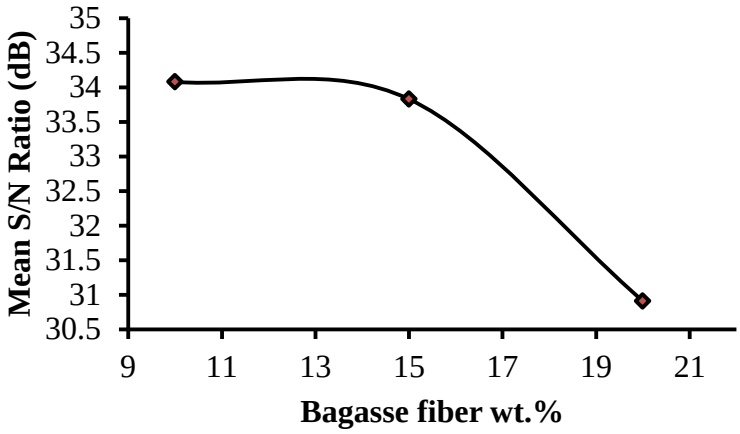


Figure 4. 6 Flexural strength main effects plot for S/N ratio

B. Effect of Each Parameter on Flexural Strength Using S/N Ratios



(a)



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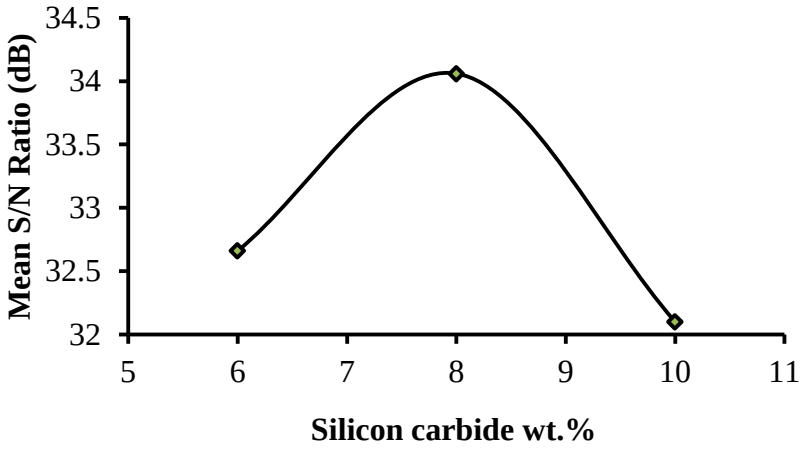


(c)

Figure 4. 7 (a) Al_2O_3 wt.% vs flexural strength (b) bagasse fiber wt.% vs flexural strength (c) SiC wt.% vs flexural strength

Figure 4.7 (a) Shows that Al_2O_3 wt.% versus mean S/N ratio for flexural strength. From this 6-8 wt.% of alumina, the mean S/N ratio was reduced. From 8-10 wt.% of alumina, the mean S/N ratio of flexural strength was increased. At 10 wt.% of alumina, the mean S/N ratio was maximum flexural strength. Flexural strength increased with an increased filler content of alumina. Composite with 10 wt.% of alumina filler shows higher flexural strength. The properties of alumina to offer greater resistance to crack initiation and propagation in the composites may lead to the increased flexural strength in filled i.e. up to 10 wt.% filler alumina. This alumina increased the flexural strength of composite was good

agrees with (Biswas et al., 2014). This alumina at 10wt.% results in high flexural strength of the composite. If alumina wt.% was increased the flexural strength of composite also increased.

Figure 4.7 (b) Show that bagasse fiber wt.% versus mean S/N ratio of flexural strength. At 10 wt.% of bagasse fibers, the mean S/N ratio of flexural strength was high. When bagasse fiber 10-15 wt.% increased S/N ratios of flexural strength decreased. Further up to 20 wt.% increased of bagasse fiber, the S/N ratio of composite was decreased. From this, the maximum S/N ratio of flexural strength was at 10 wt.% of bagasse fiber. Flexural strength was increased with wt.% of bagasse fiber increased. The maximum flexural strength resulted at 10 wt.% of bagasse fiber and flexural strength was decreased with increased in weight percentage of bagasse fiber. This result was good agrees with (Tripathi and Kumar, 2016).From this at 10 wt.% of bagasse fiber, the flexural strength was maximum.

Figure 4.7 (c) Shows that silicon carbide wt.% vs mean S/N ratio of flexural strength. At 6-8 wt.% of SiC, the mean S/N ratio was increased. At 8 wt.% of SiC result the maximum S/N ratio. From 8-10 wt.% of SiC mean S/N ratio was reduced. Further increased in SiC filler wt.% leads to a decreased in flexural strength gradually. The reason for the reduction in flexural strength was that when the wt.% was high, the bonding between the fibers was not remaining strong. This result was good agrees with (Kumar, 2016) result. The results indicate that when Al_2O_3 wt.% increased the flexural strength of composite was increased. From taguchi optimization the flexural strength was a maximum at 10 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of SiC. As Al_2O_3 wt.% was increased the flexural strength was increased and more than 10 wt.% of bagasse fiber and 8 wt.% of SiC the flexural strength was decreased.

C. Analysis of Variance for S/N Ratios of Flexural Strength

From analysis of variance shown in Table 4.6 indicated the percentage of contribution of each process parameter for flexural strength. Bagasse fiber weight percentage was the highest level of percentage contribution of 57.83%. Silicon carbide weight percentage was the second percentage contribution of 19.029% and alumina weight percentage was the third percentage contribution of 0.1316%.

Table 4. 6 Analysis of variance for S/N ratios of flexural strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	0.00313	0.00313	0.001567	0.01	0.994	0.1316%
Bagasse fiber	2	1.37602	1.37602	0.688009	2.51	0.285	57.83%
Silicon carbide	2	0.45276	0.45276	0.226379	0.83	0.547	19.029%
Residual Error	2	0.54733	0.54733	0.273664			
Total	8	2.37924					

4.4. Hardness Test

From experimental work the hardness and S/N ratios of hybrid composite materials were given in Table 4.7.

Table 4. 7 Hardness and signal to noise ratio results from experiment

Specimens	Alumina wt.%	Bagasse fiber wt.%	Silicon carbide wt.%	Hardness (HV)	S/N ratio (dB)
S1	6	10	6	49.75	33.936
S2	6	15	8	58.55	35.351
S3	6	20	10	55.55	34.894
S4	8	10	8	66.3	36.430
S5	8	15	10	56.85	35.095
S6	8	20	6	62.4	35.904
S7	10	10	10	33.95	30.617
S8	10	15	6	48.4	33.697
S9	10	20	8	75.05	37.507

Figure 4.8 shown the hardness test results were varies for all specimens fabricated hybrid composite. The hardness of specimens 1, 2, and 3 were 49.75, 58.55, and 55.55 HV

respectively. The hardness of specimens 4, 5, and 6 were 66.3, 56.85, and 62.4 HV respectively. The hardness of specimens 7, 8, and 9 were 33.95, 48.4, and 75.05 HV respectively. Hardness of composites materials were changed due to types of filler materials and wt.% of filler materials and bagasse fiber. SiC wt.% was more influence the hardness of composite materials. 6-8 wt.% of SiC increased hardness of composite materials and 8-10 wt.% of SiC the hardness of composite materials was decreased. Bagasse fiber and alumina wt.% increased the hardness of composite material was increased. Specimens 9 results with maximum hardness value which was fabricated from 8 wt.% of SiC, 20 wt.% of bagasse fiber and 10 wt.% of alumina. Specimen 7 was fabricated from 10 wt.% of SiC, alumina and bagasse fiber. Figure 4.9 shows the hardness test values and deformation area of specimen 6 and 9 during the hardness test.

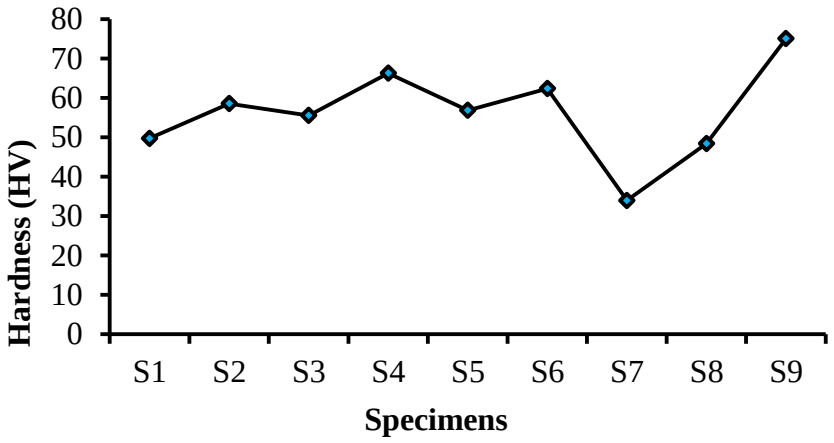


Figure 4. 8 Hardness test result

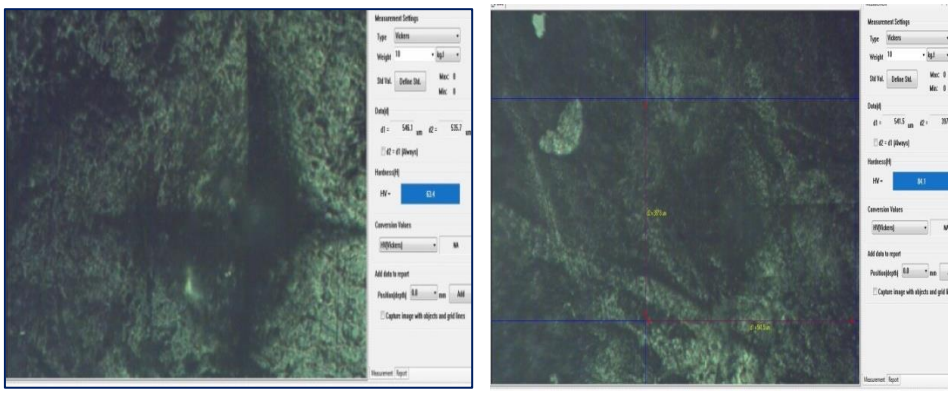


Figure 4. 9 Measurement of hardness for specimen 6 and 9

A. Taguchi analysis Using S/N Ratios for Hardness

From the Table 4.8 shows the signal-to-noise ratios of hardness shows silicon carbide weight percentage was first ranker contributed factor in increased the hardness of the

composite with a delta number of 2.89. Bagasse fiber weight percentage was the second ranker contributed factor in increased the hardness of the composite with a delta number of 2.44 and the third ranker contributed factor was alumina weight percentage with a delta number of 1.87. The optimal parameter combinations on larger the better quality character with possible parameter combinations for increased the hardness of hybrid composite was A2B3C2. Figure 4.10 shows the main effect plot for S/N ratios with larger were better for the hardness. The S/N ratios were optimum at alumina content of level 2, bagasse fiber content of level 3 and silicon carbide content of level 2. From this the possible optimal parameter combinations of S/N ratio of the hardness was A2B3C2 which contained 8 wt.% of Al_2O_3, 20 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. This analysis leads to the conclusion that the process parameter combinations was A2B3C2 gave the maximum hardness.

Table 4. 8 Response for signal to noise ratios of hardness

Level	**Alumina fiber content**	**Bagasse fiber content**	**Silicon carbide Content**
1	34.73	33.66	34.51
2	35.81	34.71	36.43
3	33.94	36.10	33.54
Delta	1.87	2.44	2.89
Rank	3	2	1

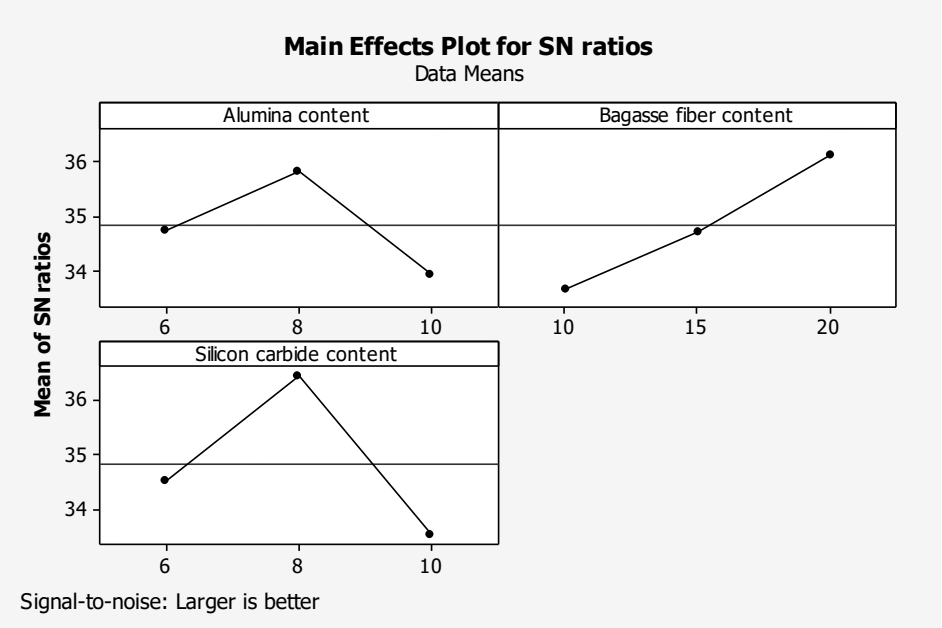
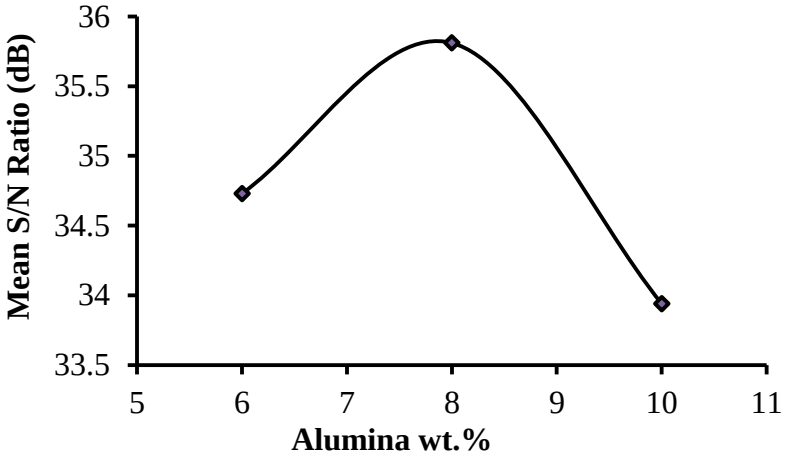
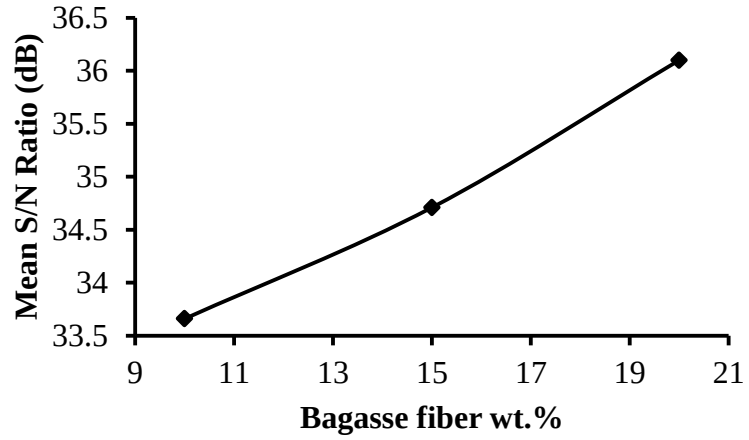


Figure 4. 10 Hardness main effects plot for S/N ratio

B. Effect of Each Parameter on Hardness Using S/N Ratios



(a)



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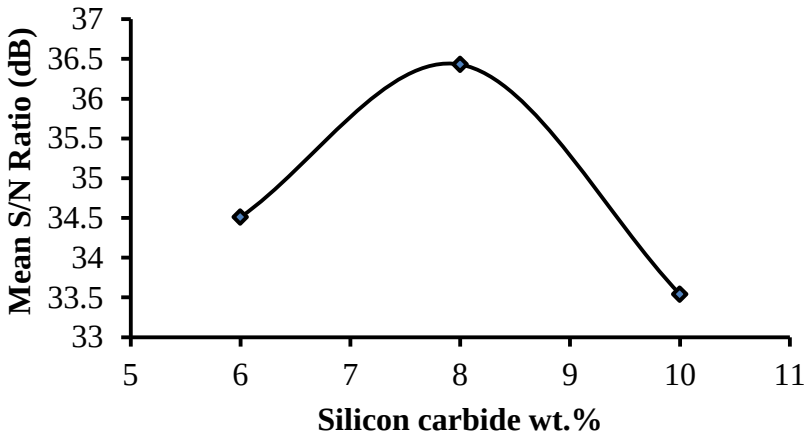


(c)

Figure 4. 11 (a) Alumina wt.% vs hardness (b) bagasse fiber wt.% vs hardness (c) SiC wt.% vs hardness.

Figure 4.11 (a) shows alumina wt.% versus mean S/N ratio for vicker hardness of the composite. Mean S/N ratio for vicker hardness value was increased for alumina 6-8 wt.%. The maximum hardness value of was recorded at 8 wt.% of alumina. From the obtained results it was observed that Al_2O_3 wt.% was increased the hardness of the composites also increased. Further up to 10 wt.% of alumina the hardness value was reduced. Because increased of filler materials to composites leads to a decreased in hardness due to more filler distribution and filler materials dominated in the materials. This result was agrees with (Devendra and Rangaswamy, 2012).

Figure 4.11 (b) shows bagasse fiber wt.% versus mean S/N ratio for vicker hardness of the composite. Mean S/N ratio for vicker hardness value increased for bagasse fiber increased from 10-20 wt.%. The hardness increased when the resistance of the materials to the deformation increased. This happens when more filler was added; the composite becomes harder and the materials' hardness improved. This finding was agrees as reported in (Subramonian et al., 2016). From this, the optimum hardness was obtained at 20 wt.% of bagasse fiber.

Figure 4.11 (c) shows silicon carbide wt.% versus mean S/N ratio for vicker hardness of the composite. Mean S/N ratio for vicker hardness increased from 6-8 wt.% of SiC. The S/N ratio of vicker hardness maximum at 8 wt.% SiC. From 8-10 wt.% of SiC resulted with decreased the mean S/N ratio of the hardness of the composite. This increased in the addition of SiC wt.% increased the hardness of the composite. This was due to the uniform dispersion of SiC particles and decreased inter-particle distance with increased particle loading in the matrix results in an increased of resistance to indentation. This idea was agrees with (Devendra and Rangaswamy, 2012). From this result the hardness was maximum at 8 wt.% of Al_2O_3, 20 wt.% of bagasse fiber, and 8 wt.% of SiC. As wt.% of bagasse fiber was increased the hardness of composite also increased. More than 8 wt.% of Al_2O_3 and SiC hardness of composite was decreased.

