MECHANICAL PROPERTIES EVAUATION OF ALUMINA FILLED BANANA FIBER POLYESTER COMPOSITE

Lamrot Kebede Kassa

A Thesis Submitted to

The department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in manufacturing engineering

Office of Graduate Studies

Adama Science and Technology University

October, 2021
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled “Mechanical properties evaluation of alumina filled banana fiber polyester composite” 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.

Lamrot Kebede Kassa _____ _____

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 “Mechanical properties evaluation of alumina filled banana fiber polyester composite” prepared under my guidance by Lamrot Kebede Kassa submitted in partial fulfillment of the requirements for the degree of Masters of Science in manufacturing engineering.

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

Dr. Moera Gutu Jiru (PhD) _____ _____

Advisor Signature Date

APPROVAL

I, the advisors of this thesis entitled “Mechanical properties evaluation of alumina filled banana fiber polyester composite” and developed by Lamrot Kebede Kassa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Moera Gutu Jiru (PhD)	_____	_____
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Lamrot Kebede Kassa have read and evaluated the thesis entitled “Mechanical properties evaluation of alumina filled banana fiber polyester composite” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in manufacturing engineering.

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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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Before anything else, I would like to Thank and Praise, God, the Almighty, and Holy Virgin Mery for the things that have been done to me, for the blessing, and the grace that has been given to carry out this thesis work. The Compilation of this thesis work could not have been fulfilled without the assistant of My Advisor Dr. Moera Gutu I would love to reveal my big and deepest gratitude to him for his encouragement, guidance, and understanding. It was a great honor for me to study under his advice. I would also like to thank Dr. Devandra Kumar for his priceless help and encouragement in completing this thesis and for binging nano powders form India.

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NOMENCLATURE

φ	Distinguishing coefficient
ρ_a	Actual/measured density of composite
ρ_c	Density of composite
ρ_f	Density of fiber
ρ_m	Density of matrix
ρ_p	Density of particulate
ρ_t	Theoretical density
ρ_w	Density of water
b	Width of the sample
d	Athematic mean of two diagonals
D	Indentation surface
F	Applied force for indentation
L	Number of levels
M_C	Mass of composite
M_F	Fiber mass fraction
M_f	Mass of fiber
Mf	Matrix mass fraction
Mm	Mass of matrix
Mp	Mass of particulate
Mp	Mass of polyester
Mt	Total mass
P	Number of factors
S/N	Signal to noise ratio
Vb	Volume of banana fiber
Vf	Fiber volume fraction
Vm	Matrix volume fraction
VP	Volume of Polyester
Vv	Void content
W %	Percentage of water absorption
Wa	Weight of the sample in air
Wf	Final weight of sample after immersed

Wf	Weight of fiber
Wi	Initial weight of sample before immersed
Wm	Weight of matrix
Wp	Weight of particle
Wt. %	Weight percentage
Ww	Weight of the sample in water

LIST OF ACRONYMS AND ABBREVIATIONS

BFRPMC	Banana fiber reinforced polymer matrix composite
CM	Composite material
CMC	Ceramic Matrix Composites
FRPMC	Fiber Reinforced Polymer matrix composite
GFRPC	Glass Fiber Reinforced Polymer composite
GRA	Grey relational analysis
GRC	Grey relational coefficient
GRG	Grey relational grade
HDF	High density fiberboard
HV	Vickers hardness number
MMCs	Metal Matrix Composites
NFs	Natural fibers
NFRPC	Natural fiber reinforced polymer composite
OA	Orthogonal array
OPEFB	Oil palm empty fruit bunch
PMCs	Polymer matrix composites
PRPCs	Particle reinforced polymer composites
TOPSIS	Technique for order of performance by similarity to ideal solution
UPR	Unsaturated Polyester Resin
UTM	Universal Testing Machine
UTS	Ultimate tensile strength or peak stress
UV	Ultraviolet radiation

ABSTRACT

The rising need of eco-friendly, low density, stiff and light weight products in today's world leads to the development of natural fiber reinforced polymer composites to suit various applications in the field of construction, manufacturing, and automotive. Composite consists of two phases fiber and matrix, where each of this has significant advantages. In this study, small scale laboratory composite was fabricated by simple hand layup method using polyester as matrix and nano alumina powder of particle size ≤ 50nm and banana fiber as reinforcing materials. During preparation of specimens, the fiber was taken as random orientation with length of (10mm, 15mm and 20mm) and treated with 0%, 2.5% and 5% NaOH solution. Nine samples were made by varying the weight percentage of banana fiber (10wt.%, 15wt.% and 20wt.%) and nano alumina powder (2wt.%, 4wt.% and 6wt.%). Tests were conducted to evaluate mechanical and physical properties such as tensile, flexural, impact strength, hardness, water absorption, void fraction, microstructural analysis and machinability of the composite. Taguchi based grey relational analysis was used to develop a statistical model to describe the relationship between physical and mechanical properties of composite; independent parameters were selected to optimize the process parameters. The maximum tensile, flexural and impact strength were 61.74MPa, 108.47MPa and 19KJ/m^2 respectively at 15wt.% fiber loading, 2wt.% Al_2O_3, 15mm length and 5% alkali treatment. The minimum tensile strength was 23.7MPa for untreated fiber reinforced composite. Maximum hardness was 164 HV for untreated 20mm length, 4wt.% alumina and 15wt.% fiber loading. The minimum water absorption rate was 2.97% obtained at 10wt.% fiber loading, 6wt.% Al_2O_3, 20mm fiber length and 5%NaOH concentration. Smaller void content of 0.98 was obtained for untreated 10 wt.% fiber loading, 2 wt.% Al_2O_3 and length of 20mm. Morphological analysis depicted alkali treated fiber reinforced composites showed better bonding and void content due to surface modification. Drilled holes had better surface finish for 10mm length fiber at lower fiber loading. The optimum combination obtained through Taguchi based grey relational analysis was 15 wt.% fiber loading, 2wt.% Al_2O_3, 15mm fiber length and 5%NaOH concentration. The investigation revealed the suitability of chopped banana fiber as an effective reinforcement in composite materials. The developed composite material had good mechanical and metallurgical properties besides high strength to weight ratio.

Keywords: *Composite, Matrix, Reinforcement, Hardness, Machinability, Taguchi, Grey relational analysis.*

CHAPTER ONE

INTRODUCTION

1.1. Back ground of the study

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

As the load increases, it takes even more amount of fuel whilst the world gasoline availability is running out beside continuous price increment. Applying high strength, lightweight materials instead of high strength steel reduces fuel consumption. Reducing the weight of the vehicles that transport people and goods is a key for improving the fuel economy and payload (Murugan et al., 2020). Weight reduction can be accomplished by minimizing the amount of material needed to support the structural loads (Singh et al., 2017). The rising environmental concerns, global warming, waste controlling concerns, declining fossil resources, as well as increasing oil prices have resulted in demand for new innovative materials that are environmentally friendly, low density, high strength and cost effective. Green products are being increasingly promoting for sustainable development (Bakri et al., 2017). In the last few decades, research and engineering interest have been shifted from traditional huge materials to fiber reinforced polymer-based materials. Heavy metals were replaced with polymer reinforced with natural /synthetic fibers such as different plants, animal, wood, glass, and carbon fibers due to their exceptional advantages of high strength to weight ratio, non-corrosive property and high fracture toughness.

Composite materials are kind of materials which can be made from one or more constituent materials having different chemical or physical properties and combined to give new material. The properties of composite materials are functions of the properties of matrix and reinforcement material. The matrix material is continuous material which was used for binding the reinforcements and determines the quality of the surface. The matrix materials can be metallic, ceramic or polymeric. Reinforcements added to enhance mechanical properties of matrix and offer quality to composites. The reinforcement in composites could

be either fibrous or non-fibrous. Again fibrous composites are either natural fiber reinforced or synthetic fiber reinforced composites. The factors which affect the properties of fiber reinforced polymer composites are fiber parameters (orientation, length and treatment), fiber-matrix interfacial bonding etc. (Kumar, 2014a). The development of composite materials shows the advancement in history as they make possible the use of an entire class of solid materials and ceramics in many applications. The most important advantages of using composites in automotive is the weight reduction; composites are up to 35% lighter than aluminum and 60% lighter than steel and the use of composites in automotive can reduce overall vehicle weight up to 10% (Kutz & Wiley, 2015).

Agricultural waste and forestry derived natural fibers reinforced polymer composites are attracting the attention of the researchers, professionals, engineers, and scientists than synthetic fiber reinforced composites (Faruk et al., 2012a). The fibers from the natural sources offer certain advantages over synthetic reinforcement fibers for instance low cost, non-toxicity, comparable strength, small density; also minimum waste disposal problems (Kumar, 2014c). Bio - composite materials which are also known as green composites as the name suggests eco - friendly materials manufactured by a matrix and reinforcement of natural fiber. They can be fully bio – materials or partial bio – materials based on the type of fiber reinforcement and the matrix used. Natural fibers are affordable, degradable, manageable, recyclable, and renewable (Bakri et al., 2017). The structure and chemical composition of natural fibers are greatly dependent on climatic condition, soil type, and age of plant and the individual characteristics of each plant variety (Jordan & Chester, 2017). The major drawback of the natural fibers is their hydrophilic nature. This phenomenon reduces the interfacial bonding between the polymer matrix and fiber which has an impact on mechanical properties. This problem should be solved by treating the fiber, which helps to remove the impurities like pectin, fats and lignin in the fiber, resulting in improvement of the bond between fiber and matrix; also increases mechanical properties of fabricated component (Jordan & Chester, 2017; Srinivas et al., 2017).

Among the natural fibers, banana fiber is widely used in many textile, automotive and construction applications. Banana fiber is a lingo-cellulosic fiber with low density, good absorption, soft, thin and has shining attractive appearance (Subramanya et al., 2020); it is a bast fiber which has relatively good mechanical properties and can be obtained at low production cost as it is obtained from agricultural waste. The fiber can be extracted in different ways; manually using iron ribbon/bamboo stripper, mechanically using machine,

chemically using chemicals, natural retting method and biologically using enzymes. As reported by (Dandesa., 2016) all the extraction methods have their own benefits and limitations.

Ceramic-fillers reinforced polymer matrix composites have the potential to replace traditional materials. The advantage of using fillers as reinforcement in composite materials is to improve toughness, mechanical and tribological properties. Composites have been using in large industries besides aerospace and have an increasing number of commercial mechanical engineering applications, such as internal combustion engines; machine components; thermal management and electronic packaging; automobile, train, and aircraft structures and mechanical components, such as brakes, drive shafts, flywheels, tanks, and pressure vessels, dimensionally stable components, process industries' equipment requiring resistance to high-temperature corrosion, oxidation, and wear; offshore and onshore oil exploration and production; marine structures; sports and leisure equipment; ships and boats; and biomedical devices (Kutz & Wiley, 2015).

1.2. Classification of Composite

Composite materials can be classified into many categories depending upon types of matrix material, types of reinforcing material, and nature of reinforcement.

1.2.1. According to the type of matrix materials

According to the type of matrix materials, composite materials are classified into three categories as shown in Figure 1.1. Metal matrix composites, ceramic matrix composites and polymer matrix composites (Ouarhim et al., 2018).

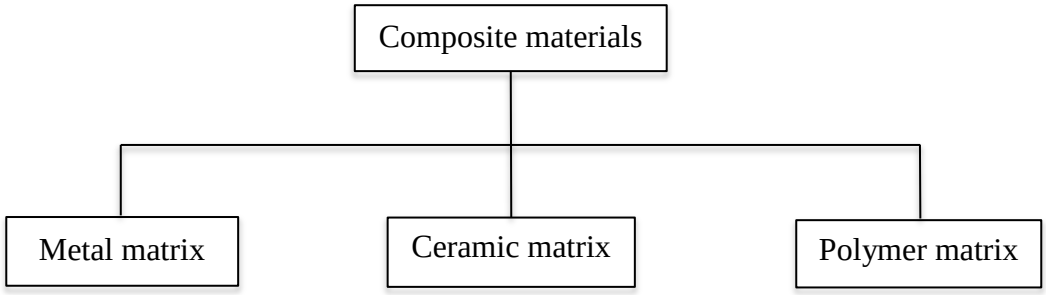

Figure 1.1 Classification of composite based on matrix

i. Metal matrix composites

Composites consisting of metal matrix such as Mg, Al, and Fe are called metal matrix composites. The matrix phase is a metal, which enhances the strength, stiffness, abrasion resistance, thermal conductivity, creep resistance and dimensional stability of the composite

material. They have good engineering properties, exhibit good stiffness, light weight, and low specific weight compared to other metal alloys and metals. Although MMCs have an advantages of low cost remains a major point of interest for many applications (Gaurav et al., 2019).

ii. **Ceramic Matrix Composites**

Composites consisting of a ceramic material combined with a ceramic dispersed phase. The composite is formed by one or more ceramic material embedded into a matrix of another ceramic. The reinforcement phases of ceramic matrix composites are particles, whiskers or fibers. Because of availability of new technologies, the need for high performance products and processing methods, have together improve the growth of advanced ceramic products, however their brittleness still remain as major disadvantage. Advantages include high hardness, light in weight, strength, wear and corrosion resistance (Gaurav et al., 2019).

iii. **Polymer Matrix Composites**

PMCs are made by addition of reinforcement in to a polymer matrix. The reinforcement provides high strength and stiffness to the composite (Ouarhim et al., 2018). Types of reinforcements, type of polymer and the interface between them mainly determines the properties of PMCs (Dixit et al., 2017). Among these three types of matrices, polymer matrix composites were commonly used, because of its advantages such as high strength, low cost, simple manufacturing principle. The demand of polymeric materials in this modernized world is increasing rapidly. Since, it has wide range of advantages over traditional material in terms of high strength to weight ratio, cost, high toughness, high tensile strength and high creep resistance at higher temperatures. Polymers are categorized in to three as shown in Figure1.2.

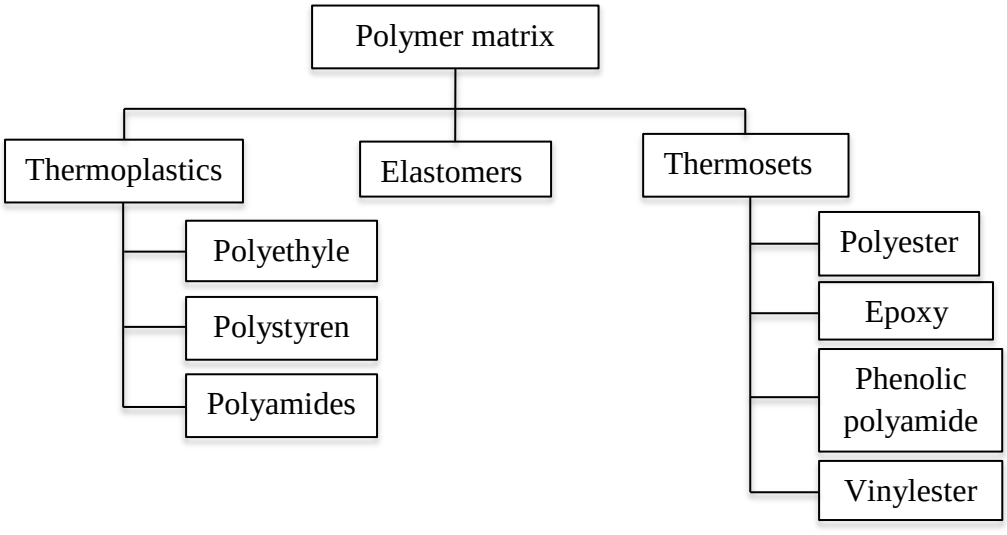

Figure 1.2 Classification of polymer matrix (Ouarhim et al., 2018)

Thermoplastics can be reshaped by heat/pressure, possess high viscosity, but show poor wettability results in gaps between the fiber and final solidified matrix and fibrous surface damage at elevated temperature. Thermoplastic have various properties such as light weight, low thickness. A thermosetting polymer becomes irreversibly hardened upon cured and cannot be re-melted in order to be reshaped. They are not moldable and soften when they are warmed. Thermoset materials offer greater dimensional stability, better rigidity, and higher chemical, electrical, and solvent resistance (Ouarhim et al., 2018). Among various thermoset matrix polyester is most widely used due to its advantages like low cost, low viscosity, fast curing time, not impacted by UV radiation which is essentials for application exposed to the sun, good adhesion to other materials, good mechanical properties (Gaurav et al., 2020). Elastomer is a kind of polymer is determined from flexible polymer, is frequently utilized reciprocally. Elastomers have properties like low density and high disappointment strain compare with other materials.

1.2.2. According to type of reinforcement

Polymer composites classified based on reinforcing material into three groups as shown in Figure 1.3. Fiber reinforced polymer matrix composites, particulate reinforced polymer matrix composites and structural composites.

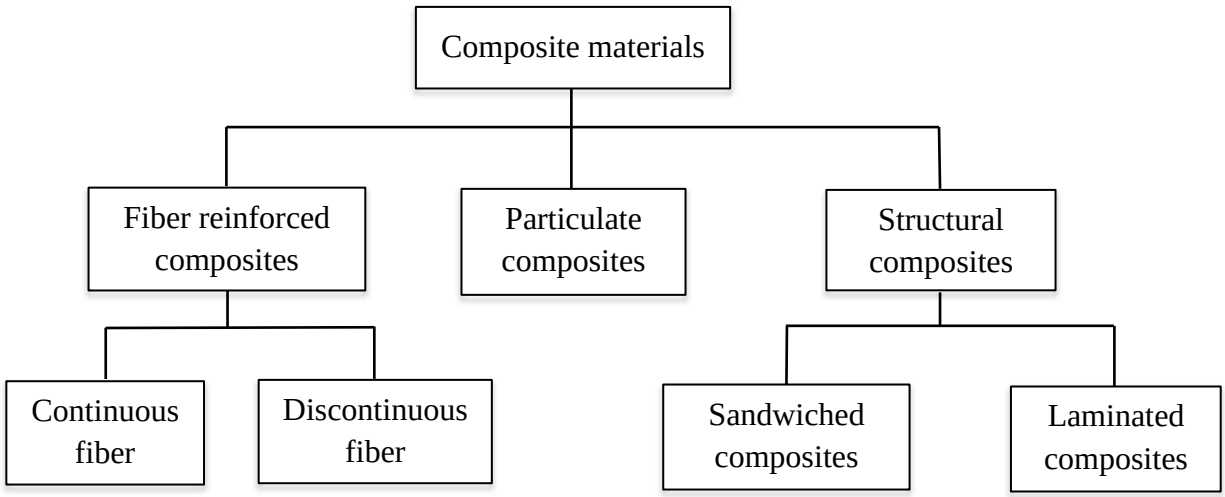

Figure 1.3 Classification of composite based on reinforcement (Rajak et al., 2019)

i. Particulate Reinforced Composites

A composite whose reinforcement is a particle called as particulate reinforced composites. Particulates are non-fibrous and having no long dimension. The size of particulate used as reinforcement determines its effect on the properties of the composite. The reinforced particles share the load up to very small limit than those of fibers in the fibrous composites;

therefore particles are offered good stiffness but not strength. Particles are added to improve the mechanical properties of the composite material. It also increases wear resistance and abrasion resistance, surface hardness and machinability and also reduces the cost of the material (Gaurav et al., 2019). Ceramics, metal, inorganic and organic particles restrict the deformation of the material and provide good material stiffness (Rajak et al., 2019).

ii. Fiber Reinforced Composites

FRCs is prepared by embedding fibers in to the matrix. The matrix binds the fiber in to the proper place and though the matrix, the load is transferred to fibers. Fibrous composites can be: continuous/long or discontinuous/short. Continuous fibers are stiffer and tougher as compared to the matrix, it can be unidirectional in which the fibers are arranged in one direction or bidirectional in which the fibers are arranged in both directions. The composites of unidirectional arrangement are very strong in the longitudinal direction of fiber but generally weak in the perpendicular direction to fibers (Rajak et al., 2019). In bidirectional reinforcement, the strength in both directions is equal. In some applications, very less amount of reinforcement is provided in perpendicular direction to prevent damage and separation of fiber in handling due to the poor strength in another fiber direction. In such cases, the strength in the transverse direction is less as compare to the strength in the direction of reinforcement. In short fiber reinforced composite, the length of fiber affects the properties of composite. This type of composite is prepared by randomly arrange short fibers in liquid resin. The properties of short fiber composite are isotropic in nature (Gaurav et al., 2019). Hybrid fiber reinforced composites are those where two or more types of fiber are reinforced in a single matrix (Rajak et al., 2019).

Various fibers were used as reinforcement in polymer composites. Among the various natural fibers banana fiber was used as reinforcement in the present work. The mechanical and physical properties of hybrid composite was evaluated and assessed for potential utilization in the automotive industry.

iii. Hybrid Composites

Hybrid composite is the new kind of fiber-reinforced composite; it can be made with the combination of two or more different kind of fiber in a single matrix system. Utilization of hybrid composite improves the properties and also it helps to reduce the cost. In hybrid composite different fibers are combined with the matrix for a better property that cannot be obtained in single fiber matrix composite. In polymer composite, fibers are divided as man-

made fibers known as synthetic or natural fibers. Some common man-made fibers are carbon, aramid, and glass. Nowadays multiple different sources of natural fibers have been experimentally studied for utilizing in plastics such as flax, hemp, jute, rice husk, bamboo, kenaf, oil palm, sisal, coir, banana fiber, pineapple leaf fiber etc. Hybrid composites are also formed by incorporation of filler material into fiber–matrix composite. These filler particles are of nanometer or molecular level. Filler materials are also used to reduce the cost of fiber and to improve the properties such as abrasion resistance, hardness and shrinkage of the composite. Filler materials are classified as conventional and non-conventional filler. Conventional fillers are TiO2, Al_2O_3, SiC, SiO_2, etc and Non-conventional fillers are Nano clay, and industrial wastes like fly ash (Gaurav et al., 2019).

1.3. Statement of Problem

The major challenge in automobile industry was the weight of the vehicles, which has a direct influence on fuel consumption. A significant rise in the amount of energy used by vehicles is due to the use of more steel, which increases the weight of the vehicle. Automobile fuel consumption and emissions were also issues in the automotive industry. Most of the time, automobile bodies and spare parts have been imported from industrialized nations abroad into developing countries including Ethiopia. These imported materials are heavy, expensive and have an impact on the environment. Nowadays natural fiber composite has been replacing heavy metals and glass fiber composites, which have positive environmental effects after disposal and require less manufacturing costs, in aerospace, automotive, and marine applications due to their beneficial features. Among many agricultural products banana is one of the major sources of fruit in Ethiopia, it covers about 68 % of the total fruit (Woldu et al., 2015). The increase in the demand of banana fruit leads to higher production annually. After the fruits have been cultivated, the stem has being disposed as biomass waste in case of our country's trend. Hence this increase in waste is also a big challenge for farmers those had high production, which covers many hectares of banana plantation. Therefore, utilizing banana fiber as alternative for composite materials in automotive body parts will play a vital role in manufacturing sector, which reduces the weight of a vehicle component, reduce file consumption and energy and also reduce biomass waste. Economic benefits were also gained for farmers from waste products. However, banana fiber is hydrophilic in nature; literatures revealed that to avoid this fiber treatment, incorporating micro/nanoparticle or hybridizing with other natural fibers improves its mechanical property. Reinforcing natural fiber with nano particle is believed to improve the mechanical properties, reduce the cost and weight of

the composite. The reason for this study was to produce automotive body from nano alumina filled banana fiber reinforced material of having better strength, long service time, light weight and cost effective to replace metals and reduce import of parts and biomass waste.

1.4. Objectives

1.4.1. General objective

The general objective of this thesis was mechanical properties evaluation of alumina filled banana fiber polyester composite for automotive interior body application.

1.4.2. Specific objective

- To perform chemical treatment of banana fibers to improve its interfacial adhesion,
- To fabricate nano Al_2O_3 filled chopped banana fiber reinforced polyester composite materials with various weight fraction,
- To conduct tensile, flexural, impact, hardness, density and void fraction tests on composite specimens,
- To investigate water absorption and morphological analysis of composite specimens,
- To study the influences of fabrication process parameters such as fiber length, fiber content, filler content and NaOH concentration on physical and mechanical properties of composites and optimize those parameters using Taguchi and Gray relational analysis,
- To test the machinability of the fabricated composite.

1.5. Scope of the study

This work includes all the necessary steps to the preparation of composite samples with varying proportions of nano Al_2O_3 filler and chopped banana fiber at the laboratory scale. Preparation of specimens from the fabricated composites, and the mechanical and physical properties were tested. The influences of fabrication process parameters such as fiber content, filler content, fiber length and alkali treatment concentration were evaluated and optimization of those process parameters through Taguchi based grey relational analysis was also included in this work.

1.6. Significance of the study

Natural fiber reinforced polymer composites have potential benefits such as low density, less expensive and environmentally friendly when compared to synthetic composite products, thus providing advantages to be used in commercial applications (automotive and aerospace

industry, buildings, and constructions). Modification of matrix phase with micro/nano sized particles resulted in positive impact on the mechanical behavior of polymer composites.

Advantages of the study:

- Manufacture low specific weight, higher specific strength and high stiffness material in automotive components such as doors, roof liner, various damping and insulation parts, wheel arch, heed rest and bumper.
- Economic benefits for farmers cultivating banana fruit in our country Ethiopia,
- Options for new production technologies and materials,
- Cheaper, non-hazardous manufacturing process and easy disposal after use.

1.7. Limitation of the study

For performing the research there were several constraints faced; these constraints are described below;

- Non availability of nano-particles and epoxy resin supply in Ethiopia,
- Non availability of composite manufacturing facilities in ASTU,
- The machineries used for this research were in different cities and laboratories. Working in various laboratories caused waste of time and incur of extra cost.
- The various machines used were also designed for metals and getting the desired information was difficult when testing.

1.8. Organization of the thesis

The organization of the thesis had been done as follows. Chapter one includes introduction in which the background, statement of problem, objectives, scope of the study, significance of the study and limitations were described. Chapter two includes the literature survey, a summary of the literature, and the research gaps. Chapter three covers the material and methods, which include the fabrication and characterization of mechanical and physical properties. Whereas chapter four deals with the results and discussion. This implies that the result for every response in addition to this the optimization of parameters were included using the Taguchi method and the gray relational analyses. Chapter five comprises the conclusion and recommendation. The interpretations of the obtained results were analyzed and recommendation and future work was directed.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In this chapter a review of available literature was offered to provide background information on the issues to be focused in this thesis and to highlight the importance of the present study. The review deals with various aspects of the polymer composites with a special reference to ceramic powder filled fiber reinforced polymer composites. This chapter contains review of existing research reports:

- On natural fiber and mechanical properties of natural fiber composites
- On mechanical properties of banana fiber reinforced polymer composites
- On Particulate filled Fiber Reinforced Polymer Composites
- On manufacturing of natural fiber reinforced polymer composite
- On Taguchi and Grey analysis method of optimization and finally summery and research gap were presented.

2.2. Natural fibers and mechanical properties of natural fiber reinforced composites

Fibers are classified in two main groups as natural and synthetic fibers. Our concern in this study was mainly focused on natural fibers. The attraction in utilizing natural fiber as reinforcement in composites has increased radically in last few years. This was because society starts to concern about their environment and lightweight materials were demanded in many industrial sectors.

Natural fibers obtained from plants, animals and minerals were the main constituent of NFRPCs. Natural fibers become more popular reinforcement material in polymer composites since they possess light weight, low cost, biodegradable, renewable and easily available in nature (Waghmare, 2017). The abundant availability and accessibility of plant fibers are two main reasons for the growing interest in sustainable technologies (Ramesh et al., 2017). The mechanical property of natural fibers varies from fiber to fiber. It can be influenced by origin, age, type of fiber, soil fertility, volume fraction, physical properties, various structure, environmental conditions as well as processing methods. Different matrix systems have also different properties (Arpitha & Yogesha, 2017).

Natural fibers are one such successful material that replaces the synthetic fibers and its products are relevant for the light weight and energy-conserving applications. Automotive and aircrafts industries were actively emerging with special forms of herbal fibers, especially on hemp, flax, banana, sisal and bio-resins structures for their indoor components (Sathishkumar et al., 2014).

2.2.1. Classification of natural fiber

A natural fiber is a group of cells having extended length and insignificant diameter. They can be obtained as continuous filaments or discrete elongated pieces like threads. Natural fibers can be classified into three types on the basis of the origin of source as follows (Hasan et al., 2020):

i. Plant/Vegetable fiber

Plant fibers are fibers which were directly obtained from parts of plants, the most popular and most abundant natural sources of reinforcement used in manufacturing of composites. Based on the parts of plant from which they are obtained they can be classified as shown in Table 2.1. These fibers have higher tensile strength than other fibers (Hasan et al., 2020). As a result they are used for durable yarn, fabric, packaging, and paper (Faruk et al., 2012b). Hard fibers are those which are obtained from leaves like sisal and agave or from fruit like coir around the hard shell of coconuts. Plant fiber mainly composed of cellulose and those are most widely used to make paper and cloth. Cellulose produces long, often highly shiny fibers when suitably prepared (Saba et al., 2014).

Table 2.1 Sources of vegetable/plant fiber and their varieties (Hasan et al., 2020; Saba et al., 2014)

Source	Types (varieties)
Bast	Flax, Jute, Hemp, Ramie, Roselle, Rattan, Kenaf, Mesta, Banana
Leaf	Sisal, Manila, Abaca, Banana, Palm, Henequen, Date palm, Pineapple, Agave, Raphe
Wood	Hardwood, Soft wood, Saw dust
Seed	Kapok, Cotton, Loofah, Milkweed, Alfalfa
Fruit	Coconut, Betel nut, Coir, Oil palm
Stalk	Rice, Wheat, Barley, Oat, Rye, Maize
Grass	Bamboo, Bagasse, Corn, Saibai, Rape, Esparto, Canary

The constituents of natural fibers are cellulose, hemicellulose, lignin, pectin etc. The detail compositions of some selected natural fibers were displayed in Table 2.2.