C. Analysis of Variance for S/N Ratios for Hardness

From analysis of variance shown in Table 4.9 indicated the percentage of contribution each of process parameter for hardness. Silicon carbide weight percentage was the highest level of percentage contribution of 40.57%. Bagasse fiber weight percentage was second level of percentage contribution of 28.85% and alumina weight percentage was the third level percentage contribution of 17.99%.

Table 4. 9 Analysis of variance for S/N ratios for hardness

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	0.3676	0.3676	0.1838	1.43	0.412	17.99%
Bagasse fiber	2	0.5893	0.5893	0.2947	2.29	0.304	28.85%
Silicon carbide	2	0.8286	0.8286	0.4143	3.22	0.237	40.57%

Residual Error	2	0.2571	0.2571	0.1285
Total	8	2.0426		

4.5. Impact Strength Test

From experimental work the impact strength and S/N ratios of hybrid composite materials were given in Table 4.10.

Table 4. 10 Impact strength and signal to noise ratio results from experiment

Specimens	**Alumina wt.%**	**Bagasse fiber wt.%**	**Silicon carbide wt.%**	**Impact (J)**	**S/N ratio (dB)**
S1	6	10	6	5	13.979
S2	6	15	8	14	22.923
S3	6	20	10	6.5	16.258
S4	8	10	8	8.5	18.588
S5	8	15	10	5	13.979
S6	8	20	6	10	20
S7	10	10	10	5.5	14.807
S8	10	15	6	7.5	17.501
S9	10	20	8	5	13.979

Figure 4.12 shows the impact test results were varies for all specimens. From this results the specimens 1, 5, and 9 were impact values 5J. Specimens 2 and 3 were impact values of 14 and 6.5 J. Specimens 4 and 6 were impact values of 8.5 and 10 J. Specimens 7 and 8 were impact values 5.5 and 7.5 J. From general observation of the result the impact strength of composite material were changed due to types of filler materials and wt.% of filler materials and bagasse fiber.

When SiC wt.% was more influence the hardness of composite materials. 6-8 wt.% of SiC increased impact strength of composite materials and 8-10 wt.% of SiC impact strength of composite materials was decreased. When 10-15 wt.% of bagasse fiber increased impact strength of composite materials and 15-20 wt.% of bagasse fiber, impact strength of composite materials was decreased. While 6-8 wt.% of alumina increased impact strength

of composite materials and 8-10 wt.% of alumina the impact strength of composite materials was decreased. The maximum impact strength was obtained at specimen 2 with 14J and which was fabricated from 6 wt.% of Al_2O_3, 20 wt.% of bagasse fiber and 8 wt.% of SiC.

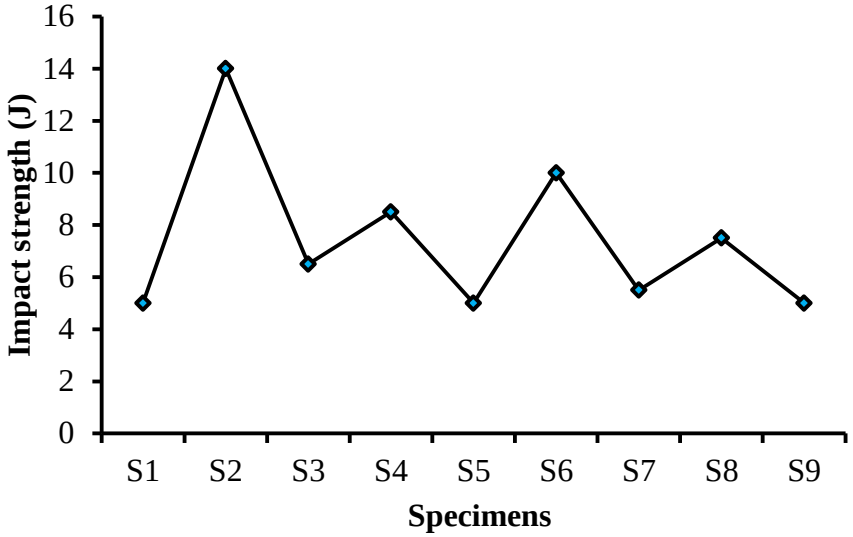


Figure 4. 12 Impact strength test result

A. Taguchi Analysis Using S/N Ratio for Impact Strength

Table 4.11 shows the response table for signal to noise ratios for the impact strength test. From this silicon carbide content was the first ranker in the contribution increased the impact strength with a delta value of 3.48. Bagasse fiber content was the second ranker in the contribution of increased the impact strength with a delta value of 2.34. Alumina content was the third ranker in the contribution of increased the impact strength with a delta value of 2.29. Figure 4.13 shows the main effect plot for S/N ratio with larger is better for the impact strength. The S/N ratio was optimum at alumina content of level 1, bagasse fiber content of level 2 and silicon carbide content of level 2. From this the possible optimal parameter combinations of S/N ratios of impact strength was A1B2C2 which contained 6 wt.% of Al_2O_3, 15 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. This analysis leads to the conclusion that the process parameter combinations of A1B2C2 gave the maximum impact strength of hybrid composite.

Table 4. 11 Response for signal to noise ratios of impact strength

Level	Alumina content	Bagasse fiber content	Silicon carbide content
1	17.72	15.79	17.16
2	17.52	18.13	18.50
3	15.43	16.75	15.01
Delta	2.29	2.34	3.48
Rank	3	2	1

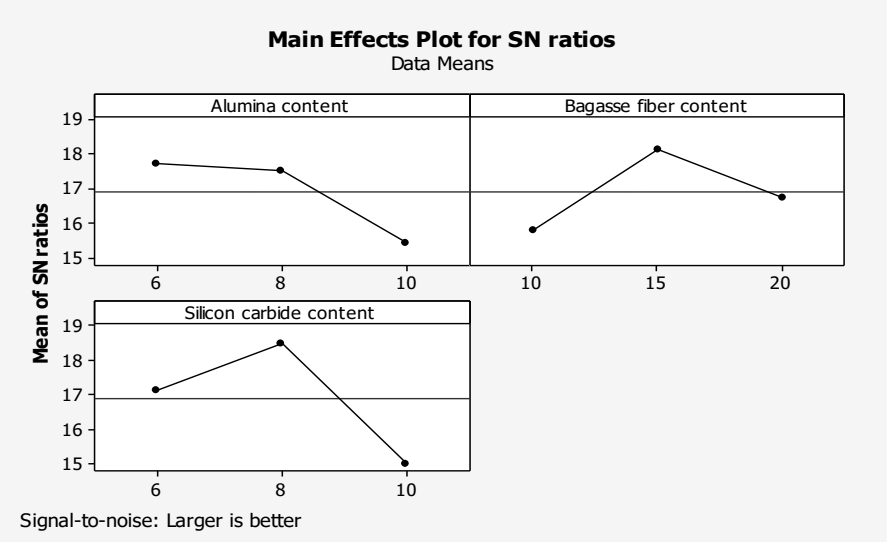
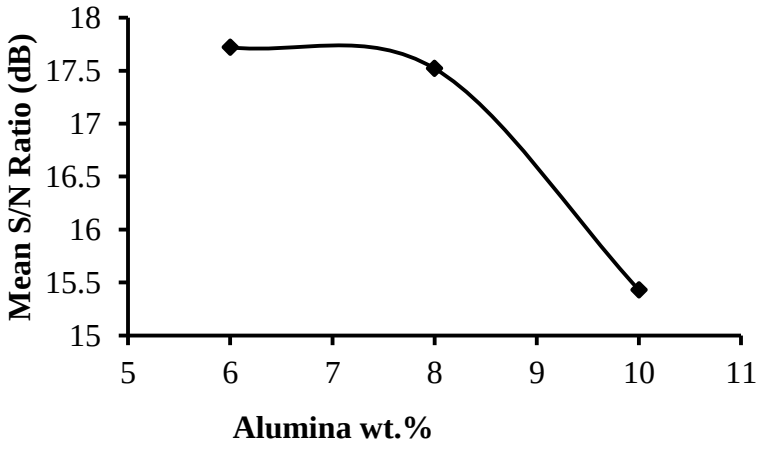
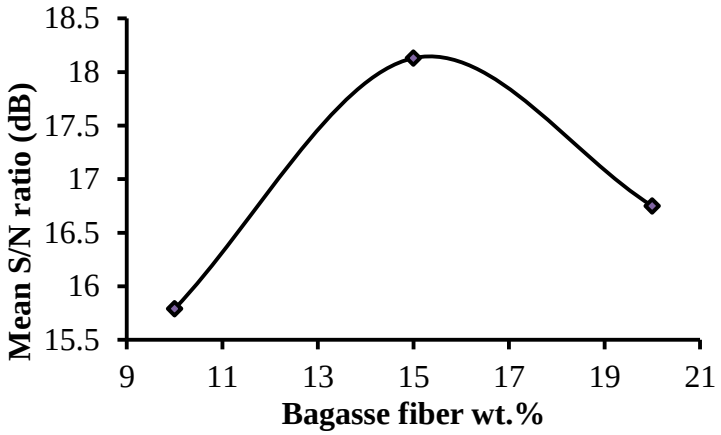


Figure 4. 13 Impact main effects plot for S/N ratio for impact strength

B. Effect of Each Parameter on Impact Strength Using S/N Ratios



(a)



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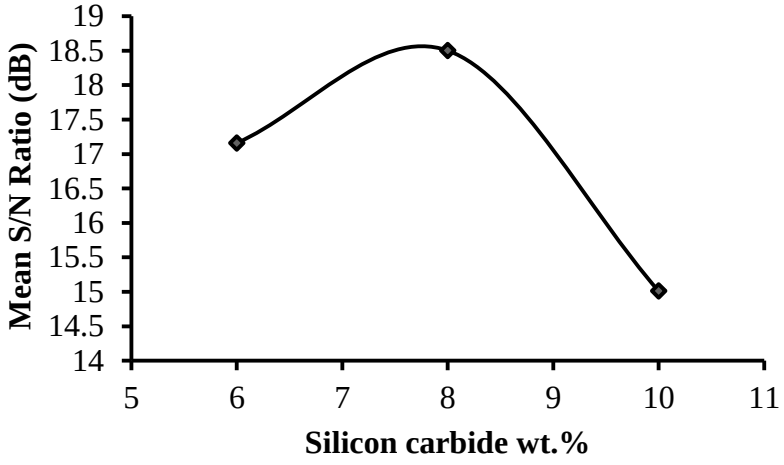


(c)

Figure 4. 14 (a) Alumina wt.% vs impact (b) bagasse fiber wt.% vs impact (c) SiC wt.% vs impact.

Figure 4.14 (a) shown alumina wt.% vs mean S/N ratio for the impact of composite. Mean S/N ratio for impact strength decreased for alumina increased from 6-10 wt.%. This result agrees with (Rajesh et al., 2014). High loading of alumina from 6-10 wt.% reduced the ability to absorb impact energy this was because the fillers disturb matrix continuity and each filler was a site of stress concentration, which was act as a microcrack initiator and reduced the adhesion and energy absorption capacity of composite materials this idea was agreed with (Devendra and Rangaswamy, 2012). From this maximum impact was gained at 8 wt.% of alumina.

Figure 4.14 (b) shows bagasse fiber wt.% versus mean S/N ratio for the impact of composite. The mean S/N ratio for impact strength increased from 10-15 wt.% of bagasse fiber. The maximum impact obtained at 15 wt.%. From 15-20 wt.% of bagasse fiber, the mean S/N ratio decreased. Figure 4.14 (c) shows silicon carbide wt.% versus mean S/N ratio for the impact of composite. The mean S/N ratio for impact strength increased from 6-8 wt.% of SiC. The maximum impact obtained at 8 wt.%. From 8-10 wt.% of SiC, the mean S/N ratio decreased.

When SiC filled composites has high impact strength due to the good bonding strength between filler, matrix, and fiber and flexibility of the interface molecular chain resulted in absorbs and disperses more energy, and prevented the cracks initiator effectively. High loading of SiC from 8-10 wt.% has less ability to absorb impact energy this was because the fillers disturb matrix continuity and each filler was a site of stress concentration, which was act as a microcrack initiator and reduced the adhesion and energy absorption capacity of composite materials. This result was agreed with (Devendra and Rangaswamy, 2012). From this maximum impact was gained at 8 wt.% of silicon carbide. From optimization method the impact strength was a maximum at 6 wt.% Al_2O_3, 15 wt.% bagasse fiber, and 8 wt.% SiC. More than 6 wt.% of Al_2O_3, 15 wt.% of bagasse fiber and 8 wt.% of SiC impact strength of composite was decreased.

C. Analysis of Variance for S/N Ratios for Impact Strength

From analysis of variance shown in Table 4.12 indicate the percentage of contribution of each process parameter for impact strength. Silicon carbide weight percentage was the highest level of percentage contribution of 21.87%. Alumina weight percentage was second level of percentage contribution of 11.36% and bagasse fiber was third level of percentage contribution of 9.27%.

Table 4. 12 Analysis of variance for S/N ratios for impact strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	2.198	2.198	1.0992	0.20	0.835	11.36%
Bagasse fiber	2	1.793	1.793	0.8963	0.16	0.861	9.27%
Silicon carbide	2	4.231	4.231	2.1155	0.38	0.724	21.87%
Residual Error	2	11.126	11.126	5.5630			
Total	8	19.348					

4.6. Water Absorption Test

From experimental work the water absorption and S/N ratios of hybrid composite material was given in Table 4.13.

Table 4. 13 water absorption and signal to noise ratio results from experiment

Specimens	Alumina wt.%	Bagasse fiber wt.%	Silicon carbide wt.%	WA (%)	S/N ratio (dB)
S1	6	10	6	0.495	6.108
S2	6	15	8	0.334	9.533
S3	6	20	10	0.341	9.355
S4	8	10	8	0.436	7.210
S5	8	15	10	0.440	7.131
S6	8	20	6	0.307	10.249
S7	10	10	10	0.250	12.027
S8	10	15	6	0.567	4.933
S9	10	20	8	0.256	11.822

Water absorption was the important aspect considering the usage of the natural fiber polymer composite material in various industry applications with different place

conditions. The water absorption was resulted in the reduction of the mechanical properties and dimensional stability of composites due to water absorption was lead to swelling of the fiber, micro cracks and forming voids at the fiber-matrix interface region. The water absorption was carried out for 8 days and the average values of the results were taken for analysis. The result of the water absorption test was given in Table 4.14.

Table 4. 14 Water absorption test result

Specimen	**Mass (g)**	**Measuring duration of water absorption test**								**Average**
		24hrs	**48hrs**	**72hrs**	**96hrs**	**120hrs**	**144hrs**	**168hrs**	**192hrs**	**WA (%)**
S1	5.166	5.217	5.267	5.281	5.297	5.306	5.338	5.357	5.374	0.495
WA (%)		0.987	0.958	0.266	0.303	0.170	0.603	0.356	0.317	
S2	6.334	6.388	6.412	6.427	6.464	6.479	6.495	6.570	6.580	0.334
WA (%)		0.853	0.376	0.234	0.576	0.232	0.247	0.002	0.152	
S3	7.653	7.712	7.728	7.763	7.786	7.795	7.811	7.840	7.864	0.341
WA (%)		0.771	0.207	0.453	0.296	0.116	0.205	0.371	0.306	
S4	5.564	5.628	5.638	5.690	5.706	5.707	5.743	5.753	5.761	0.436
WA (%)		1.150	0.178	0.922	0.281	0.018	0.631	0.174	0.139	
S5	5.279	5.326	5.353	5.386	5.419	5.428	5.490	5.500	5.520	0.440
WA (%)		0.890	0.507	0.616	0.613	0.166	0.184	0.182	0.363	
S6	5.552	5.590	5.624	5.645	5.655	5.670	5.680	5.685	5.690	0.307
WA (%)		0.684	0.608	0.373	0.177	0.265	0.176	0.088	0.087	
S7	5.941	5.985	6.029	6.041	6.045	6.054	6.056	6.060	6.061	0.250
WA (%)		0.740	0.735	0.199	0.066	0.148	0.033	0.066	0.016	
S8	5.285	5.339	5.382	5.425	5.503	5.510	5.516	5.521	5.529	0.567
WA (%)		1.021	0.805	0.799	1.438	0.127	0.109	0.091	0.145	
S9	7.285	7.336	7.378	7.388	7.396	7.415	7.433	7.439	7.441	0.256
WA (%)		0.700	0.573	0.136	0.108	0.257	0.242	0.011	0.026	

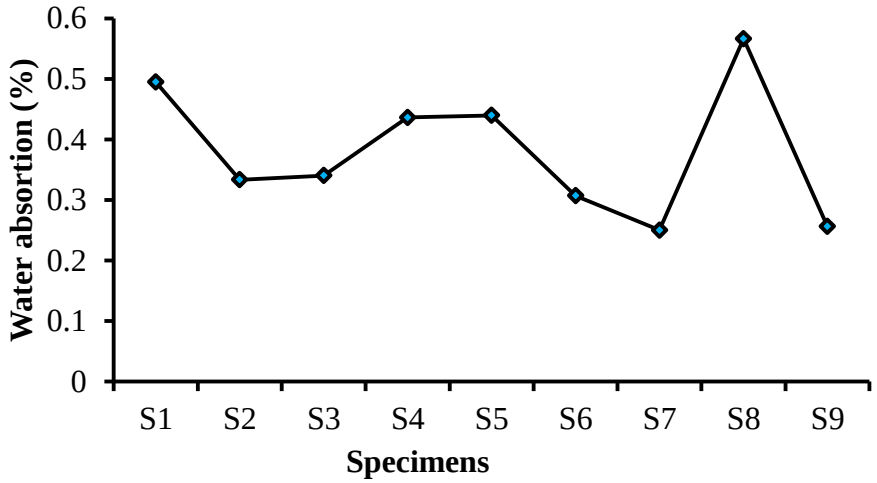


Figure 4. 15 water absorption test results for 8 days

Table 4.14 and Figure 4.15 shown water absorption test results performed for eight days. From this observation amount of water absorption of specimen 7 and specimen 9 were 0.250 and 0.256% respectively. These two specimens absorb a small amount of water. Specimen 7 was fabricated from 10 wt.% of alumina, 10 wt.% of silicon carbide and 10 wt.% of bagasse fiber. Specimen 9 was fabricated from 10 wt.% of alumina, 20 wt.% of bagasse fiber and 8 wt.% of silicon carbide. From two specimens specimen 7 absorbs the smallest amount of water in 8 days. This shows that the bonding between the matrix and reinforcement of bagasse fiber was best. If the weight percentage of bagasse fibers increased, the water absorption was increased. This idea was good agreed with (Dhibar et al., 2018). From this water absorption was a minimum for minimum weight percentage of bagasse fibers.

A. Taguchi Analysis Using S/N Ratio for Water Absorption Test

Table 4.15 shows the response for signal to noise ratios for the water absorption tests. The water absorption of fabricated composite material was minimum for real life. From this the bagasse fiber weight percentage was the first ranker in the contribution of the water absorption with a delta value of 3.48. Silicon carbide weight percentage was the second ranker in the contribution of water absorption with a delta value of 2.425. Alumina weight percentage was the third ranker in the contribution of water absorption with a delta value of 1.397. Figure 4.16 shows the main effect plot for S/N ratio with smaller is better for the water absorption. S/N ratio was optimum at alumina content of level 2, bagasse fiber content of level 2 and silicon carbide content of level 1. From this the possible optimal parameter combinations of S/N ratio of the water absorption was A2B2C1 which contained

8 wt.% of Al_2O_3, 15 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. This analysis was leads to the conclusion that the process parameter combinations of A2B2C1 gave the minimum water absorption of hybrid composite.

Table 4. 15 Response for signal to noise ratios of water absorption

Level	Alumina content	Bagasse fiber content	Silicon carbide content
1	8.332	8.448	7.097
2	8.197	7.199	9.522
3	9.594	10.475	9.504
Delta	1.397	3.276	2.425
Rank	3	1	2

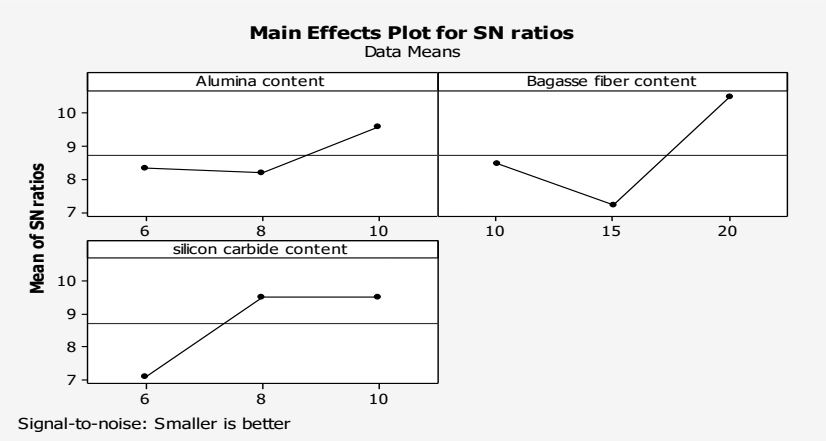
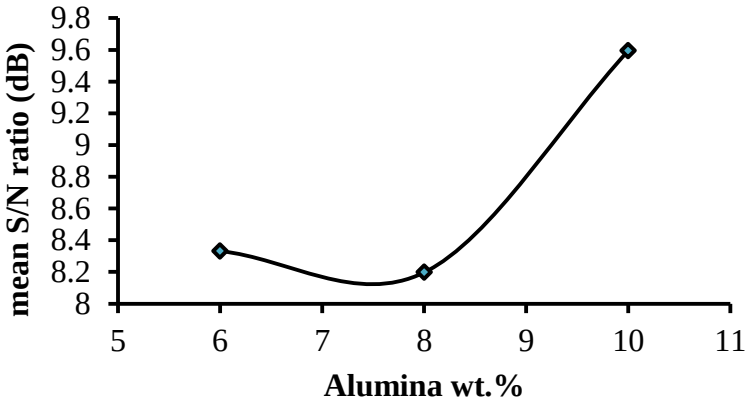
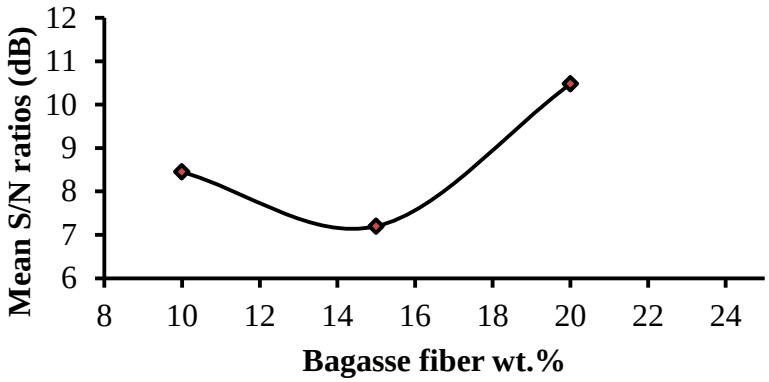


Figure 4. 16 main effects plot for S/N ratio for water absorption

B. Effect of Each Parameter on Water Absorption Using S/N Ratios



(a)



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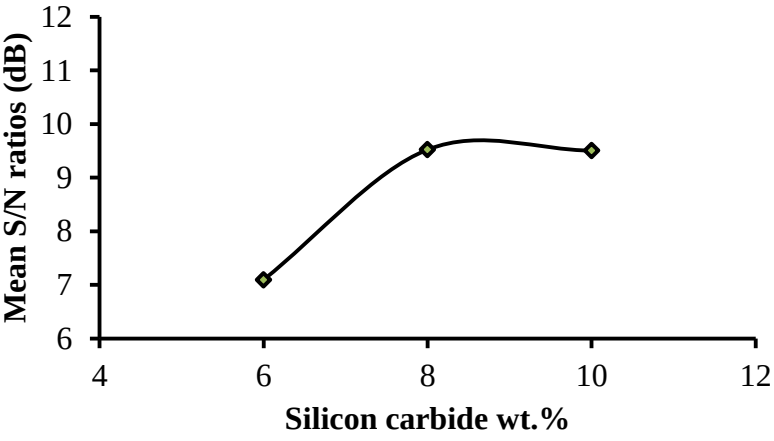

(c)

Figure 4. 17 (a) Alumina wt.% vs water absorption (b) bagasse fiber wt.% vs water absorption (c) SiC wt.% vs water absorption.

Figure 4.17 (a) shown alumina wt.% versus mean S/N ratio for water absorption. Alumina from 6-8 wt.% the S/N ratio for water absorption decreased. At 8 wt.% of alumina, the water absorption was minimum. From 8-10 wt.% alumina the S/N ratio for water absorption was increased. Figure 4.17 (b) shows bagasse fiber wt.% versus mean S/N ratio for water absorption. Bagasse fiber from 10-15 wt.% the S/N ratio for water absorption decreased. At 15 wt.% of bagasse fiber, the water absorption was minimum. From 15-20 wt.% bagasse fiber the S/N ratio for water absorption was increased. Bagasse fiber absorbs water very easily due to the presence of hydroxide groups in their fiber cellulose (Hoque et al., 2019). If the weight percentage of bagasse fiber increased, the water absorption increased. This idea was best agrees with (Dhibar et al., 2018).

Figure 4.17 (c) shows silicon carbide wt.% versus mean S/N ratio for water absorption. When SiC at 6 wt.% the S/N ratio for water absorption was minimum. Silicon carbide from 6-10 wt.% S/N ratios for water absorption increased. If the percentage of filler increased, the water absorption increased. From optimization method the water absorption was minimum at 8 wt.% Al_2O_3, 15 wt.% bagasse fiber, and 6 wt.% SiC. As Al_2O_3, bagasse fiber and SiC wt.% were increased the percentage of water absorption of composite was also increased.

C. Analysis of Variance for S/N Ratios for Water Absorption

From analysis of variance shown in Table 4.16 indicated the percentage of contribution of each process parameter for water absorption. Bagasse fiber weight percentage was the highest percentage contribution value of 33.75% in water absorption. Silicon carbide weight percentage was the second percentage contribution value of 27.46% in water absorption. Alumina weight percentage was the third contribution value of 2.18% in water absorption.

Table 4.16 Analysis of variance for S/N ratios for water absorption

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	1.230	1.23	0.6151	0.06	0.944	2.18%
Bagasse fiber	2	19.037	19.037	9.5184	0.92	0.520	33.75%
Silicon carbide	2	15.492	15.492	7.7458	0.75	0.571	27.46%
Residual Error	2	20.650	20.650	10.3249			
Total	8	56.408					

4.7. Actual Density of Composite

Density of a composite material depends on the relative proportion of reinforcing and matrix materials and it was one of the key factors in determining the properties of the composites. The theoretical and experimental densities of the composite materials were given in Table 4.17. It was observed that theoretical densities of composite values were calculated theoretically from weight fractions were not equal to the experimentally

measured values. This difference was due to the presence of void content in the composites. Theoretical density was calculated from weight fraction of composite materials.

Table 4. 17 Actual density and signal to noise ratio results from experiment

Specimens	Alumina wt.%	Bagasse fiber wt.%	Silicon carbide wt.%	Theoretical density (g/cm^3)	Actual density (g/cm^3)	S/N ratio (dB)
S1	6	10	6	1.262	1.252	-1.952
S2	6	15	8	1.284	1.273	-2.097
S3	6	20	10	1.3	1.286	-2.185
S4	8	10	8	1.298	1.285	-2.178
S5	8	15	10	1.323	1.308	-2.332
S6	8	20	6	1.32	1.303	-2.299
S7	10	10	10	1.33	1.313	-2.365
S8	10	15	6	1.319	1.302	-2.292
S9	10	20	8	1.332	1.315	-2.379

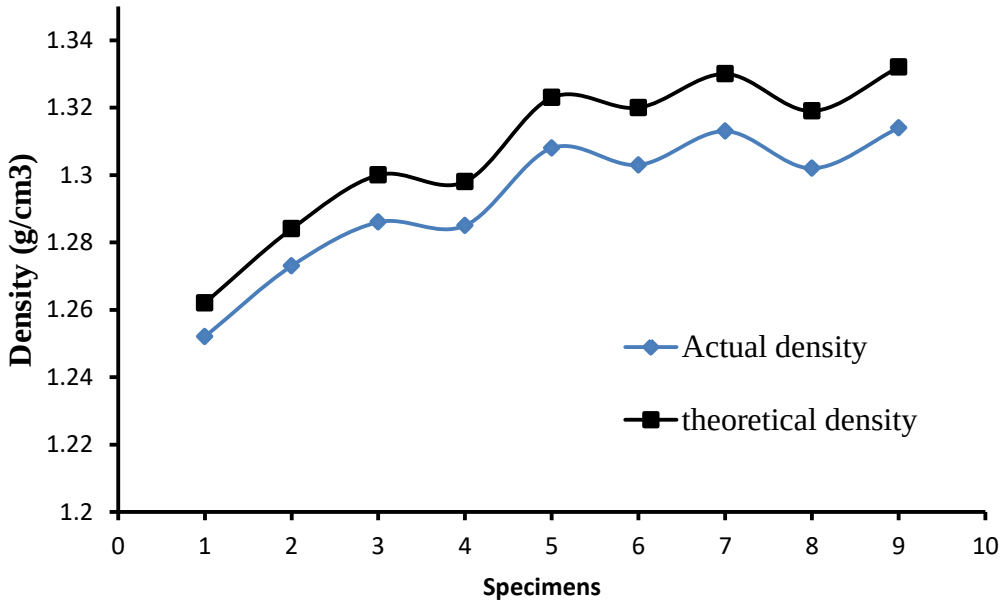

Figure 4. 18 Actual and theoretical densities of composite specimens

Actual densities of composite materials were calculated experimentally from archimedes principle. Figure 4.18 shows the comparisons of theoretical and actual density of composite specimens. When bagasse fiber, alumina, and silicon carbide wt.% were increased actual and theoretical density of composite were also increased. This result was agreed with (Swain and Biswas, 2017).

A. Taguchi Analysis Using S/N Ratio for Actual Density of Composite

Table 4.18 shows the response for signal to noise ratios for actual density test. The actual density of prepared composites materials were minimum for real life. From this alumina weight percentage was the first ranker in the contribution of actual density with a delta value of 0.268. Bagasse fiber weight percentage was the second ranker in the contribution of actual density with a delta value of 0.122. Silicon carbide weight percentage was the third ranker in the contribution of actual density with a delta value of 0.113. Figure 4.19 shows the main effect plot for S/N ratio with smaller is better for actual density. When S/N ratio of actual density was optimum at alumina content of level 1, bagasse fiber content of level 1 and silicon carbide content of level 1. From this the possible optimal parameter combinations of S/N ratio of actual density was A1B1C1 which contained 6 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. This analysis leads to the conclusion that the process parameter combinations of A1B1C1 gave the minimum actual density of hybrid composite.

Table 4. 18 Response for signal to noise ratios of actual density

Level	**Alumina content**	**Bagasse fiber content**	**Silicon carbide content**
1	-2.078	-2.165	-2.181
2	-2.270	-2.240	-2.218
3	-2.345	-2.287	-2.218
Delta	0.268	0.122	0.113
Rank	1	2	3

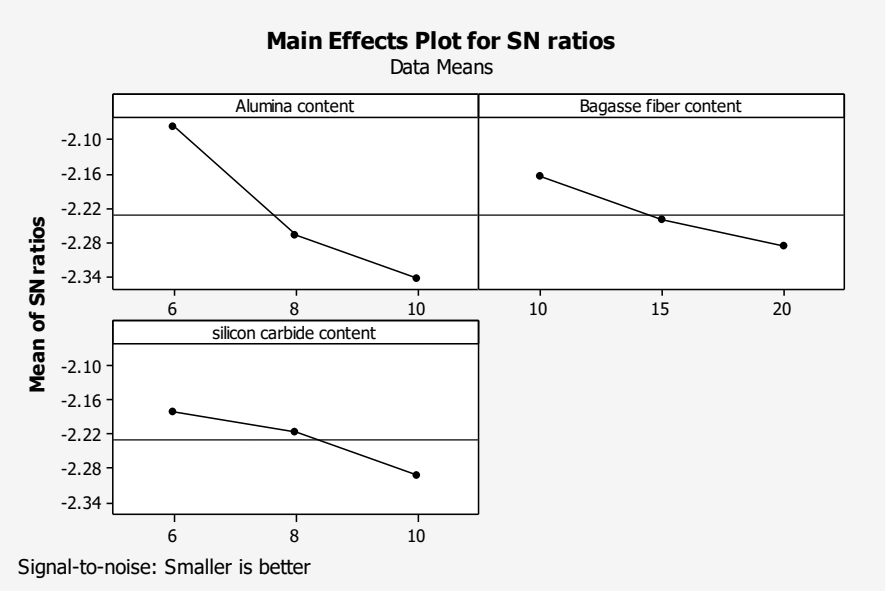

Figure 4. 19 Main effects plot for S/N ratio for actual density

B. Analysis of Variance for S/N Ratios for Actual Density of Composite

From analysis of variance shown in Table 4.19 indicated the percentage of contribution of each process parameter for actual density. Alumina weight percentage was the highest level of percentage contribution of 71.69%. Bagasse fiber weight percentage was second level of percentage contribution of 14.46% and silicon carbide was third level of percentage contribution of 12.57%.

Table 4. 2 Analysis of variance for S/N ratios of actual density

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	0.114	0.114	0.057	49.32	0.02	71.69%
Bagasse fiber	2	0.023	0.023	0.011	9.86	0.092	14.46%
Silicon carbide	2	0.020	0.020	0.010	8.62	0.104	12.57%
Residual Error	2	0.002	0.002	0.001			
Total	8	0.159					

4.8. Testing of Void Content of Composite

From experimental work the void content and S/N ratios of hybrid composites materials were given in Table 4.20.

Table 4. 3 Void content and signal to noise ratio results from experiment

Specimens	Alumina wt.%	Bagasse fiber wt.%	Silicon carbide wt.%	Void content (%)	S/N ratio (dB)
S1	6	10	6	0.8	1.938
S2	6	15	8	0.9	0.915
S3	6	20	10	1.1	-0.828
S4	8	10	8	1.01	-0.086
S5	8	15	10	1.2	-1.584
S6	8	20	6	1.3	-2.279
S7	10	10	10	1.28	-2.144
S8	10	15	6	1.29	-2.212
S9	10	20	8	1.3	-2.279

The void content considerably affected the mechanical properties and even the performance of composites in the workplace. It was understandable that a good composite should have less void content. Presence of void content was unavoidable in composite making particularly through hand-lay-up methods. When bagasse fiber, alumina and silicon carbide wt.% was increased void content of composite was also increased. This result was good agreed with (Swain and Biswas, 2017).

A. Taguchi Analysis Using S/N Ratio for Void Content of Composite

Table 4.21 shows the response for signal to noise ratios for void content of hybrid composite test. The void content of fabricated composite material was minimum for real life using of material. From this alumina weight percentage was the first ranker in the contribution of void content with a delta value of 2.887. Bagasse fiber weight percentage was the second ranker in the contribution of void content with a delta value of 1.698. Silicon carbide weight percentage was the third ranker in the contribution of void content with a delta value of 1.035. Figure 4.20 shown the main effect plot for S/N ratio with smaller is better for void content. The S/N ratio of void content was optimum at alumina

content of level 1, bagasse fiber content of level 1 and silicon carbide content of level 2. From this the possible optimal parameter combinations of S/N ratio of void content was A1B1C2 which contained 6 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. This analysis leads to the conclusion that the process parameter combinations of A1B1C2 gave the minimum void content of hybrid composite which improved mechanical properties.

Table 4. 21 Response for signal to noise ratios for void content

Level	Alumina content	Bagasse fiber content	Silicon carbide content
1	0.675	-0.097	-0.851
2	-1.316	-0.960	-0.483
3	-2.212	-1.795	-1.519
Delta	2.887	1.698	1.035
Rank	1	2	3

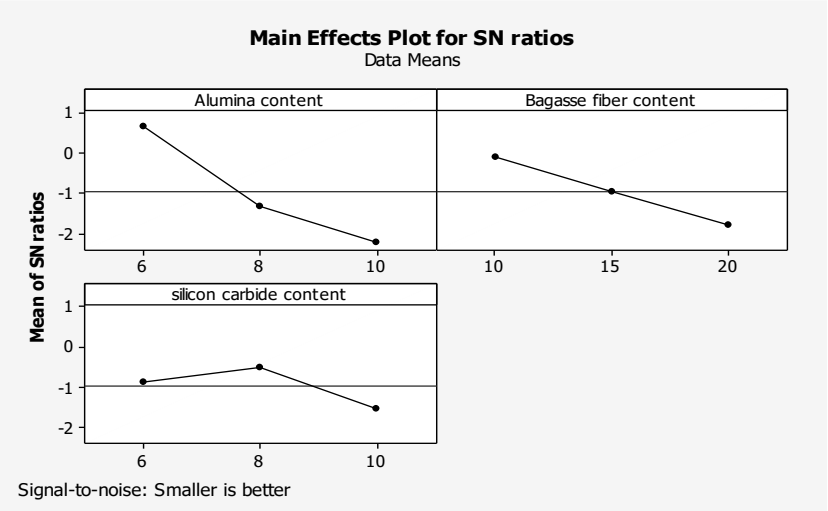

Figure 4. 20 Main effects plot for S/N ratio for void content

B. Analysis of Variance for S/N Ratios for Void Content of Composite

From analysis of variance shown in Table 4.22 indicate the percentage of contribution of each process parameter for void content. Alumina weight percentage was the highest level of percentage contribution of 67.07%. Bagasse fiber weight percentage was second level of

percentage contribution of 22.14% and silicon carbide was third level of percentage contribution of 8.46%.

Table 4.22 Analysis of variance for S/N ratios for void content

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	13.101	13.101	6.551	28.770	0.034	67.07%
Bagasse fiber	2	4.324	4.324	2.162	9.500	0.095	22.14%
Silicon carbide	2	1.653	1.653	0.826	3.630	0.216	8.46%
Residual Error	2	0.455	0.455	0.228			
Total	8	19.533					

4.9. Grey Relational Analysis of Composite

The response of all tests performed such as tensile strength, flexural strength, hardness, impact strength, water absorption, actual density, and void content were taken for grey relational analysis of hybrid composite was shown in Table 4.23.