Table 2.2 Composition of some commonly used natural fibers (Hasan et al., 2020)

Fiber	Cellulose (wt. %)	Hemicellulose (wt. %)	Lignin (wt.%)	Pectin (wt. %)	Moisture (wt.%)	Waxes
Cotton	85-90	5.7	_	0-1	7.85-8.5	0.6
Bamboo	60.8	0.5	32	_	_	_
Flax	71	18.6-20.6	2.3	2.2	8-12	1.7
Hemp	70-74	17.9-20.4	3.7-5.7	0.9	6.2-12	0.8
Jute	61.1-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5
Kenaf	45-47	21.5	8-13	3-5	_	_
Ramie	68.6-76.2	13.1-16.7	0.6-0.7	1.9	7.5-17	0.3
Sisal	66-78	10-14	10-14	10	10-22	2
Banana	63-64	19	5	_	10-12	_
Coir	32-43	0.15-0.25	40-45	3-4	8	_
Bagasse	32-34	19-24	25-32	_	6-12	_

ii. Mineral Fibers

Mineral fibers are those which are obtained from minerals. These are naturally happening fiber or somewhat changed fiber. Many fibers are made from natural mineral sources or are manufactured from inorganic and mineral salts. These fibers are mainly the derivatives of silica or other metal oxides. In addition, metal fibers either alone or mixed in a suitable organic polymer can be produced (Dandesa, 2016). The common feature of these fibers is their inorganic or metallic composition and tendency to be heat resistant and nonflammable, with the exception of polymer-coated metallic fibers. Some common mineral fibers are serpentine, amphiboles and anthophyllite (Hasan et al., 2020).

iii. Animal Fibers

Animal fibers are natural fibers that consist of largely particular proteins. Instances are silk, hair/fur, wool and feathers (Saba et al., 2014). The animal fibers used most commonly both in the manufacturing world as well as by the hand spinners are wool from domestic sheep and silk. Not all animal fibers have the same properties, and even within a species the fiber is not consistent.

Natural fiber composites exhibit good electrical resistance, good thermal and acoustic insulating properties, improved mechanical properties and higher resistance to fracture.

Common application of natural fibers-reinforced composites includes interior paneling for aircraft, and automobiles, household tables, chairs, window frames, laptop cases, and other consumer items. Natural fibers composite are appreciated for their sustainability and light weight compared to similar conventional composites, which makes them especially popular in the automotive industry (Jordan and Chester, 2017). Among various NFs, banana fiber was considered as a potential reinforcement in polymer composites due to its many advantages like easy availability, low cost, biodegradable, comparable strength properties etc.

Prasad et al., (2020) carried out experiments to evaluate the physical behavior of chemically treated sugarcane bagasse fiber reinforced epoxy composite. The effect of NaOH treatment, fiber length and fiber varieties on mechanical and physical properties of the composite were studied. Fibers of different length (5, 10, 15mm) were chopped and treated with 5%NaOH solution for 24hrs. Composite samples were fabricated by conventional hand layup method. Test results showed that minimum void fraction was obtained for 5mm fiber length of all varieties. For the ultimate tensile strength, elongation and hardness 10mm fiber length reinforced composite was optimum fiber length. The maximum wear was obtained for 5mm length and minimum for 10mm sample.

Sajin et al., (2020) studied the influence of fiber length on mechanical properties of jute fiber reinforced polyester composites. The fiber was chopped in to various lengths (5mm, 10mm, 15mm, 20mm and 25mm) and composite samples were fabricated by compression molding method. The tensile, flexural, impact strength and morphology of the composite were assessed. The optimum mechanical properties for the developed composites were obtained at fiber length of 5mm compared with other samples. They concluded that jute fiber of 5mm length exhibited significant properties.

Naik et al., (2018) investigated the fracture toughness and mechanical properties of short banana fiber reinforced polymer composite. Fibers with varying weight percentage of banana (30%, 35% and 40%) and fiber length (4, 6 and 8mm) were fabricated by simple hand layup method. Test results proved that with an increase in fiber weight percentage fracture toughness increase. The tensile strength of 30% banana was 17.1MPa which was the best result compared with other samples.

Kumar & Singh, (2020) studied the mechanical properties of bidirectional basalt fiber mat based epoxy composite. The specimens were prepared by varying fiber orientation of 45^0, 60^0 and 90^0 by hand layup technique. Mechanical properties such as tensile strength, tensile

modulus, flexural strength and flexural modulus, impact strength (Charpy and Izod) as well as micro hardness were evaluated experimentally. The result indicated that maximum mechanical properties were obtained for 90^0 fiber orientation; Lower value was obtained for 45^0 fiber orientation.

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

Lokesh et al., (2020) analyzed the mechanical properties of bamboo fiber reinforced epoxy composite. The specimens were fabricated by varying the weight percentage of bamboo fiber with hand layup method followed by compression molding. Depending on the test result they have concluded that the mechanical properties such as tensile, flexural and impact strength were influenced by the NaOH treatment used. Lower values of impact strength and flexural strength were obtained at higher weight percentage of bamboo fiber.

Prasad et al., (2021) discussed the effect of fiber loading and fiber variety on physical and mechanical properties of rambans fiber reinforced polyester composite. Various weight percentage of fiber (5%, 10%, 15% and 20%) chopped (10mm) length fiber, and unidirectional mat was used to prepare the samples. Four chopped fiber samples, four unidirectional mat samples and pure polyester were fabricated by compression molding method and optimized by TOPSIS. The test results indicated that specimen with 15wt.% fiber load has superior mechanical properties and ranked 1 by TOPSIS. The tensile strength was obtained as 95.25MPa showing an increase of 225.93% against pure polyester sample. Impact and flexural strength also increased with fiber loading up to 15% and decline beyond 15%fiber loading. The hardness decreased with an increase in fiber loading.

2.3. Banana fiber extraction techniques

Banana is one of the oldest cultivated plants in the world; it has been cultivated as garden plant for several years in Ethiopia. Nowadays it is cultivated in both small scale farmers and state farmers. Banana fibers can be easily extracted through different methods from the pseudo steam of banana plant after the fruits were collected and the leaf was utilized (Waghmare, 2017). The physical properties of banana fiber which includes the tensile strength, density and young's modulus was shown in Table 2.4. Mechanical properties of

short banana fiber as reported by (Kumar, 2014b) indicates that: the volume fraction of the short banana fiber significantly affects the dynamic mechanical properties of fiber reinforced polyester composites. The chemical composition of banana fiber was shown in Table 2.3.

Table 2.3 Chemical composition of banana fiber(Adhikari & Gowda, 2017)

Chemical property	Range in (%)
Cellulose	60-65
Hemicellulose	6-19
Lignin	5-10
Pectin	3-5
Ash	1-3
Extractives	3-6

Table 2.4 Physical properties of banana fiber (Adhikari & Gowda, 2017)

Property	Range
Tensile strength (MPa)	529-914
Specific tensile strength (MPa)	392-677
Young's modulus (GPa)	27-32
Specific Young's modulus (GPa)	20-24
Failure strain (%)	1-3
Density (Kg/m^3)	750-950

The mechanical properties of natural fibers are influenced by the composition, structure and the number of defects in a fiber. Natural cellulose fibers can be extracted from lignocellulosics by products using bacteria and fungi, mechanical and chemical methods. Retting is also a traditional method to extract fibers which uses bacteria and fungi in the environment to remove pectin, lignin and other substances. As reported by (Amel et al., 2013) extraction techniques allow the increase and decrease of mechanical properties of natural fiber. Banana fiber can also be extracted through different methods.

2.3.1. Manual Extraction

Manual extraction involves stripping, it is most widely used and oldest technique of putting off fibers from the leaf sheaths. Banana fiber can be extracted from waste stalk, leaf and roots of banana plant. But most abundant of banana fiber is obtained from the surface near to the outer sheath of the steam. It can be peeled of easily using ribbons or hand. It was simple

stripping process in which trunks were pulled apart and sheath was undressed. Finally the fiber can be obtained by removing pulpy part using ribbons (Dandesa, 2016).

2.3.2. Chemical Extraction

For chemical extraction per magnetite, alkali or peroxide treatment is used. The alkali NaOH, sulfuric acid, hydrogen peroxide, protease, pectinase, and sodium citrate are used. NaOH is the most commonly used chemical for fiber extraction. Chemical concentration, temperature and the period of treatment are the main factor for the quality of extracted fiber.

Kumar, (2014d) studied retting extraction techniques of naturally occurring banana fibers. The retting was conducted in four different NaOH concentration; 0.0M, 0.01M, 0.05M and 0.1M solutions. The PH of the solution was obtained, at the range of 6.71 to 7.60 while the optimum PH was found to be 7.39. From the result they concluded that the higher the retting media, the longer it takes the retting solution to come up to the region of optimum PH value.

Chengoué et al., (2020) investigated the effect of extraction process on the physico-mechanical behavior of banana trunk fibers used as reinforcement in composite materials. The study was carried out in three extraction process; soaking in cold caustic soda, cooking in water and water retting, then characterization was done on fibers resulting from these extraction processes. The test yields the physico-mechanical properties of fibers vary according to extraction method used. Result shows that the highest physical characteristics were obtained by extraction after cooking in water with a maximum density of 1.02 g/cm^3 and maximum absorption rate of 15.17% for water retting. It can be concluded that extraction after cooking in water revealed the best tensile characteristics of the fibers, tensile strength (816.6 MPa) and elongation at break (2.83%).

2.3.3. Mechanical Extraction

It is extraction of fiber using decorticator machine. The simple, non-laborious and in short time high fiber was extracted, however it is expensive and machines are not easily available.

2.3.4. Enzyme Treatment

The use of enzyme technology is becoming increasingly substantial for the processing of natural fibers. Currently, the use of enzymes in the field of textile and natural fiber modification is also rapidly increasing. A major reason for embracing this technology was the fact that the application of enzymes was environmentally friendly; however, this method is very expensive (Faruk et al., 2012a).

2.4. Mechanical properties of banana fiber reinforced polymer composite

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

Sanjay et al., (2016) studied the physical and mechanical properties of Banana and E-Glass reinforced polyester composites. The density and water absorption properties of each laminates were also evaluated. The result indicated that, the maximum tensile strength of pure glass layer laminate was 250 MPa and minimum of pure banana layer laminate was 6.45 MPa. The maximum flexural strength, maximum impact strength and maximum hardness was observed for pure glass fabric laminate and minimum for pure banana fabric laminate. Pure E-glass fabric laminate absorbs more amount of water and pure banana fabric laminate absorbs minimum amount of water. They also found that as the glass layer in the laminate increases its mechanical properties enhanced.

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

Prasad et al., (2019) studied the mechanical properties of banana and jute fiber reinforced polyester composite. Composite samples were fabricated by varying the volume fraction of the 5%, 10%, 15%, 20% and 25% and length of 10mm for both banana and jute fibers. The thickness of the fabricated samples varied from 3mm to 5mm. Tensile and flexural tests were conducted. Results revealed that there was an increase in tensile strength of BFRPC and

JFRPC with an increase in fiber volume fraction and the optimum tensile strength was achieved at a fiber volume fraction of 25%. The flexural strength of BFRPC and JFRPC also increases with the increase in fiber volume fraction up to 20% and further increase decrease the flexural strength.

Venkateshwaran et al., (2011) investigated the tensile, flexural, impact, water absorption and SEM analysis of banana fiber reinforced epoxy composite. Composite samples were made of fiber length (5, 10, 15 and 20mm) and weight ratio (8, 12, 16 and 20) through hand layup method. The results showed that the optimum fiber length and weight % for tensile, flexural and impact strength were 15mm and 16% respectively as shown in Figure 2.1. The maximum values were 16.39MPa, 57.53MPa and 2.25J/m respectively. The moisture absorption of the composite was highly influenced by fiber content than fiber length and for all samples the value was around 5%. SEM image showed that increasing the fiber content above 16% yield in poor interfacial adhesion between fiber and matrix. They have reported that the main factors that affect the properties of composite material were fiber length and content.

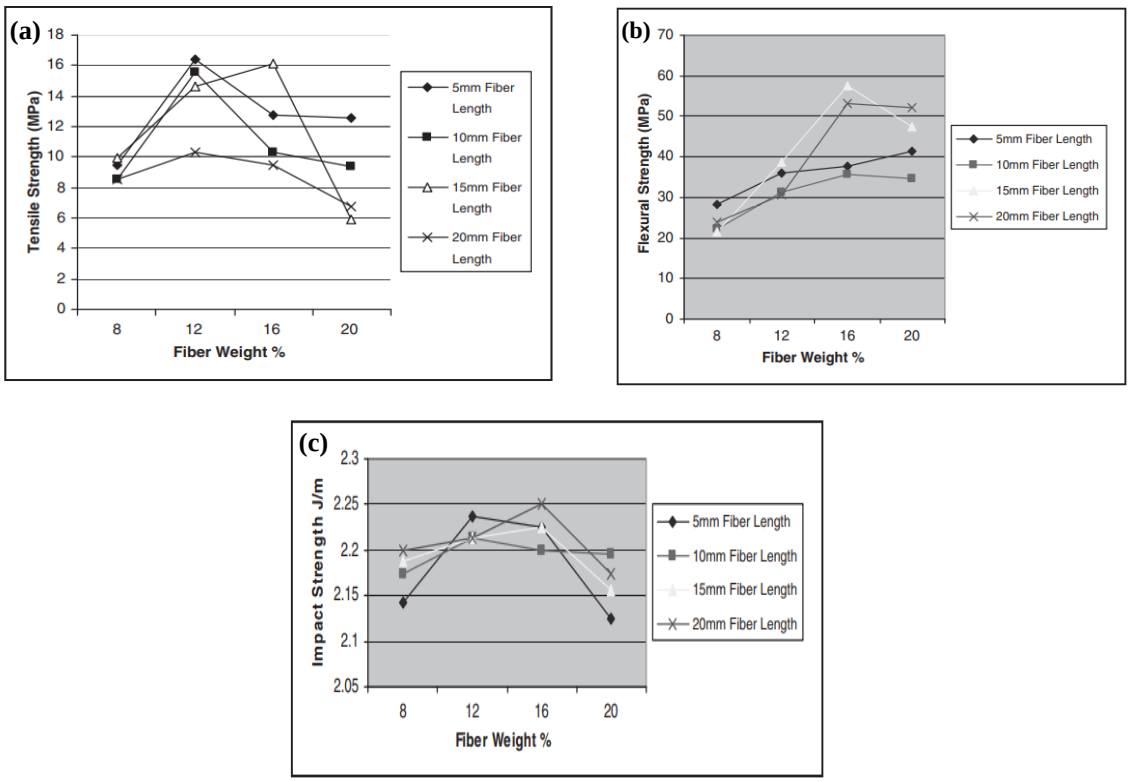

Figure 2.1 Effect of fiber wt.% and length on (a) tensile strength (b) flexural strength (c) impact strength

Adhikari & Gowda, (2017) studied the tensile, flexural, and impact strength of short randomly oriented banana/jute hybrid polyester composite. They have taken 25%, 20%, 15%,

10% and 5% fiber volume fraction by maintaining banana/jute volume in 1:1 ratio. The specimens were prepared for 3mm as well as 5mm thickness. The optimum fiber volume fraction for tensile as well as flexural strength was found at 15% and impact strength increase in fiber loading continuously up to 25%. The mechanical properties slightly increase with the increase in thickness of specimen.

Balaji et al., (2020) evaluated the mechanical and thermal properties of banana fiber reinforced epoxy composite. Banana fiber was chopped in to a length of 10mm and 20mm and treated with 5% NaOH solution for 2 hr. The samples were made by compression molding technique. Test result showed that composite sample of 15wt.% and 20mm length had the highest mechanical strength. The maximum tensile, flexural, impact strength and hardness were 30.4MPa, 56.3MPa, 2.7J/mm^2 and 68HRB respectively. With further increase in the weight percentage of banana fiber reinforcement, the mechanical strength decreased. Flexural strength, impact strength and hardness were optimal for 15wt.% fiber loading and 20mm fiber length.

Ramesh et al., (2014) studied the mechanical properties of banana fiber reinforced epoxy composite. Three composite samples of varying length and volume fraction were prepared by using conventional hand layup technique followed by compression molding. Sample1 (40% banana fiber and 60% epoxy), sample2 (50% banana fiber and 50% epoxy) and sample3 (60% banana fiber and 40% epoxy resin). Tensile, flexural, impact and SEM analysis tests were conducted according to the ASTM standard. Results showed that the maximum tensile strength obtained was 112.58MPa for sample2 and the maximum flexural strength was 76.53MPa hold by the same combination as shown in Figure 2.2. The maximum impact strength was 11.22J hold by sample3 and followed by sample2 of 9.48J.

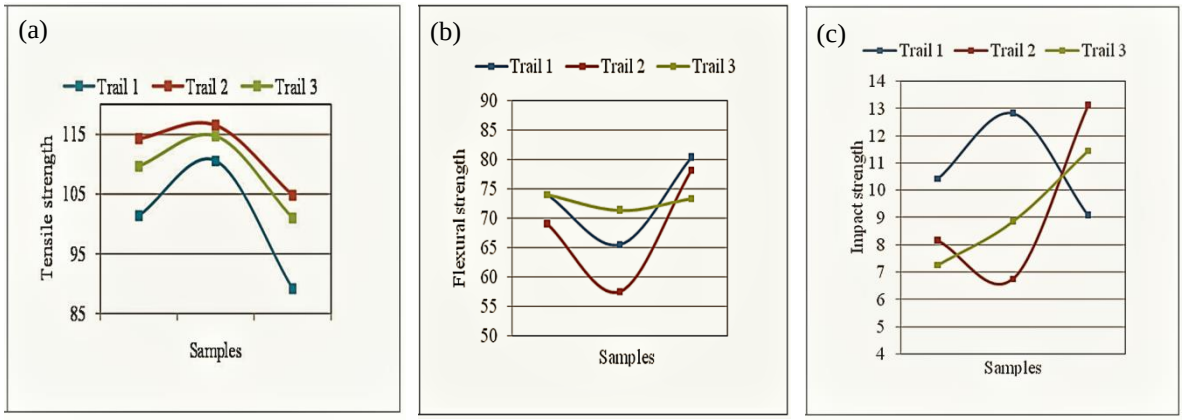

Figure 2.2 Comparison of (a) tensile strength (b) flexural strength and (c) impact energy of samples

Parre et al., (2020) investigated the effect of alkali treatment on mechanical properties of banana fiber. NaOH concentration of (0%, 1%, 3%, 5%, 7% and 9%) were used to treat the fibers for 24hr. Alkali treated fibers showed improved chemical, thermal and morphological properties of the composite. The treatment effectively removed the non-cellulosic materials and impurities from the surface. The optimum NaOH concentration was 5%.

Khan et al., (2019) studied the effect of alkali treatment on mechanical properties of banana fiber reinforced epoxy composite. Four composite samples were fabricated by compression molding technique by varying the alkali treatment concentration (0%, 2.5%, 4.5% and 6.5%) for 4hr. Tensile, compressive and inter laminar shear strength were conducted on the samples to assess the influence of alkali treatment concentration on mechanical properties. Samples made from fiber treated with 4.5% NaOH showed the highest tensile, compressive and inter laminar shear strength, further increase of NaOH concentration reduce the strength as showed in Figure 2.3. Results yield that overall improvement in the mechanical properties was obtained due to fiber treatment.

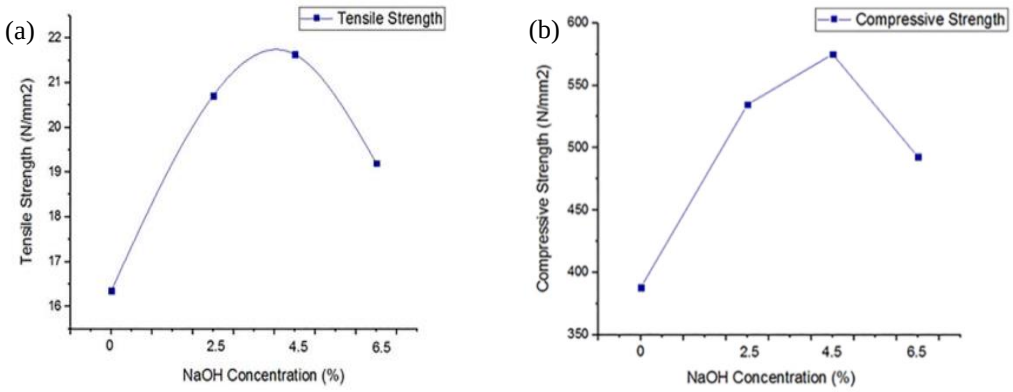

Figure 2.3 NaOH concentration Vs (a) tensile strength (b) compressive strength

2.5. Fiber/nano particulate reinforced polymer composites

The particle reinforced composites mainly consisting of reinforcing material that is in the form particle. The filler materials include organic, inorganic and metallic particulate materials in both micro and Nano sizes. Incorporating organic or inorganic fillers into a matrix enhances various physical and mechanical properties and reduces the cost of the material. In general, mechanical properties of particulate filled polymer composites depend on size, shape and distribution of filler particles in the polymer matrix.

Various literatures revealed that decreasing the particle size, mechanical properties increase more. Nano particles are presently considered as high potential filler for the improvement of

mechanical and physical properties of a polymer composite (Chee et al., 2012). Nano filler can be organic and inorganic, the particles like SiO_2, TiO_2, $CaCO_3$ and etc. are in organic fillers, however, the filler such as coir nano filler, carbon black and cellulosic nano filler and many other are derived organically and naturally present organic fillers (Saba et al., 2014). Hybridization involving the combination of nano filler and natural fiber in the matrix results reduction of water absorption properties and increase in the mechanical properties. Nano fillers are incorporated in polymer matrices at the rates from 1% to 10% (in mass). Reviewed literatures stated by (Olayil et al., 2021) shows nano filler incorporated composites resulted in excellent enhancement in properties because of high surface to volume ratio possessed by nano fillers. As reported by (Mohanty et al., 2014) Al_2O_3 nano particles are most widely used engineering ceramic filler materials because of their ability to make the composite with high elastic modulus, high wear resistance, chemical corrosion resistance, stability and high temperature application. However, high brittleness and accumulation of particles during fabrication causes limitations in its usage.

Mohanty et al., (2014) studied the tensile strength and elastic modulus of alumina nano particle/glass fiber/carbon fiber reinforced epoxy composite. The composite specimens were prepared in the first type by addition of 1wt.%-5wt.% (in an interval of 1%) of alumina nano particle to the epoxy matrix, whereas the second and third type were prepared with the addition of 1-5wt.% of short glass fiber and carbon fibers to the matrix. The fourth type was prepared by incorporating alumina (2wt. %) and both fibers to the matrix. Result showed that longitudinal modulus was significantly improved because of the addition of filler. Both tensile strength and modulus were further better for hybrid composites consisting alumina particles and glass/ carbon fibers.

Fathy et al., (2017) investigated the experimental and statistical behavior of unidirectional glass fiber reinforced epoxy composite filled with nano particles of alumina and silica at four different weight fractions (0.5, 1.0, 2.0 and 3.0 wt.%). Tensile test was carried out to evaluate the effect of nano particles. Result showed that the addition of alumina nano particles up to 3wt.% improved the tensile strength by 54.76% over the pure glass fiber reinforced epoxy composite. For silica nano particles the addition of 0.5wt.% improved the tensile strength by 31.2%, however further increase of silica content decrease tensile strength. The fatigue life of glass fiber reinforced epoxy composite rods incorporated with alumina increased as the content of nano particles increased. The addition of silica showed an insignificant improvement in the fatigue life of the composite.

Swain et al., (2013) reported that the incorporation of 1wt.% of nano alumina into polyurethane matrix, increased the tensile strength by 50% and the addition of silica nano particle increased the tensile strength by 41% at the same concentration. Saba et al., (2016) reported that addition of 3% of nano oil palm empty fruit bunch fiber (OPEFB) filler into kenaf epoxy composites considerably improves the mechanical and morphological properties.

Prasad et al., (2018) studied the effect of nano titanium oxide in improving the mechanical, thermal and water absorption behavior of flax fiber reinforced epoxy composite. The composite specimen was prepared by compression molding technique. Epoxy was modified with nano TiO_2 (50nm size) varying weight percentage (0%, 0.5%, 0.7%, 0.9%). The maximum tensile and flexural strength were 78.85MPa and 88.77MPa respectively. The result showed that the incorporation of nano TiO_2 significantly enhanced the mechanical properties of the composite, increased tensile, flexural, impact and inter laminar shear strength were obtained 10.95%, 20.05%, 10.45% and 18.8% respectively at 0.7wt.% of nano TiO_2. As reported by (Gull et al., 2015) incorporating zinc oxide in to glass fiber polymeric composite enhanced the flexural strength up to 62.12% at 3wt.% of ZnO when compared to the unfilled specimens. An increase in ZnO loading also enhanced the hardness, impact strength and thermal stability.

Rostamiyan et al., (2015) studied the effect of nano silica, nano clay and fiber orientation on flexural strength of epoxy/glass fiber/ nano SiO_2/ nano clay hybrid composite. Response surface methodology was used for optimizing the flexural strength. The result showed that the best flexural strength obtained from software was 17.77MPa at 3.5wt.% of nano SiO_2, 4wt.% of nano clay and 0^0 fiber orientations. The test result indicated that the average flexural strength was 17.2MPa.

Wang et al., (2015) evaluated the influence of nano TiO_2 on tensile and bonding properties of the single fiber and unidirectional fiber reinforced epoxy composite. Flax fiber was grafted with measured grafting content of the nano TiO_2 ranged from 0.89wt.% to 7.14wt.% depending on the suspension concentration. As a result the tensile strength of the flax fiber and interfacial shear strength to an epoxy resin were enhanced by 23.1% and 40% respectively.

Seshanandan et al., (2016) investigated the effect of nano titanium oxide fillers on the properties of hybrid Jute/glass fiber reinforced plastic composite. Specimens of glass fiber chopped strand mat, woven jute mat polyester resin and nano TiO_2 composite were fabricated

by conventional hand layup technique. TiO_2 filler was incorporated at various wt.% (2%, 4% and 6%) the mechanical properties were evaluated. Result showed that addition of nano TiO_2 enhanced the mechanical properties of the composite. The tensile strength increased from 62 MPa for 0wt.% to77MPa for 6wt.% TiO_2 hybrid fiber reinforced plastic. The flexural strength increased from121 MPa for 0wt.% TiO_2 to 182 MPa for 6wt.%TiO_2. Shear strength also increased from 48MPa for 0wt.% TiO_2 to 69 MPa for 6wt.%TiO_2.

Ramezanzadeh et al., (2011) studied the effect of ZnO nanoparticles on mechanical properties and curing behavior of epoxy nano composite. Specimens were prepared by the addition of various mass ratios (2%, 3.5%, and 6.5%) of ZnO average particle size of 40nm. Result indicated that at lower loadings of nano particles, increase in the surface roughness of composite was observed. As the filler content increased the surface roughness decreased. ZnO nano particle also significantly affected the curing behavior of epoxy coating.

Fong et al., (2018) studied the mechanical properties of sugarcane bagasse fiber reinforced epoxy composite. Short fiber of varying weight fraction and 1% nano silica reinforced epoxy composite specimen was fabricated by hand layup method. Tensile and flexural strengths were evaluated to know the effect of particulate filler on the performance of the composite. 1wt% of short fiber reinforced composite exhibits the highest tensile and flexural properties among all the samples. Results indicated that the incorporation of nano silica further enhanced the mechanical performance of the alkali treated fiber particulate composite.

Ramakrishnan et al., (2021) investigated the mechanical and free vibrational characteristics of untreated and treated jute fiber and nano clay reinforced epoxy composite. The fiber was treated by varying the weight concentration of NaOH (2.5%, 5% and 7.5%) and weight of nano clay (1, 3, 5 and 7wt.%) was used to prepare jute/nano clay epoxy hybrid composite by compression molding method. They found that 5% of NaOH treated fiber composites incorporated with 5wt.% of nano clay shows better performance in terms of viscoelastic and free vibration properties.

2.6. Fabrication methods of natural fiber reinforced composite

The process of producing finished products of fiber reinforced composites in different cases is quite different from that of metals and plastics. For metals and plastics, the material was first made and then processed at a later stage. However fiber reinforced composites can be made simultaneously with the creation of the material. In thermosetting resin matrix, the composite is typically formed during final molding of products for example, by hand layup,

spray up, pultrusion, filament winding, resin transfer and etc. For some cases like compression molding the composite is first shaped to an intermediate stage and material properties were obtained during curing of resin. The methods of fabricating fiber reinforced thermoset are described as follows (Salit et al., 2015).

2.6.1. Hand Layup

The oldest, simplest and most commonly used method for manufacturing of both small scale and large fibers reinforced products. Typical applications include boats, wind turbine blades, swimming pool, chemical thanks and so on (Rajak et al., 2019). Hand layup is best for production volume is low and other forms of production would be prohibitive because of cost and size requirements. A mold can be made from wood, metal, plastics or any combination of these materials. Fiber reinforcements and resin are placed manually against the mold surface. Thickness is controlled by the layers placed against the mold.

2.6.2. Resin Transfer

Resin transfer is a wet impregnation process, mostly used for making large complex parts with tight dimensional tolerance and high surface finish. Typical applications include truck panels, boat hulls, wind turbines blades, aerospace and automotive parts. Dry fiber is first placed in a closed mold, and then liquid resin is injected to fill the mold cavity. The resin displaces air and outlets for air to escape. When the mold is full, the resin supply is disconnected; the mold inlets and outlets are sealed. Curing of the product is accomplished by applying heat. Resins that are normally used in this process include polyester, epoxy, vinyl ester, and phenolic (Lotfi et al., 2019; Salit et al., 2015).

2.6.3. Filament Winding

Filament winding is a composite manufacturing process used to produce components that are circular in shape. Products of revolved surfaces such as pipes, tubes, cylinders, cylinder tanks and spheres are fabricated through this technique. Process involves winding continuous fibers, impregnated with resin over a rotating cylindrical surface (mandrel), while the fiber feed carriage transverses back and forth parallel to mandrel axis. Winding angle and pattern are chosen based up on the strength requirement of the product. Products with excellent properties are obtained due to good control on fiber placement; however poor surface finish and difficulty of producing complex shapes are the limitations (Rajak et al., 2019).

2.6.4. Pultrusion

Pultrusion is a combination of two words: pull and extrusion. The process is similar to extrusion process, but in pultrusion, the product is developed by pulling the materials rather than pushing the materials through the die as in the case of extrusion. Continuous, constant cross-section profiles for structural application. Beams, channels section, angle and etc. are manufactured through this technique. The process most suited for thermosetting resins that cure without condensation byproduct (polyester and epoxy resin). Reinforcements can be in the form of continuous fiber, roving, chopped strand mat or a combination of both. The resulting impregnated fiber composites leave the resin bath and are being pulled and passed through a series of forming dies. The shape of the final product follows the shape of the cross of the dies and the shape can be circular, rectangular, square, and I-shaped and H-shaped sections. The composite is also cured in one of the dies (Rajak et al., 2019).

2.6.5. Compression Molding

Compression molding is a composite manufacturing process normally used to produce composite components in high production volume such as automotive components. There are two types of compression molding process, i.e. cold compression and hot compression moldings. In compression molding process, only pressure is applied in the case of cold press while pressure and temperature are applied in hot press after the materials are placed in a mold cavity. In cold compression molding, curing process takes place at room temperature, while for hot press it takes place by applying heat to the mold and it in turn being transferred to the composites. Matrices used in this process include unsaturated polyester, vinyl ester and phenolic (Lotfi et al., 2021).

2.6.6. Vacuum Bagging

Vacuum bagging is a composite manufacturing process that utilizes a vacuum bag to provide compaction pressure and joining of plies within the laminate. It is an extended version of hand or wet lay-up process. In this process, a mold base is placed horizontally. Then composite prepreg laminates are stacked onto the mold base. Then a series of equipment's and materials are covered onto the composite layers such as release film layer, air-bleeder layer, blocked film layer, and breather layer. Finally, a vacuum bag is placed to cover the composite laminate and all the layers. The vacuum bag is then sealed by means of sealers. Matrix materials that can be used in this process include epoxy, phenolic, and polyimide (Salit et al., 2015).

2.6.7. Injection Molding

Injection molding is one of the most widely used manufacturing processes to produce plastic components. It can also be used to produce polymer matrix composites, but the fibers used are in the form of particles or powder (Rajak et al., 2019).

2.7. Hybrid Taguchi based Grey relational analysis optimization

A design of experiment is a systematic, organized method for determining the relationship between factors affecting a process and output of that process. Through various design of experiments, Taguchi method is a statistical approach that is widely used to optimize process parameters and to improve the quality of manufactured products (Singh et al., 2019). The method uses a unique design of orthogonal arrays to provide a reduced variance for the experiment with the optimum setting of process parameters. Orthogonal array is a table (array) whose entries come from a fixed set of symbols arranged in such a way that is an integer n, so that for every section of n columns of the table all ordered-tuples of the symbols formed by taking the entries in each row restricted to those columns, appear the same number of times (Onyekwere et al., 2021).

Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio. S/N is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. These S/N ratios are derived from the quadratic loss function and among the three quality exhibition. The optimal setting is the parameter combination that has highest S/N ratio. The statistical analysis of the data is performed by analysis of variance to study the contribution of the factor and interactions and to explore the effects of each process on the observed value (Onyekwere et al., 2021).

The advantage of Taguchi's optimization method is that it allows the optimization of the process parameter with a minimum number of experiments. It enables the collection of critical data to discover which elements have the greatest impact on a product's quality with the least amount of trial, saving time and resources. However, the Taguchi method only works effectively for optimization of single performance characteristic (Onyekwere et al., 2021; Sumesh & Kanthavel, 2020a). In this study, multiple performance characteristics are involved.

Grey system theory developed by Prof. Deng in 1982 has proved to be a useful tool in dealing with poor, incomplete and uncertain information. GRA is a method of calculating grey

relational degree and determining the contribution measure of the main behavior of the system or the influence degree between the system factors. The measure of correlation between two factors or between two systems is called grey relational grade. GRA based on the grey system theory can also be used to solve the complicated interrelationships among the multiple performance characteristics effectively. The Taguchi based GRA method was implemented to conduct multi-objective optimization for process parameters (Kopparthi et al., 2021). The Grey relational analysis procedure is used to combine all the considered performance characteristics into a single value that can be used as the single characteristic in optimization problems (Pandya & Rathod, 2020). The GRG obtained was analyzed by Analysis of Variance (ANOVA), which is a statistical method to analyze variation in a response variable measured under conditions defined by discrete factors. Thus, the study focuses on simplifying optimization of the complicated multiple response of the process using the Taguchi based Grey relation method. All the tabulations were performed using Microsoft excel and Minitab 16 software.

2.8. Data analysis of responses

The data from experimentation were hand in to Minitab software and transformed into Signal to Noise ratio (S/N) ratio. Signal to noise ratio is interpreted as the ratio of the mean value of the signal to the standard deviation of noise value. It is used to arbitrate the rank of input process factors or parameters.

In the Taguchi method the response variation was studied using S/N ratio and minimization of variation due to uncontrollable parameter. Taguchi has postulated three objective functions these are (Onyekwere et al., 2021):

S/N ratio for larger the better which can be calculated using the following formula;

$$S/N = -10\log\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Yi^2} \quad \text{..... (2.1)}$$

Where n and Yi are number of replication on tests and response.

S/N ration for smaller the better can be also calculated by using the following formula:

$$S/N = -10\log\frac{1}{n}\sum_{i=1}^{n}Y_i^{\,2} \quad \text{..... (2.2)}$$

S/N ratio for nominal the better

$$S/N = -10\,log\frac{Y}{S^2Y} \quad \text{..... (2.3)}$$

2.9. Phases of optimization by GRA

After obtaining the signal to noise ratio from Taguchi, in order to optimize with GRA we have to proceed with the following steps:

2.9.1. Normalizing S/N ratios

In the GRA optimization process, the S/N ratio obtained from Taguchi is normalized between 0 and 1. The purpose of this normalization was to remove the variations in the range of responses. In order to normalize the following equation is used (Onyekwere et al., 2021)

$$\text{Larger the better; Xij} = \frac{Y_{ij} - \min Y_{ij}}{\max Y_{ij} - \min Y_{ij}} \quad \text{..... (2.4)}$$

$$\text{Smaller the better; } Xij = \frac{maxY_{ij} - Y_{ij}}{maxY_{ij} - minY_{ij}} \quad \text{..... (2.5)}$$

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

2.9.2. Calculating the Grey relational coefficients

To determine the gray relational grade, first we have to calculate the gray relational coefficient form the normalized S/N value according to the following equation (Onyekwere et al., 2021; Sumesh & Kanthavel, 2020b)

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

Where GCij is the gray relational coefficient, Δmin and Δmax are the minimum and maximum absolute difference, respectively, which is a deviation from the target value. φ is the distinguishing coefficient. The distinguishing coefficient can be used to distinguish the important of each response based on the particular application. φ is a constant value between 0.5 and 1, was assumed as 0.5 for all responses in this study.

2.9.3. Determination of Grey relational grade

Grey relational grade were calculated from the relational coefficients. High value of gray relational grade indicates stronger relational degree between ideal sequence and present sequence. The ideal sequence is the best response. Higher gray grade indicates closer to the optimal response in the process. Grey relational grade is obtained from the relational coefficient according to equation (Sumesh & Kanthavel, 2020b).

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

Where GRG is the gray relational grade, m is the number of response and GCij is the grey relational coefficient.

2.9.4. Optimal parameter setting

Grey Relational Grade was calculated for each experiment data and considered as response for the next analysis. At this stage, the best quality characteristic 'larger the better' was used for further analysis, as it give the best performance characteristics. The GRG obtained was analyzed by ANOVA and the optimal parameter settings was determined (Onyekwere et al., 2021).

2.9.5. Conformation Experiment

Once the optimal levels for each of the factors were determined, a confirming experiment with factors set at the optimal levels should be conducted to validate the earlier results. The gray relational grade value from the confirmation experiment then compared to the predicted value (Onyekwere et al., 2021).

Vignesh et al., (2016) optimized process parameters of bone powder impregnated coir fiber reinforced polyester composite using Taguchi L9 orthogonal array in combination with Gray relation analysis. The factors considered were coir fiber diameter, coir fiber length; bone powder content and bone powder size each at three different levels. The mechanical properties such as tensile strength, impact strength, flexural strength and compressive strength were selected as quality targets. An optimal parameter combination of composite was obtained through GRA. ANOVA was performed to identify the most influential factor. The optimal parameter levels were 0.5mm coir diameter, 80mm coir length, 20wt% bone powder and 120Nm bone powder size which was taken from the response table and graph.

Kopparthi et al., (2021) optimized multi responses of bamboo fiber reinforced unsaturated polyester resin through Taguchi based Grey relation analysis. Composite samples were prepared with untreated, mercerized, acetylated and mercerized acetylated bamboo fiber at fiber contents of 10, 20, 30, 40 and 50wt.% through hand layup method. Multi response optimization implies that the optimal design parameter was mercerized-acetylated fibers at 50wt.%. From the result it was found that 51.1% improvement in Grey relational analysis obtained with respect to the initial parameter selection after optimization with Grey relation analysis. The optimum level of the factors will be the level with the highest gray relational grade as shown in Figure 2.4.

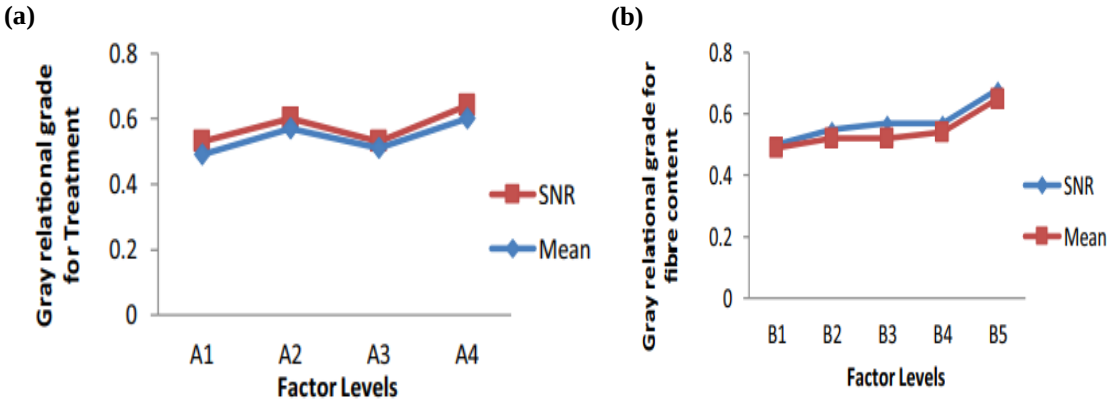

Figure 2.4 Effect of parameter setting on (a) GRG of treatment (b) GRG of fiber amount

Sumesh & Kanthavel, (2020) investigated a multi response optimization of sisal and banana fiber reinforced epoxy composite. 10% sisal, 15% banana, 8% NaOH, 50MPa pressure and 100^0c and 20% sisal, 10% banana, 5% NaOH, 10MPa pressure and 120^0c temperature combined samples were fabricated by compression molding method. S/N ratio showed that the optimal condition was 20%sisal/15% banana/5% NaOH/ 10MPapressure and 100^0c combination. For tensile strength sisal fiber has the highest influence. While for flexural strength both sisal and banana fiber at 10% increased the S/N ratio from 36.16 to 37.34 and 36.01 to 37.49 respectively.

2.10. Summary of literatures

Through an exhaustive literature review, it has been observed that natural fiber reinforced polymer matrix composites have becoming potential replacement of synthetic fibers in different applications. In alkaline treatment, the concentration of NaOH used varies from 1% -10%, concentration increase up to 10% improves the mechanical property. Fiber and matrix volume fraction of hybrid composite the fiber from different weight percentage (10%-40%) and the matrix weight percentage also varies from (60%-80%) and the mixing ratio of hardener varies from 1-3% of the polyester resin in weight ratio. The addition of micro or nano sized fillers to the matrix phase increases the mechanical property of the matrix. Less than 10% nano particulate filler are incorporated in to a matrix to improve the mechanical properties. Taguchi based GRA is a multi-parametric optimization method used in various engineering and industrial sectors to improve the products performance characteristics.

2.11. Research Gaps

Banana covers around 68% of the total fruits in Ethiopia; however the pseudo steam is not utilized yet. Instead it is thrown away as biomass waste. In developed countries pseudo steam fibers were utilized well in many industrial applications such as textile, paper, automotive and construction sectors. Also several researchers have carried out experimental investigation on banana fiber reinforced polymer composite. However, no experimental study is carried out on nano alumina filled banana fiber reinforced polymer composite through hybrid Taguchi and GRA yet. Various researchers optimized some parameters of banana fiber reinforced composites; however they are not able to eliminate the limitation of the Taguchi method which is optimization of single response at a time. But this research had overcome this limitation by making optimization of multi responses through hybrid Taguchi and grey relational analyses.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

In this chapter the materials and methods used for the preparation of composites material were described. In addition to this the equipment's and machines used to conduct mechanical tests, physical tests, machinability and morphological analysis were also presented.

3.2. Materials

Materials used to prepare composite samples were listed in Table 3.1 and their quantity was shown.

Table 3.1 List of materials used and quantity

Materials	Banana fiber	Polyester resin	Nano alumina powder	NaOH	Distilled water	Honey wax
Quantity	1Kg	4.5Kg	186g	375g	20L	1

3.2.1. Banana fiber

Banana belongs to Musaceae family and there are approximately 300 species, but only 20 varieties are used for consumption. Approximately 70million tones of banana were produced by the tropical and subtropical regions of the world (Ramesh et al., 2017). Banana fiber used in this thesis work was collected from Arbaminch city area. The extraction was done by manual/traditional method; the extracted fiber was washed with water and dried by air for 24h as shown in Figure 3.1. Combing was carried out to remove dirty and impurities. Then fiber was treated with 0%, 2.5% and 5% NaOH to improve physical, chemical and mechanical properties of the fibers. Again, it was washed by distilled water to neutralize the chemicals and dried by air for 48h.

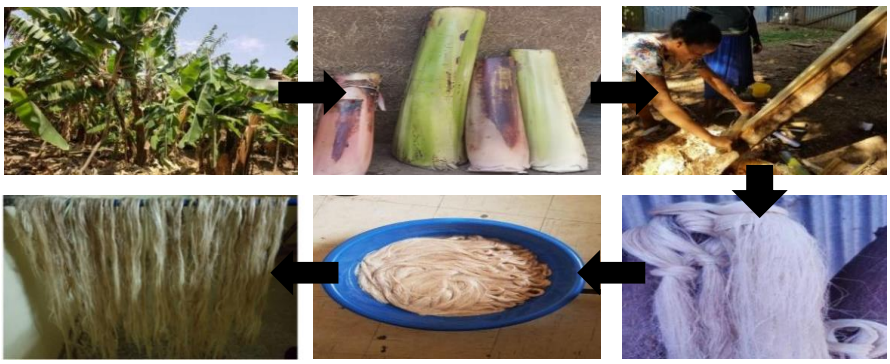

Figure 3.1 Banana fiber extraction and preparation

3.2.2. Unsaturated Polyester Resin

Low cost natural fiber reinforced composites is successfully fabricated with many thermoset matrices. Among the various thermosetting matrix types epoxy, polyesters and vinyl esters are commonly used in automotive, aircraft, marine, chemical, electrical and infrastructural applications. Adhesive properties, mechanical properties and degradation from water entrance are the characteristics to choose the resin for composite fabrication (Nurazzi et al., 2017). The resin used for this study was unsaturated polyester resin. UPR is a thermoset, which is capable of being cured from a liquid to solid state when subject to the right condition. Low viscosity for fast wet-out, convenient for hand lay-up applications, low cost, exhibits good mechanical and good chemical resistance, low pressure molding and capability to cure at room temperature are the advantage of UPR when compared to other thermosetting resins. The mechanical properties for the matrix are shown in Table 3.2. It was supplied by World Fiber Glass and Water Proofing Engineering PLC. The weight percentage for each sample resin-hardener mixture was measured on digital mass balance as shown Figure 3.2 in Chemical Engineering laboratory, ASTU, Ethiopia.

Table 3.2 Mechanical properties of polyester resin (Ouarhim et al., 2018)

Thermoset resin	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation (%)
Polyester	1.09-1.35	50-65	3	2-3

Figure 3.2 Unsaturated polyester resin

3.2.3. Hardener

The hardener creates a chemical reaction that allows the resin to change from a liquid to a solid state to make polyester resin useful for its intended purpose. This transformation was referred to as "curing" or "polymerization." Topaz-1110 TP; thixotropic hardener is the chemical hardener used with unsaturated polyester resin. The thickness of the laminate, temperature and humidity or other are considered when estimating the amount of catalyst to

add to polyester resin to achieve the curing speed desired. The ratio of catalyst was 2% to the total volume of resin to be used (Nurazzi et al., 2017). Generally, it was mixed with polyester resin at normal atmospheric temperature it was measured using syringe as shown in Figure 3.3. It was also supplied by World fiber Glass and Water Proofing Engineering PLC.

Figure 3.3 Hardener

3.2.4. Aluminum oxide

Aluminum oxide is a chemical compound of aluminum and oxygen with the chemical formula Al_2O_3, it is commonly called alumina. It has strong ionic inter-atomic bonding and commonly occurs in its crystalline polymorphic phase α-Al_2O_3. Alumina is ceramic material used as the filler in the present investigation were purchased from Mombai, India. These Al_2O_3 powder with particle size of $\leq$ 50nm has a density of 0.79 g/cm^3 (Patel & Dhanola, 2016). The packed and measured powder was shown in Figure 3.4 and properties were shown in Table 3.3. Al_2O_3 was chosen over other ceramics because of it is hard and wear-resistant, has high strength and stiffness and also it serves as filler in plastics (Fathy et al., 2017). It was added to resin and hardener based on the calculated weight percentage (2, 4 and 6) by measuring the mass on digital balance at Chemical Engineering laboratory, ASTU, Ethiopia.

Table 3.3 Properties of nano alumina powder

Particle size	Melting point	Boiling point	Density	Molecular weight
≤ 50nm	2040 ^{0}c	2977^{0}c	0.79g/cc	101.96

Figure 3.4 Nano alumina powder

3.2.5. Sodium Hydroxide

Sodium hydroxide, also known as lye or caustic soda, has the molecular formula NaOH and is a highly caustic metallic base and alkali salt. Pure sodium hydroxide is a whitish solid, which is available in pellets, flakes, granules, and as a 50% saturated solution. Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and readily absorbs moisture and carbon dioxide in air. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents (Dandesa., 2016). In the present work NaOH in flakes form was used as displayed in Figure 3.5, purchased from local suppliers with the brand name and batch no of SELAB, S-6827389 respectively and performed chemical treatment of banana fiber.

Figure 3.5 NaOH flakes

3.2.6. Honey wax

Figure 3.6 shows the mold Release agent, honey Wax (M-08 v 2.0) used in this research work. It allows easy release of fabricated composite from the mold material. Applying a thin coat of wax and wipe off or polish the haze/obscure/ part using a cloth towel is recommended for better surface finish and performance of the material.

Figure 3.6 Honey wax

3.2.7. Distilled water

Distilled water is neutral water having a PH of 7, was used for treating and washing the fiber after treatment. Figure 3.7 shows the distilled water used for modifying the fiber surface.

Figure 3.7 Distilled water

3.3. Process parameters

The process parameters are the factors that were varying in this process and selected based on literature reviews. Banana fiber weight percentage and length were the factors that affect the strength of composite materials. Aluminum oxide weight percentage was expected to increase the mechanical property of the composite material. In addition to this the sodium hydroxide was proved to enhance the strength of the material by reducing the pectin, lignin and impurities from fiber surface. In this experimental investigation all the parameters were utilized to investigate the effect of each parameter on the composite and obtain the optimum process parameter from the selected factors.

3.3.1. Banana fiber weight percentage and length

Fiber weight percentage has major influence on mechanical properties of composite material. Reviewed literatures revealed that less amount of fiber reinforcement reduces the utilization of natural fiber. In this research banana fiber was selected in three levels 10wt.%, 15wt.% and 20wt.%.

Fiber length and orientation were also influencing factors in polymer composites. Short fiber was used for this study and it was selected due to the reason that the matrix phase was mixed with nano particles, in long fibers distribution cannot be uniform. For complete mixing of matrix and reinforcement short fibers were selected in three levels 10mm, 15mm and 20mm length.

3.3.2. Alumina weight percentage

In several researches nano particulate filled composite materials were reinforced below 10wt.%. The weight percentage of Al_2O_3 was designed at three levels. In this investigation 2wt.%, 4wt.% and 6wt.% was chosen in order to enhance the mechanical properties by incorporating small amount of particle on matrix phase.

3.3.3. Alkali treatment concentration

Treatment of natural fibers has gained potential benefits in enhancing the mechanical properties of NFRC. Alkali treatment as mentioned in literatures was one of the most effective treatment for banana fiber, which modifies the fiber surface and yield good bonding between fiber and matrix. Three levels were selected to be utilized in this study; these were 0%, 2.5% and 5%. It was believed to have big difference between treated fiber reinforced samples and untreated fiber reinforced samples.

3.4. Sample Preparation Method

Before going to sample preparation first materials were selected based on their availability, environmental concern and cost. The selected materials which were available in market were purchased and the fiber was collected from farm area. Then random orientation of fiber was selected due to isotropic nature of short fiber reinforced composite.

The step by step procedure used to fabricate composite samples was shown in Figure 3.8.

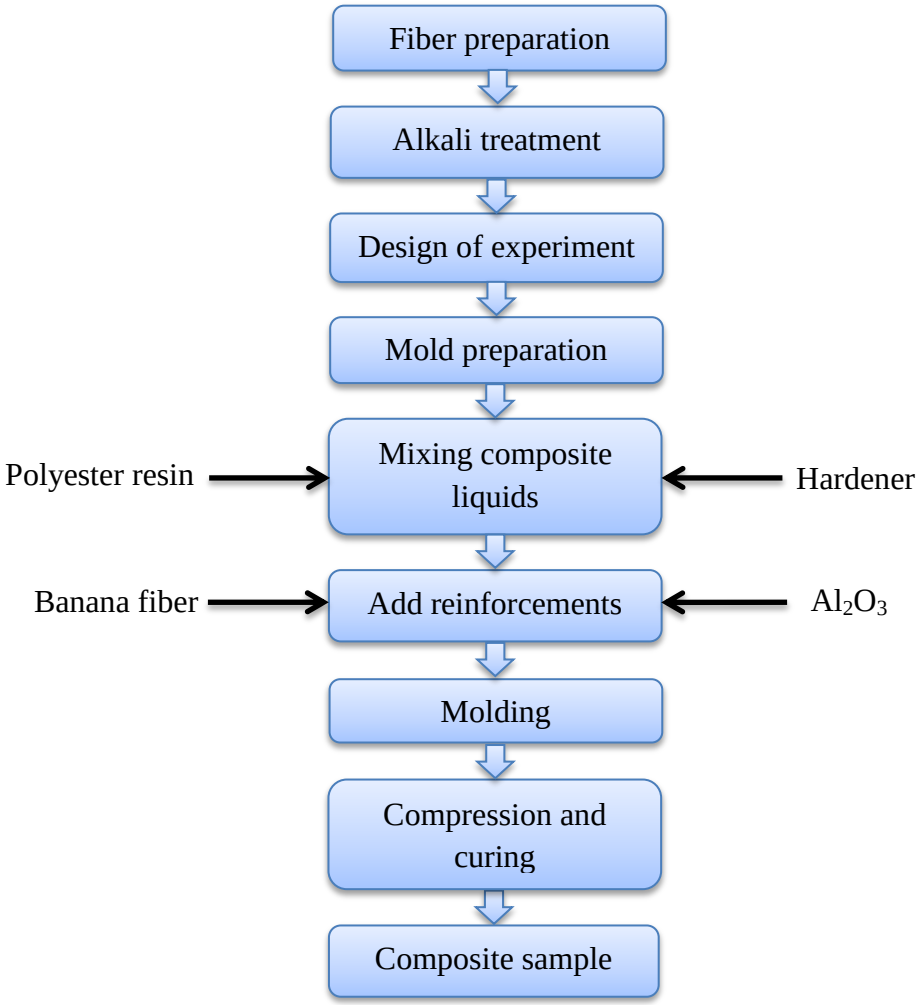

Figure 3.8 Flow diagram of banana fiber reinforced composite sample preparation

3.4.1. Preparation of banana fiber

The fiber was chopped to a length of 10mm, 15mm and 20mm using scissor and ruler as shown in Figure 3.9.

Figure 3.9 Chopped banana fiber

3.4.2. Alkali treatment of banana fiber

The main drawback of natural fibers was their hydrophilic nature resulting in poor adhesion between fiber and matrix. Literatures mentioned that this limitation can be improved by the use of chemical treatment like thermal, alkali, potassium, permanganate and benzoyl chloride on the fiber, which is aimed to remove the impurities like pectin, fats and lignin in the fiber, resulting in improvement in the bond between fiber and matrix (Verma et al., 2013). As a result increased mechanical (tensile, flexural and compression) properties of fabricated composite was obtained.

Alkali treatment also known as mercerization is the oldest and most widely used chemical treatment for natural fibers. In which the natural fibers were immersed in a known concentration of aqueous NaOH for a given temperature and period of time (Faruk et al., 2012a). The concentration of alkali solution that was used to treat the fibers was in the range of 0.5% up to 28%, but most of the researchers used below 10% alkali solution. The temperature and soaking time to treat fiber in the solution were in the range of 20-180^{0}C and 15 min to 48 hour period of time. The required temperature to dry natural fiber should be below 80^{0}c for 24hr period of time (Naveen & Maheswaran., 2015). The aim of chemical treatment was to improve poor interfacial adhesion between fiber and matrix that lead to poor wetting of fiber with matrix, improve bonding strength, lowers water absorption, increase fiber strength and improve mechanical properties (Faruk et al., 2012a).

In this study alkali treatment of 2.5% and 5% was used to treat the fibers. NaOH flakes were weighted according to the calculation; 50g NaOH was dissolved in 1L distilled water to make 5% NaOH solution (Zin et al., 2018). The fiber was immersed in the alkali solution for 6hr at

room temperature. The solution was kept under vacuum condition; once the immersion time ended the fibers were washed thoroughly with distilled water. Finally the fibers were left to dry by air for 2days as we can see from Figure 3.10.

Fiber – OH + NaOH ⟶ Fiber – O – Na + H_2O

Figure 3.10 Alkali treatment of banana fiber

3.4.3. Design of Experiment

DOE is a technique for defining and investigating all possible conditions involving variables, multiple factors and parameters in an experiment. To observe the most influential process parameters in the fabrication of Al_2O_3/banana fiber reinforced polyester composite, the selected process parameters, levels and their values at different levels were depicted in Table 3.4.

Table 3.4 Experimental design factors and levels

Factors	Designation	Level 1	Level 2	Level 3
Banana fiber content	A	10	15	20
Al_2O_3 content	B	2	4	6
Fiber length	C	10	15	20
NaOH concentration	D	0.0	2.5	5.0

The selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiment 4 factors each at 3 levels were selected.

Degree of Freedom can be calculated by the formula given below.

$$DOF = P * (L - 1) \quad \text{...} \quad (3.1)$$

where P is the number of factors and L is the number of levels

$$\mathrm{DOF} = 4 * (3 - 1) = 8$$

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

Table 3.5 L9 orthogonal array

Experiment run	A	B	C	D
1	10	2	10	0.0
2	10	4	15	2.5
3	10	6	20	5.0
4	15	2	15	5.0
5	15	4	20	0.0
6	15	6	10	2.5
7	20	2	20	2.5
8	20	4	10	5.0
9	20	6	15	0.0

Nine different composites were manufactured with different parameters and at different levels.

The signal to noise ratio used for this thesis was larger the better and smaller the better. For tensile, flexural, impact strength and hardness larger is better criteria was utilized, since the goal was obtaining higher mechanical properties. In water absorption and void fraction tests smaller is better criteria was utilized, moisture absorption and availability of voids negatively affect the strength of the material.

There are number of optimization techniques that deal with optimization of process parameters of composites, among them Grey Relational Analysis (GRA) was used for multi-objective optimization problems. Complex problems having minimal information can be solved by grey theory, it is an evaluation technique based on the random uncertainty of small samples. The ‘white’ systems means, the system which has complete information and represented by 1, whereas in a ‘black’ system has no known information and denoted by 0. Any system lies between these two that is a ‘grey’ system with limited information.

3.4.4. Weight fraction of the particulate, fiber and matrix for samples

The mechanical properties of composite significantly influenced by incorporation of particulate, fiber and matrix materials. These materials can be expressed either as volume fractions or as mass fractions. While mass fractions are easier to obtain during fabrication of composites, volume fractions are harder in theoretical analyses of composites. The composition of each sample was shown in Table 3.6.