Table 4. 23 Response taken from all the performed tests

Samples	TS (MPa)	FS (MPa)	H (HV)	IS (J)	WA (%)	AD (g/cm^3)	VC (%)
S1	35.3	56.1	49.75	5	0.495	1.252	0.8
S2	36.9	54.79	58.55	14	0.3337	1.273	0.9
S3	33.5	28.33	55.55	6.5	0.3406	1.286	1.1
S4	36.6	51	66.3	8.5	0.436	1.285	1.01
S5	35.6	51	56.85	5	0.44	1.308	1.2
S6	29.5	33.2	62.4	10	0.3073	1.303	1.3
S7	37.2	45.27	33.95	5.5	0.2504	1.313	1.28
S8	35.1	42.5	48.4	7.5	0.5667	1.302	1.29
S9	39.9	46.04	75.05	5	0.2564	1.315	1.3

Table 4. 24 Determination S/N ratio (dB) for responses

Samples	TS	FS	H	IS	WA	AD	VC
S1	30.955	34.979	33.936	13.979	6.108	-1.952	1.938
S2	31.341	34.774	35.351	22.923	9.533	-2.097	0.915
S3	30.501	29.045	34.894	16.258	9.355	-2.185	-0.828
S4	31.270	34.151	36.430	18.588	7.210	-2.178	-0.086
S5	31.029	34.151	35.095	13.979	7.131	-2.332	-1.584
S6	29.396	30.423	35.904	20.000	10.249	-2.299	-2.279
S7	31.411	33.116	30.617	14.807	12.027	-2.365	-2.144
S8	30.906	32.568	33.697	17.501	4.933	-2.292	-2.212
S9	32.019	33.263	37.507	13.979	11.822	-2.379	-2.279

Table 4. 25 Determination of normalized S/R ratio

Samples	TS	FS	H	IS	WA	AD	VC
S1	0.594	1.000	0.482	0.000	0.166	1.000	1.000
S2	0.741	0.965	0.687	1.000	0.648	0.661	0.757
S3	0.421	0.000	0.621	0.255	0.623	0.454	0.344
S4	0.714	0.860	0.844	0.515	0.321	0.470	0.520
S5	0.622	0.860	0.650	0.000	0.310	0.109	0.165
S6	0.000	0.232	0.767	0.673	0.749	0.187	0.000
S7	0.768	0.686	0.000	0.093	1.000	0.031	0.032
S8	0.576	0.594	0.447	0.394	0.000	0.202	0.016
S9	1.000	0.711	1.000	0.000	0.971	0.000	0.000

Table 4.26 Determination of deviation Sequence of normalized S/N ratio

Samples	TS	FS	H	IS	WA	AD	VC
S1	0.406	0.000	0.518	1.000	0.834	0.000	0.000
S2	0.259	0.035	0.313	0.000	0.352	0.339	0.243
S3	0.579	1.000	0.379	0.745	0.377	0.546	0.656
S4	0.286	0.140	0.156	0.485	0.679	0.530	0.480
S5	0.378	0.140	0.350	1.000	0.690	0.891	0.835

S6	1.000	0.768	0.233	0.327	0.251	0.813	1.000
S7	0.232	0.314	1.000	0.907	0.000	0.969	0.968
S8	0.424	0.406	0.553	0.606	1.000	0.798	0.984
S9	0.000	0.289	0.000	1.000	0.029	1.000	1.000

Table 4.27 Determinations of grey relational coefficients, GRG and rank

Samples	**TS**	**FS**	**H**	**IS**	**WA**	**AD**	**VC**	**GRG**	**Rank**
S1	0.552	1.000	0.491	0.333	0.375	1.000	1.000	0.663	3
S2	0.659	0.935	0.615	1.000	0.587	0.596	0.673	0.716	1
S3	0.463	0.333	0.569	0.402	0.570	0.478	0.433	0.464	8
S4	0.636	0.782	0.762	0.508	0.424	0.485	0.510	0.593	4
S5	0.570	0.782	0.588	0.333	0.420	0.359	0.374	0.500	6
S6	0.333	0.394	0.682	0.605	0.666	0.381	0.333	0.466	7
S7	0.683	0.614	0.333	0.355	1.000	0.340	0.341	0.544	5
S8	0.541	0.552	0.475	0.452	0.333	0.385	0.337	0.452	9
S9	1.000	0.634	1.000	0.333	0.945	0.333	0.333	0.697	2

A. Taguchi Analysis Using S/N Ratio for GRG of Composite

Table 4.28 shows the response for signal to noise ratios of GRG of hybrid composite. From this silicon carbide weight percentage was the first ranker in the contribution of grey relational grade with a delta value of 2.471. Alumina weight percentage was the second ranker in the contribution of grey relational grade with a delta value of 1.350. Bagasse fiber weight percentage was the third ranker in the contribution of grey relational grade with a delta value of 1.01.

Figure 4.21 shows the main effect plot for S/N ratio with larger is better for GRG. S/N ratio of GRG was optimum at alumina content of level 1, bagasse fiber content of level 1 and silicon carbide content of level 2. From this the possible optimal parameter combinations of S/N ratio of GRG was A1B1C2 which contained 6 wt.% of Al_2O_3, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. This analysis leads to the conclusion that the process parameter combinations of A1B1C2 gave the maximum GRG of hybrid composite.

Table 4. 28 Responses for signal to noise ratios for GRG

Level	Alumina content	Bagasse fiber content	Silicon carbide content
1	-4.383	-4.468	-5.700
2	-5.733	-5.277	-3.526
3	-5.107	-5.478	-5.997
Delta	1.350	1.010	2.471
Rank	2	3	1

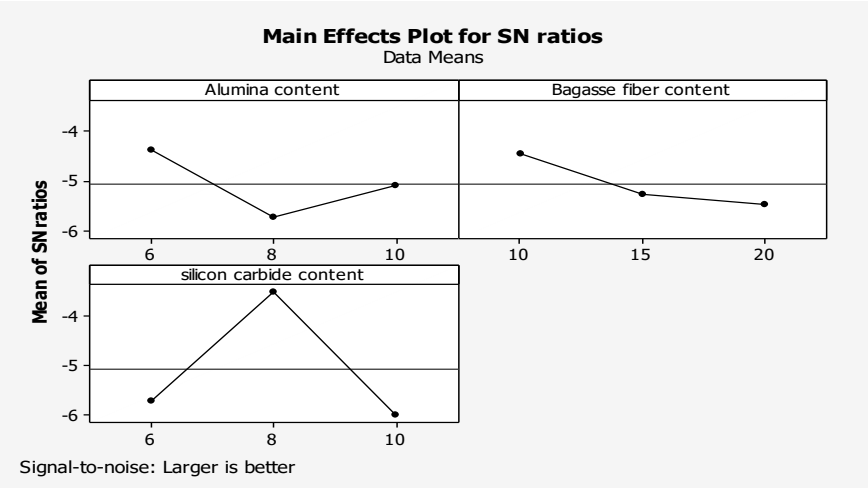

Figure 4. 21 S/N ratios for grey relational grade

❖ **Confirmation of the Experiment**

The optimal level of parameters obtained from grey relational analysis was A1B1C2 which means 6 wt.% of alumina, 10 wt.% of bagasse fiber and 8 wt.% of silicon carbide. Combination of these optimum levels was not performed. This thesis recommends optimum levels of parameters combination for prepared of hybrid composite material results improve the mechanical and physical properties.

B. Analysis of Variance for S/N Ratios of GRG

From analysis of variance shown in Table 4.29 indicate the percentage of contribution of each process parameter for grey relational grade. Silicon carbide weight percentage was the highest level of percentage contribution of 69.33%. Alumina weight percentage was second level of percentage contribution of 26.018% and bagasse fiber was third level of percentage contribution of 2.46%.

Table 4. 29 Analysis of variance for S/N ratios of GRG

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	PC
Alumina	2	6.4122	6.4122	3.2061	11.85	0.078	26.018%
Bagasse fiber	2	0.6054	0.6054	0.3027	1.12	0.472	2.46%
Silicon carbide	2	17.0871	17.0871	8.5436	31.59	0.031	69.33%
Residual Error	2	0.5409	0.5409	0.2705			2.195%
Total	8	24.6456					100%

4.10. Comparison with the Previous Works

This study was compared with the previous work by different properties of composite materials were given in Table 4.30. From this filling alumina and silicon carbide in bagasse fiber was improved the properties of hybrid composite.

Table 4. 30 Comparison with the previous work

No	Authors	Matrix type	Fiber type and filler	Methods	Results
1	Dhibar et al., (2018)	Polyester	Bagasse fiber	Hand lay-up technique	Tensile and compression strength were 12.73 and 2.315 MPa respectively. water absorption was 27.66%
2	Ramlee et al., (2019)	Phenolic	OPEFB and bagasse fiber	Hand lay-up technique	Tensile strength was 5.56 MPa, water absorption was 15.4% , density was 0.521g/cm^{3}and void content was 6.45%

3	Cao et al., (2006)	Polyester	Bagasse fiber	Hot mounting Press	Tensile and flexural strength were 26.77 and 50.86 MPa respectively. Impact strength was 11.27KJ/m^2
4	Subramonian et al., (2016)	Polypropylene	Bagasse fiber	Hot pressed	Tensile and flexural strength were 19.6 and 57 MPa respectively. hardness was 104.7 HRC
5	Zakaria et al., (2020)	Polyester	Bagasse fiber	Hot pressed	Tensile and flexural strength were 18 and 38 MPa
6	Mathur et al., (2018)	Epoxy	Bagasse fiber	Hand lay-up technique	Tensile and flexural strength were 22.085 and 36.62 MPa respectively
7	Current work	Polyester	Bagasse fiber and Al_2O_3 and SiC	Hand lay-up technique	Tensile and flexural were 39.9 and 56.1 MPa respectively. Hardness was 75.05 HV, impact was 14J, Water absorption was 0.2504%, density was 1.252g/cm^3 and void content was 0.8% resulted.

4.11. Machinability Test

The machinability tests result shows that the surface of machined had good surface finishing. Figure 4.22 shows drilled holes on the surface of specimen of the composite. The specimen was drilled with 5 mm and 7 mm size diameters of drill bit under the same speed and feed rate. From this the problem of drilling composite was the formation small crack on the opposite side of specimen. When the drilled holes cut and the observed inner surface was smooth which helps easily assembling of the composite.

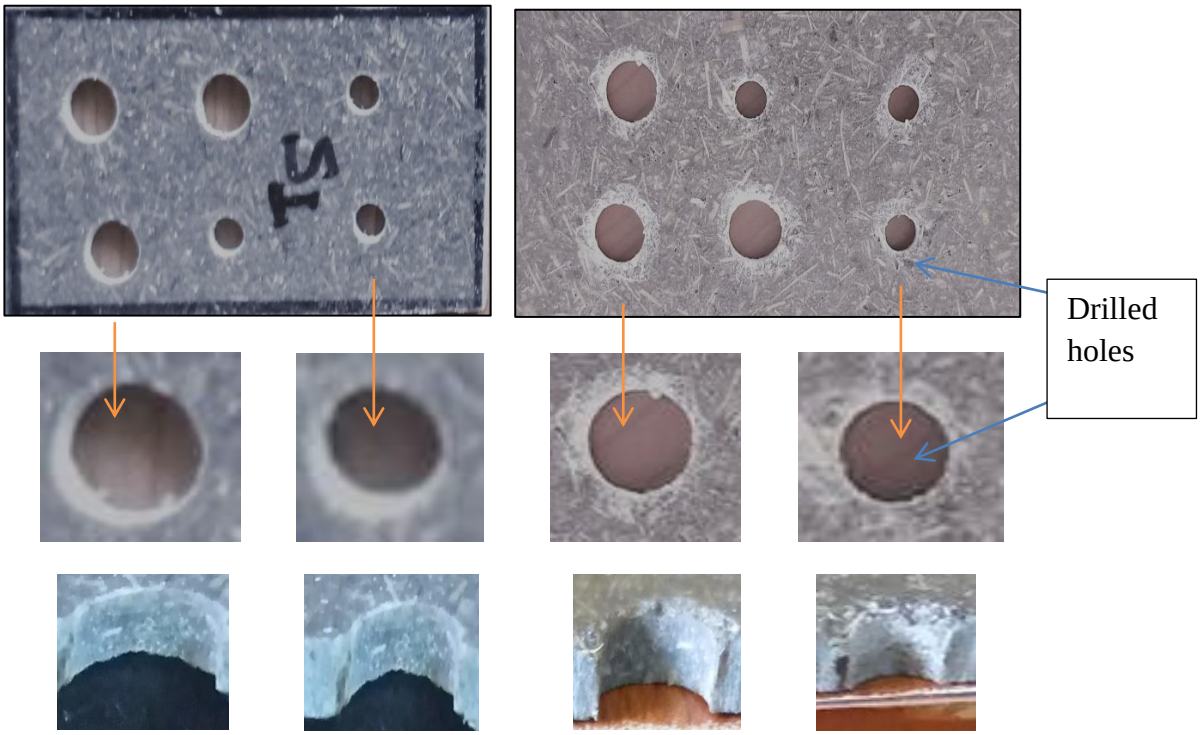

Figure 4. 22 Specimen1 for machinability test

4.12. Morphology Analysis

Morphology was used to check the bonding and filler materials distribution in the matrix. SEM images were taken for the specimens to observe the microstructure. The images were taken for the hybrid composite made from alumina and silicon carbide reinforced with bagasse fiber and polyester and the images were analyzed in the scanning electron microscope. The scanning electron microscope image showed the dispersion of the bagasse fiber and filler materials such as alumina and silicon carbide with the polyester matrix as shown in Figure 4.23. There found no major defects in the composite fabricated. Micro cracks, and desegregations were not observed at higher magnification.

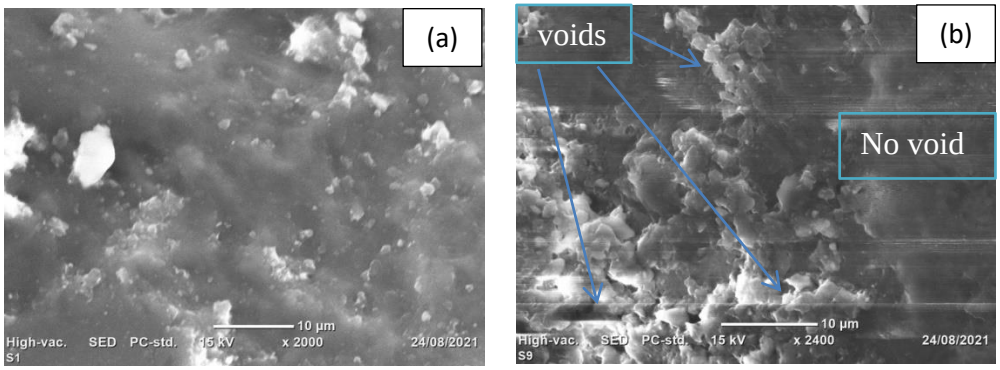

Figure 4. 23 Image of SEM (a) specimen1 (b) specimen 9

CHAPTRER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The prepared of hybrid composites reinforced with Al_2O_3/SiC, bagasse fibers and polyester performed at three levels and three weight percentages were successfully produced by the hand lay-up method. The following conclusions were made based on the study carried out:-

- The composites containing alumina and silicon carbide 6, 8, and 10 wt.% and bagasse fiber 10, 15, and 20 wt.% were prepared.
- Tensile strength of specimen 9 was 39.9 MPa. The tensile strength was maximum at 10 wt.% Al_2O_3, 10 wt.% bagasse fiber, and 8 wt.% SiC. The results indicated that the increased Al_2O_3 wt.% tensile strength was increased. It decreased after adding more than 8 wt.% of SiC and 10 wt.% of bagasse fiber.
- Flexural strength for specimen 1 was 56.1MPa. It was a maximum at 10 wt.% Al_2O_3, 10 wt.% bagasse fiber, and 8 wt.% SiC. When Al_2O_3 wt.% was increased, its flexural strength was also increased. While it was decreased when more than 10 wt.% of bagasse fiber, and 8 wt.% of SiC were added.
- The hardness for specimen 9 was 75.05 HV. The maximum hardness was achieved at 8 wt.% Al_2O_3, 20 wt.% bagasse fiber, and 8 wt.% SiC. As wt.% bagasse fiber of increased the hardness of composite was increased. More than 8 wt.% of Al_2O_3 and the SiC hardness of the composites were decreased.
- The impact strength for specimen 2 was 14 J. It was a maximum of 6 wt.% Al_2O_3, 15 wt.% bagasse fiber, and 8 wt.% SiC. More than 6 wt.% of Al_2O_3, 15 wt.% of bagasse fiber and 8 wt.% of SiC impact strength of composite was decreased.
- Water absorption was minimum at specimen 7 with 0.250%. It was a minimum of 8 wt.% Al_2O_3, 15 wt.% bagasse fiber, and 6 wt.% SiC. As Al_2O_3, bagasse fiber and SiC wt.% were increased, the percentage of water absorption of the composite was less.
- Actual density of composite material was minimum at specimen 1 with 1.252 g/cm^3. Actual density was a minimum of 6 wt.% Al_2O_3, 10 wt.% bagasse fiber, and 6 wt.%

SiC. As Al_2O_3, bagasse fiber, and SiC wt.% were increased, the actual density of the composite was increased.

- Void content of composite material was minimum at specimen 1 with 0.8%. It was a minimum of 6 wt.% Al_2O_3, 10wt.% bagasse fiber, and 6 wt.% SiC. As Al_2O_3, bagasse fiber, and SiC wt.% increased, the percentage void content of the composite increased. It affects the mechanical properties of the composite.
- From grey relational analysis of multi responses at a time, the optimum levels were A1B1C2 which means 6 wt.% of alumina, 10 wt.% of bagasse fiber and 8 wt.% of silicon carbide. At these levels, all the mechanical and physical properties of the studied hybrid composite were optimum.
- From the machinability tests, the smooth surface finishing was observed on drilled surface and little cracking was observed on the opposite side of the drilled surface.
- From morphology analysis of hybrid composite material by using SEM, void content was observed in small areas of hybrid composites.
- Using Al_2O_3 and SiC powder as filler materials, the properties of the developed hybrid composite are greatly improved.

5.2. Recommendations

Considering the fabrication and characterization of the hybrid composites reinforced with Al_2O_3/SiC, bagasse fibers, and polyester, the following recommendations were considered.

- This thesis recommends higher institutes, automotive companies, manufacturing companies, construction sector and government to conduct on how to utilize this abundant waste of bagasse fiber resource.
- The trend of replacing heavy metals with low density, biodegradable, renewable, environmental friendly, and green composites should have to get attention in countries dependent on agricultural sector, like Ethiopia.
- This thesis recommends that bagasse fiber shows a great potential to substitute conventional reinforcement. This can turn waste bagasse fiber into high value able products.