Table 3.6 Composition of particulate, fiber and matrix used for sample preparation

Sample	Compositions
S_1	Polyester + banana fiber (10mm) (10wt.%) + Al_2O_3 (2wt.%)
S_2	Polyester + Banana fiber (15mm) (10wt.%) + Al_2O_3 (4wt.%)
S_3	Polyester + Banana fiber (20mm) (10wt.%) + Al_2O_3 (6wt.%)
S_4	Polyester + Banana fiber (15mm) (15wt.%) + Al_2O_3 (2wt.%)
S_5	Polyester + Banana fiber (20mm) (15wt.%) + Al_2O_3 (4wt.%)
S_6	Polyester + Banana fiber (10mm) (15wt.%) + Al_2O_3 (6wt.%)
S_7	Polyester + Banana fiber (20mm) (20wt.%) + Al_2O_3 (2wt.%)
S_8	Polyester + Banana fiber (10mm) (20wt.%) + Al_2O_3 (4wt.%)
S_9	Polyester + Banana fiber (15mm) (20wt.%) + Al_2O_3 (6wt.%)
S_{10}	Polyester + Banana fiber (10-15mm) (5wt.%)

Particle, Fiber and matrix mass fraction content of the composites

The mass of composite matrix and reinforcements were calculated

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

$$Mc = Mm + Mf + Mp \quad \text{..... (3.2)}$$

$$\text{Fiber mass fraction} = \frac{\text{mass of fiber}}{\text{total mass}} = \mathrm{M_F} = \frac{\mathrm{Mf}}{\mathrm{Mt}}$$

$$\text{Particulate mass fraction} = \frac{\text{mass of particulate}}{\text{total mass}} = \mathrm{Mp} = \frac{\mathrm{Mp}}{\mathrm{Mt}}$$

$$\text{Matrix mass fraction} = \frac{\text{mass of matrix}}{\text{total mass}} = \mathrm{Mf} = \frac{\mathrm{Mm}}{\mathrm{Mt}}$$

$$Mp + Mf + Mm = 1 \quad \text{..... (3.3)}$$

Where, M_F is fiber mass fraction, Mf is mass of fiber, Mt is total mass, Mp is particulate mass fraction, Mp is mass of particle, Mf is matrix mass fraction and Mm is matrix mass fraction.

Particulate, fiber and matrix volume fraction

$$\text{Volume of fiber} = \frac{\text{mass of fiber}}{\text{density of fiber}} = \mathrm{V_f} = \frac{\mathrm{Mf}}{\rho\mathrm{f}}$$

$$\text{Volume of particulate} = \frac{\text{mass of particulate}}{\text{density of particulate}} = \mathrm{V_p} = \frac{\mathrm{Mp}}{\rho\mathrm{p}}$$

$$\text{Volume of matrix} = \frac{\text{mass of matrix}}{\text{density of matrix}} = \mathrm{Vm} = \frac{\mathrm{Mm}}{\rho\mathrm{m}}$$

$$Vc = Vm + Vf + Vp \quad \text{..... (3.4)}$$

Where, Vf is volume of fiber, Mf is mass of fiber, ρf is density of fiber, Vp is volume of particulate, Mp is mass of particulate, ρp is density of particulate, Vm is volume of matrix, Mm is mass of matrix, ρm is density of matrix and Vc is volume fraction of composite.

$$\text{Fiber volume fraction} = \frac{\text{volume of fiber}}{\text{total volume}} = V_F = \frac{Vf}{Vf+Vm+Vp}$$

$$\text{Particulate volume fraction} = \frac{\text{volume of particulate}}{\text{total volume}} = V_P = \frac{Vp}{Vf+Vm+Vp}$$

$$\text{Matrix volume fraction} = \frac{\text{volume of matrix}}{\text{total volume}} = V_M = \frac{Vm}{Vf+Vm+Vp}$$

Where, VF is fiber volume fraction, Vf is volume of fiber, VP is particulate volume fraction, Vp is volume of particle, VM is matrix volume fraction and Vm is volume of matrix.

3.4.5. Calculation of Mass of Fiber, Particulate and Matrix for each sample

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

$$\textit{Volume of the die} = L \times w \times t \quad \text{..... (3.5)}$$

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

Density of banana fiber, nanoAl_2O_3 powder and polyester resin:

Banana fiber = 1.32g/cm^3

Al_2O_3 = 0.79g/cm^3

Unsaturated polyester resin = 1.15g/cm^3

$$\textit{Volume of composite} = V_{banana} + V_{Polyester} + V_{Al_2O_3} \quad \text{..... (3.6)}$$

Where, Vbanana is volume of banana fiber, $V_{polyester}$ is volume of polyester resin and $V_{Al_2O_3}$ is volume of alumina powder.

For sample 1

Polyester resin = 88wt.%

Banana fiber = 10wt.%

Al_2O_3 = 2wt.%

The density of the composite can be calculated by the rule of law of mixture method and obtained first by adding the volume fraction of the resin, banana fiber and nano alumina powder for each sample. Then the mass of polyester, particulate and fiber was calculated and shown in Table 3.7.

$$\frac{mc}{\rho c} = \frac{Mpolyester}{\rho polyester} + \frac{Mbanana}{\rho banana} + \frac{MAl_2O_3}{\rho Al_2O_3} \text{ ……...…….. (3.7)}$$

Where, Mc is mass of composite, ρc is density of composite, Mpolyester is mass of polyester, Mbanana is mass of banana fiber and M Al_2O_3, ρpolyester is density ofpolyester, ρbanana is density of banana and ρ_{Al2O3} is densitu of alumina.

From equation 3.7 density of composite material can be calculated as follows:

$$\frac{1}{\rho c} = \frac{0.88}{1.15} + \frac{0.1}{1.32} + \frac{0.02}{0.79}$$

$$\rho c = 1.1543 \text{g/cm}^3$$

$$mc = \rho c \times Vc \text{....…….……} \quad (3.8)$$

Where, Mc is mass of composite, ρc is density of composite and Vc is volume of composite.

Volume of the die = L × w × t

$$= 300\text{mm} * 300\text{mm} * 5\text{mm} = 450\text{cm}^3$$

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

$$mc = \rho c \times Vc$$

$$= 1.1543\text{g/cm}^3 * 450\text{cm}^3$$

$$= 519.435\text{g}$$

To obtain the mass of Al_2O_3, epoxy resin and banana fiber mass of composite can be multiplied by each weight percentage.

Mass of polyester resin = mass of composite $* 0.88$

$$= 457.102\text{g}$$

Mass of banana fiber = mass of composite $* 0.1$

$$= 51.943\text{g}$$

Mass of Al_2O_3 = mass of composite $* 0.02$

$$= 10.389\text{g}$$

Table 3.7 Tabulated composition of polyester, banana fiber and alumina

Designation	Composition (wt.%)			Mass(g)			
	Polyester	Banana	Al_2O_3	Polyester	Banana	Al_2O_3	Total
S_1	88	10	2	457.120	51.945	10.389	519.455
S_2	86	10	4	442.682	51.474	20.589	514.746
S_3	84	10	6	428.502	51.012	30.607	510.122
S_4	83	15	2	433.953	78.425	10.456	522.835
S_5	81	15	4	419.632	77.709	20.722	518.064
S_6	79	15	6	405.570	77.007	30.802	513.380
S_7	78	20	2	410.481	105.251	10.521	526.258
S_8	76	20	4	396.283	104.285	20.857	521.426
S_9	74	20	6	382.344	103.336	31.000	516.681
S_{10}	85	15	0	444.409	30.122	0.000	474.531
Total	729	150	40	4,220.976	730.566	185.943	

3.4.6. Hand layup method

After choosing the suitable thermoset matrix and reinforcement, the fabrication phase is an important step which had influence on quality of the final product (Ouarhim et al., 2018). There are various techniques to manufacture composites from those we have used hand layup method to fabricate the samples.

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

This process involves the following steps:

The first step was preparing a mold from metal/wood/plastic, next coating the mold surface with a releasing anti-adhesive agent to avoid sticking on the surface, then applying the fiber with resin on the mold surface and finally distributing the mixture around the mold surface.

- Mold: a wood plate surfaces was made from HDF board 300 mm x 300 mm x 9 mm.

- Mold release: mold release was used for preventing the polyester from sticking to the mold. The most common type and the one for this work was Mold Release honey Wax 8.2. It was chosen because of its excellent release properties, easy application, and exceptional mirror finish shine.

Then mixture of polyester risen, nanoAl_2O_3 powder, hardener and banana fiber was placed on the surface of the mold. Then it was rolled/ hammered by ceramic to obtain uniform thickness. The process was repeated for each sample of reinforcement and matrix till the required thickness was achieved. Releasing agent coated upper mold was placed on the top surface, and then it was gripped by c-clamp at four corners as we can see from Figure 3.11. Then it was left for 24 hours to be cured, after curing at room temperature, mold was opened and the fabricated composite was removed from the mold.

Figure 3.11 Fabrication through hand layup method

The following steps were used for fabricating samples:-

I. The masses of the Banana fiber, Al_2O_3 and polyester resin were measured according to the calculated weight fractions as shown in Figure 3.12. The hardener was added 10:2 ratio with polyester resin.

Figure 3.12 Weight measurements of alumina, fiber and polyester

II. The polyester resin and hardener were mixed for about 5minute and nano Al_2O_3 was added and mixed well for 5minutes at room temperature continuously and slowly to avoid bubbling during mixing. The mixing was performed in the mixing container (bowl), the bowl was made of plastic and the mix was done slowly to avoid oxidation of the powder.

Finally as shown in Figure 3.13 chopped banana fiber was added to the mixture and mixed well with the matrix and filler for 10minutes.

Figure 3.13 Mixture of polyester, hardener, alumina and banana fiber

III. The mold of 300mm*300mm*9mm was prepared from HDF wood and placed the mixture according to the calculated weight for each sample. The mold was pressed with C-clamp and sample was then left to be dried. The composite gets dried up in 24 hours in which the Banana fiber and the mixture adheres itself tightly in the presence of hardener.

IV. Fabricated samples were shown in Figure 3.14 and specimen preparation is preceded.

Figure 3.14 Prepared samples

V. The specimens were cut according to the ISO and ASTM standard for each test (tensile, flexural, hardness, density and void fraction and water absorption tests) using jig saw.

3.5. Equipment's and Machines used

The instruments and tools used for characterization of composite material were given as follows:

3.5.1. Analytical (digital) balance

The digital mass balance in the ASTU chemistry labs are very sensitive instruments used to accurately measure mass. Their reliability has a range between 0.1mg to 0.01mg. This device is also important to measure while mixing the composites and to characterization physical properties. The mass balances used in this experiment were shown in Figure 3.15.

Figure 3.15 Digital mass balances

3.5.2. Universal Testing Machine

The universal testing machine is a computer equipped materials testing machine used to test the tensile, compression, bending (flexural) and shear test for all kinds of metals and nonmetals by simply changing the jaws and modes of operations. The mechanical properties of the material under different load conditions were then studied. The main components of the UTM are, actuator, attachment kit, safety devices frame, engine, and gear, screws, and crosshead grips extensometer, hardware and software control. The control unit composed of computer control system, it process stress, strain and displacement control modes, the test data can be stored, and the data and curves can be reanalyzed. Part amplified and data re-edition, test conditions (specimen, measurement) are programmable. All the mechanical properties can be obtained automatically and print whole test report and curve. The UTM machine used for tensile test was shown in Figure 3.16.

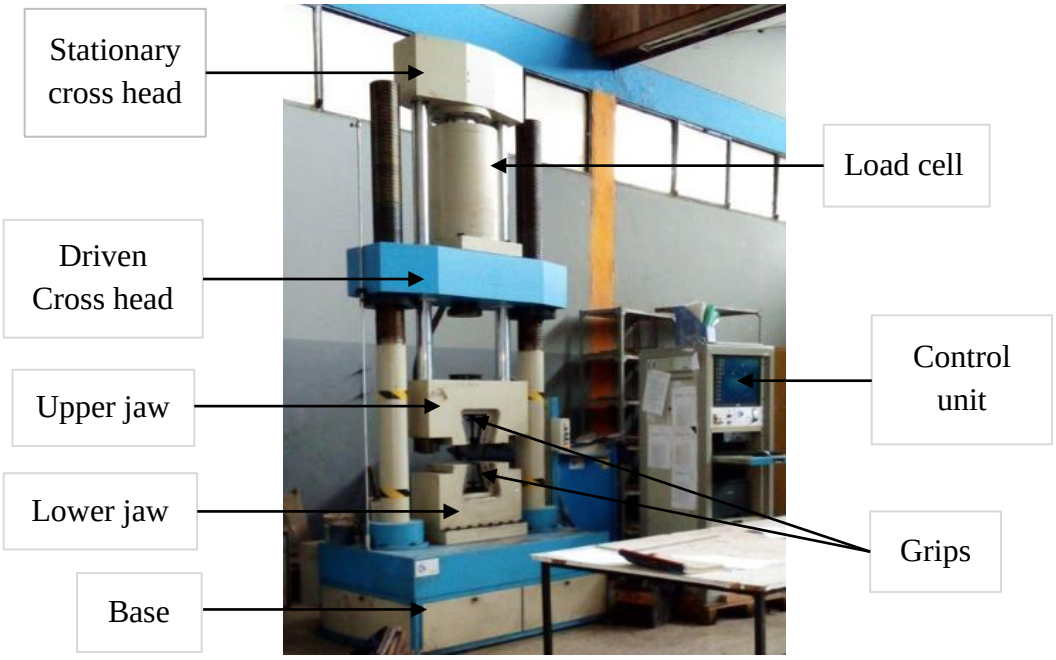

Figure 3.16 Universal testing machine

3.5.3. SEM Testing Device

SEM is the most common method for imaging the microstructure and morphology of materials. An electron beam with low energy is radiated to the material and scans the surface of the sample. Several different interactions occur as the beam reaches and inters the materials, which leads to the emission of photons and electrons near the sample surface. In order to form imaging the receiving signals produced from the electron-sample interactions are detected with different modes of SEM exist for characterization of materials such as x-ray mapping, secondary electrons imaging, back scattered electrons imaging, electron channeling and auger electron microscopy. The morphological analysis of particulate reinforced composites material was studied using scanning electron microscopy at Biology department ASTU, Ethiopia. The instrument used for SEM imaging was shown in Figure 3.17 S4 and S5 were selected for study; specimens were prepared according to the requirement.

Figure 3.17 SEM testing device

3.5.4. Pendulum Impact Testing Machine

Impact test is a single point test that measures the materials resistance to impact from a swinging pendulum. Impact strength of a material is its capacity to absorb and dissipate energies under impact/shock loading. The Charpy impact test is also known as the Charpy V-notch test. It is a standardized high strain-stress test that determines the amount of energy absorbed by a material during fracture. The machine used was shown in Figure 3.18.

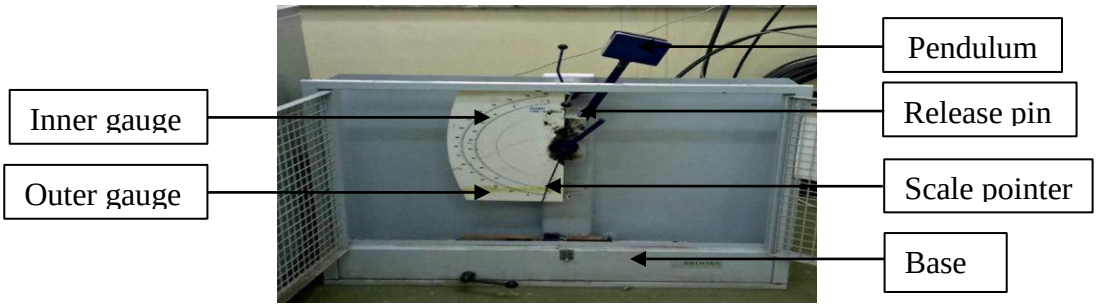

Figure 3.18 Charpy impact testing machine

3.5.5. Hardness Testing Machine

The Vickers hardness test uses square-based pyramid diamond indenter with an angle of 136^0 between the opposite faces at the vertex, which is pressed into the surface of the test piece using a prescribed force, F. The HVS-50 machine used for this thesis was shown in Figure 3.19 which has measuring rage: 5 to 2900 HV, Test Force: 9.807, 49.03, 98.07, 196.1, 294.2, 490.3N, maximum height of test piece: 180mm, depth of throat: 125mm, magnifications of the measuring system: 125X, 250X and minimum scale value of the optical micrometer: 0.5µm.

$$HV = \frac{constant \times test\ force}{surface\ of\ indentation} \quad \text{..... (3.8)}$$

$$= \frac{0.102 \times 2F(sin\frac{136^0}{2})}{d^2}$$

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

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

The above equation was taken from manual of HVS-50 machine of ASTU.

Figure 3.19 Vickers hardness testing machine

3.5.6. Drilling Machine

Natural fiber composites have been comprised by car manufacturers and suppliers to substitute a large section of the synthetic and mineral fillers in several automotive interior and exterior parts. As a result of a wide range of NFRCs usage in several industrial applications, the machining of these materials needs to be perceived accurately with regard to their different behavior than machining of conventional metallic materials. Machining of NFRC is a rather complicated task due to the mechanically anisotropic and nonhomogeneous structure, high abrasiveness, and hard reinforced fibers of composite materials. Some difficulties can be found in the machining processes, especially in drilling, including delamination, fiber peel-up, fiber pullout, holes shrinkage, fuzzing, and thermal degradation. The undesirable damages

induced by the drilling process result in lowering strength against fatigue, which can be extremely detrimental to the long-term performance of composites (Lotfi et al., 2019). A bench type drill shown in Figure 3.20 was used to perform drilling operation

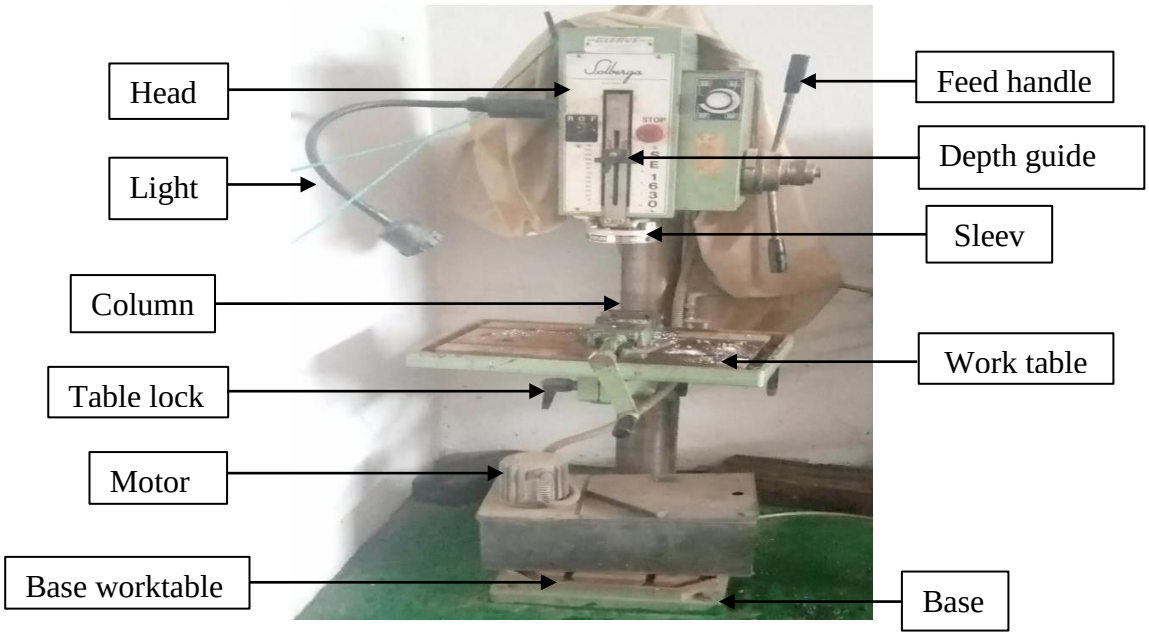

Figure 3.20 Drilling machine

Other instruments used in this research work were Varner caliper, ruler, scissor, jig saw, wood stirrer, c-lamp and grinding machine.

3.6. Characterization of Composite

Specimen for each test was prepared based on the dimensional requirements of ASTM and ISO standards.

3.6.1. Tensile Strength

Tensile strength is the maximum load that a material can support without fracture when being stretched, divided by the original cross-sectional area of the material. The dimension requirement for tensile strength test on 2000KN UTM of Ethiopian Conformity Assessment Enterprise based on ISO 6892-1 was 300×30×4.5mm. Jig saw was used to cut the specimens and then polished by sand paper. Specimens before and after tensile test were shown in Figure 3.21. During the test the specimens were placed in the grips and axial load was applied through both the ends of the specimen as we can see from Figure 2.22. Then the samples were left to brake till the ultimate tensile strength occurs. The stress-strain curve was plotted, for the determination of ultimate tensile strength (UTS). It was plotted from the data generated directly from the machine for the tensile test.

The tensile strength and elongation at break of the sample can be calculated by using equation 3.9 and 3.10. Percentage elongation is an increase in percent of length of specimen at its breaking point. All the required information was inserted to control unit and the calculated strength value was displayed in the computer screen.

$$Tensile\ strength = \frac{Breaking\ load(KN)}{Original\ crossectional\ area\ (m^2)} \quad \text{.....(3.9)}$$

$$\%elongation = \frac{L - L_O}{L_O} \times 100 \quad \text{.....(3.10)}$$

Where, Lo is initial length and L is final length at break.

Figure 3.21 Tensile test specimens before and after test

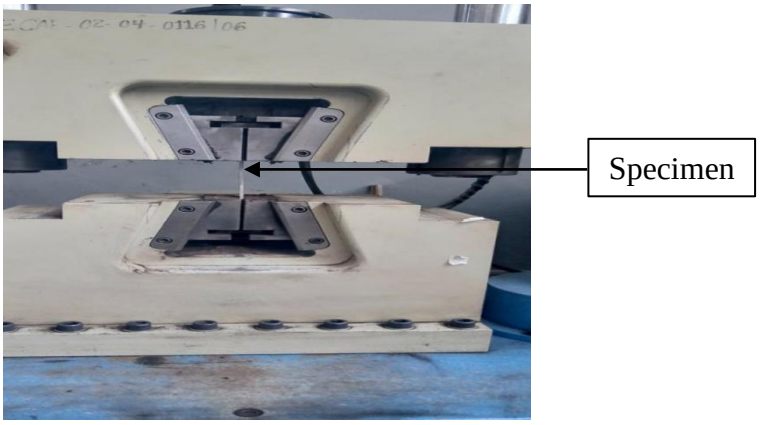

Figure 3.22 Specimen under tensile test

3.6.2. Flexural Strength Test

Flexural strength is defined as a materials' ability to resist bending deformation under load. In flexure, the specimen is typically loaded flat on two solid support rods. A third rod is used for loading. This three-point loading setup helps to act the force from the center loading point to two support rods. The flexural Strength of composites was performed according to ASTM-D790 standard using UTM. The loading arrangement was shown in Figure 3.23. The dimension of the specimen was (170 x 25) mm for (4-5) mm specimens and (130 x 25) mm for (3-3.5) mm thickness as shown in Figure 3.24. The test was conducted in Defense university engineering collage, Bishoftu, Ethiopia.

Flexural strength of the fabricated composite was calculated using equation 3.11.

$$\sigma_b = \frac{3FL}{2bd^2} \quad \text{.....(3.11)}$$

Where, σ_b is flexural strength, F is applied load, L is span length, b is width of specimen and d is depth of beam.

The maximum bending moment of composite material can be calculated by using equation 3.12.

$$M_{bmax} = \frac{Fmax\ L}{4} \quad \text{.....(3.12)}$$

$$W = \frac{bh^2}{6} \quad \text{.....(3.13)}$$

Where, Fmax is the maximum load applied, h is thickness and b is width of specimen.

Figure 3.23 Specimen under flexural test

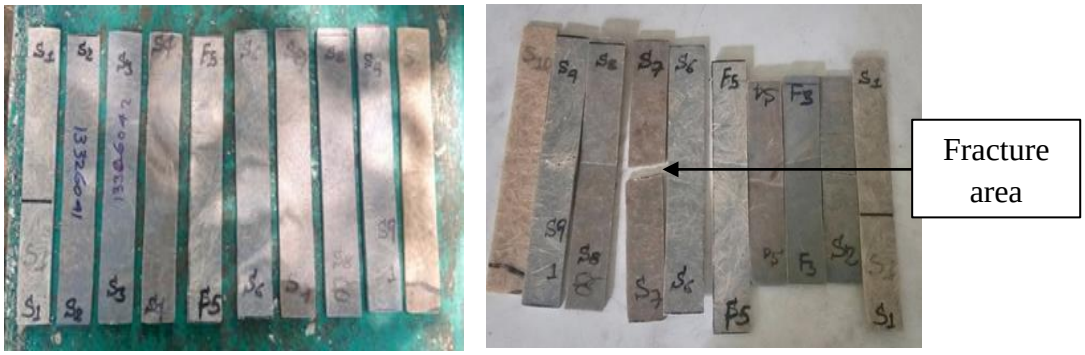

Figure 3.24 Flexural test specimens before and after test

3.6.3. Impact Strength Test

The test was performed over the samples of length 55*10*(3-6)mm and notch depth of 2.5mm according to ASTM D256. The impact speed of the hammer was 3.8m/s having a 30Kg weight mounted pendulum. The notch cut on the specimen shall be facing the opposite direction of the striker. The quantitative result of impact tests the energy needed to fracture material can be measured. The impact test specimen before and after test were shown in

Figure 3.25. The test was conducted at Defense university engineering college, Bishoftu, Ethiopia.

The energy absorbed by the specimen can be calculated by using equation 3.14.

$$\sigma = \frac{E}{t \times b} \quad \text{.....(3.14)}$$

Where, σ is impact strength, E is energy absorbed by the material during test, t is thickness and b is width of specimen.

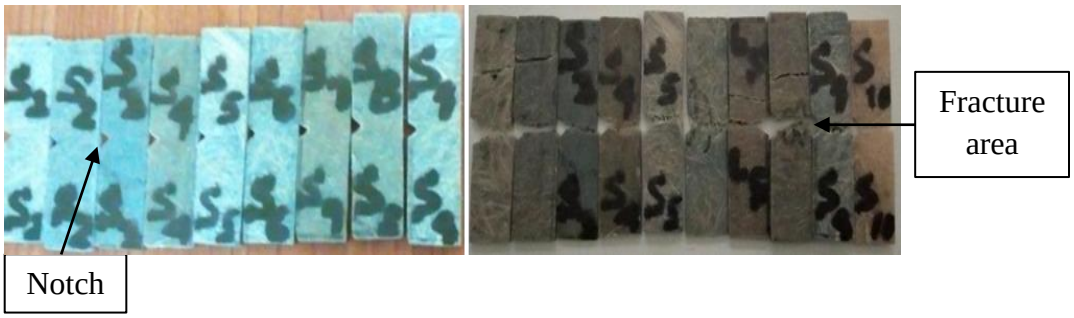

Figure 3.25 Specimens before and after impact test

3.6.4. Vickers Hardness Test

The hardness of a material implies a resistance to deformation. Hardness tests involve measuring the amount of force required to implant a specified indentation in the surface of a specimen. The hardness of the specimens was measured by Vickers hardness testing machine (HVS-50) with test force of 10kgf and 10 sec of dwelling time. The flat surface was indented at two different positions and the average of the mean diagonal lengths of two indentations was calculated. The surface-projected diagonal lengths of the resulting impression of each sample were then measured immediately after unloading using an upright optical. One specimen for each sample, two reputations were done on two positions and the average value was taken. The experiment was conducted at Material science department, ASTU, Ethiopia.

3.6.5. Machinability

Machinability of a composite considerably depends on the mechanical properties and relative content of the reinforcement and the matrix material, which depend on many parameters such as fiber orientation, surface characteristics of the fiber, volume fraction, physical and mechanical properties of the fiber, and the structure of the composite. These parameters have a significant impact on the machinability of fiber-reinforced composites (FRCs) as it has been reported over the past years (Lotfi et al., 2019).

Performing drilling after fabrication of the polymer matrix composites material is important to observe and minimize the failures on composite material during machining operation. In

this study drilling of the fabricated composite was carried out with different drill bits. The heat generated due to drilling operation may damage the surface of the drilled composite. To avoid these problem cutting speed and feed rate must be controlled. The drilling operations, take place with radial drill, with a diameter of the drill bit 5mm, 7.5mm, 10mm. The purpose of drilling was to observe the surface finish through hole. It helps to identify the materials 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 bolt.

3.6.6. Density and Void fraction

Density is one of the most important issues in determining the properties of a composite. It can be measured using one of three methods: The Archimedes principle, the sink-float method, or the density gradient method. For this work, the actual density (ρa) of composite is determined by the Archimedes principle using distilled water as a medium. Archimedes principle states that an object fully or partially immersed in a fluid is buoyed up by a force equal to the weight of that the object displaces. This is demonstrated by simple experiments using graduated beakers. The sample was prepared according to ASTM D570 having 30mmx30mm dimension. One specimen was tested per each sample as shown in Figure 3.26 was taken to assess the density, the experiment was carried out in Thermal and aerospace engineering department Laboratory, ASTU, Ethiopia. The volume of each sample was obtained from displaced water level during immersion of composite into water and before immersion. The actual density of composites can be calculated by the following equation given by (Das & Biswas, 2016).

$$\rho_a = \frac{\rho_w W_a}{\rho_t - w_w} \quad \text{..... (3.15)}$$

Where, ρa and ρw is the actual/measured density of composite and density of water
Wa is weight of the sample in air and Ww is weight of the sample in water.
The theoretical density of composite materials (ρt) in terms of weight fraction can easily be obtained as per the following equation:

$$\rho_t = \frac{1}{{}^{Wf}/_{\rho f} + {}^{Wm}/_{\rho m} + {}^{Wp}/_{\rho p}} \quad \text{..... (3.16)}$$

$$W_f = \left(\frac{\frac{\rho f}{\rho c}}{\frac{\rho f}{\rho c} \times vf + vc}\right) * vf = \frac{mf}{mc} \quad \text{..... (3.17)}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, p and m stand for the fiber, particulate and matrix material respectively. The presence of voids will

add to the total volume, but not the weight of the composite. (Vv) is the void content which is then expressed as:

$$V_v = \frac{\rho t - \rho a}{\rho t} \quad \text{..... (3.18)}$$

Figure 3.26 Density test specimen

3.6.7. Water absorption

Water absorption test is required to know how much water the specimen can absorb from the surroundings. The water absorption test of Al_2O_3/banana fiber reinforced polyester composite was done as per ASTM D570 by immersing the samples in distilled water for eight days at room temperature as shown in Figure 3.27 (c). The specimens were weighted before immersed in water as shown in Figure 3.27 (b). Then the specimen are removed from water and cleaned by dry materials and their weights were measured within 24hrs interval. Moisture absorption of a composite material can be calculated by using the following formula (Ding et al., 2016):

$$W\% = \frac{W2 - W1}{W1} * 100 \quad \text{..... (3.19)}$$

Where, W% is percentage of water absorption, W1 is initial weight of sample before immersed and W2 is final weight of sample after immersed.