5.3. Future Works

- In this study, bagasse fiber of 10 to 20 wt.% was used. This can further be extended to other bagasse fiber weight percentage to study the effect of weight percentage on mechanical and physical properties of the composite.
- Investigate the mechanical and physical properties of bagasse fiber in combination with other types of natural fibers
- In study samples preparation was limited to the hand lay-up method. However, other available manufacturing methods can be used for future work.
- Using the filler materials with nanoparticle fillers.
- Using different techniques for the treatment of bagasse fiber
- Bagasse 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 bagasse fiber composite
- The work extended to study other properties such as creep, fatigue, compressive, shear strength, chemical resistance and electrical properties

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RERFERENCES

Acharya, S. K., Mishra, P., Mehar, S. K., and Dikshit, V. (2008). Weathering Behavior of Bagasse Fiber Reinforced Polymer Composite. Journal of Reinforced Plastics and Composites, 27 (16-17), 1839-1846.

Adugna, D. (2018). Manufacturing and Investigation on Mechanical Properties of False Banana Fiber and Glass Fiber Composite Material for Vehicles Body Panel (Doctoral Dissertation, ASTU).

Athijayamani, A., Stalin, B., Sidhardhan, S., and Boopathi, C. (2016). Parametric Analysis of Mechanical Properties of Bagasse Fiber-Reinforced Vinylester Composites. *Journal of Composite Materials*, *50* (4), 481 – 493. https://doi.org/10.1177/0021998315576555.

Ayele, N., Getaneh, A., Negi, T., and Dilnesaw, Z. (2014). Effect of Planting Density on Yield and Yield Components of Sugarcane at Wonji-Shoa. *Scholarly Journal of Agricultural Science, 4* (12), 583–586. http://www.scholarly-journals.com/SJAS

Aynalem, G. F., and Sirahbizu, B. (2021). Effect of Al_2O_3 on the Tensile and Impact Strength of Flax/Unsaturated Polyester Composite with Emphasis on Automobile Body Applications. *Advances in Materials Science and Engineering*, *2021*. https://doi.org/10.1155/2021/6641029

Azlina Ramlee,A., N, Jawaid, M., Abdul Karim Yamani, S., Syams Zainudin, E., and Alamery, S. (2021). Effect of Surface Treatment on Mechanical, Physical and Morphological Properties of Oil Palm/Bagasse Fiber Reinforced Phenolic Hybrid Composites for Wall Thermal Insulation Application. *Construction and Building Materials, 276,* 122239. https://doi.org/10.1016/j.conbuildmat.2020.122239

Balaji, A., Karthikeyan, B., and Sundar Raj, C. (2015). Bagasse Fiber – The Future

Biocomposite Material: A Review. *International Journal of ChemTech Research*, *7*(1), 223–233.

Bartos, A., Anggono, J., Farkas, Á. E., Kun, D., Soetaredjo, F. E., Móczó, J., Antoni, Purwaningsih, H., and Pukánszky, B. (2020). Alkali Treatment of Lignocellulosic Fibers Extracted from Sugarcane Bagasse: Composition, Structure, Properties. *Polymer Testing*, *88*(January). https://doi.org/10.1016/j.polymertesting.2020.106549

Bellal Hoque, B., M., Sahadat Hossain, M., and A. Khan, R. (2019). Study on Tensile, Bending and Water Uptake Properties of Sugarcane Bagasse Fiber Reinforced Polypropylene Based Composite. *Journal of Biomaterials*, *3*(1), 18. https://doi.org/10.11648/j.jb.20190301.13

Cao, Y., Shibata, S., and Fukumoto, I. (2006). Mechanical Properties of Biodegradable Composites Reinforced with Bagasse Fibre Before and After Alkali Treatments. *Composites Part A: Applied Science and Manufacturing*, *37*(3), 423–429. https://doi.org/10.1016/j.compositesa.2005.05.045

Chandramohan, D., and Marimuthu. (2011). A Review on Natural Fibers. *International Journal of Research and Reviews in Applied Sciences*, *8*(2), 194–206. http://www.arpapress.com/Volumes/Vol8Issue2/IJRRAS_8_2_09.pdf

Chavhan, G. R., and Wankhade, L. N. (2020). Improvement of the Mechanical Properties of Hybrid Composites Prepared by Fibers, Fiber-Metals, and Nano-Filler Particles-A Review. *Materials Today: Proceedings*, *27*, 72–82. https://doi.org/10.1016/j.matpr.2019.08.240

Chethanbabu, H. M., and Ramachandra, M. (2019). Evaluation of Mechanical Properties of Polypropylene Fibre Reinforced Epoxy Composite Filled with Silicon Carbide Particulates. *Materials Today: Proceedings*, *46*(xxxx), 4400–4406.

https://doi.org/10.1016/j.matpr.2020.09.669

David, A. C., and Naidu, A. L. (2017). *A Review on Manufacturing Techniques and Chemical Properties of Natural Composite Materials*. *4*. www.ijrdt.org

De Souza, L. G. M., da Silva, E. J., and Meira de Souza, L. G. V. (2020). Obtaining and Characterizing a Polyester Resin and Cement Powder Composites. *Materials Research*, *23*(5). https://doi.org/10.1590/1980-5373-MR-2018-0894

Devadiga, D. G., Bhat, K. S., and Mahesha, G. T. (2020). Sugarcane Bagasse Fiber Reinforced Composites: Recent Advances and Applications. *Cogent Engineering*, *7*(1). https://doi.org/10.1080/23311916.2020.1823159

Devendra, K., and Rangaswamy, T. (2012). 29.Determination Of Mechanical Properties of Al_2O_3, $Mg(OH)_2$ and Sic Filled E-Glass/ Epoxy Composites. *International Journal of Engineering Research and Applications (IJERA) Www.Ijera.Com*, *2*(5), 2028–2033. www.ijera.com

Dhibar, B., Singh, S. V., Anwar, S., and Singh, A. (2018). Sugarcane Bagasse Reinforced Polyester Composites. *International Research Journal of Engineering and Technology*, 4204–4211. www.irjet.net

Elanchezhian, C., Ramnath, B. V., Ramakrishnan, G., Rajendrakumar, M., Naveenkumar, V., and Saravanakumar, M. K. (2018). Review on Mechanical Properties of Natural Fiber Composites. *Materials Today: Proceedings*, *5*(1), 1785–1790. https://doi.org/10.1016/j.matpr.2017.11.276

Fasil, A. (2020). Fabrication and Experimental Analysis of False Banana Jute Glass Fibers Reinforced Hybrid Composite for Automotive Body Panel Application (Doctoral dissertation, ASTU).

Gairola, S. P., Tyagi, Y. K., Gangil, B., and Sharma, A. (2020). Fabrication and

Mechanical Property Evaluation of Non-woven Banana Fibre Epoxy-Based Polymer Composite. *Materials Today: Proceedings*, *44*(xxxx), 3990–3996. https://doi.org/10.1016/j.matpr.2020.10.103

Hemant Mohan Kawade and Narve N.G. (2017). Natural Fiber Reinforced Polymer Composites: A Review. International Journal for Scientific Research and Development| Vol. 5, Issue 09, 2017 | ISSN (online): 2321-0613

Ibrahim, M. I. J., Sapuan, S. M., Zainudin, E. S., and Zuhri, M. Y. M. (2020). Preparation and Characterization of Cornhusk/Sugar Palm Fiber Reinforced Cornstarch-Based Hybrid Composites. *Journal of Materials Research and Technology*, *9*(1), 200–211. https://doi.org/10.1016/j.jmrt.2019.10.045

Karuppusamy, K., Ramanaicker, P., and Somasundaram, V. (2015). Investigation of the Mechanical Properties of Bagasse Fiber-Reinforced Epoxy Composite Using Taguchi and Response Surface Methodology. *BioResources*, *10*(2), 3749–3756. https://doi.org/10.15376/biores.10.2.3749-3756

Kiran, M. D., Govindaraju, H. K., and Jayaraju, T. (2018). Evaluation of Mechanical Properties of Glass Fiber Reinforced Epoxy Polymer Composites with Alumina, Titanium dioxide and Silicon Carbide. *Materials Today: Proceedings*, *5*(10), 22355–22361. https://doi.org/10.1016/j.matpr.2018.06.602

Kopur, G. (2019). Modal Analysis of Silicon Carbide - Banana Fiber Epoxy Composites using an Experimental Set Up. *International Journal for Research in Applied Science and Engineering Technology*, *7*(11), 750–754. https://doi.org/10.22214/ijraset.2019.11125

Kordkheili, H. Y., Hiziroglu, S., and Farsi, M. (2012). Some of the Physical and Mechanical Properties of Cement Composites Manufactured from Carbon Nanotubes

and Bagasse Fiber. *Materials and Design*, *33*(1), 395–398. https://doi.org/10.1016/j.matdes.2011.04.027

Krishnaiah, K., and Shahabudeen, P. (2012). *Applied Design of Experiments and Taguchi Methods*. https://books.google.com/books?id=hju9JYVhfV8C&pgis=1

Mishra, S., Nayak, C., Sharma, M. K., and Dwivedi, U. K. (2021). Influence of Coir Fiber Geometry on Mechanical Properties of SiC Filled Epoxy Composites. *Silicon*, *13*(2), 301–307. https://doi.org/10.1007/s12633-020-00425-1

Mittal, V., Saini, R., and Sinha, S. (2016). Natural Fiber-Mediated Epoxy Composites - A Review. *Composites Part B: Engineering*, *99*, 425–435. https://doi.org/10.1016/j.compositesb.2016.06.051

Mochane, M. J., Mokhena, T. C., Mokhothu, T. H., Mtibe, A., Sadiku, E. R., Ray, S. S., Ibrahim, I. D., and Daramola, O. O. (2019). Recent Progress on Natural Fiber Hybrid Composites for Advanced Applications: A review. *Express Polymer Letters*, *13*(2), 159–198. https://doi.org/10.3144/expresspolymlett.2019.15

Mukesh Mathur, M., N., Bairwa, K., Singh, A., and Professor, A. (2018). *Experimentation and Optimization of Sugar Cane Bagasse (SCB) Dust Reinforced Epoxy Based Composite*. *8*(179), 179–188.

Naidu, A. L., and Rao, P. S. V. R. (2016). a Review on Chemical Behaviour of Natural Fiber Composites. *Int. J. Chem. Sci*, *14*(4), 2223–2238. www.sadgurupublications.com

Oladele, I. O. (2014). Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites. *The Journal of the Association of Professional Engineers of Trinidad and Tobago*, *42*(1), 12–15.

Pradhan, T. (2016). *A Study on Thermal Characteristics of Epoxy Composites Reinforced*

with Short Bagasse Fibres. 1–67. www.nitrkl.ac.in

Robale, D. (2020). Experimental Investigation of Aluminum Matrix Composite Reinforced by Aluminum Oxide and Graphite Micro Particles (Doctoral dissertation, ASTU).

R, S. M., and Yogesha, B. (2016). Study on Water Absorption Behaviour of Jute and Kenaf Fabric Reinforced Epoxy Composites: Hybridization Effect of E-Glass Fabric. *International Journal of Composite Materials*, *6*(2), 55–62. https://doi.org/10.5923/j.cmaterials.20160602.03

Rajesh, S., Vijaya Ramnath, B., Elanchezhian, C., Aravind, N., Vijai Rahul, V., and Sathish, S. (2014). Analysis of Mechanical Behavior of Glass Fibre/Al_2O_3-SiC Reinforced Polymer Composites. *Procedia Engineering*, *97*, 598–606. https://doi.org/10.1016/j.proeng.2014.12.288

Ramlee, N. A., Jawaid, M., Zainudin, E. S., and Yamani, S. A. K. (2019). Tensile, Physical and Morphological Properties of Oil Palm Empty Fruit Bunch/Sugarcane Bagasse Fibre Reinforced Phenolic Hybrid Composites. *Journal of Materials Research and Technology*, *8*(4), 3466–3474. https://doi.org/10.1016/j.jmrt.2019.06.016

Rao, D. N., Mukesh, G., Ramesh, A., and Anjaneyulu, T. (2020). Investigations on the Mechanical Properties of Hybrid Goat Hair and Banana Fiber Reinforced Polymer Composites. *Materials Today: Proceedings*, *27*, 1703–1707. https://doi.org/10.1016/j.matpr.2020.03.586

Selvam, R., Ravi, S., and Raja, R. (2017). Fabrication of SiC Particulate Reinforced Polyester Matrix Composite and Investigation. *IOP Conference Series: Materials Science and Engineering*, *197*(1). https://doi.org/10.1088/1757-899X/197/1/012052

Singh, L., Ram, B., and Singh, A. (2013). Optimization of Process Parameter for Stir Casted Aluminium Metal Matrix Composite Using Taguchi Method. International

Journal of Research in Engineering and Technology, 02(08), 375–383. https://doi.org/10.15623/ijret.2013.0208059

Srinivas, K., Lakshumu Naidu, A., and Raju Bahubalendruni, M. V. A. (2017). A Review on Chemical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites. *International Journal of Performability Engineering*, *13*(2), 189–200. https://doi.org/10.23940/ijpe.17.02.p8.189200

Srivastava, N., and Prakash Dwivedi, S. (2019). Development of Green Hybrid Metal Matrix Composite Using Agricultural Waste Bagasse as Reinforcement-A Review. *IOP Conference Series:Materials Science and Engineering*, *691*(1). https://doi.org/10.1088/1757-899X/691/1/012051

Subramonian, S., Ali, A., Amran, M., Sivakumar, L. D., Salleh, S., and Rajaizam, A. (2016). Effect of Fiber Loading on the Mechanical Properties of Bagasse Fiber-Reinforced Polypropylene Composites. *Advances in Mechanical Engineering*, *8*(8), 1–5. https://doi.org/10.1177/1687814016664258

Suresh, A., Bhargavi, P., and Kiran Kumar, M. (2020). Simulation and Mechanical Characterization on Kevlar Epoxy Reinforced Composite with Silicon Carbide Filler. *Materials Today: Proceedings*, *38*(xxxx), 2988–2995. https://doi.org/10.1016/j.matpr.2020.09.321

Swain, P. T. R., and Biswas, S. (2017). Influence of Fiber Surface Treatments on Physico-Mechanical Behaviour of Jute/Epoxy Composites Impregnated with Aluminium Oxide Filler. *Journal of Composite Materials*, *51*(28), 3909–3922. https://doi.org/10.1177/0021998317695420

Tadesse, T. (2017). Extraction, Characterization and Evaluation of Reinforcing Nanocellulose in Polyvinyl Alcohol (PVA) (Doctoral dissertation, Addis Ababa

University).

Tripathi, P., and Kumar, D. (2016). Study on Mechanical Behaviour of Sugarcane Bagasse Fiber Reinforced Polymer Matrix Composites. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology*, *8*(01), 34–42. https://doi.org/10.18090/samriddhi.v8i1.11410

Vasanthi, P., and Selvan, S. S. (2020). Optimization of Mixing Parameters in Nanosilica Toughened Cement Mortar Using Taguchi-Grey Relational Analysis. *Silicon*. https://doi.org/10.1007/s12633-020-00791-w

Verma, D., Gope, P. C., Maheshwari, M. K., and Sharma, R. K. (2012). Bagasse Fiber Composites-A Review. *Journal of Materials and Environmental Science*, *3*(6), 1079–1092.

Vidyashri, V., Lewis, H., Narayanasamy, P., Mahesha, G. T., and Bhat, K. S. (2019). Preparation of Chemically Treated Sugarcane Bagasse Fiber Reinforced Epoxy Composites and their Characterization. *Cogent Engineering*, *6*(1). https://doi.org/10.1080/23311916.2019.1708644

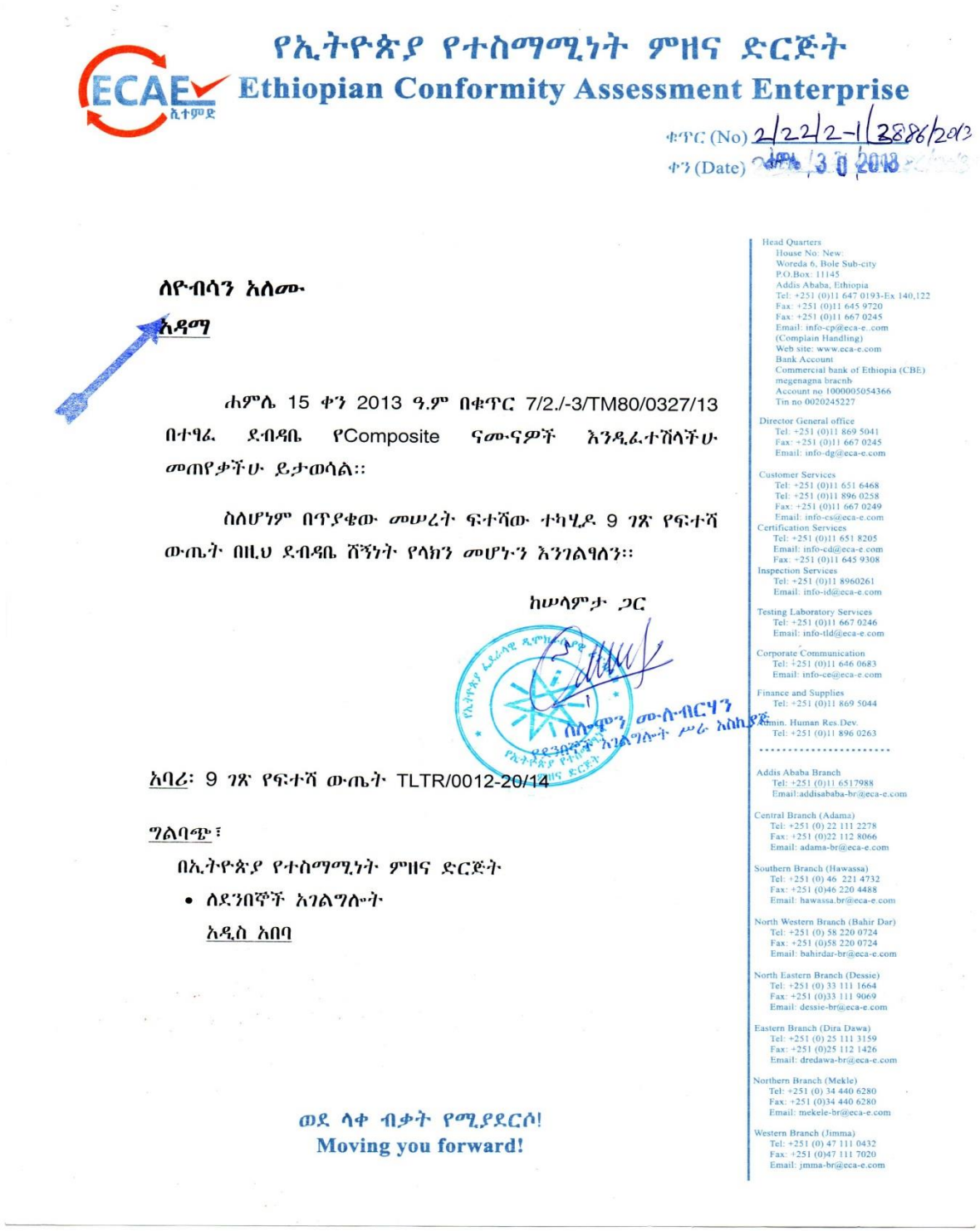
Xiong, W. (2018). Bagasse Composites: A Review of Material Preparation, Attributes, and Affecting Factors. *Journal of Thermoplastic Composite Materials*, *31*(8), 1112–1146. https://doi.org/10.1177/0892705717734596

Yohanes, G. (2020). Experimental Investigation on Mechanical Properties of Hybrid Composite of Polyester Matrix Reinforced by Ceramic Particles and Jute Fiber (Doctoral dissertation, ASTU).

Zakaria, M. S., Musa, L., Nordin, R. M., and Halim, K. A. A. (2020). Sugarcane Bagasse Reinforced Polyester Composites: Effects of Fiber Surface Treatment and Fiber Loading on the Tensile and Flexural Properties. *IOP Conference Series: Materials Science and Engineering*, *957*(1). https://doi.org/10.1088/1757-899X/957/1/012032

APPENDICES

Appendix A: Tensile Test Result



የኢትዮጵያ የተስማሚነት ምዘና ድርጅት
Ethiopian Conformity Assessment Enterprise

ቁጥር (No) 2/22/2-1/2886/2013
ቀን (Date) ሚያ 30 2013

ለዮብሳን አለሙ
አዳማ

ሐምሌ 15 ቀን 2013 ዓ.ም በቁጥር 7/2./-3/TM80/0327/13 በተፃፈ ደብዳቤ የComposite ናሙናዎች እንዲፈተሽላችሁ መጠየቃችሁ ይታወሳል።

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አባሪ፡ 9 ገጽ የፍተሻ ውጤት TLTR/0012-20/14

ግልባጭ፣
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ወደ ላቀ ብቃት የሚያደርሶ!
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Email: jmma-br@eca-e.com

ECAE አ.ተ.ም.ድ	የኢትዮጵያየተስማሚነትምዘናድርጅት Ethiopian Conformity Assessment Enterprise	Document No: TLD/F7.08-1	
		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትእንጂሰርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0012/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S1	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327006	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	35.3	-

Remark

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Ashenafi Abebe Position Analyst III *Sign.*

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Web site: www.eca-e.com
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ADDISABABA, ETHIOPIA

ECAE ኢ.ተ.ም.ድ	የኢትዮጵያየተስማሚነትምዘናድርጅት Ethiopian Conformity Assessment Enterprise	Document No: TLD/F7.08-1	
		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትአንጂስርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0013/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S2	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327007	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	36.9	-

Remark

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Ashenafi Abebe Position Analyst III *Sign.*

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		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትአንጂሰርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0014/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S3	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327008	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	33.5	-

Remark

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		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትእንጂሰርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0015/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S4	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327009	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	36.6	-

Remark

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		Copy No.: -	Rev No.: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትአንጂሰርተፍኬትአይደለም	Page No.: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0016/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S5	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327010	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	35.6	-

Remark

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		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትእንጂሰርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0017/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S6	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327011	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	29.5	-

Remark

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		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትእንጂለርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0018/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S7	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327012	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	37.2	-

Remark

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		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህየናሙናፍተሻሪፖርትአንጂሰርተፍኬትአይደለም	Page No: 1 of 1	Effective Date: 01 Sep 19

1	Name and address of client:	Yobsan Alemu, Adama	Test Report No:	TLTR/0019/14
2	Tel:	+251-942-16-32-54	Test Order No:	7/2.1.3/7ጠ80/0327/13
3	Fax:	---	Date of sampling:	Not specified
4	E-mail:	---	Place of Sampling:	Not specified
5	Date of Sample Recived:	02/08/2021	Sampled by:	Client
6	Client sample code:	S8	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13327013	Method Specification	---

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Tensile Stress in MPa	ISO 6892-1	-	-	-	35.1	-

Remark

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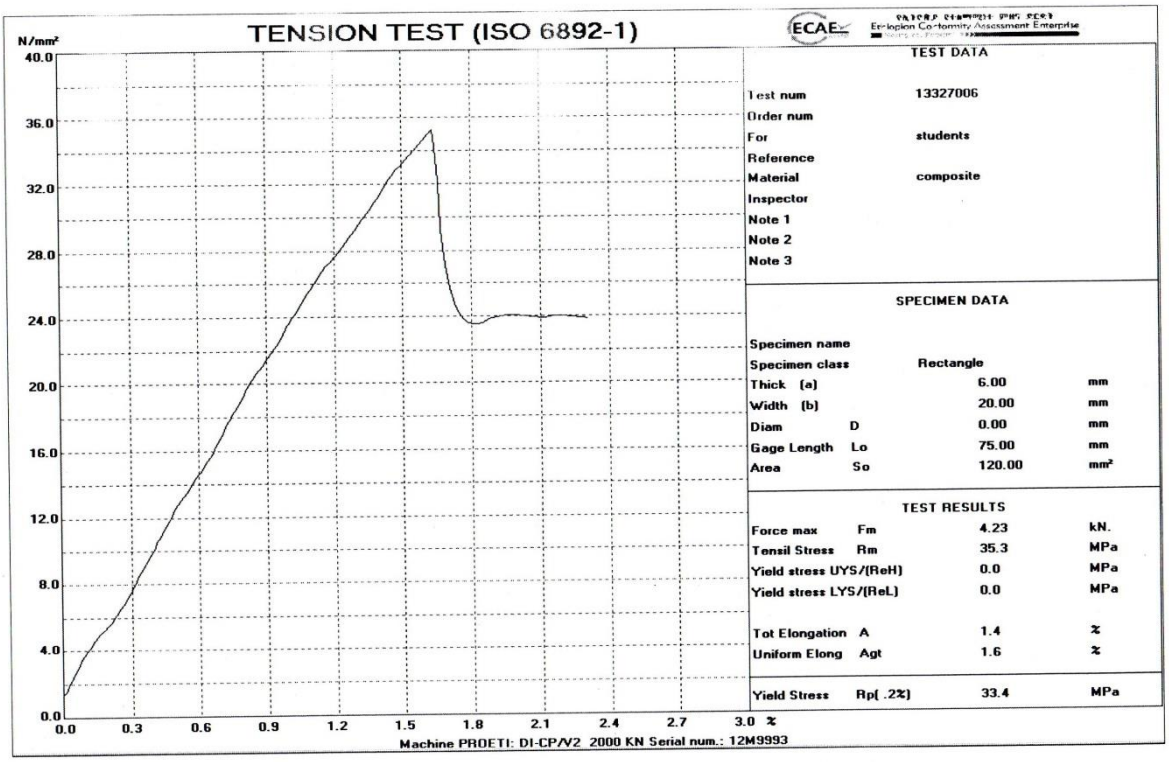
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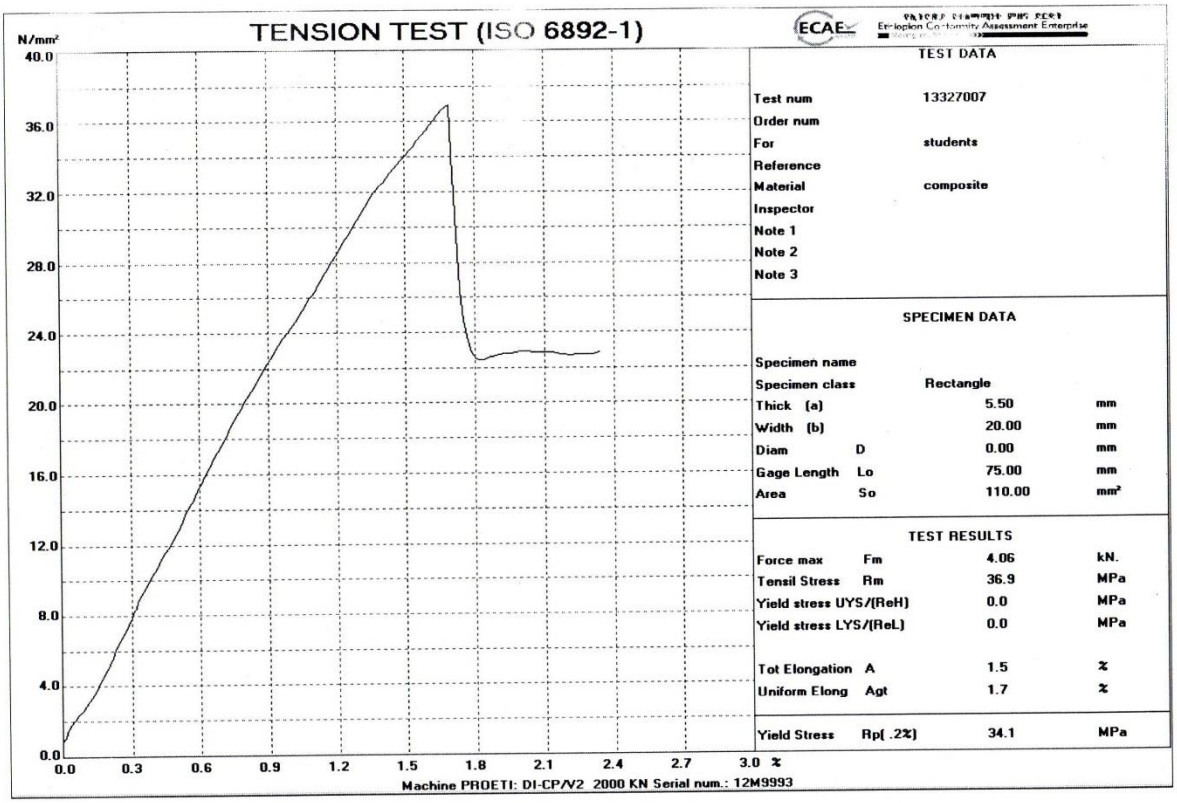
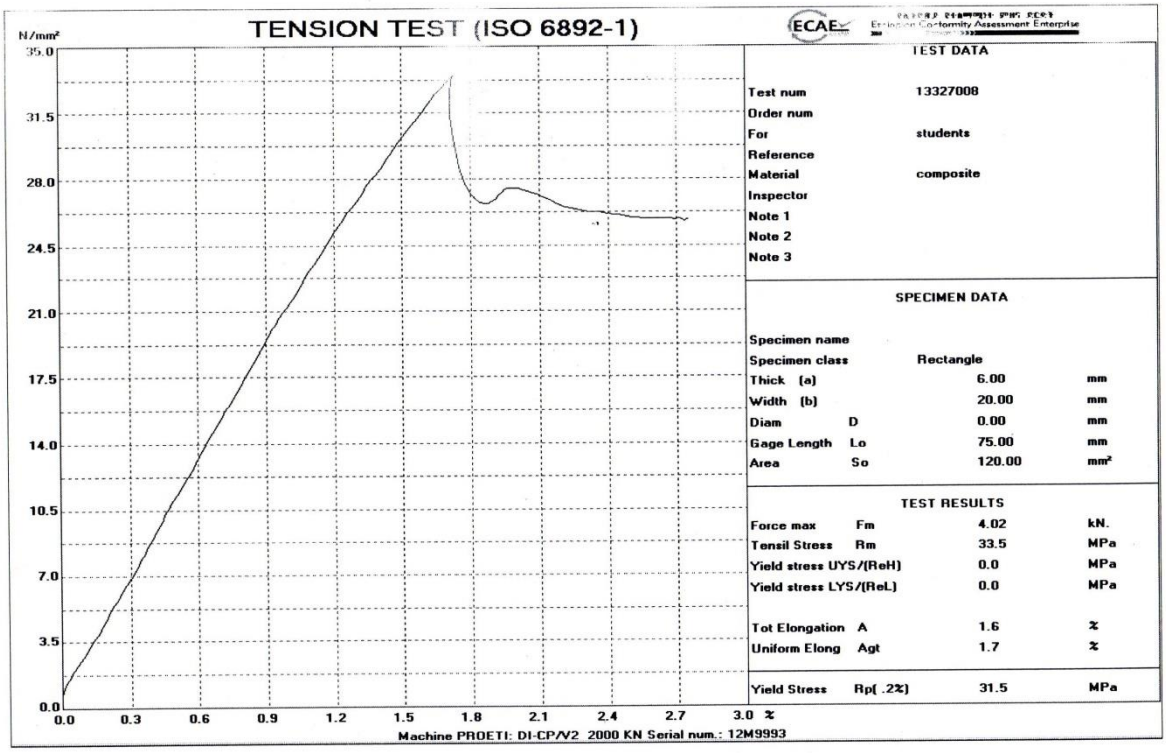
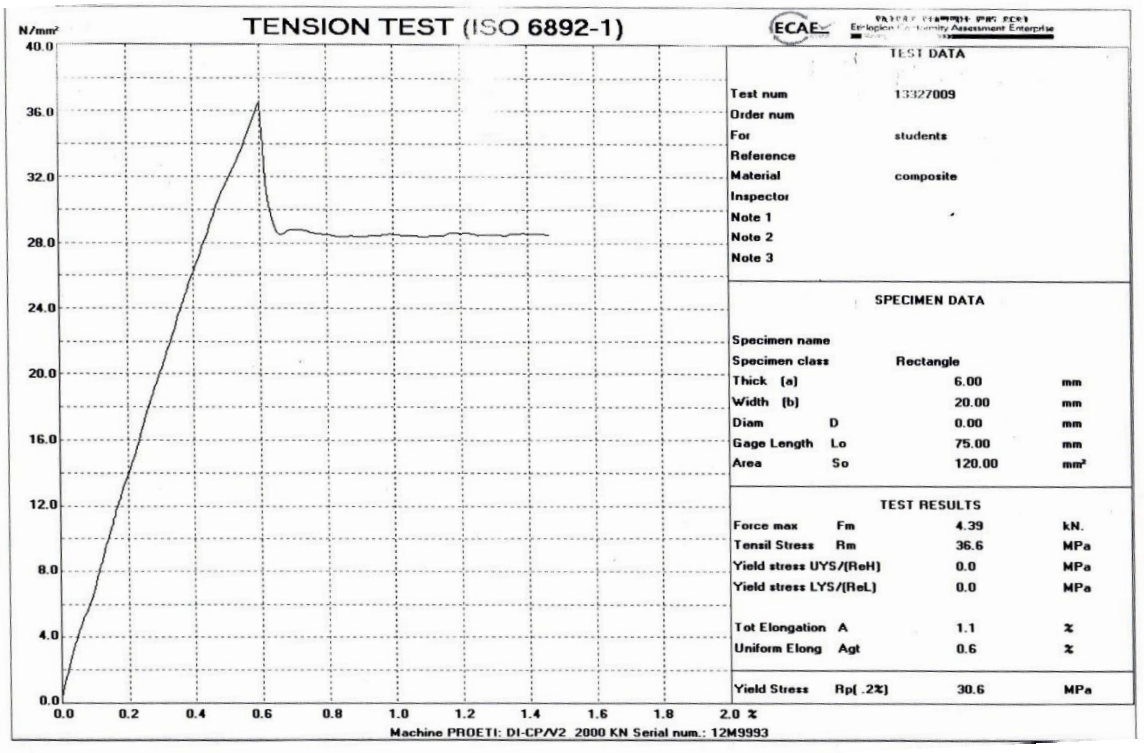
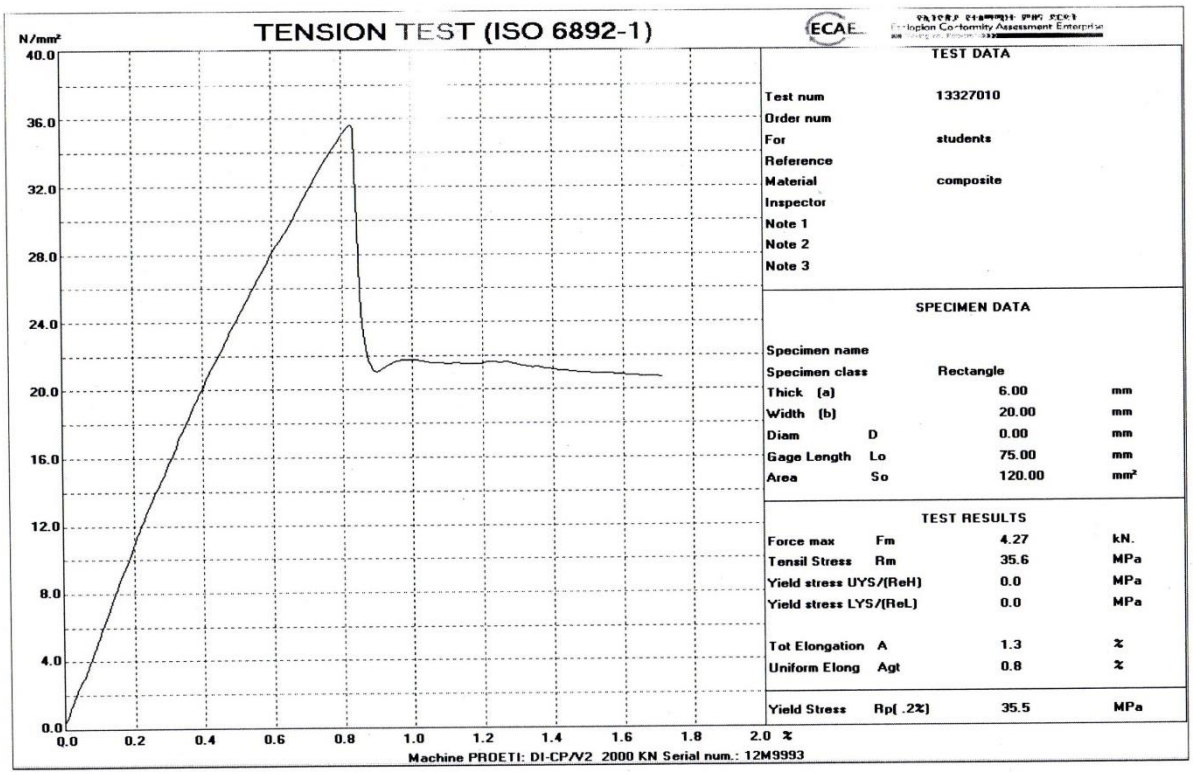
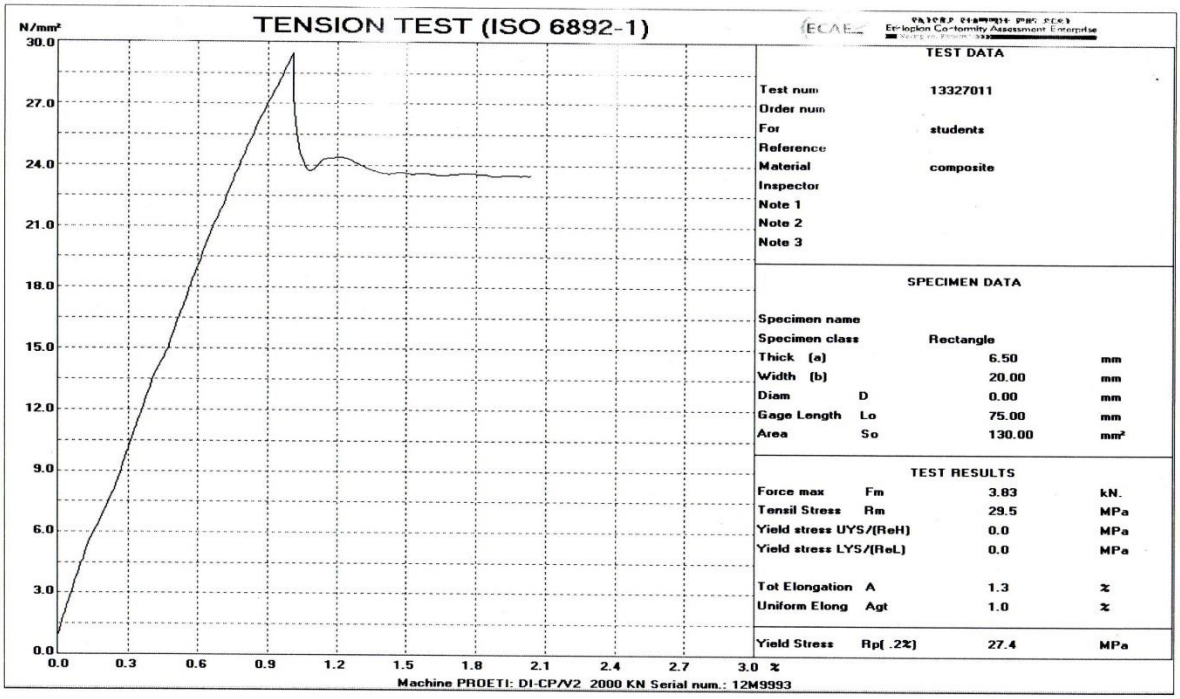
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
ECAE
TEST DATA
Test num 13327006
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 120.00 mm²
TEST RESULTS
Force max Fm 4.23 kN.
Tensil Stress Rm 35.3 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.4 %
Uniform Elong Agt 1.6 %
Yield Stress Rp(.2%) 33.4 MPa