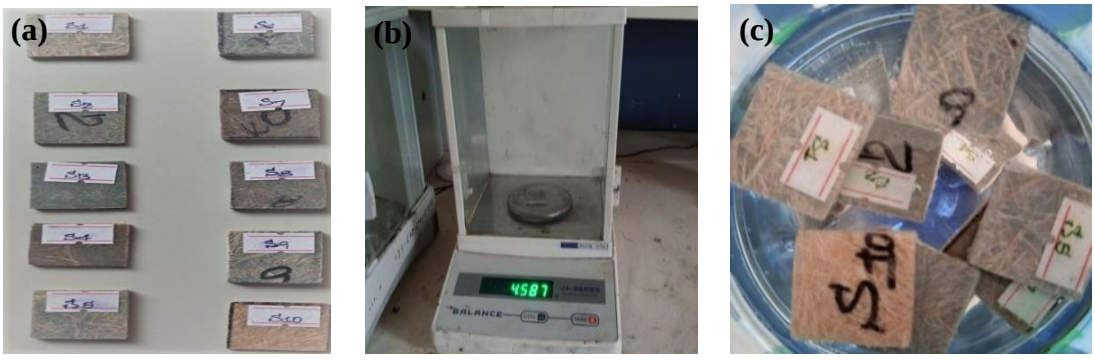

Figure 3.27 (a) water absorption specimens (b) measuring weight before immersion (c) specimens immersed in water

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

In this chapter, the results of the experimental works were discussed in detail. In different sub section tensile, flexural, impact, hardness, density, water absorption, machinability and SEM analysis test results were discussed. Hybrid Taguchi based grey relational analysis method of optimization was discussed for all the results.

4.2. Tensile Test

Al_2O_3 filled banana fiber reinforced polyester composite were fabricated by varying the weight percentage of banana fiber, alumina, fiber length and NaOH treatment. For tensile strength evaluation nine specimens were tested, one specimen for each sample under UTM. The tensile strength, maximum load and S/N ratios were shown in Table 4.1.

Table 4.1 Tabular description of design of experiment and tensile strength result

Expt. No	**Banana fiber wt%**	**Al_2O_3wt%**	**Banana fiber length**	**NaOH%**	**Tensile strength (MPa)**	**Maximum load (KN)**	**S/N ratio**
1	10	2	10	0.0	23.7	1.90	27.495
2	10	4	15	2.5	45.2	2.71	33.102
3	10	6	20	5.0	47.9	2.87	33.597
4	15	2	15	5.0	**61.7**	4.32	35.811
5	15	4	20	0.0	28.5	2.85	29.096
6	15	6	10	2.5	47.1	4.26	33.464
7	20	2	20	2.5	32.3	3.10	30.184
8	20	4	10	5.0	30.5	3.05	29.674
9	20	6	15	0.0	23.7	2.84	27.495

For all untreated fiber reinforced composites the tensile strength had minimum value, the minimum tensile strength of 23.7MPa was obtained for S1 and S9. At 15wt.% fiber loading and 4wt.% alumina improved strength of 28.5 was obtained for untreated fiber reinforced composite. 5% and 2.5% NaOH treated fiber reinforced composites showed good tensile strength results.

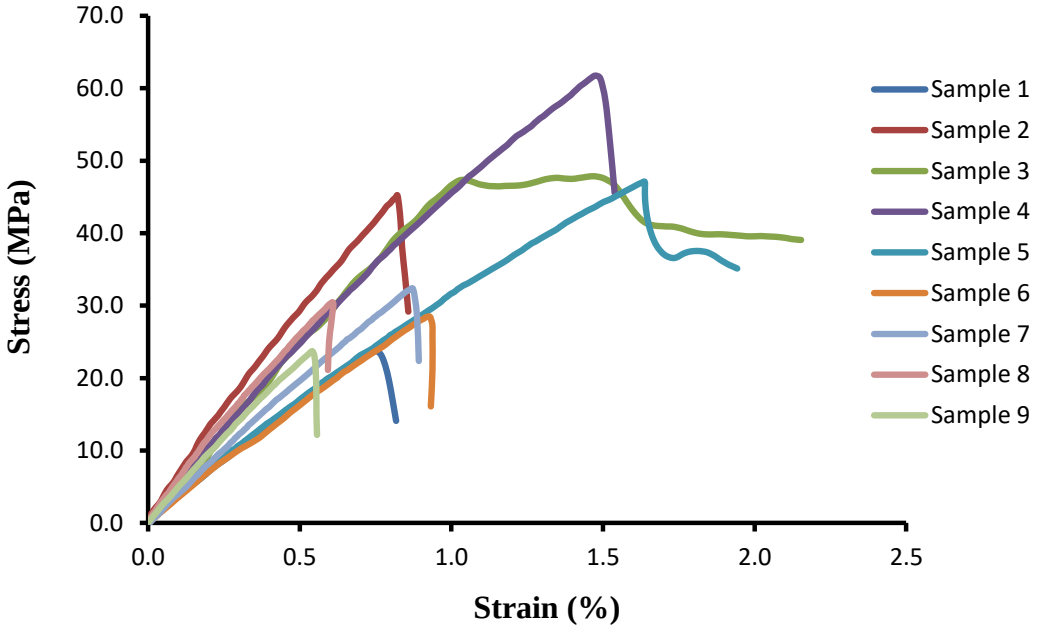

Figure 4.1 Stress –strain graphs

The result of tensile strength for the nine specimens was shown in Figure 4.1. From the graph it was observed that sample 4 has the maximum tensile strength of 61.7MPa for treated fiber and 28.5MPa for untreated fiber reinforced composite. Sample 9 and sample 8 have lower elongation; this implies that the material had brittle nature. S1, S2, S6 and S7 have medium elongation this indicates that the materials had less brittle and stiffer. S3, S4 and S5 had more elongation values this means the materials were ductile and stiff. The tensile strength of the material was diminished at 20wt.% banana fiber due to the increased amount of fiber resulted in poor bonding between matrix and reinforcements.

Figure 4.2 (a) shows that as fiber loading increases the average tensile strength increased from 38.93MPa to 45.66MPa. Increasing the fiber loading from 15wt.%-20wt.% reduced the tensile strength from 45.66MPa to 28.83MPa. The increase in tensile strength from 10wt.% to 15wt.% was due to the fiber amount was insufficient to share the applied load at 10wt.%. For this reason the tensile strength increased with the increase in fiber loading up to 15wt.%. The reduction in tensile strength after reaching 15wt.% was because of the polyester resin was insufficient for 20wt.% fiber and additional filler, thus the adhesion was less. From the results superior tensile strength value of 61.74MPa at 15wt.% banana fiber loading. This result was in sound with (Bakri et al., 2017; Parre et al., 2020; Prasad et al., 2021).

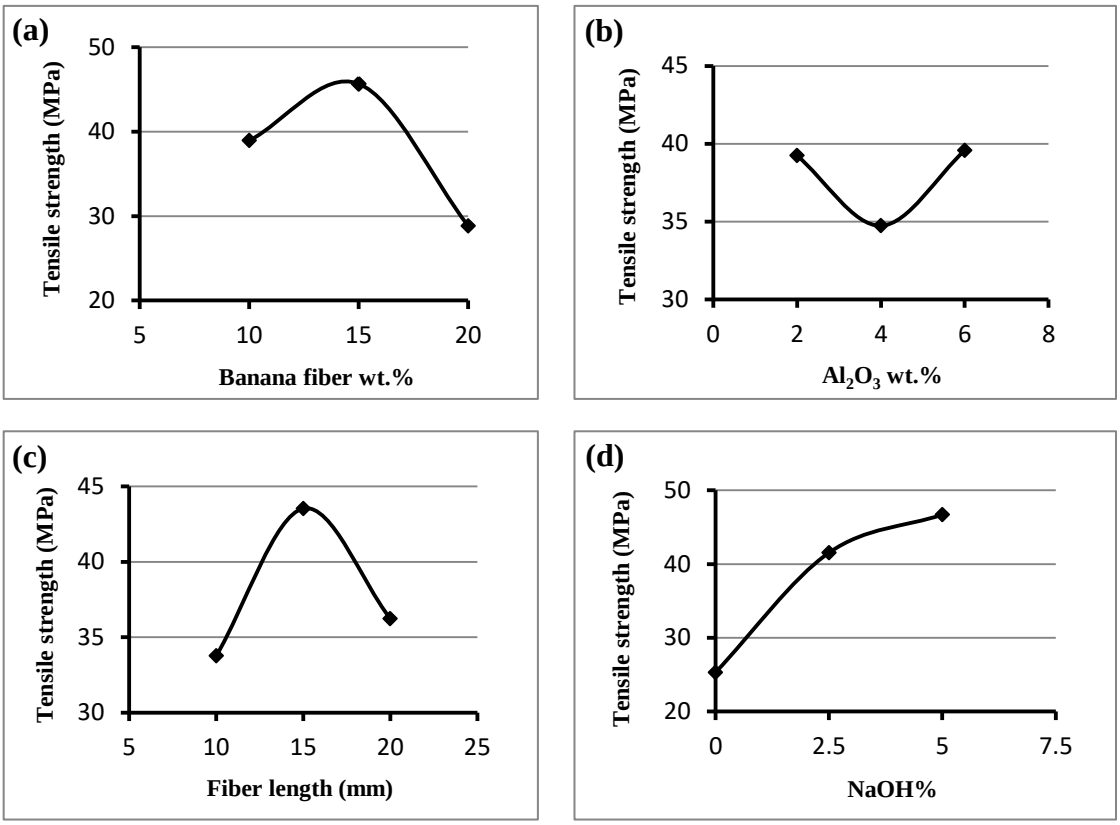

Figure 4.2 Tensile strength Vs (a) Banana fiber wt% (b) Al_2O_3 wt.% (c) Fiber length and (d) NaOH %

The addition of nano alumina also increased the tensile strength of the composite as shown in Figure 4.2 (b). Tensile strength of untreated banana fiber reinforced polymer composite also increased with the incorporation of Al_2O_3 powder. This was due to good dispersion of nano particles in the matrix yield in better adhesion of fiber and matrix. The addition of more alumina in the matrix causes reduction in the strength due to weak bonds formed by the ceramic particles with each other. Results proved that the incorporation of 2wt.% nano Al_2O_3 enhanced the tensile strength. The result is in well agreement with (Manjunath et al., 2016; Olayil et al., 2021; Ozsoy et al., 2015).

Regarding banana fiber length the tensile strength increase with an increase in fiber length from 10mm-15mm and for 20mm length the strength was reduced. At 10mm the strength was reduced due to the fiber length was insufficient to distribute the applied load. At 15mm it reaches its maximum and further addition of fiber length reduced the strength this was due longer fiber lengths were incompatible with the matrix. The maximum tensile strength obtained was 61.74MPa at 15mm fiber length as shown in Figure 4.2 (c). The result was in well agreement with (Karthick et al., 2018). Concerning the NaOH% Figure 4.2 (d) shows

maximum tensile strength was obtained at 5% concentration. It was clearly seen that alkali treatment of banana fiber improved the mechanical property of the composite; as a result of surface modification good fiber-matrix interfacial adhesion was achieved. Untreated banana fiber reinforced samples had minimum tensile strength value of 23.7MPa compared with alkali treated banana/alumina composite and untreated 4wt% alumina filled banana fiber composites. This results are in well agreed with (Khan et al., 2019; Parre et al., 2020).

4.2.1. Analysis of main effect plot of tensile strength

Figure 4.3 shows the main effect plot for S/N ratios of tensile strength. The graph implies that the optimum condition (level) for tensile strength was 15wt.% fiber loading, 6wt.% Al_2O_3, 15mm fiber length and 5% alkali treatment. Using these combination better results can be obtained for tensile strength.

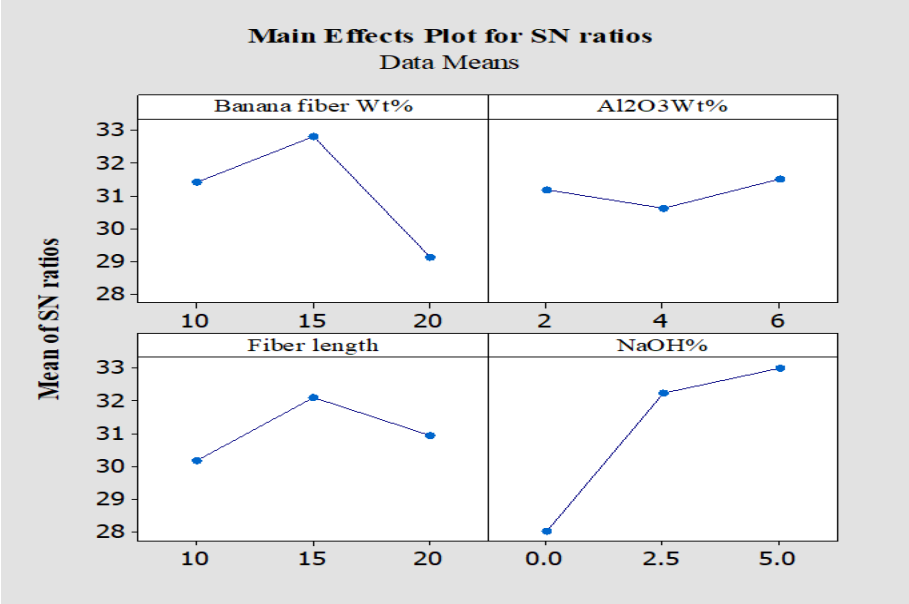

Figure 4.3 Main effect plot of tensile strength

4.2.2. Response table for S/N ratios of tensile strength

Response of tensile strength was displayed in Table 4.2 indicates alkali treatment had the highest effect for the increase in the tensile strength of the composite with delta number of 21.4. Whereas banana fiber loading was the second most contributing factor in increasing the tensile strength with delta value of 16.93. Fiber length ranked third contributing factor with delta value of 9.77 and alumina wt.% was the fourth contributing factor with delta value of 4.83. The optimum combination was A2B3C2D3.

Table 4.2 Response for S/N ratios of tensile strength

Level	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	38.93	39.23	33.77	25.30
2	45.77	34.73	43.53	41.53
3	28.83	39.57	36.23	46.70
Delta	16.93	4.83	9.77	21.40
Rank	2	4	3	1

4.2.3. Analysis of variance of tensile strength

The ANOVA table for tensile strength was shown in Table 4.3 below. It shows that NaOH concentration had the highest effect for the increase in tensile strength with percentage contribution of 61.0%. The second influencing parameter was banana fiber wt.% with percentage contribution of 29.0%. The third and fourth contributed factors were fiber length and alumina wt.% with percentage contribution of 5.9% and 2.7% respectively. P-value shows that factor A, C and D are highly significant and factor B is less significant.

Table 4.3 Analysis of variance of tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	20.629	20.629	10.314	2.609	0.000	29.0%
Al_2O_3 wt.%	2	1.216	1.216	0.608	0.153	0.991	2.7%
Fiber length	2	5.651	5.651	2.825	0.714	0.000	5.9%
NaOH %	1	43.413	43.413	21.706	11.088	0.000	61.0%
Residual Error	1	3.952					1.4%
Total	8	70.910					100%

4.3. Flexural Test

The results obtained during flexural test on composite specimens of different fiber, filler loading, NaOH treatment and fiber length were shown in Table 4.4. In addition to the nine samples, sample 10 was fabricated with chopped and 5% NaOH treated banana fiber and polyester resin without addition of filler and tested for comparison with particle filled samples.

Table 4.4 Tabular description of flexural strength test result

Expt. No	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH %	Flexural strength (MPa)	Maximum load (KN)	S/N ratio
1	10	2	10	0.0	63.7	0.08	36.082
2	10	4	15	2.5	103.5	0.13	40.298
3	10	6	20	5.0	86.6	0.08	38.750
4	15	2	15	5.0	108.3	0.10	40.692
5	15	4	20	0.0	66.3	0.13	37.558
6	15	6	10	2.5	75.5	0.12	38.233
7	20	2	20	2.5	81.6	0.16	36.434
8	20	4	10	5.0	66.3	0.13	36.430
9	20	6	15	0.0	56.6	0.16	35.056
10	5	0	15	5.0	63.7	0.08	-

The flexural strength of banana fiber reinforced pure polyester composite sample shows the same result of 63.7 MPa with 5% NaOH treated, 2 wt% alumina filled, 10 Wt% banana fiber reinforced polyester composite.

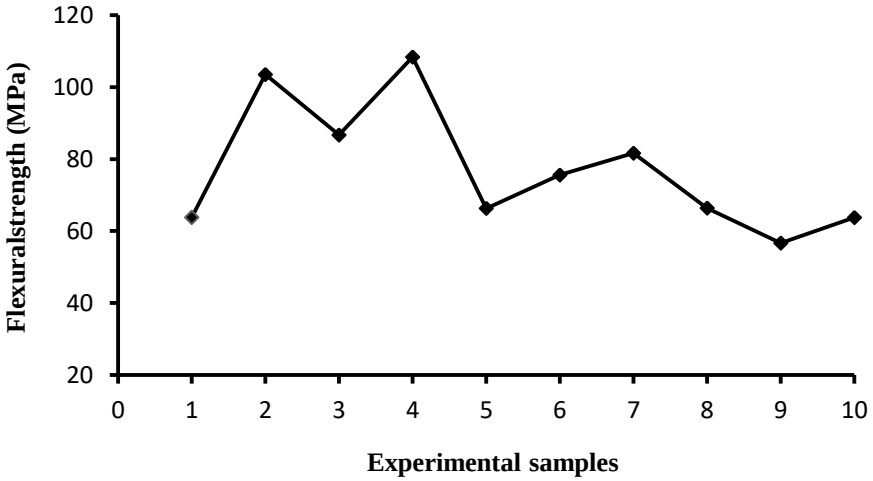

Figure 4.4 Flexural strength Vs experiment number

From Figure 4.4 it was observed that the maximum flexural strength at 15 wt.% banana fiber loading was 108.33MPa, at 10 wt.% fiber loading 103.47MPa and 20wt.% fiber loading 81.62MPa. Sample 9 showed the minimum flexural strength due to high amount of fiber and filler resulted in poor adhesion between matrix and reinforcement. Incorporation of 2wt.%

alumina in untreated fiber reinforced composite was comparable with 5% alkali treated pure banana polyester composite.

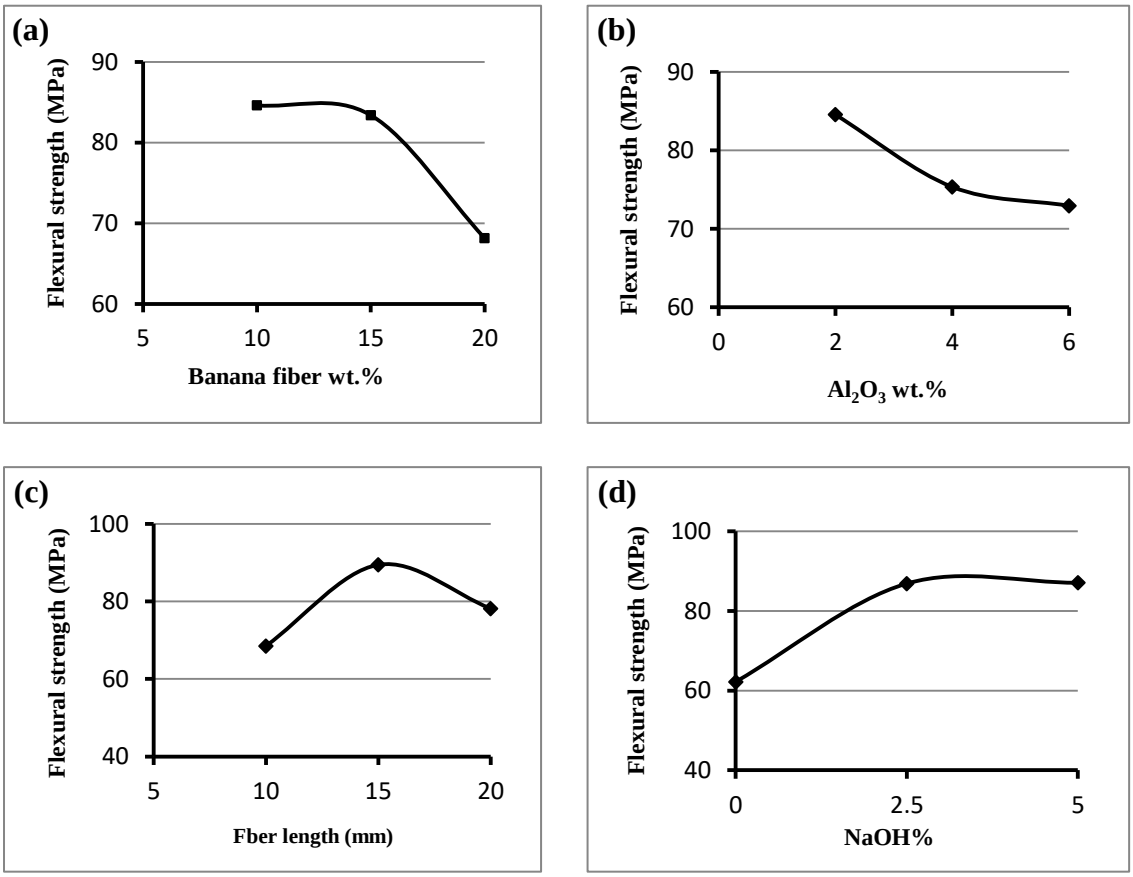

Figure 4.5 Flexural strength Vs (a) Banana fiber wt.% (b) Al_2O_3 wt.% (c) Fiber length and (d) NaOH%

The effect of banana fiber loading on flexural strength was shown in Figure 4.5 (a). The result shows that flexural strength increased with increase in fiber loading. Fiber loading at 10wt.% and 15wt.% has almost same effect on the flexural strength. Further fiber addition resulted in reduced of flexural strength because of lower fiber–matrix adhesion and the quantity of fiber content being more than matrix. The maximum flexural strength obtained at 10, 15 and 20wt.% was 103.47MPa, 108.33MPa and 81.6MPa respectively. This result was well agreed with (Prasad et al., 2021; Venkateshwaran et al., 2011). The effect of Al_2O_3 filler on the flexural strength of the composite was also depicted in Figure 4.5 (b). Results yield that the addition of 2wt.% alumina nano filler in the matrix enhanced the flexural strength of the composite, further addition of nano particles reduced the flexural strength. This was due to the agglomeration of filler particle which reduced the interfacial adhesion between polyester and reinforcement. The maximum flexural strength obtained at 2wt.% filler loading was 108.33MPa. The result was in sound with (Ashok et al., 2020; Ozsoy et al., 2015).

Regarding the effect of fiber length on flexural strength the result was shown in Figure 4.5 (c). The flexural strength increased with an increase in fiber length from 10mm to 15mm and reduced from 15mm to 20mm in the above graph. It was found that the maximum flexural strength was 108.33 MPa at fiber length of 15 mm. The result was similar with (Venkateshwaran et al., 2011b). Figure 4.5 (d) show the effect of alkali treatment on flexural strength of the composite. As the graph indicated untreated fiber reinforced composite had minimum flexural strength than the treated one. 2.5% and 5% NaOH treated fiber reinforced composite reviled improved flexural strength, since alkali treatment effectively removed the non-cellulosic materials and impurities from the fiber surface and provide good adhesion between fiber and matrix. The sample made with 2.5% and 5% treatment had the maximum flexural strength of 103.47MPa and 108.33MPa respectively. The observed result was in sound with (Khan et al., 2018; Parre et al., 2020).

4.3.1. Analysis of main effect plot of flexural strength

The main effect plot for S/N ratios of flexural strength was shown in Figure 4.6. The graph implies that the optimum condition for the flexural strength was 10wt.% banana fiber, 2wt.% Al_2O_3, 15mm fiber length and 2.5 %NaOH treatment. Using these combination better results could be obtained.

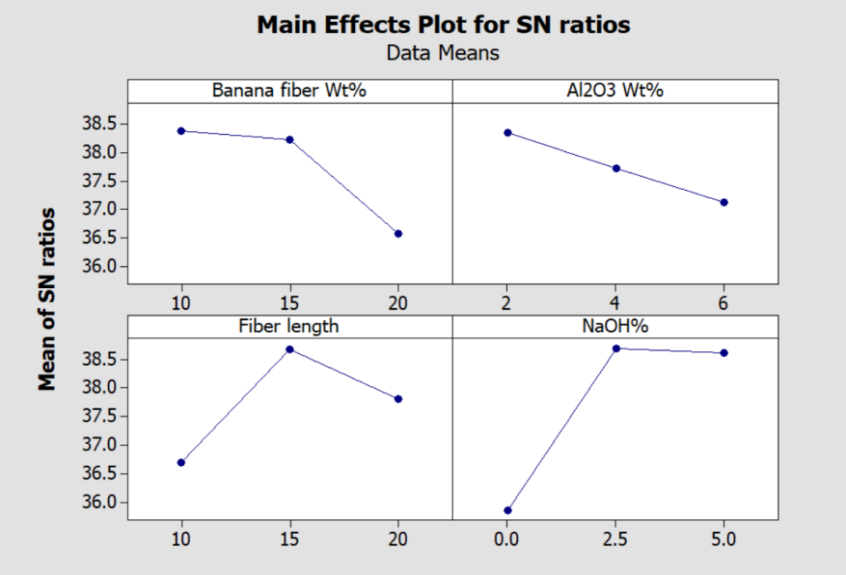

Figure 4.6 Main effect plot of flexural strength

4.3.2. Response table for S/N ratios of flexural strength

The response Table 4.5 shows that NaOH had the highest contribution in increasing the flexural strength with delta number of 2.84 .While fiber length was the second contributed

factor with delta number of 1.99. The third ranked factor was fiber weight percentage with delta number of 1.80. Likely alumina weight percentage takes the fourth rank with delta number of 1.21. It can be concluded that alkali treatment concentration was the most influencing factor for an increase in the flexural strength. The optimum combination for the flexural strength was A1B1C2D2.

Table 4.5 Response table for S/N ratio

Level	Fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	38.38	38.34	36.69	35.86
2	38.23	37.72	38.68	38.70
3	36.57	37.12	37.81	38.62
Delta	1.80	1.21	1.99	2.84
Rank	3	4	2	1

4.3.3. Analysis of variance for flexural strength

From the ANOVA Table 4.6 it can be discussed that alkali treatment percentage contributed 47.28%. The second contributed factor was fiber length with percentage contribution of 24.48%. The third and fourth contributed factors were fiber wt.% and Al_2O_3 wt.% with percentage contribution of 19.39% and 7.83% respectively. From the p-value alkali treatment was more significant factor and the rest were significant factors.

Table 4.6 Analysis of variance for flexural strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	502.90	502.90	251.448	31.185	0.085	19.39%
Al_2O_3 wt.%	2	203.00	203.00	101.501	12.586	0.053	7.83%
Fiber length	2	660.70	660.70	330.352	40.966	0.066	24.48%
NaOH %	1	1225.85	1225.85	612.923	76.011	0.036	47.28%
Residual Error	1	8.064					1.02%
Total	8	2592.45					100%

4.4. Impact Test

The results of impact strength were shown in Table 4.7 below. The charpy impact testing machine had two readings the inner reading was the impact energy in Jules and the outer reading was the angle of inclination in degree. The results were seen and recorded form the inner line manually after the specimens were raid with pendulum.

Table 4.7 Tabular description of design of experiment and impact energy results

Expt. No	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH %	Impact energy (J)	S/N ratio
1	10	2	10	0.0	10.0	20.000
2	10	4	15	2.5	12.0	21.583
3	10	6	20	5.0	14.5	23.227
4	15	2	15	5.0	19.0	25.575
5	15	4	20	0.0	17.5	24.860
6	15	6	10	2.5	10.0	20.000
7	20	2	20	2.5	12.0	21.583
8	20	4	10	5.0	11.5	21.214
9	20	6	15	0.0	9.0	19.084
10	5	0	15	5.0	7.0	-

From the results the maximum impact strength of banana/alumina polyester composite was 19J and the minimum impact strength was 7J for pure banana polyester composite. The increase in the impact strength was due to the addition of alumina powder. The maximum results at 10wt.% fiber loading 14.5J, 15wt.% fiber loading 19J and 20wt.% fiber loading 12J.

Figure 4.7 (a) show the effect of banana fiber loading on impact energy of the composite. As the amount of fiber increases from 10wt.% to 15wt.% the impact strength increased and further addition reduced the impact strength. The increase in the impact energy from 10-15wt.% was due to smaller amount of fiber was not sufficient to carry suddenly applied load. The decrease in impact energy from 15-20wt.% was since the matrix was insufficient for the reinforcement and this leads to poor adhesion between fiber and matrix. The maximum impact strength was 19J at 15wt.% banana fiber loading. The results were supported by the study carried out by (Prasad et al., 2021). Concerning the effect of Al_2O_3 wt.% on impact strength result was presented in Figure 4.7 (b). The impact strength of the composite decreased as the amount of filler increased from 2wt.% to 6wt%. The drop in the strength was due to the agglomeration of nanoparticles together by weak force, which results in micron sized entities. The maximum impact strength was 19J/m for 2wt.% Al_2O_3 filler. Generally the addition of nano alumina to the matrix phase enhanced the impact strength of the composite. The result was supported by study carried out by (Girimurugan et al., 2020).

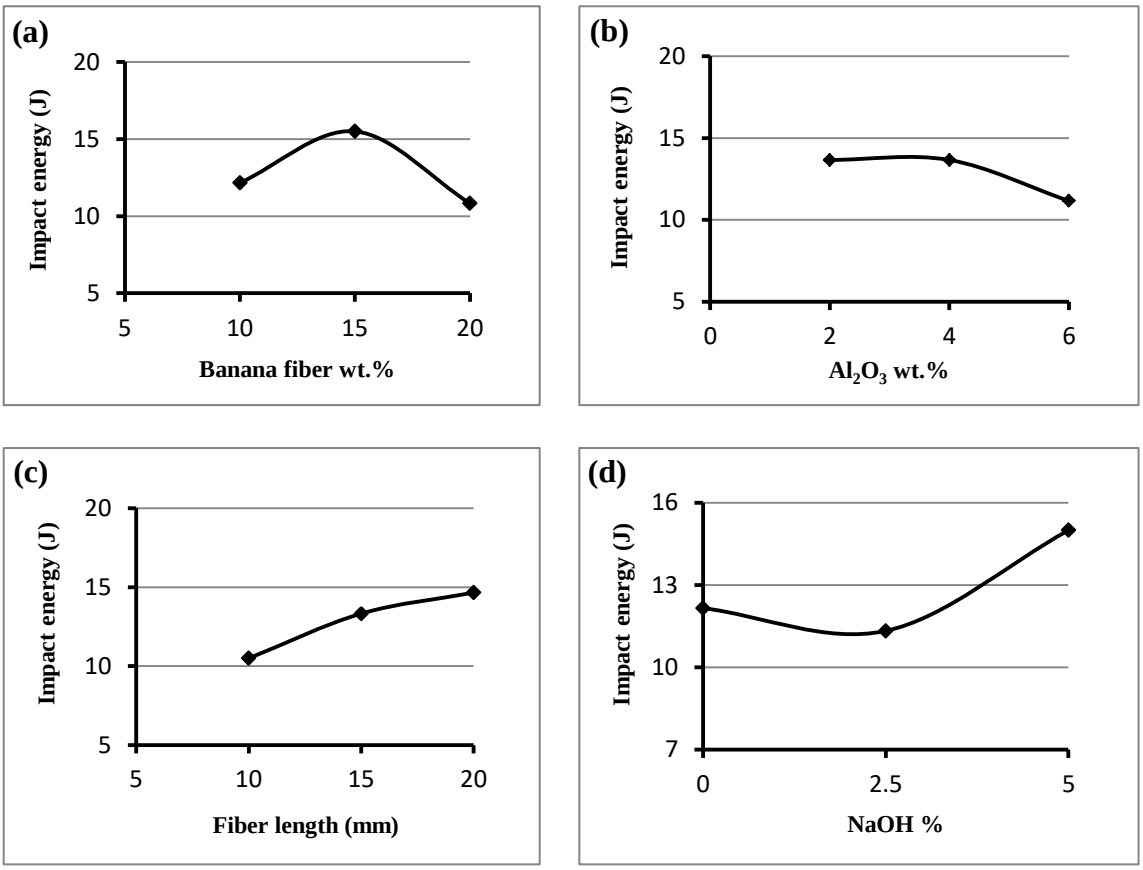

Figure 4.7 Impact strength Vs (a) Banana fiber wt.% (b) Al_2O_3 wt.% (c) Fiber length and (d) NaOH %

Figure 4.7 (c) depicted the effect of banana fiber length on impact strength. The increase in the fiber length resulted in enhanced impact strength. The maximum impact strength at 20mm fiber length was 17.5J/m. The result in Figure 4.7 (d) revealed that fiber treatment resulted in improved impact strength. For all the results discussed above the treatment improved the mechanical properties of the composite. The same is true here the impact strength improved with the surface modification of fibers with NaOH solution. The maximum impact strength for alkali treated fiber reinforced composite and untreated fiber reinforced composite was 19J/m and 17.5J/m respectively.

4.4.1. Analysis of Main effect plot of Impact Strength

The main effect plot for S/N ratios of impact strength was shown in Figure 4.8. The graph implies that the optimum condition for the impact strength was 15wt.% banana fiber, 4wt.% Al_2O_3, 20mm fiber length and 5% NaOH concentration.

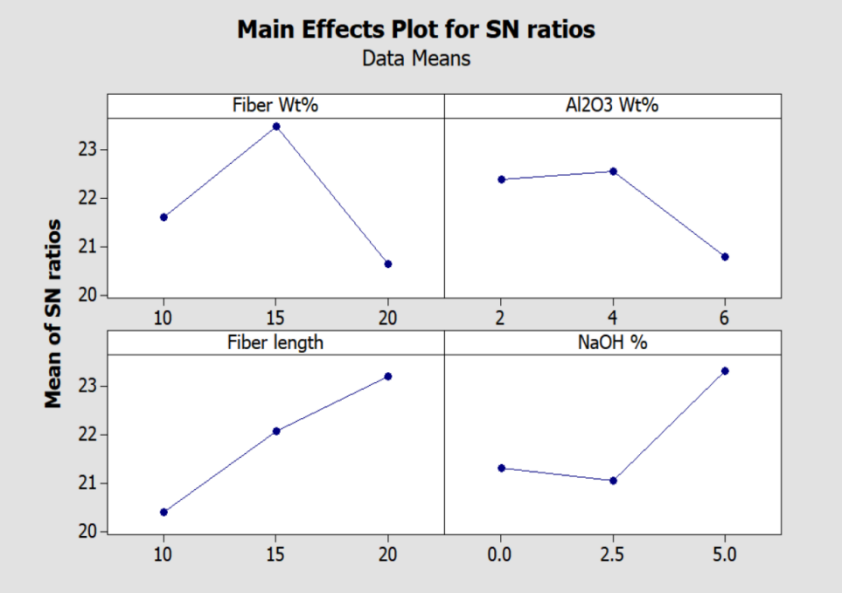

Figure 4.8 Main effect plot for impact strength

4.4.2. Response table for S/N ratios of Impact strength

From the response Table 4.8 below it can be discussed that banana fiber length had the highest contribution in increasing the impact strength of the composite with delta value of 2.85. While second contributed factor was fiber length with delta value of 2.82. Likely NaOH concentration and Al_2O_3 were the third and fourth contributed factor with delta value of 2.28 and 1.78 respectively. The optimum level combinations were A2B2C3D3.

Table 4.8 Response table for S/N ratios of impact strength

Level	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	21.60	22.39	20.40	21.32
2	23.48	22.55	22.08	21.06
3	20.63	20.77	23.32	23.34
Delta	2.85	1.78	2.82	2.28
Rank	1	4	2	3

4.4.3. Analysis of variance of impact strength

The ANOVA Table 4.9 shown below illustrates the percentage contribution of each factor in improving the impact strength of the composite material. Banana fiber weight percentage had the highest contribution of 31.61% for the increase in impact strength. The second most contributed factor was fiber length with percentage contribution of 29.27%. Likely alkali treatment concentration and alumina weight percentage were the third and fourth contributed

factor with percentage contribution of 22.96% and 13.58% respectively. P-value indicates that alumina was more significant factor and the rest were less significant factors.

Table 4.9 Analysis of variance of impact strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	12.597	12.597	6.298	6.115	0.075	31.61%
Al_2O_3 wt.%	2	5.813	5.813	2.906	2.821	0.029	13.58%
Fiber length	2	11.064	12.064	6.032	5.856	0.078	29.27%
NaOH %	1	9.374	9.374	4.687	4.550	0.098	22.96%
Residual Error	1	1.030					2.58%
Total	8	39.85					100%

4.5. Hardness test

The aim of hardness test was to compute the resistance of a material to plastic deformation. A higher value of hardness indicates that the material was harder, offering more resistance to penetration by other materials. As shown in Table 4.10 the maximum hardness was 164.9HV for untreated banana fiber, 4wt.% alumina filled composite sample. The minimum hardness was 45.6HV for sample 1, which was untreated banana fiber, 2wt% alumina filled composite. Sample 10 made from pure banana fiber polyester composite showed good hardness value of 67.45HV, which was better result compared with other samples.

Table 4.10 Tabular description of design of experiment and hardness test result

Experiment number	Trial 1	Trial 2	Average	S/N ratio
1	44.9	46.3	45.60	33.179
2	53.1	46.3	49.70	33.927
3	55.4	50.0	52.70	34.436
4	44.8	49.9	47.35	33.506
5	145.0	184.8	164.9	44.344
6	67.8	58.8	63.30	36.028
7	48.3	56.0	52.15	34.345
8	60.6	58.3	59.45	35.483
9	49.1	54.8	52.05	34.328
10	61.8	73.1	67.45	-

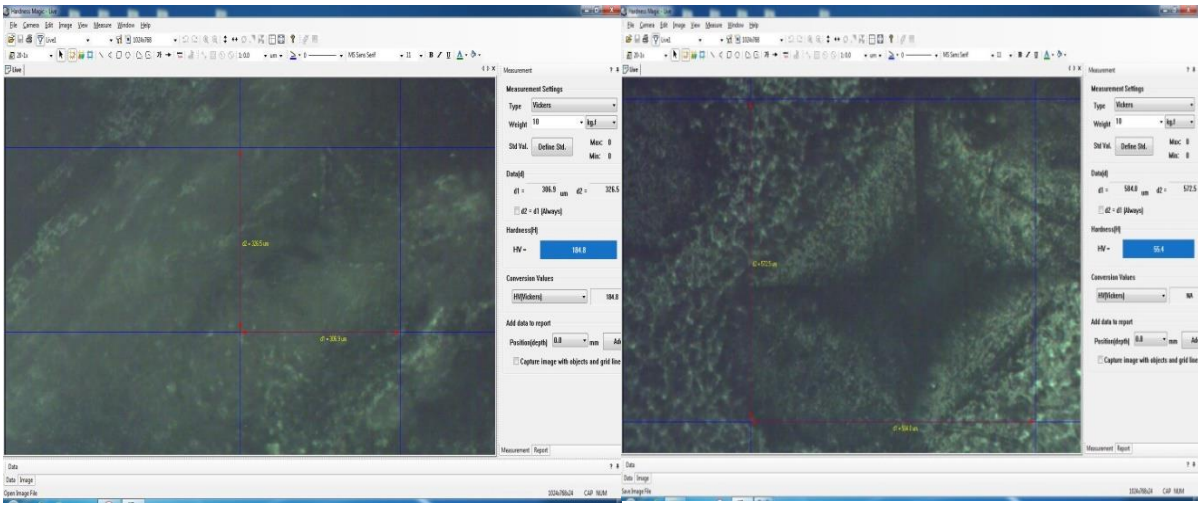

Figure 4.9 Indented area measurements of S5 and S8

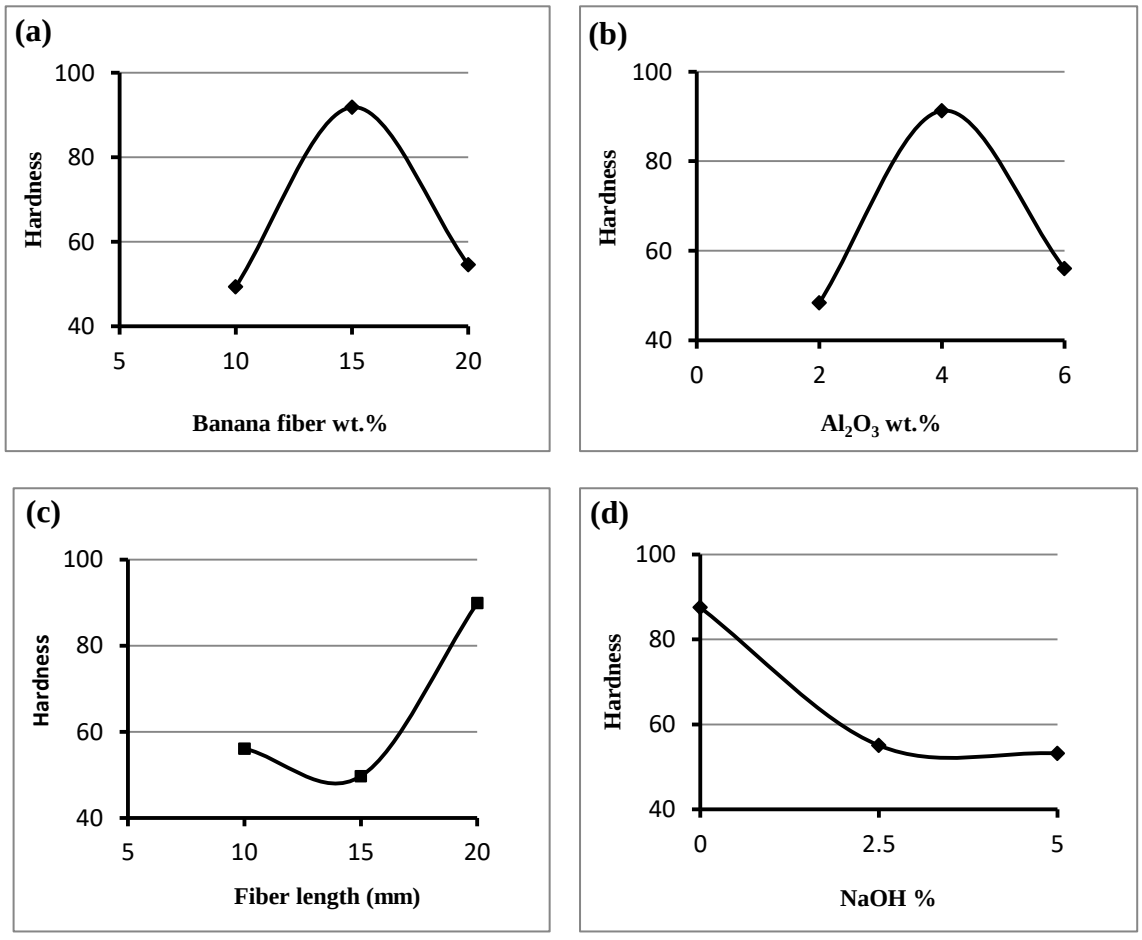

Figure 4.10 Hardness Vs (a) Banana fiber wt.% (b) Al_2O_3 wt.% (c) Fiber length (d) NaOH%

The effect of banana fiber wt.% on hardness was illustrated in Figure 4.10 (a). The hardness value of the composite increase with fiber content and reached its maximum value 164.9 HV at 15wt.% fiber loading for untreated fiber reinforced composite. Further addition of fiber and filler content reduced the hardness of the composite. The result was in sound with

(Venkateshwaran et al., 2011). As the fiber length increases the hardness also increased. The maximum hardness was 164.9 HV at 20mm fiber length. The fiber loading and fiber length result was in well agreement with (Balaji et al., 2020).

Figure 4.10 (b) illustrated the influence of Al_2O_3wt.% on hardness value of the composite. It was found that the increase in filler amount increased the hardness of the composite and further addition reduced the hardness value. Hardness of 5% treated pure banana polyester composite was 67.45 HV which was a good result compared with others. Regarding alkali treatment of untreated fiber reinforced sample showed improved hardness value.

4.5.1. Analysis of variance for main effects

Figure 4.11 the main effect plot for S/N ratio of hardness show that the optimum condition for higher Vickers hardness was untreated 15wt.% fiber loading, 4wt.% Al_2O_3 20mm fiber length.

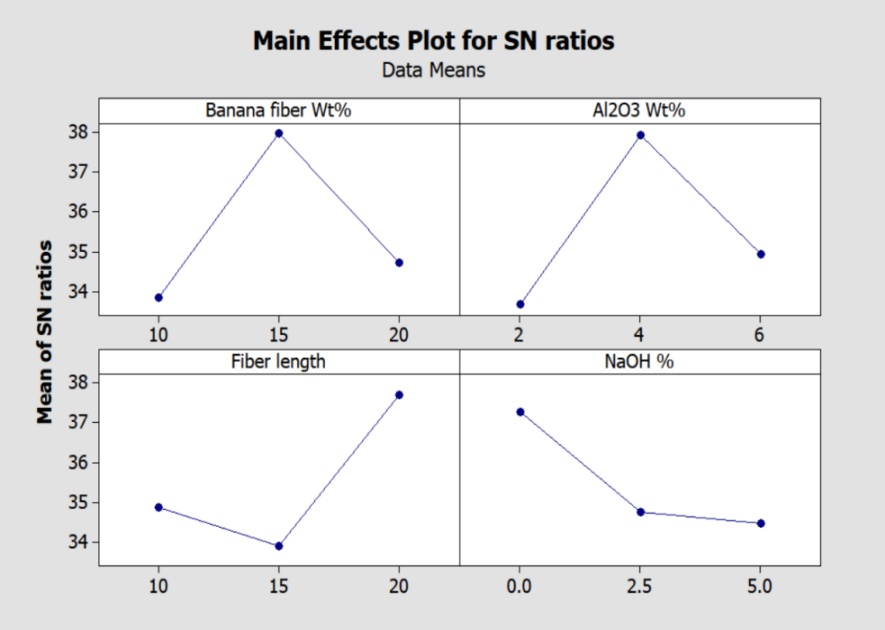

Figure 4.11 Main effect plot for hardness

4.5.2. Response table for S/N ratios of hardness

The response table of hardness presented in Table 4.11 illustrated that Al_2O_3 weight percentage had highest contribution in increasing the hardness of the composite with delta number of 4.24. While banana fiber weight percentage was the second contributed factor in increasing the hardness of the composite with delta value of 4.11. Likely fiber length and alkali concentration take the third and fourth rank with delta value of 3.79 and 2.81 respectively.

Table 4.11 Response table for S/N ratios of hardness

Level	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	33.65	33.68	34.90	37.28
2	37.96	37.92	33.92	34.77
3	34.72	34.93	37.71	34.48
Delta	4.11	4.24	3.79	2.81
Rank	2	1	3	4

4.5.3. Analysis of variance of hardness

The ANOVA table shown in Table 4.12 implies that alumina weight percentage had the highest contribution followed by banana wt.%, fiber length and alkali concentration. The percentage contribution of alumina was 30.24%, the second contributed factor was banana fiber wt.% 29.91%. The third and fourth influencing factors were fiber length and alkali treatment concentration with percentage contribution of 24.64% and 15.19% respectively.

Table 4.12 Analysis of variance of hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	28.171	28.171	14.085	11.232	0.081	29.91%
Al_20_3 wt.%	2	28.484	28.484	14.242	11.357	0.004	30.24%
Fiber length	2	23.207	23.207	11.603	9.253	0.097	24.46%
NaOH %	1	14.311	14.311	7.155	5.706	0.149	14.19%
Residual Error	1	1.254					1.12%
Total	8	94.174					100%

4.6. Water absorption test

In order to promote longer use of composites in high performance applications, it was essential to consider the effect of moisture absorption on their physical and mechanical properties. It was important to investigate this test for applying in potential outdoor working. Higher water absorption of a composite can result in reduction of the mechanical properties and dimensional stability of composites due to swelling of the fiber, micro cracks and formation of voids at the fiber-matrix interface region. Water absorption test was carried out to determine the percentage of water absorbed under specified conditions. The weight of water absorption test samples which was shown in Table 4.13 measured before immersion.

Table 4.13 Weight of samples before immersion in water

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Weight before Immersion	3.975	3.414	3.478	3.483	4.558	4.117	5.672	5.676	5.848	2.69

Weight measurement for each 24hrs difference and water absorption percentage was briefly indicated in the Table 4.14. Water absorption percentage analyzed for each days and averagely for 192hrs.

Table 4.14 Tabular description of water absorption result and S/N ratios

S. no	Immersion period in (hr)									S/N ratio
	24	48	72	96	120	144	168	192	Average	
S1	3.25	3.51	3.82	4.08	4.47	4.82	4.93%	5.02	4.26%	-12.588
S2	2.58	2.69	2.87	3.34	3.57	3.74	4.04%	4.06	3.37%	-10.552
S3	2.05	2.37	2.63	2.92	3.12	3.39	3.54%	3.58	2.97%	-9.4551
S4	1.94	2.24	2.58	2.97	3.31	3.58	3.81%	3.86	3.04%	-9.6575
S5	2.04	3.37	4.56	4.83	4.85	4.89	4.90%	4.96	4.30%	-12.669
S6	1.99	2.39	2.76	3.39	3.87	4.28	4.41%	4.49	3.46%	-10.781
S7	2.44	2.99	3.24	3.53	3.85	4.04	4.14%	4.29	3.62%	-11.174
S8	2.58	2.69	2.87	3.34	3.57	3.74	4.04%	4.10	3.37%	-10.552
S9	3.22	3.52	3.92	4.20	4.65	5.05	5.15%	5.19	4.46%	-12.986
S10	2.49	2.73	2.84	2.98	3.25	3.47	3.58%	3.64	4.47%	_

Table 4.14 can be summarized as water absorption of specimens increase with immersion period and after some days the absorption it was less and it does not change significantly. The rate of water absorption increases with increase in fiber loading composite sample with 20wt.% banana fiber loading shows more water absorption rate compared to 10wt.% fiber loading. The addition of alumina reduced the water absorption percentage due to high affinity of powder to resist water absorption. Untreated fiber reinforced samples have the highest water absorption rate compared to all samples. This is due to the absence of surface modification and reduction of impurities on the reinforced fiber. Pure banana polyester composite shows similar result with untreated 6wt.% alumina filled sample.

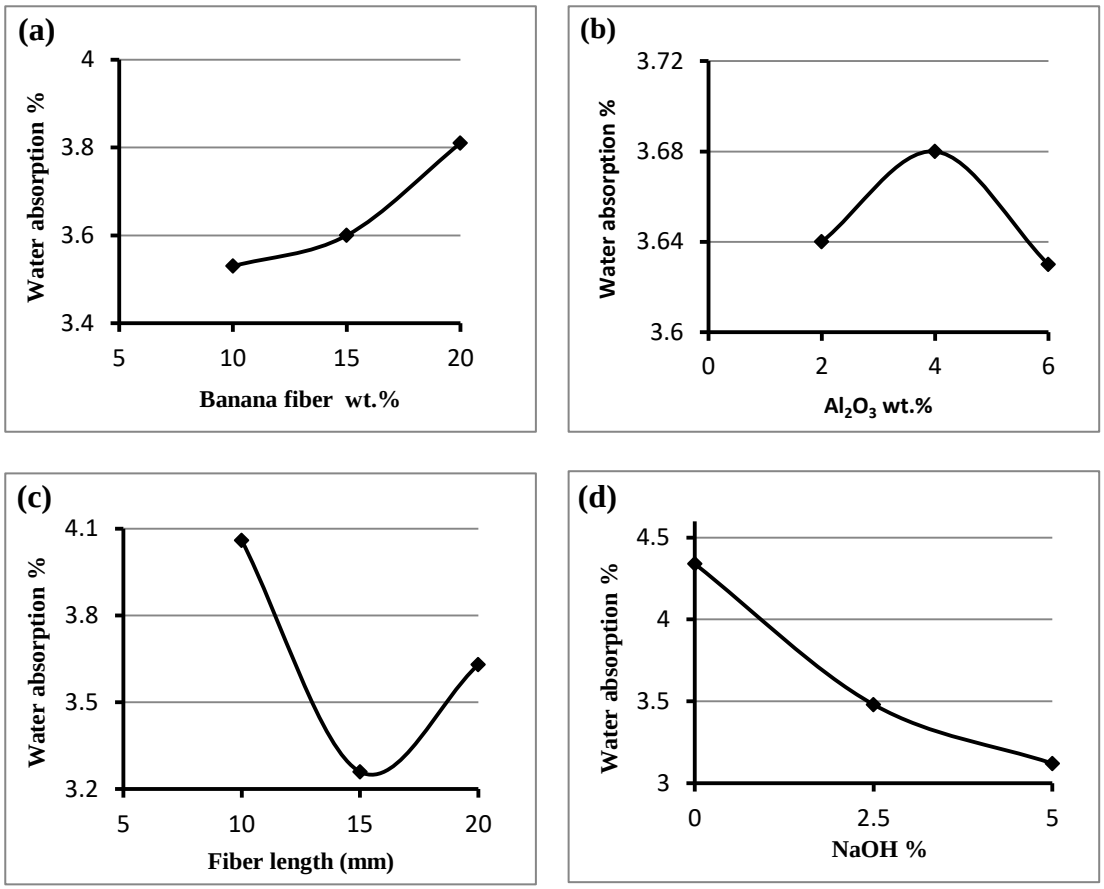

Figure 4.12 Water absorption Vs (a) Banana fiber wt.% (b) Al_2O_3 wt.% (c) Fiber length (d) NaOH %

The rate of water absorption depends on the weight percentage of the fiber as shown in Figure 4.12. Water absorption percentage increases continuously with increased amount of fiber loading. This was due to the fiber absorbed more water than the matrix and filler. From the result it was observed that the minimum water absorption percentage was 2.97% at 10wt.% banana fiber loading. As the thickness of the sample increases the water absorption rate also increased. The result was well agreed with (Muktha & Gowda, 2017). Regarding alumina weight percentage, increasing the amount of filler wt.% decreased the water absorption rate. This was due to high affinity of nano alumina to be combined with matrix material and strong affinity towards moisture. The result was agreed with (Venkateshwaran et al., 2011). Increasing the fiber length resulted in decreased water absorption rate. Alkali treated fiber reinforced composites shows minimum water absorption rate compared to untreated samples. This was due to hydrophobic NaOH reduced the hydrophilic nature of banana fiber. Pure 5% NaOH banana fiber polyester composite resulted in high absorption rate than 2.5% and 5% treated fiber/alumina filled samples.

4.6.1. Analysis of main effect plot of water absorption rate

Figure 4.13 show the main effect plots for S/N ratios of water absorption. The graph implies that the optimum condition for minimum water absorption rate was 10wt.% fiber loading, 6wt.% Al_2O_3, 15mm fiber length and 5% NaOH. Minimum water was absorbed at this optimum combination.

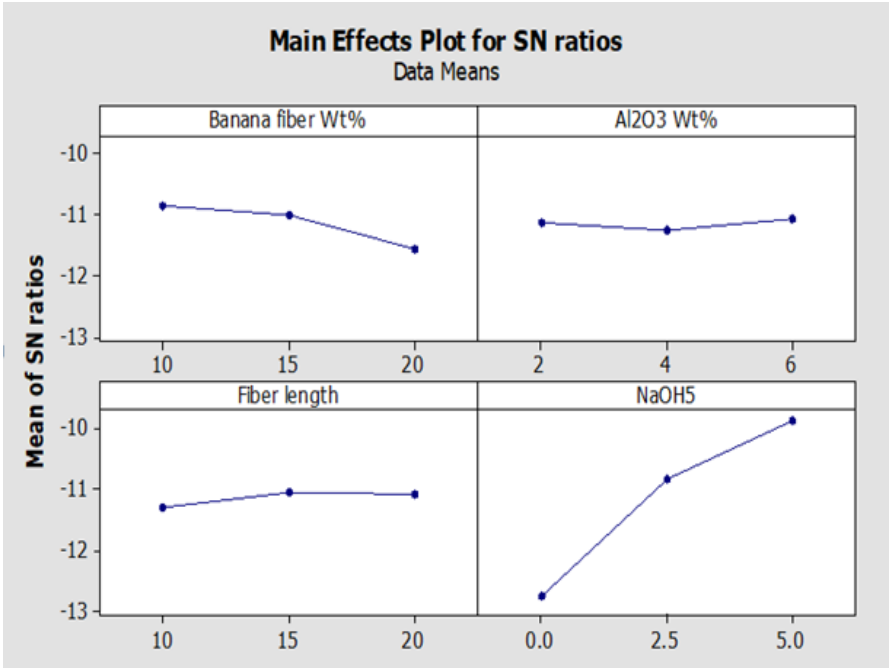

Figure 4.13 Main effect plot of water absorption

4.6.2. Response Table for Signal to Noise Ratios

The response Table 4.15 of water absorption rate shows that alkali treatment had the highest contribution in decreasing the water absorption rate with delta value of 2.86. This was due to the hydrophobic behavior of NaOH improved the hydrophilic nature of fiber. Fiber loading was the second contributed factor with delta value of 0.706. The third and fourth contributed factors were fiber length and Al_2O_3 wt.%. The optimum level combination was A1B3C2D3.

Table 4.15 Response table for S/N ratios of water absorption rate

Level	Banana fiber wt.%	Al_2O_3wt.%	Fiber length	NaOH%
1	-10.865	-11.140	-11.307	-12.748
2	-11.036	-11.258	-11.066	-10.836
3	-11.571	-11.074	-11.100	-9.888
Delta	0.706	0.184	0.242	2.860
Rank	2	4	3	1

4.6.3. Analysis of Variance for water absorption rate

The percentage of contribution was shown in Table 4.16 indicates that alkali treatment had the highest contribution of 70.19% in the reduction of water absorption rate. Fiber loading was the second contributed factor; at higher fiber loading more water was absorbed by the material with water absorption rate of 20.53%. Fiber length and alumina weight percentage were the third and fourth contributed factors with rate of 4.32% and 1.67% respectively. P-value shows that alumina and fiber loading were more significant, fiber length was significant and NaOH was less significant factor.

Table 4.16 Analysis of variance for water absorption rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	2.813	1.813	0.065	102.93	0.009	20.53%
Al_2O_3 wt.%	2	0.592	0.122	0.002	68.962	0.000	4.32%
Fiber length	2	0.229	0.099	0.049	10.177	0.089	1.67%
NaOH%	1	9.616	10.316	1.166	1.860	0.349	70.19%
Residual Error	1	0.447					3.29%
Total	8	13.700					100%

4.7. Density and void fraction

Density of a composite depends on the relative proportion of reinforcing and matrix materials and this was one of the most important factors determining the properties of the composites. This difference in the composites is the measure of voids or pores present in it. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering. The knowledge of void content is desirable for estimation of the quality of the composites. However, presence of void is unavoidable in composite fabrication through hand-lay-up method. The theoretical density, actual density and void fraction of the composites were calculated by using equation (3.15), equation (3.16), and equation (3.17) respectively. The weight of samples measured in air and water was depicted in Table 4.17.