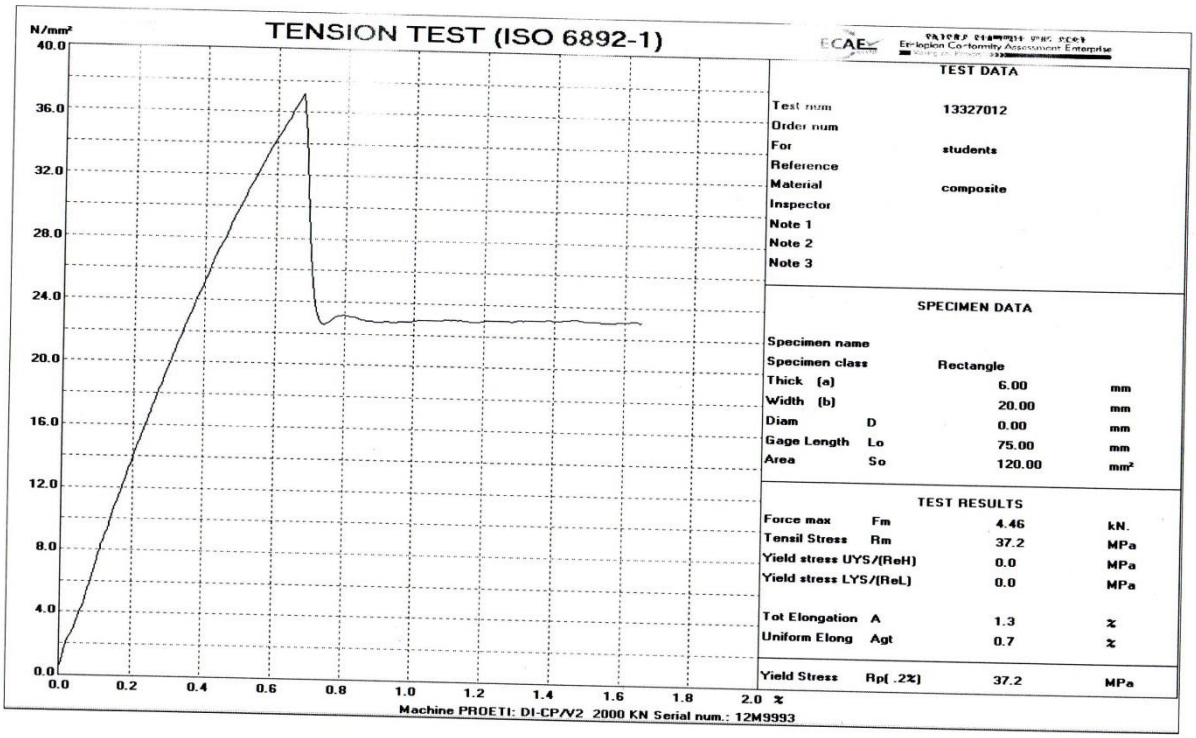

TENSION TEST (ISO 6892-1)
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
ECAE
TEST DATA
Test num 13327007
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 5.50 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 110.00 mm²
TEST RESULTS
Force max Fm 4.06 kN.
Tensil Stress Rm 36.9 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 1.7 %
Yield Stress Rp(.2%) 34.1 MPa

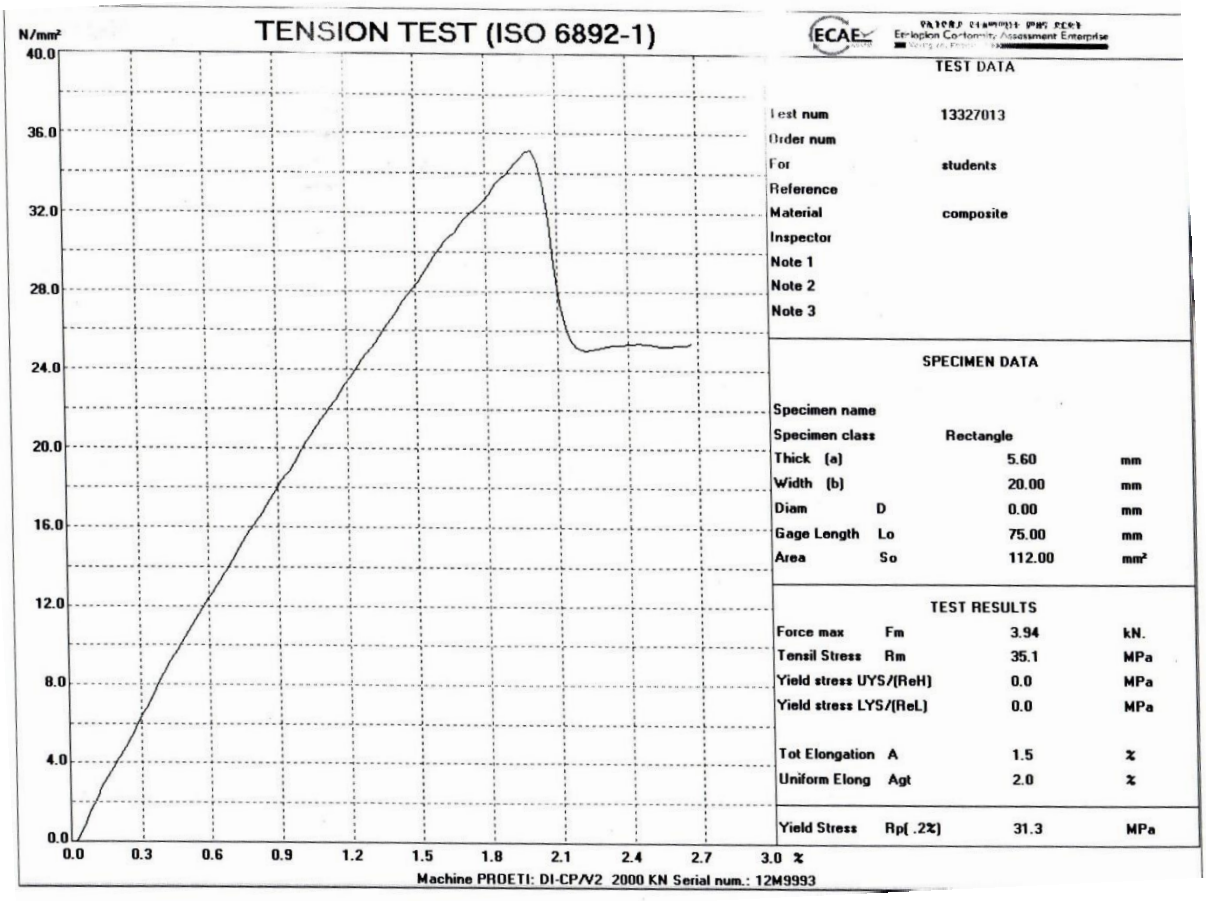

TENSION TEST (ISO 6892-1)
N/mm²
35.0
31.5
28.0
24.5
21.0
17.5
14.0
10.5
7.0
3.5
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13327008
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 120.00 mm²
TEST RESULTS
Force max Fm 4.02 kN.
Tensil Stress Rm 33.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.6 %
Uniform Elong Agt 1.7 %
Yield Stress Rp(.2%) 31.5 MPa


TENSION TEST (ISO 6892-1)
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13327009
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 120.00 mm²
TEST RESULTS
Force max Fm 4.39 kN.
Tensil Stress Rm 36.6 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.1 %
Uniform Elong Agt 0.6 %
Yield Stress Rp(.2%) 30.6 MPa


TENSION TEST (ISO 6892-1)
ECAE
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13327010
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 120.00 mm²
TEST RESULTS
Force max Fm 4.27 kN.
Tensil Stress Rm 35.6 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.3 %
Uniform Elong Agt 0.8 %
Yield Stress Rp(.2%) 35.5 MPa

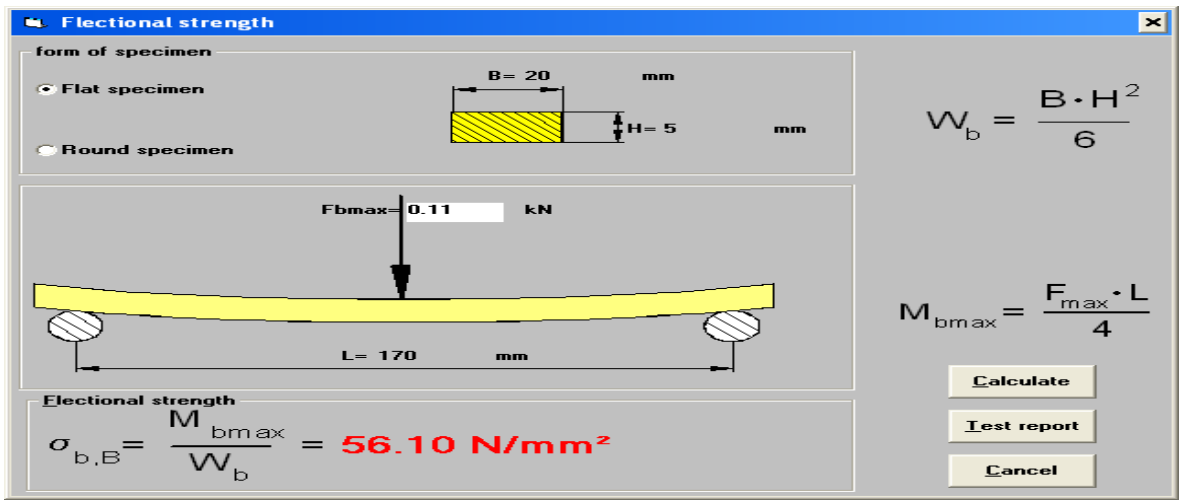

TENSION TEST (ISO 6892-1)
ECAE
N/mm²
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13327011
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.50 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 130.00 mm²
TEST RESULTS
Force max Fm 3.83 kN.
Tensil Stress Rm 29.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.3 %
Uniform Elong Agt 1.0 %
Yield Stress Rp(.2%) 27.4 MPa


TENSION TEST (ISO 6892-1)
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
ECAE
TEST DATA
Test num 13327012
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 120.00 mm²
TEST RESULTS
Force max Fm 4.46 kN.
Tensil Stress Rm 37.2 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.3 %
Uniform Elong Agt 0.7 %
Yield Stress Rp(.2%) 37.2 MPa

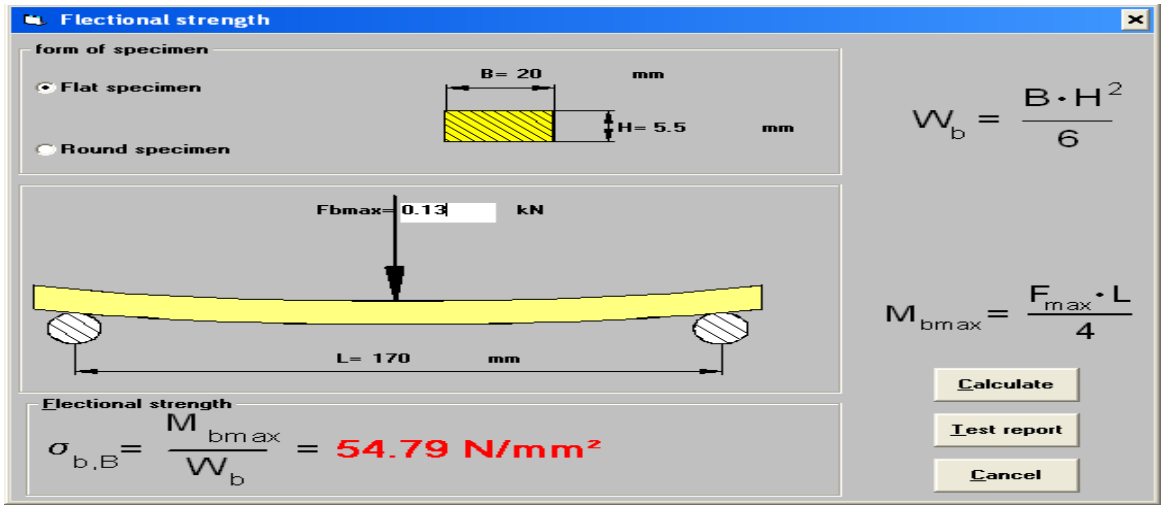

TENSION TEST (ISO 6892-1)
N/mm²
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
ECAE
TEST DATA
Test num 13327013
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 5.60 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 112.00 mm²
TEST RESULTS
Force max Fm 3.94 kN.
Tensil Stress Rm 35.1 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 2.0 %
Yield Stress Rp(.2%) 31.3 MPa