Table 4.17 Weight of sample in air and in water

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
wt. of sample in air (g)	1.48	1.45	1.42	1.43	1.72	1.66	1.71	1.59	1.78	1.5
wt. of sample in water (g)	1.233	1.24	1.22	1.27	1.29	1.27	1.28	1.28	1.29	1.25

Table 4.18 Measured density, theoretical density and void fraction of the composite

Samples	Theoretical density	Measured density	Volume fraction	S/N ratios
1	1.154	1.143	0.981	0.175
2	1.143	1.132	1.036	-0.256
3	1.133	1.120	1.045	-0.340
4	1.169	1.157	1.013	-0.086
5	1.158	1.146	1.074	-0.587
6	1.148	1.136	1.051	-0.423
7	1.184	1.172	1.062	-0.506
8	1.173	1.161	1.080	-0.668
9	1.163	1.150	1.111	-0.906
10	1.188	1.174	1.130	_

From Table 4.18 the void content for all the samples were less than 3%. Therefore this implies that the quality of the composite was good in all conditions. The obtained result was in well agreement with (Venkateshwaran et al., 2011).

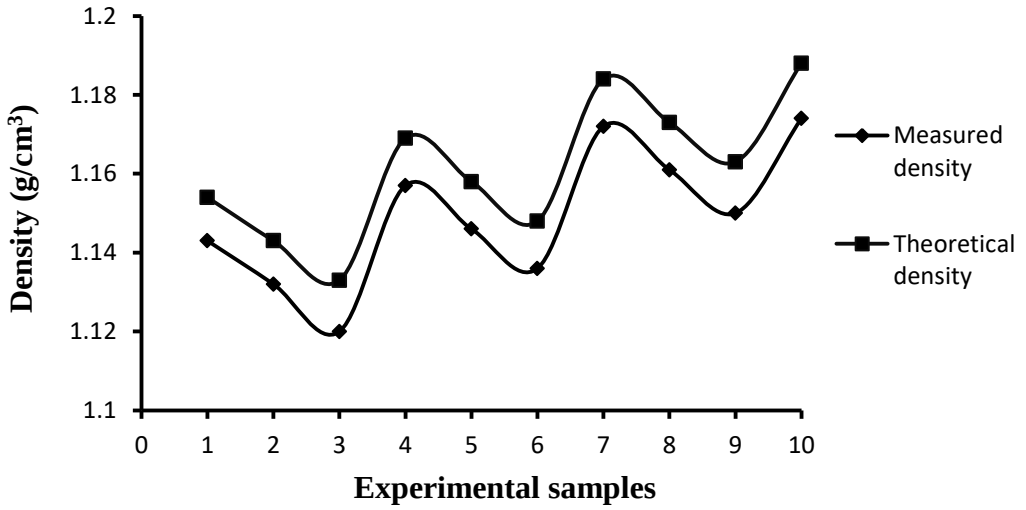

Figure 4.14 Theoretical and experimental density

Figure 4.14 depicts that theoretical and experimental density of composite material was different. The theoretical density was larger in all samples. For lower levels of fiber and filled loading the density was smaller than that of at higher levels. For 10wt.% banana fiber loading light weight composites were made, since density is directly proportional to mass.

The increase in the weight percentage resulted in increased density of the composite. The increase in alumina wt.% also increased the density and resulted in high void content in the composite. Weak inter molecular bonds formed between alumina particle was the reason for the increased void content at higher alumina loading.

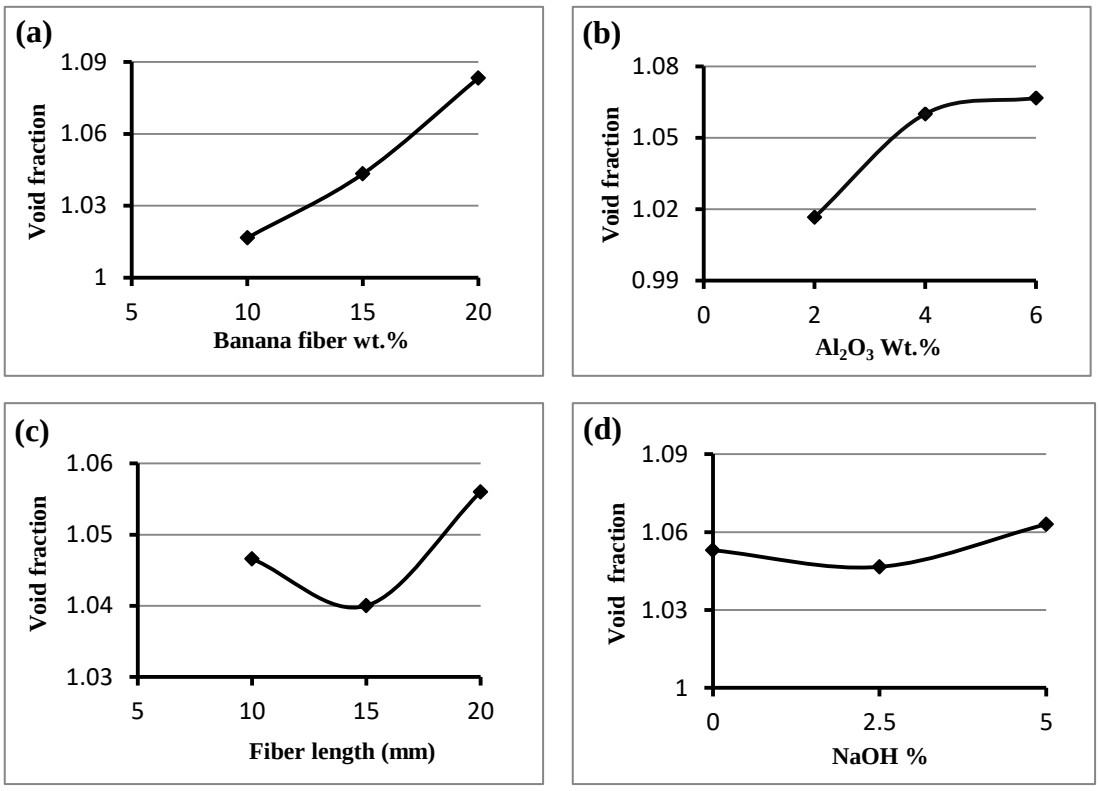

Figure 4.15 Void fraction Vs (a) Banana fiber wt.% (b) Al_2O_3 wt.% (c) Fiber length (d) NaOH %

Density of composite material increased with increase in fiber and filler loading. With increase in the composite density, the void content also increases. The addition of nano filler above 2wt.% increased the void content of the composite because of the creation of agglomeration in the composite due to high amount of filler loading. Concerning the fiber length and alkali treatment minimum void content was obtained at 15mm fiber length and 2.5% NaOH solution. The density of 10wt.% banana fiber was less than the density of 20wt.%loaded composite. Density of a material largely depends upon the amount of fiber and filler on composite. Therefore the wt.% of banana fiber and alumina highly affects the density and void fraction of the composite rather than the NaOH% and fiber length.

A void is a space that remains unfilled with polymer, fiber and filler in a composite. It can affect the mechanical properties and lifetime of the composite. It was mainly influenced by weight percentage of banana fiber and alumina powder. The increase in banana fiber

increased the void content due to the insufficient matrix resulted in poor adhesion between reinforcements and matrix. At higher amount of alumina the agglomeration/aggregate was formed due to high amount of alumina in the filer material. The weak bones formed between alumina nano particles resulted in voids and the other reason that causes voids is due to air bubble. In manufacturing a composite through hand layup method we cannot avoid voids, but it can be reduced. The minimum void content obtained was 0.981 for S1 (untreated, 2wt.% alumina, 10wt.% banana fiber and 10mm length).

4.7.1. Analysis of main effect plot of void fraction

From Figure 4.16 it can be discussed that density of composite material increased with increase in fiber content. The density of untreated fiber reinforced composite was increased compared to treated fiber reinforced composite. The optimum condition for minimum void content was 10wt.% banana fiber, 2wt.% alumina, 10mm fiber length and 5% NaOH concentration.

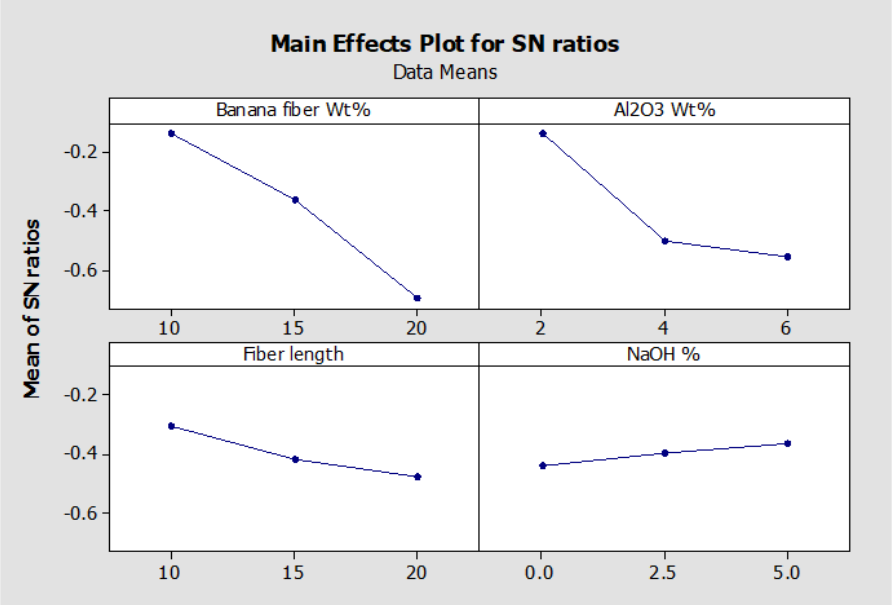

Figure 4.16 Main effect plot for S/N ratios of void fraction

4.7.2. Response table for void content

The most influencing factor for the decrease or increase in void fraction was banana fiber weight percentage as showed in Table 4.19. Banana fiber loading had the highest contribution with delta value of 0.553. The second contributed factor for the reduction in void content was alumina weight percentage with delta value of 0.4179. The third and fourth contributed factors were fiber length and alkali treatment concentration with delta values of 0.1726 and 0.0744 respectively. The optimum level combination was A1B1C1D3.

Table 4.19 Response table for S/N ratios of void fraction

Level	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	-0.140	-0.139	-0.305	-0.439
2	-0.366	-0.504	-0.416	-0.395
3	-0.693	-0.557	-0.478	-0.365
Delta	0.553	0.417	0.172	0.074
Rank	1	2	3	4

4.7.3. Analysis of variance for void content

The percentage contribution of the factors was shown in Table 4.20. The ANOVA table illustrated that fiber loading had 55.9% contribution. Alumina had percentage contribution of 36.49%. Fiber length had percentage contribution of 5.53% and NaOH% had percentage contribution of 0.46. P-value indicates that factor C was significant and other factors were less significant. As we have seen from the table density of a material and void fraction were highly influenced by banana fiber and alumina weight percentage.

Table 4.20 Analysis of variance for void fraction

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC
Banana fiber wt.%	2	0.464	0.464	0.232	0.294	0.772	55.9%
Al_2O_3 wt.%	2	0.310	0.310	0.155	0.009	0.990	36.49%
Fiber length	2	0.045	0.045	0.022	0.220	0.806	5.53%
NaOH%	1	0.003	0.008	0.004	5.219	0.160	0.46%
Residual Error	1	0.447					1.61%
Total	8	0.829					100%

4.8. Grey relational analysis of Mechanical and Physical properties

The experimental results of tensile, flexural, impact, hardness, water absorption and void content shown in Table 4.21 were transformed into Signal to-Noise (S/N) ratio using Taguchi analysis. The normalizing sequence for parameters was calculated from the S/N ratio. By using the normalizing sequence value deviation sequence was calculated. The Gray relational coefficients were calculated using the deviation sequence values. Finally the GRG is calculated from the GRC and optimum parameter was selected/ recommended. The

calculation was different for smaller the better and larger the better criteria as discussed in the previous chapter.

Table 4.21 Response table

Responses (results)						
Expt. no	**Tensile (MPa)**	**Flexural (MPa)**	**Impact (J)**	**Hardness (HV)**	**Water absorption (%)**	**Void fraction**
1	23.69	63.75	10.0	45.60	4.26	0.98
2	45.20	103.47	12.0	49.70	3.37	1.03
3	47.85	86.67	14.5	52.70	2.97	1.04
4	61.74	108.33	19.0	47.35	3.04	1.01
5	28.5	66.30	17.5	164.9	4.30	1.07
6	47.12	75.56	10.0	63.30	3.46	1.05
7	32.30	81.60	12.0	52.15	3.62	1.06
8	30.46	66.30	11.5	59.45	3.37	1.08
9	23.69	56.60	9.0	52.05	4.46	1.11

The S/N ratios obtained from Taguchi were shown in Table 4.22 for all experiments except SEM and machinability. As discussed in chapter three the next step was normalization of S/N ratios using equation (2.4) for larger the better and equation (2.5) for smaller the better.

Table 4.22 S/N ratios table

S/N ratios						
Runs	**Tensile**	**Flexural**	**Impact**	**Hardness**	**Water absorption**	**Void fraction**
1	27.493	36.089	20.000	33.179	-12.588	0.175
2	33.102	40.296	21.583	33.927	-10.552	-0.256
3	33.597	38.757	23.227	34.436	-9.455	-0.340
4	35.811	40.694	25.575	33.506	-9.657	-0.086
5	29.096	36.430	24.860	44.344	-12.669	-0.587
6	33.464	37.565	20.000	36.028	-10.781	-0.423
7	30.184	38.233	21.583	34.345	-11.174	-0.506
8	29.674	36.430	21.213	35.483	-10.552	-0.668
9	27.491	35.056	19.084	34.328	-12.986	-0.906

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

Table 4.23 Normalizing sequence tabular description

Normalizing sequence						
Runs	**Tensile**	**Flexural**	**Impact**	**Hardness**	**Water absorption**	**Void fraction**
1	0.000	0.183	0.141	0.000	0.112	1.000
2	0.674	0.929	0.385	0.066	0.689	0.600
3	0.733	0.656	0.638	0.112	1.000	0.522
4	1.000	1.000	1.000	0.029	0.942	0.757
5	0.192	0.243	0.889	1.000	0.089	0.294
6	0.717	0.445	0.141	0.255	0.624	0.446
7	0.323	0.563	0.385	0.104	0.513	0.370
8	0.262	0.243	0.328	0.206	0.689	0.219
9	0.000	0.000	0.000	0.102	0.000	0.000

The tabulated normalized values were shown in Table 4.23. By using the normalized data the deviation sequence can be calculated as $1 - X_{ij}$.1 is used because it is the highest value of quality.

were Xij is the actual value of each experiment.

Table 4.24 Tabular description of deviation sequence

Deviation sequence						
Run	**Tensile**	**Flexural**	**Impact**	**Hardness**	**Water absorption**	**Void fraction**
1	1.000	0.816	0.858	1.000	0.887	0.000
2	0.325	0.070	0.614	0.933	0.310	0.399
3	0.266	0.343	0.361	0.887	0.000	0.477
4	0.000	0.000	0.000	0.970	0.057	0.242
5	0.807	0.756	0.110	0.000	0.910	0.705
6	0.282	0.554	0.858	0.744	0.375	0.553
7	0.676	0.436	0.614	0.895	0.486	0.629
8	0.737	0.756	0.671	0.793	0.310	0.780
9	1.000	1.000	1.000	0.897	1.000	1.000

The calculated deviation sequence (quality loss) shown in Table 4.24 was used to find the grey relational coefficients. Then the grey relational coefficient was calculated by using equation (2.7). Finally the grey relational grades were calculated by using equation (2.8).

Table 4.25 Grey relational coefficients and Grey relational grade

Runs	Grey relational coefficients						GRG	Rank
	Tensile	Flexural	Impact	Hardness	Water absorption	Void fraction		
1	0.333	0.379	0.367	0.333	0.360	1.000	0.462	6
2	0.605	0.876	0.448	0.348	0.616	0.555	0.575	3
3	0.652	0.592	0.580	0.339	1.000	0.511	0.616	2
4	1.000	1.000	1.000	0.339	0.897	0.673	0.818	1
5	0.382	0.397	0.819	1.000	0.354	0.414	0.561	4
6	0.639	0.473	0.367	0.401	0.571	0.474	0.488	5
7	0.425	0.533	0.448	0.358	0.506	0.442	0.452	7
8	0.404	0.397	0.426	0.386	0.616	0.390	0.437	8
9	0.333	0.333	0.333	0.35788	0.333	0.333	0.337	9

Ranked of samples were shown in Table 4.25 and according to the GRG experiment number 4 (S4) ranked number 1 at levels of A2B1C2D3.

4.8.1. Analysis of main effect plot for S/N ratios of GRG

The main effect plot for the S/N ratios depicted in Figure 4.17 shows that the optimum condition for the experiment carried out was 15wt.% banana fiber loading, 2wt.% Al_2O_3, 15mm fiber length and 5% NaOH treatment. Best result was achieved by using parameter levels at A2B1C2D3.

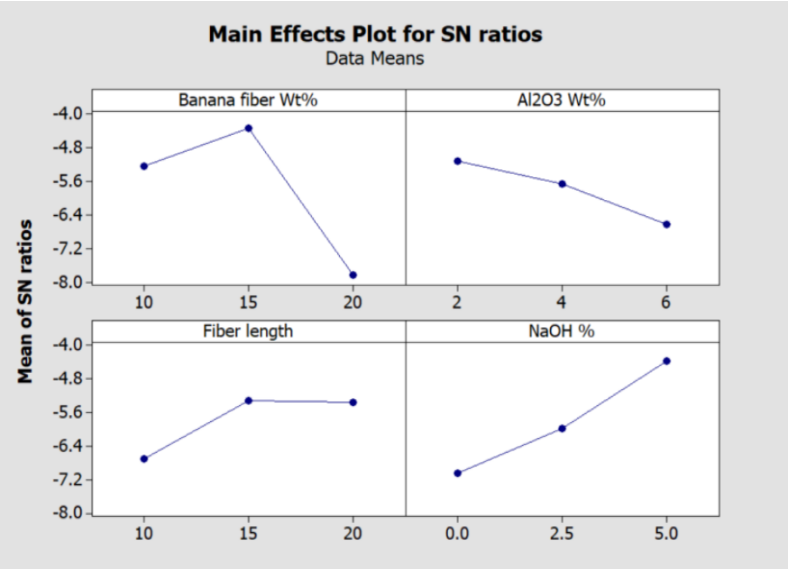

Figure 4.17 Main effect plots for S/N ratios of GRG

4.8.2. Response table for S/N ratios of Grey relational grades

The GRG response Table 4.26 shows that fiber loading had the highest contribution in increasing the tensile, flexural, impact strength and hardness of the composite material with delta number of 3.51. The second contributed factor was surface modification of the fiber with delta number of 2.671. The third and fourth contributed factors were alumina weight percentage and fiber length with delta number of 1.525 and 1.515. The obtained result was in well agreement with the literature review mentioned. From Table 4.26 A2B1C2D3 are the optimum levels, the first ranked experiment has also levels of A2B1C2D3. The optimal parameter set from the rank and grey relational analysis optimum combinations were similar. Therefore conformation experiment was not required since the experiment was already done.

Table 4.26 Response table for S/N ratios of GRG

Level	Banana fiber wt.%	Al_2O_3 wt.%	Fiber length	NaOH%
1	-5.235	-5.109	-6.706	-7.049
2	-4.327	-5.668	-5.326	-5.974
3	-7.838	-6.824	-5.366	-4.378
Delta	3.510	1.525	1.515	2.671
Rank	1	3	4	2

4.8.3. Analysis of variance for Grey relational grades

Analysis of variance for grey relational coefficient shows that banana weight percentage had the highest contribution of 51.4% for optimized experimental result. The second contributed factor was alkali treatment with percentage contribution of 28.54%. The third and fourth contributed factors were fiber length and Al_2O_3 wt.% with percentage contribution of 10.06% and 9.51% respectively. Depending up on the P-value Factor A and D were more significant factors and factor B and C were significant factors.

Table 4.27 Analysis of variance for GRG

Source	DF	Seq SS	Adj MS	F	P	PC
Banana fiber wt.%	2	19.520	9.960	55.366	0.017	51.4%
Al_2O_3 wt.%	2	3.821	1.760	9.787	0.092	10.06%
Fiber length	2	3.615	6.847	10.270	0.088	9.51%
NaOH%	1	10.839	5.419	30.126	0.032	28.54%
Residual Error	1	0.179				0.47%
Total	8	52.024				100%

4.9. Machinability of the composite

Drilling operation was performed on S3, S5, S8 and S10. The drilled hole shows that delamination and fiber pullout occurred with an increase in fiber length. Reducing the fiber length resulted in elimination of fiber pullout and good surface finish can be obtained. The surface finish of a hole is an important aspect in various application areas. The delamination occurred due to drilling operation is critical for holes since it may affect the strength of material.

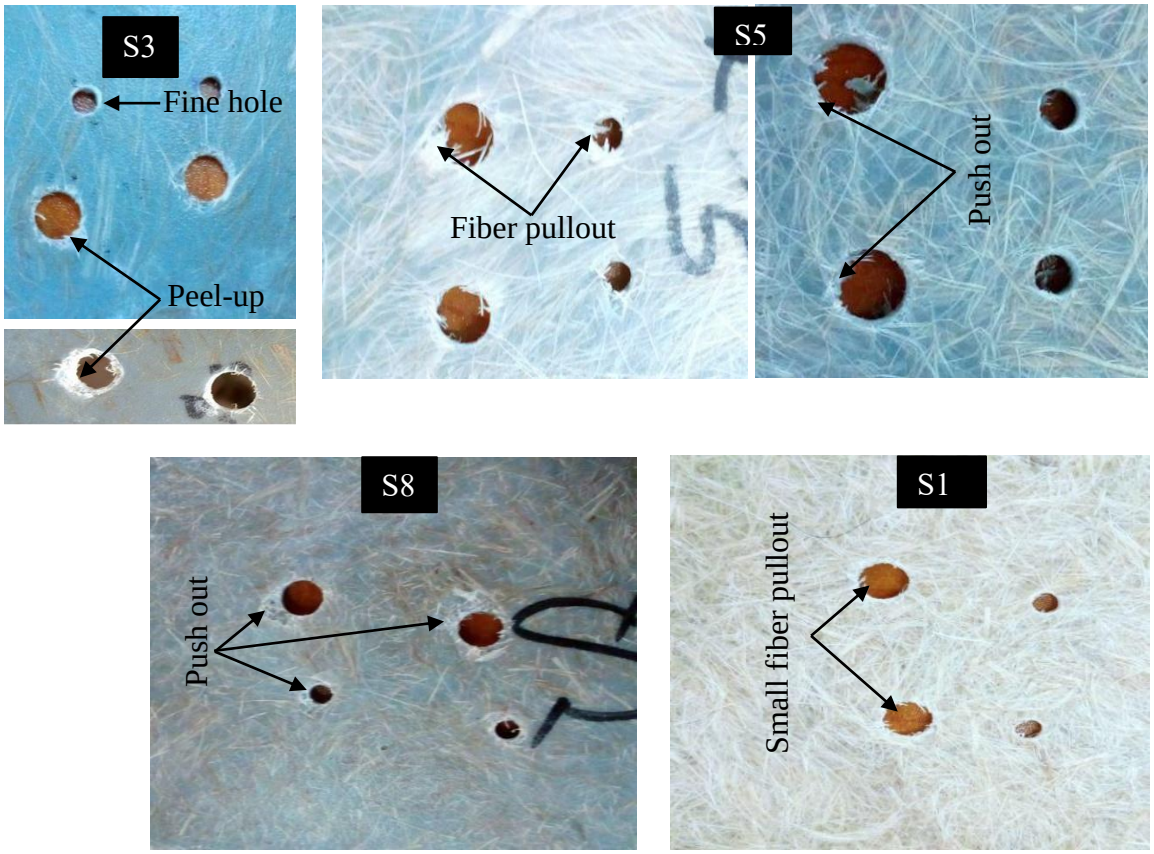

Figure 4.18 Drilled holes for S3, S5, S8 and S10

Figure 4.18 depicted that delamination of holes were caused in two cases. Peel-up delamination in S3 was occurred due to the initial contact between drill bit and composite surface. The delamination was increased when Al_2O_3 wt.% was increased. For pure banana polyester composite peel-up was reduced. In S5 and S8 push down delamination was observed. This was due to the exit of the drill bit the trust force exceeds interlaminar bond strength of the material. At this point the drill acts as a punch and pierces the specimen without cutting the bottom surface properly. The push down delamination was also not observed in S10 this was due to the brittle nature of the specimen was less, since Al_2O_3 was not incorporated. Fiber pullout was observed in S5 and there was no fiber pullout for S8. The

fiber pullout in S5 occurred due to long finer (20mm) reinforcement compared to S8 with 10mm fiber length. The fiber pullout was also very small in S10. From the observed results it can be concluded that reducing the fiber length helps to eliminate fiber pull out. Incorporation of small amount of alumina to the matrix phase reduces the pull-up and push down delamination. Alkali treatment of banana fiber was also reduced fiber pullout due to strong bonding between fiber and matrix.

4.10. Morphological analysis

The qualitative information on the distribution of particles, fiber matrix adhesion and morphology of hybrid composite specimen were shown in Figure 4.19. S4 was selected due to its highest tensile strength result and S5 was selected because of untreated fiber reinforced and highest hardness result. The result showed that the composite with the absence of voids, well yapped no cohesion and good bonding between fiber and matrix interface was observed for 5% NaOH treated fiber reinforce composite. The particle dispersion was good and aggregates of nano alumina were observed. Voids and micro crack propagation was shown for untreated fiber reinforced composite.

The morphology of the composite was affected by fabrication technique, since the scanning electron microscope result indicated that the composite with air bubbles, voids, internal crack and rough surfaces. Due to the reason that it was fabricated by hand layup technique, it was more exposed to formation of air bubbles on the surface, void space which are uncontrollable.

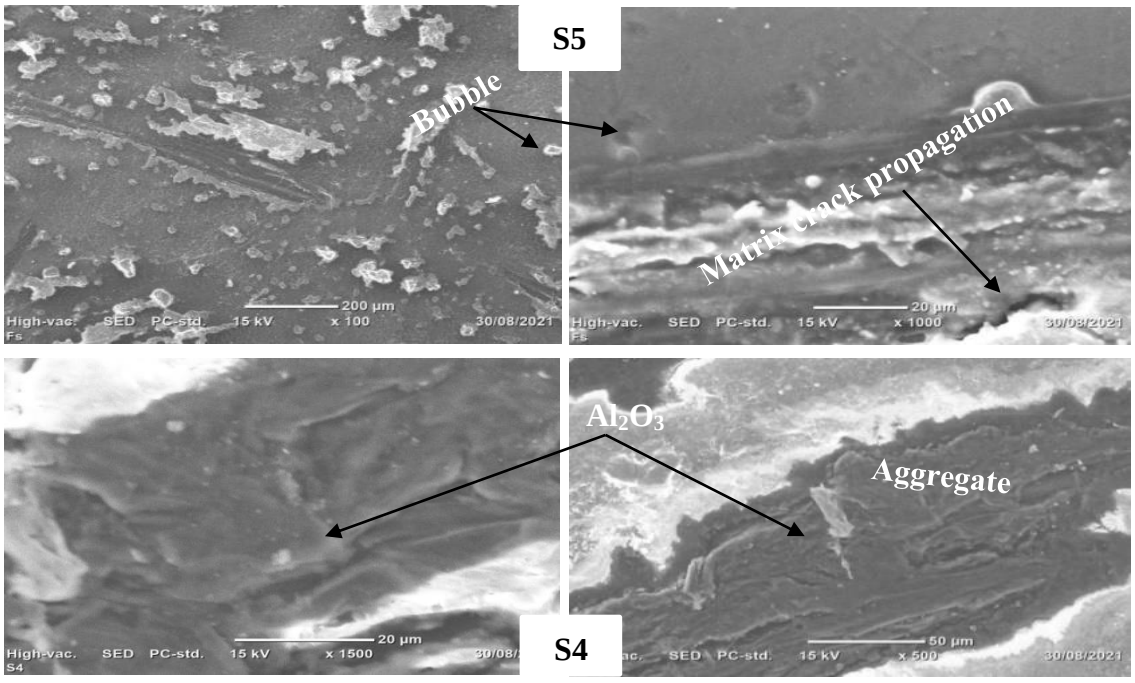

Figure 4.19 SEM analysis of S4 and S5

4.11. Comparison with previous work

Table 4.28 Effect of different processing factors on banana fiber reinforced composite

Sl. No	Authors	Matrix	Reinforcements	Methods	Inference
1	Balcha., (2018)	Polyester	Banana fiber, Al-powder (5, 10 15wt%)	Hand layup	The properties of the composite increased with the addition of aluminum powder. The maximum tensile strength was 33.07 MPa.
2	Venkateshwaran., et al (2011)	Epoxy	Banana fiber	Hand layup	The maximum tensile, flexural and impact strength are 16.39MPa, 57.53MPa and 2.25J/m at 15mm length and 16Wt%.
3	Balaji., et al (2020)	Epoxy	Banana fiber	Compression molding	Maximum tensile, flexural hardness and impact strength was 30.4MPa, 56.3MPa, 68HRB and 2.7J/mm^2
4	Prasad., et al (2018)	Epoxy	Flax fiber, nano TiO_2 (0, 0.5 0.7 and 0.9%)	Compression molding	The addition of nano TiO_2 in the matrix phase significantly improved the tensile, flexural strength and water absorption of the composite.
5	Sajin., et al (2021)	Polyester	Jute fiber (5, 10, 15, 20 and 25mm)	Compression molding	Tensile, flexural and impact strength is 29MPa, 64.66MPa and 0.61J respectively at 5mm length.
6	Prasad., (2021)	Polyester	10mm rambans fiber (5%, 10%, 15%, 20%)	Compression molding	Tensile, flexural and impact strength were maximum for 15wt% fiber loading.
7	Present work	Polyester	Banana fiber (10%, 15%, 20%), length of (10mm, 15mm, 20mm) and nano Al_2O_3	Hand layup	Mechanical properties of the composite are maximum (61Mpa tensile, 108.3Mpa flexural) for 5% NaOH treated, 15mm length, 5wt% fiber and 2wt% nano Al_2O_3.