Appendix B: Flexural Test Result

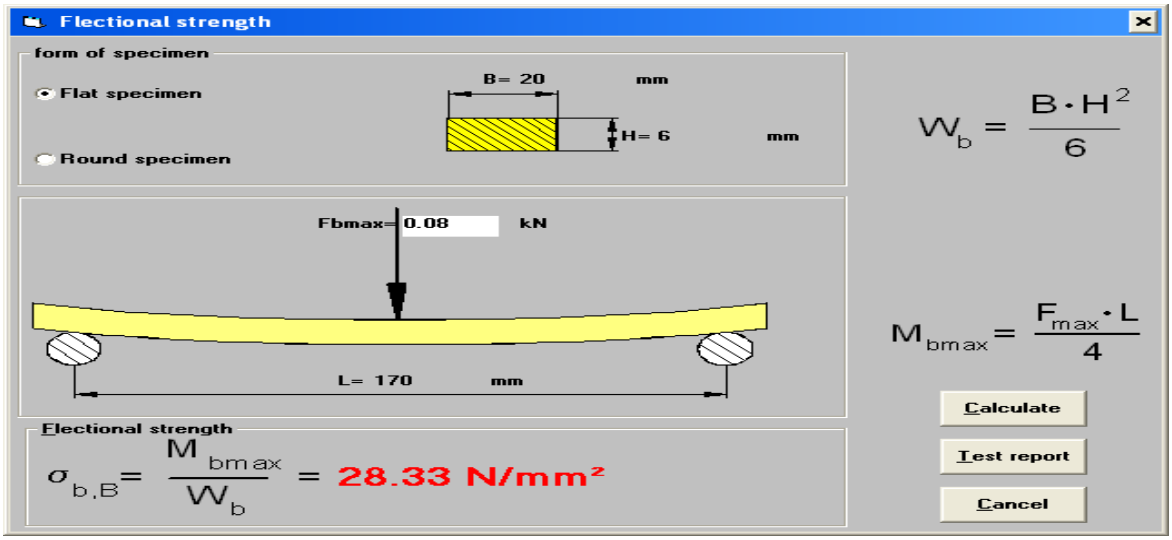
Specimen 1



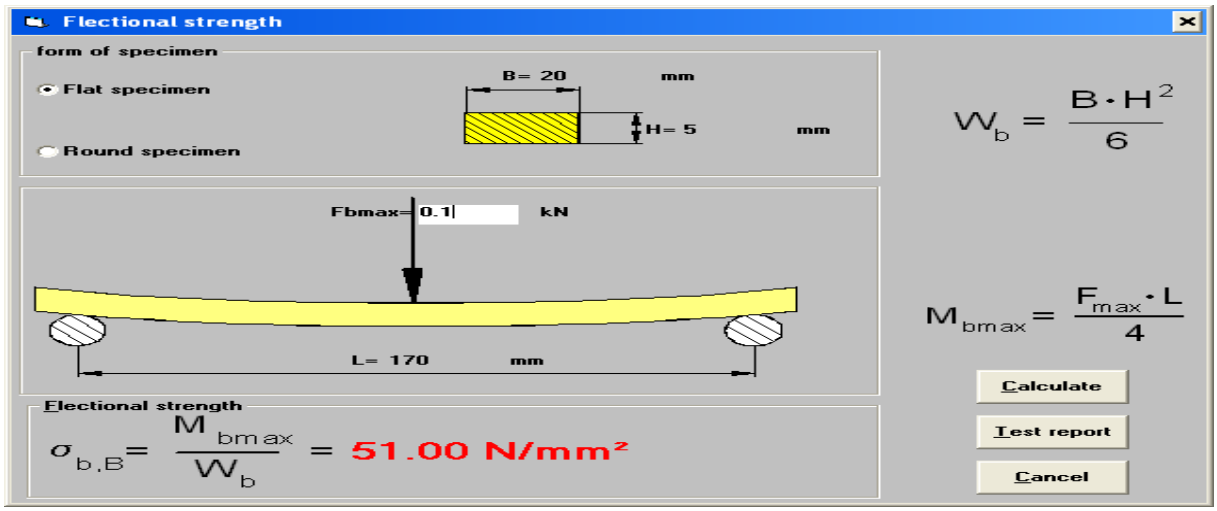
Specimen 2



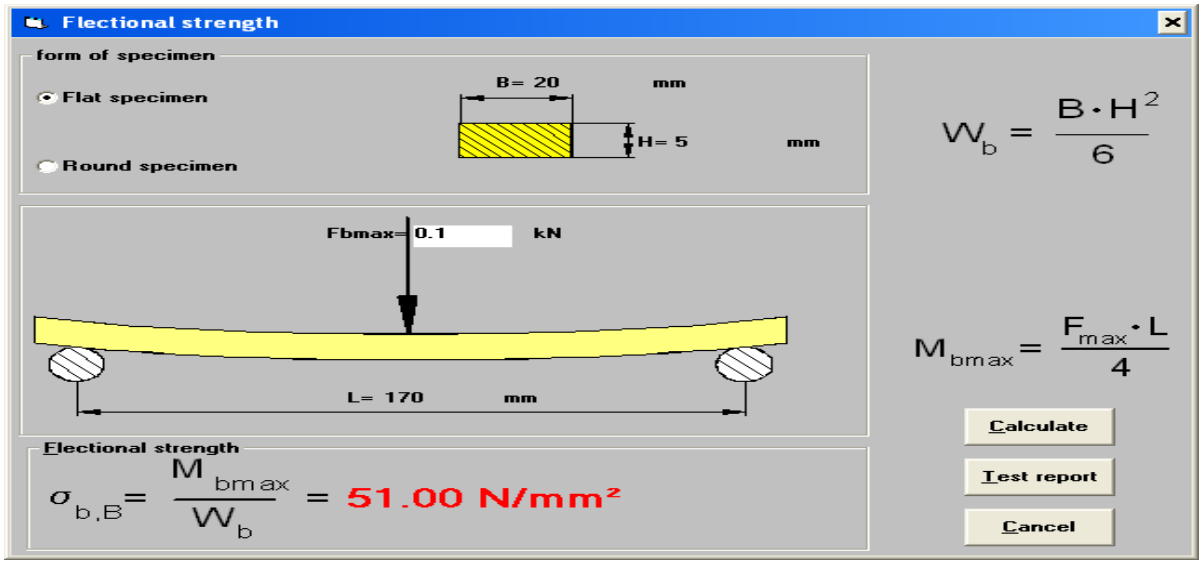
Specimen 3



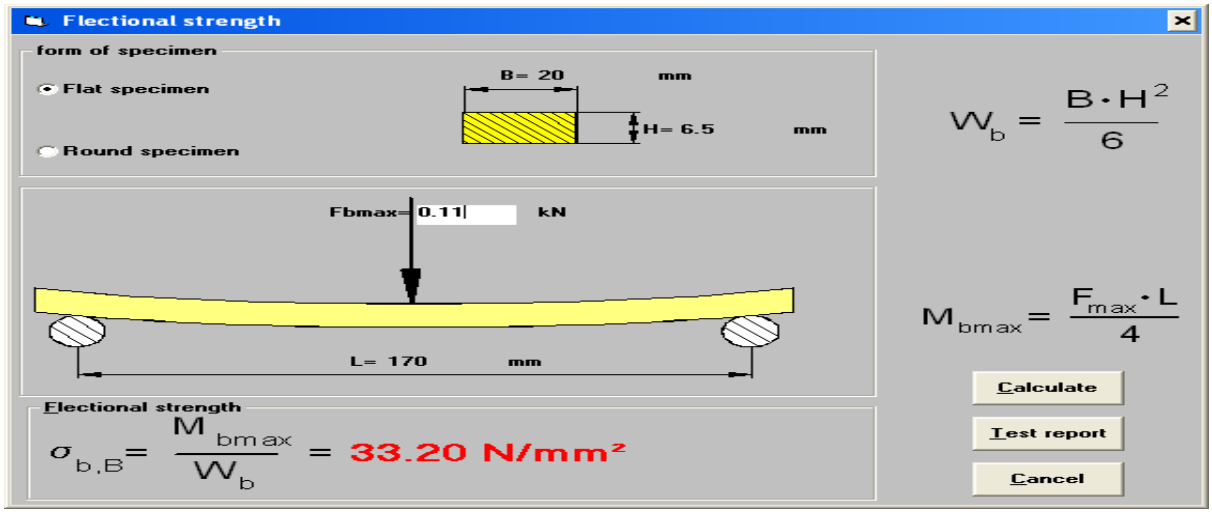
Specimen 4



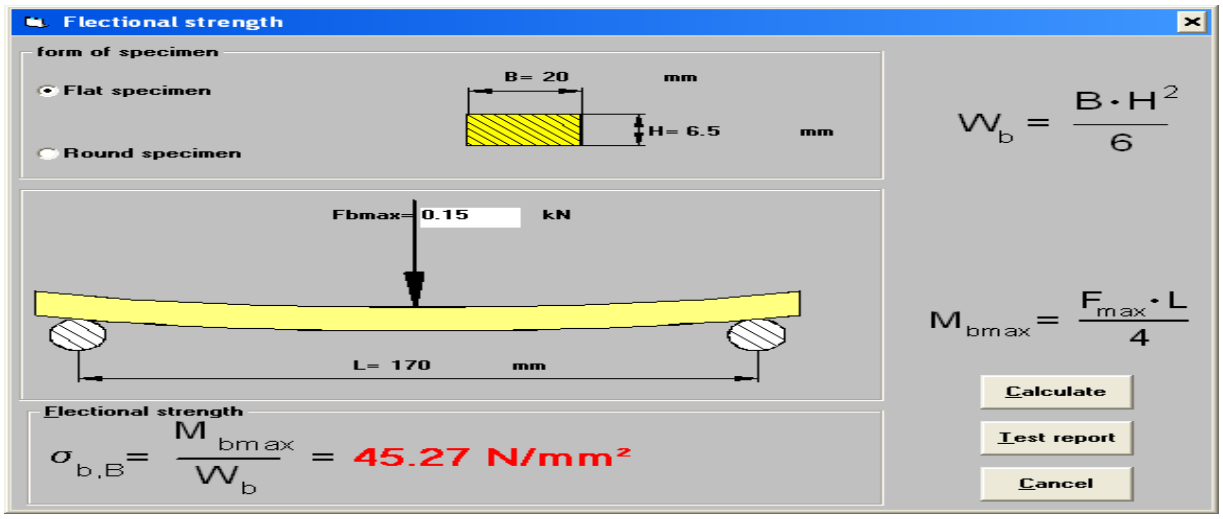
Specimen 5



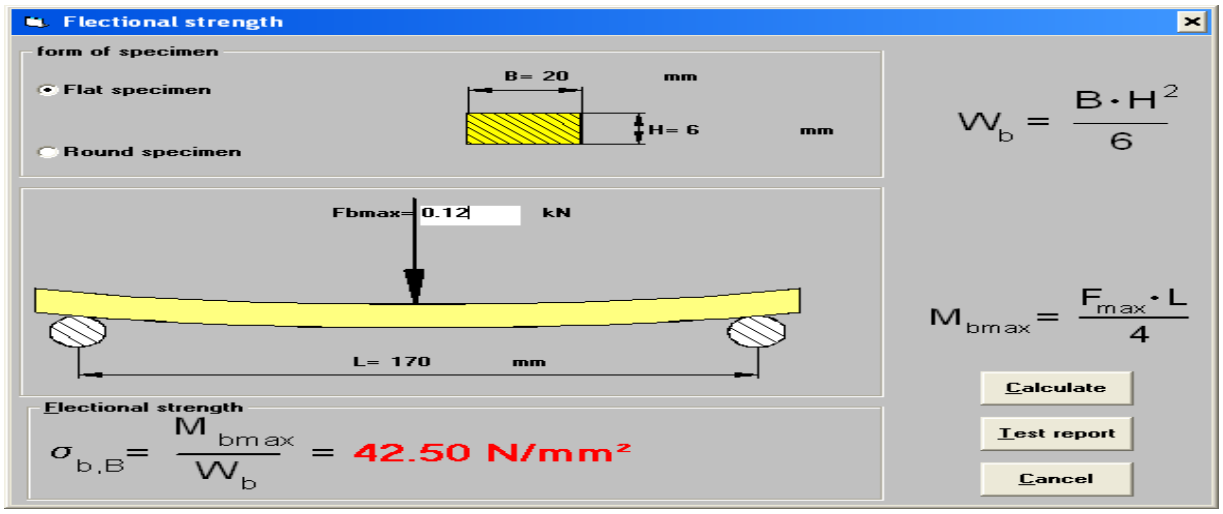
Specimen 6



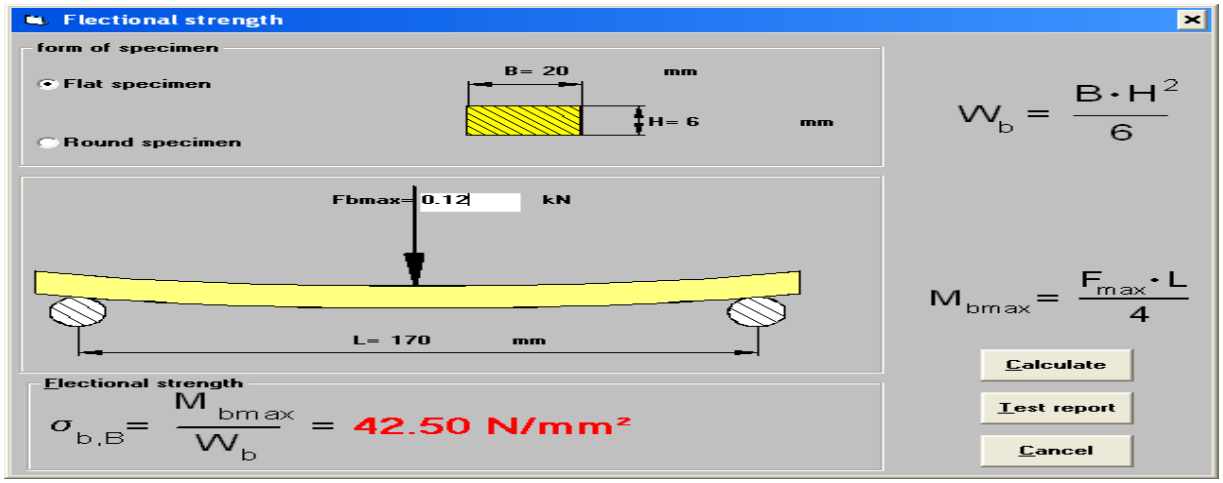
Specimen 7



Specimen 8

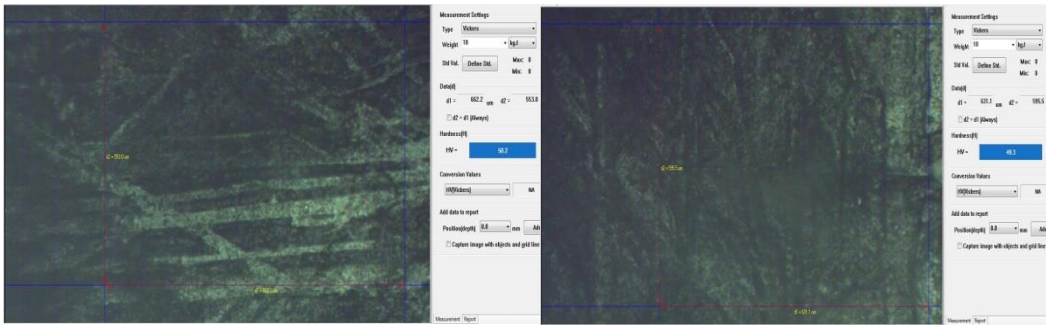


Specimen 9

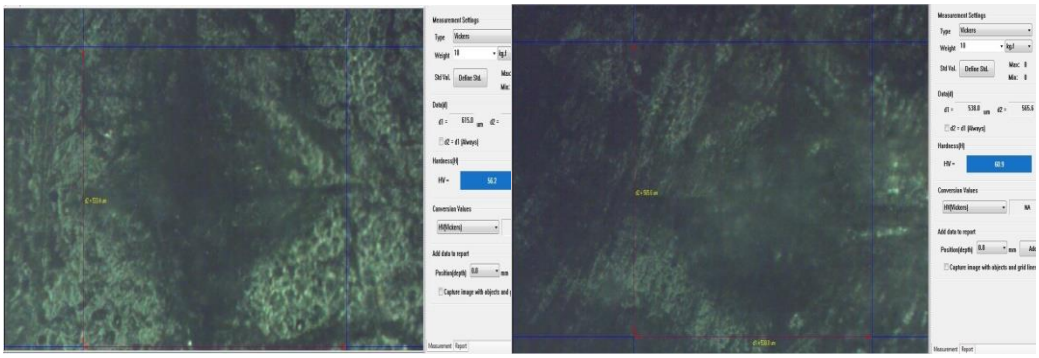


Appendix C: Hardness Test Result

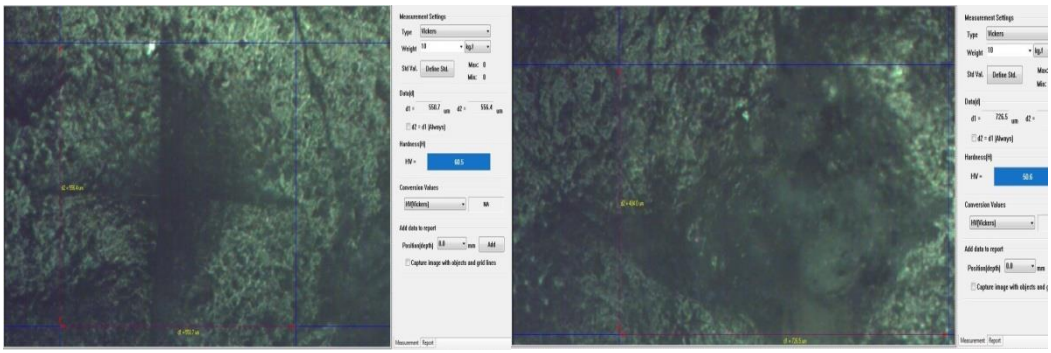
Specimen 1



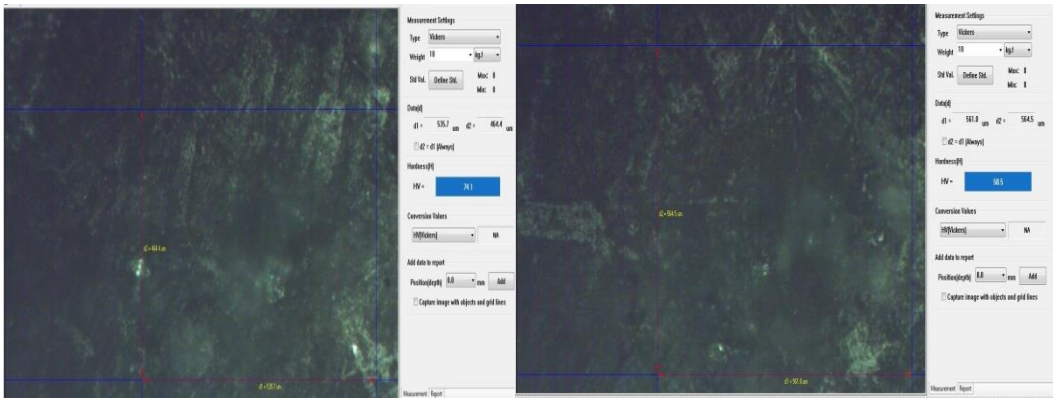
Specimen 2



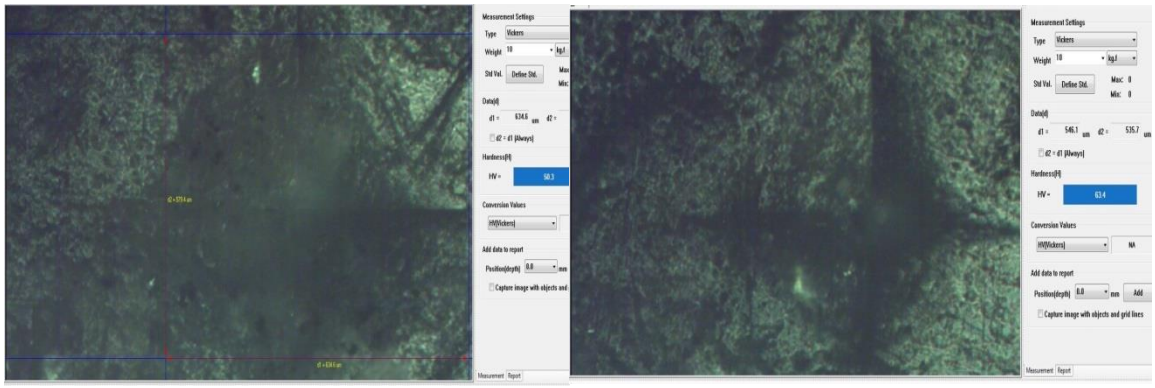
Specimen 3



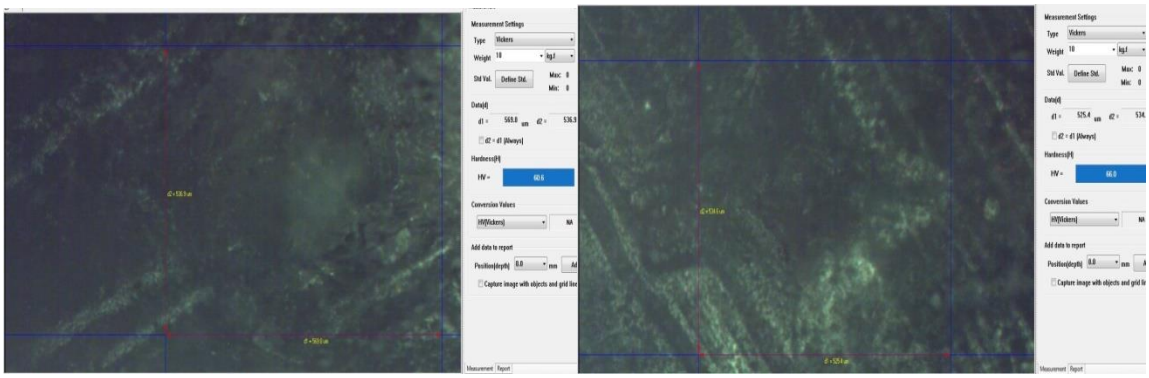
Specimen 4



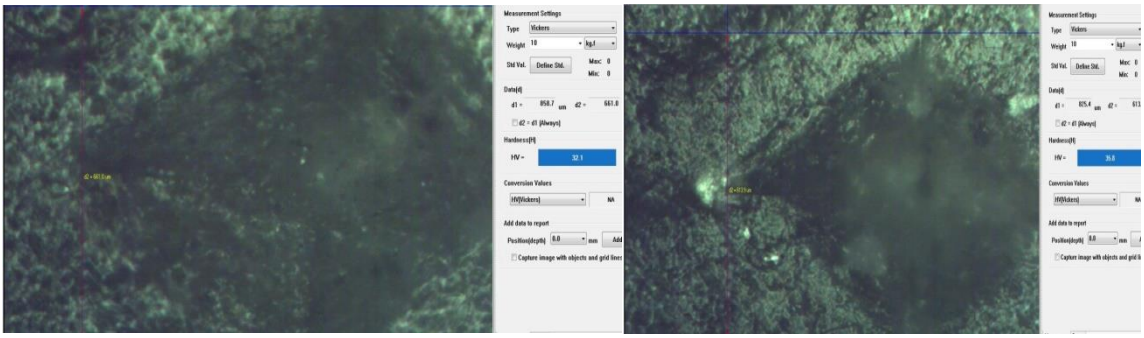
Specimen 5



Specimens 6 and 9



Specimen 7



Specimen 8