From Table 4.28 compared to other researcher results, mechanical and physical properties value obtained in this study has better tensile, flexural, impact strength, water absorption and density. The Microstructure and micro hardness of this alumina filled banana fiber reinforced polymer composite is greater than some pure light weight material hardiness.

4.12. Comparison of existing interior door panel

The strength of the fabricated composite material was compared with the existing interior body panel material. From Table 4.29 the material has good strength and it can be applicable for interior automotive panel.

Table 4.29 Door panel strength of different car manufacturers

Polymer/reinforcement	Tensile strength (MPa)	Flexural modulus(GPa)	Automaker
Kenaf- PP	58	2529	Ford
Jute-epoxy	110	1.5	Mercedes- Benz
Flax/hemp/coconut- PP	30-60	1-3	Daimler Chrysler
Flax/sisal- PUR	40-50	1.5-3.5	Audi
TOP	15-26	0.44-0.58	Dodge
Banana/alumina/Polyester	61	1-4.5	Present work

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In this research work, fiber reinforced polymer matrix composite samples were made from banana fiber, Al_2O_3 nano powder and polyester resin through conventional hand layup technique. Banana fiber reinforced polymer composite filled with Al_2O_3 exhibits excellent mechanical properties. From the selection of process parameters to physical and mechanical characterization were discussed briefly. The physical and mechanical properties such as tensile, flexural, impact, hardness, water absorption, density and void fraction were evaluated through the experimental requirements. Based on the experimental data obtained, the following conclusions were made:

- Alkali treatment of banana fiber significantly improved the mechanical property and water absorption of the composite material. However hardness was decreased for treated fiber reinforced composites.
- Incorporation of alumina nano particle in the matrix enhanced the mechanical properties for both treated and untreated fiber reinforced composite.
- The maximum tensile, flexural and impact strength was obtained at S4 (15wt.% fiber loading, 2wt.%Al_2O_3, 15mm length and 5%NaOH concentration) 61.4MPa, 108.33MPa and 19J respectively. While the maximum hardness was 164.69HV obtained at S5 (untreated 15wt.% banana fiber and 20mm length).
- The rate of water absorption was highly influenced by fiber wt.% and fiber treatment than fiber length. Minimum water absorption rate was 2.97% obtained for sample 3 (10wt.% banana fiber, 6wt% alumina, 20mm fiber length and 5%NaOH concentration). For void content sample1 (10wt.% banana fiber, 2wt.% alumina, 10mm length and untreated) had the smallest void content of 0.98%.
- The optimum condition using Taguchi based Grey relational analysis was 15wt.% banana fiber loading, 2wt.% alumina, 15mm fiber length and 5%NaOH concentration. The multi response levels and the optimum process parameter condition show the similar parameter levels.

- The machinability result shows that delamination and fiber pullout through the hole surface occurred during drilling operation. Therefore filling was required for better surface finish.

5.2. Recommendations

Considering the experimental investigation and results obtained the following recommendation is made:

- During composite fabrication through hand layup method avoiding voids is difficult, therefore it is better to use any other fabrication method.
- Epoxy resin should be used instead of polyester matrix to obtain more improved mechanical properties.
- Banana fiber of different aging, climatic condition and soil type those disposed throughout country as a waste should be utilized by conducting further researcher on their mechanical, chemical, thermal and physical properties.
- Extraction of fibers should be performed with fiber extraction machine.
- Fiber treatment period has to be investigated and optimize.

5.3. Future work

- Banana fibers as nano/micro filler in polymer composite can be further investigated for light weight application.
- Thermal and wear property of the composite can be studied for potential applications in aerospace and automotive industries.
- Finite element analysis method or ANSYS software have to be conducted to study the crash analysis of automotive body analysis.

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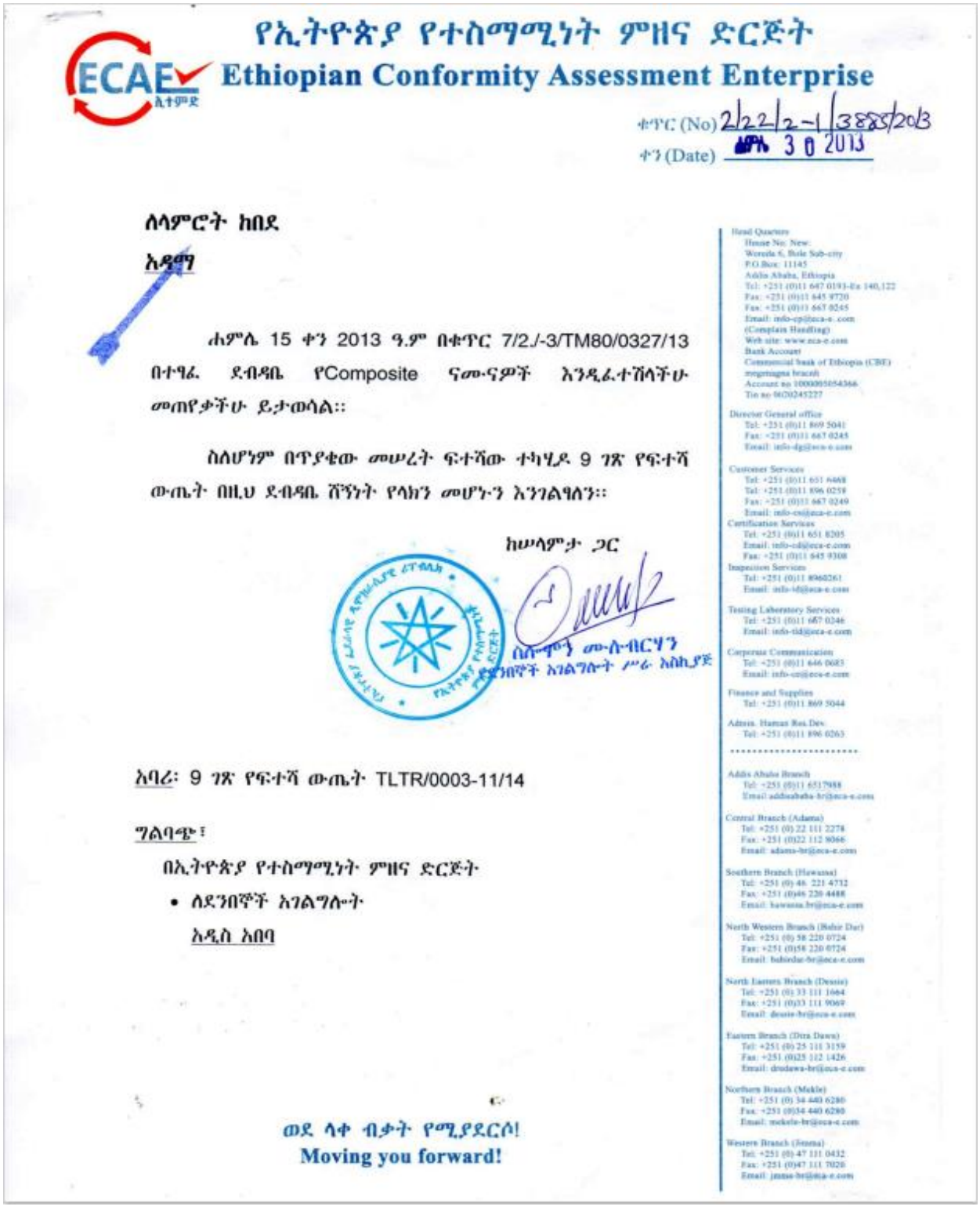
APPENDIXES

Appendix A

Tensile test



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Ethiopian Conformity Assessment Enterprise

ቁጥር (No) 2/22/2-1/3885/2013
ቀን (Date) ሰኔ 30 2013

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

ስለሆነም በጥያቄው መሠረት ፍተሻው ተካሂዶ 9 ገጽ የፍተሻ ውጤት በዚህ ደብዳቤ ሽኝነት የላክን መሆኑን እንገልፃለን::

ከሠላምታ ጋር

በሰሙኑ ሙሉብርሃን
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ግልባጭ:
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Ethiopian Conformity Assessment Enterprise

Title: TEST REPORT

ይህየናሙናናፍተሻሪፖርትአንጂሰርተፍኬትአይደለም

Document No.	
TLD/F7.08-1	
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Page No.	Effective Date
1 of 1	01 Sep 19

1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0003/14
2	Tel:	+251-925-81-17-59	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:	13326040	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	-	-	-	23.7	-

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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Ethiopian Conformity Assessment Enterprise

Title: TEST REPORT

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1 of 1	01 Sep 19

1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0004/14
2	Tel:	+251-925-81-17-59	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:	13326041	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	-	-	-	45.2	-

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.*

11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com
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ADDISABABA, ETHIOPIA

ECAE

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Ethiopian Conformity Assessment Enterprise

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TLD/F7.08-1	
Copy No.	Rev. No.
-	0
Page No.	Effective Date
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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0005/14
2	Tel:	+251-925-81-17-59	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:	13326042	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	-	-	-	47.9	-

Remark

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

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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0006/14
2	Tel:	+251-925-81-17-59	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:	13326043	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	-	-	-	61.7	-

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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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0008/14
2	Tel:	+251-925-81-17-59	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:	13326045	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	-	-	-	28.5	-

Remark

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

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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0007/14
2	Tel:	+251-925-81-17-59	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:	13326044	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	-	-	-	47.1	-

Remark

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

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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0009/14
2	Tel:	+251-925-81-17-59	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:	13326046	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	-	-	-	32.3	-

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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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0010/14
2	Tel:	+251-925-81-17-59	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:	13326047	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	-	-	-	30.5	-

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.*

This is a test report not a certificate

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1	Name and address of client:	Lamrot Kebede, Adama	Test Report No:	TLTR/0011/14
2	Tel:	+251-925-81-17-59	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:	S9	Date tested:	03/08/2021-05/08/2021
7	Type Of Sample:	composite	Reported date:	06/08/2021
8	Lab Designation Number:	13326048	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	-	-	-	23.7	-

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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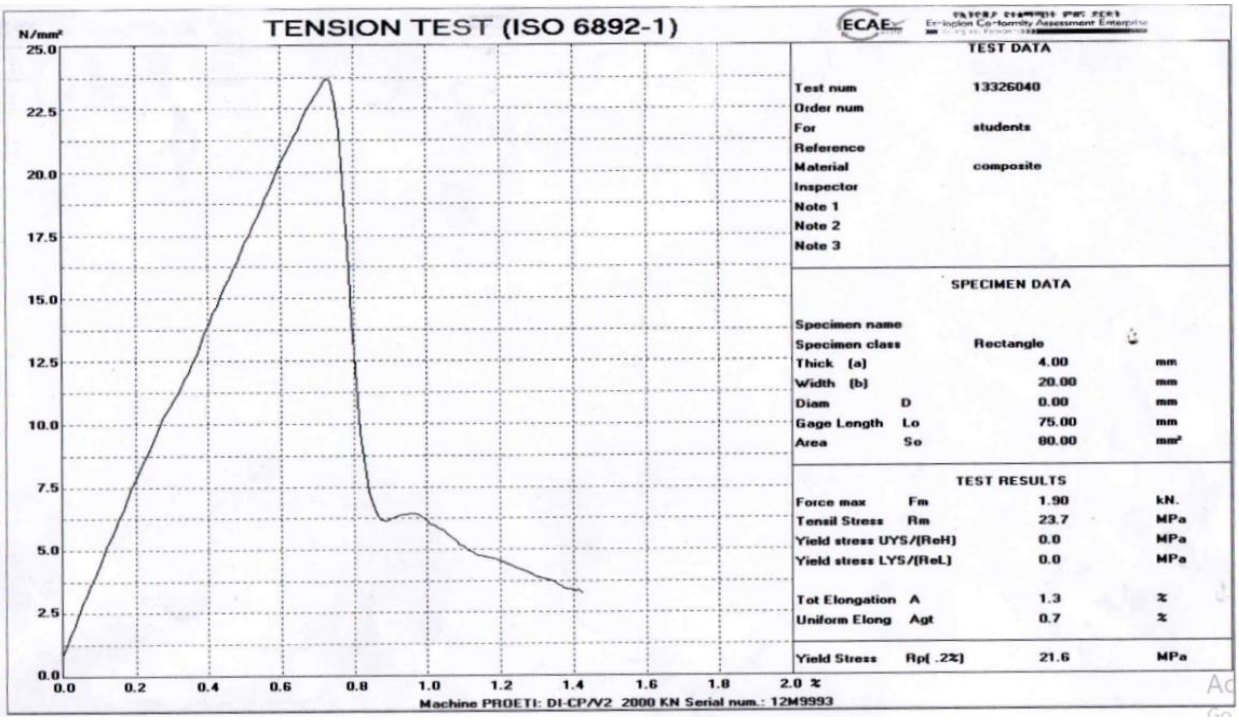
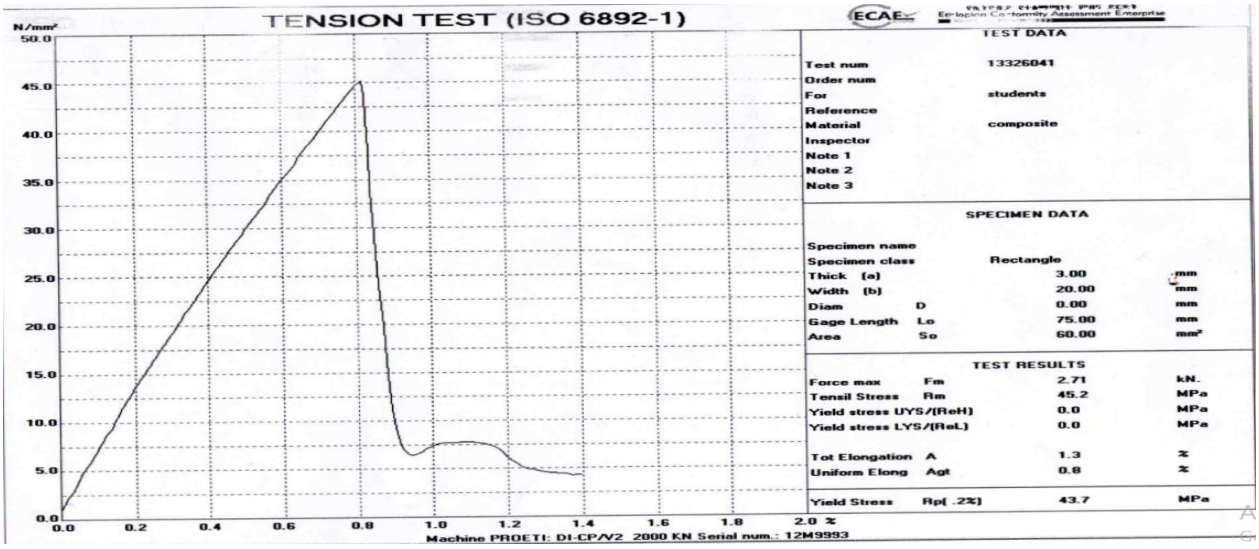
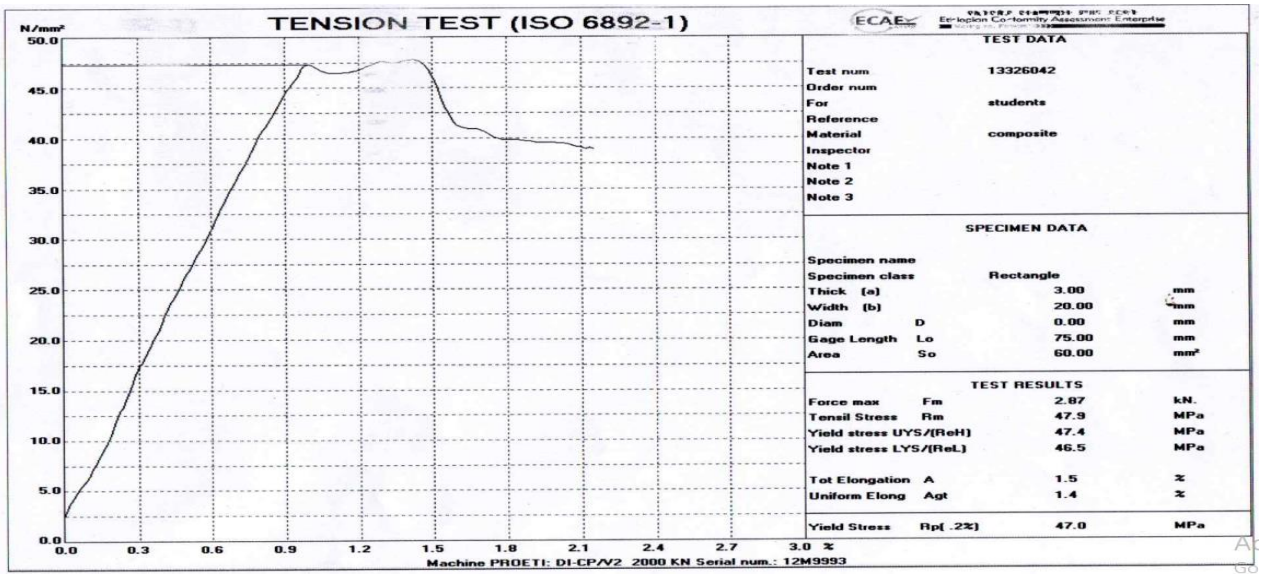
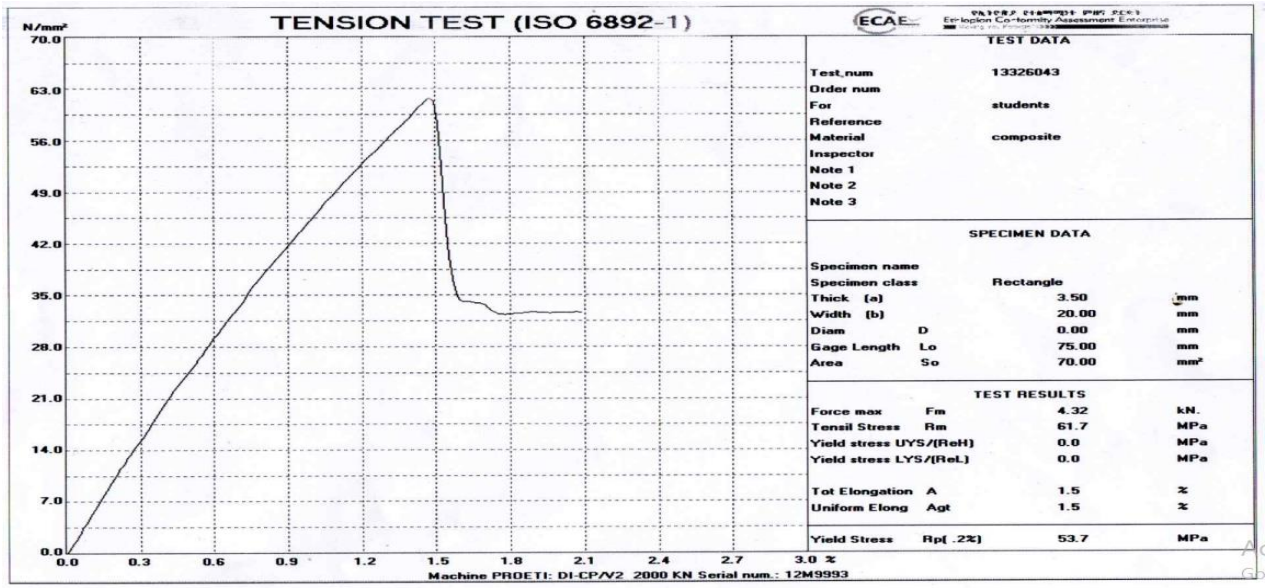
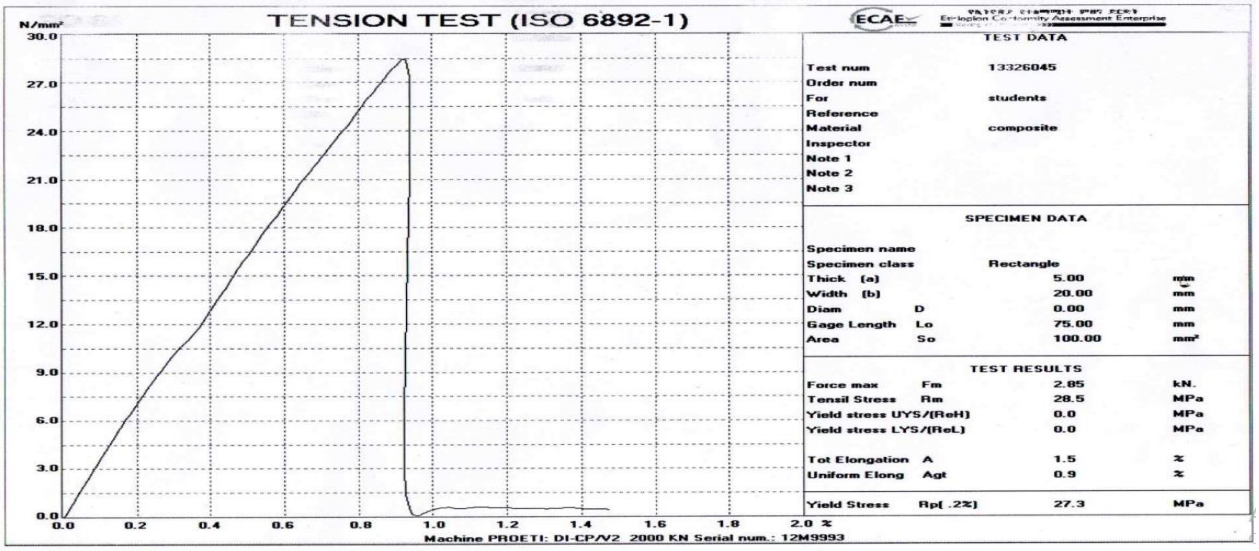
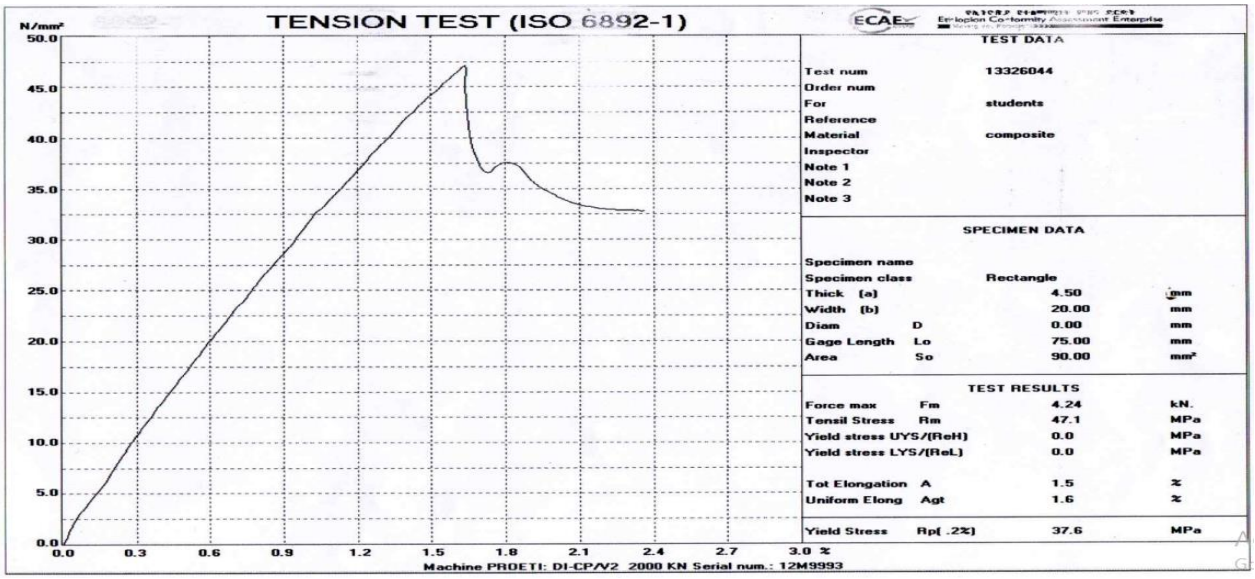


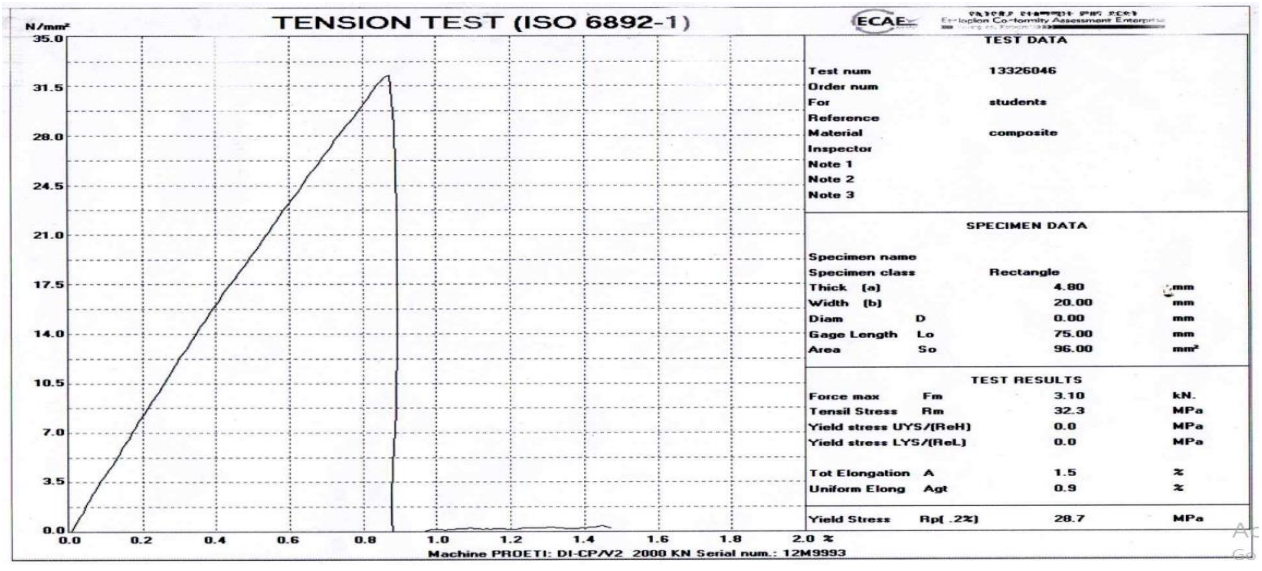

TENSION TEST (ISO 6892-1)
ECAE
N/mm²
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13326041
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 60.00 mm²
TEST RESULTS
Force max Fm 2.71 kN.
Tensil Stress Rm 45.2 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.3 %
Uniform Elong Agt 0.8 %
Yield Stress Rp(.2%) 43.7 MPa

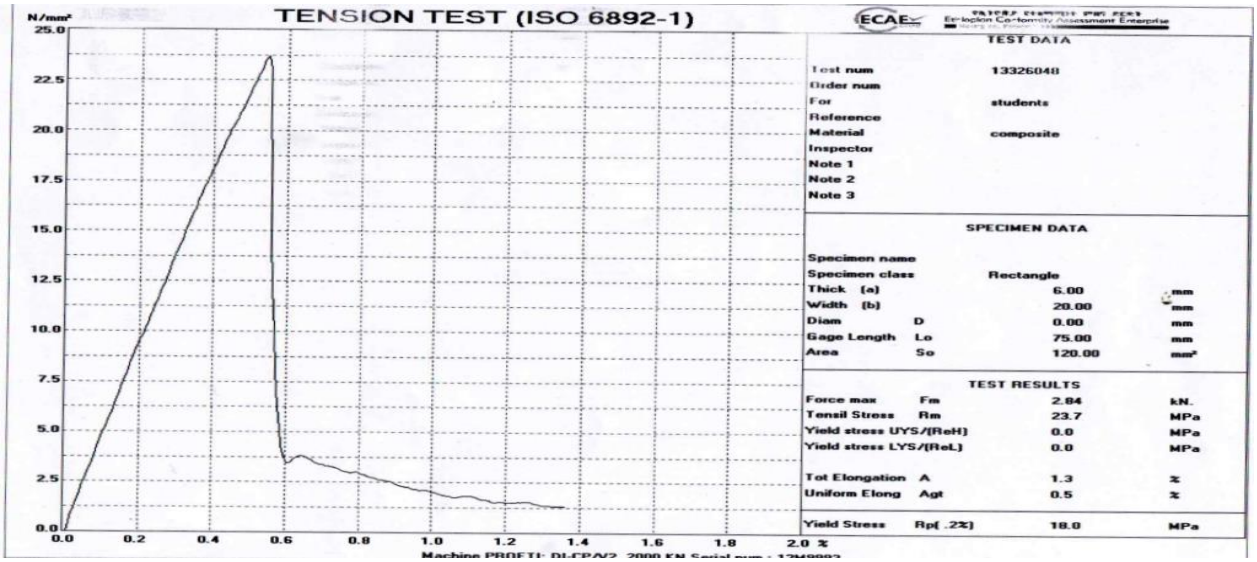

TENSION TEST (ISO 6892-1)
ECAE
N/mm²
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 %
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13326042
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 60.00 mm²
TEST RESULTS
Force max Fm 2.87 kN.
Tensil Stress Rm 47.9 MPa
Yield stress UYS/(ReH) 47.4 MPa
Yield stress LYS/(ReL) 46.5 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 1.4 %
Yield Stress Rp(.2%) 47.0 MPa


TENSION TEST (ISO 6892-1)
ECAE
N/mm²
70.0
63.0
56.0
49.0
42.0
35.0
28.0
21.0
14.0
7.0
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 13326043
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.50 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 70.00 mm²
TEST RESULTS
Force max Fm 4.32 kN.
Tensil Stress Rm 61.7 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 1.5 %
Yield Stress Rp(.2%) 53.7 MPa


TENSION TEST (ISO 6892-1)
N/mm²
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13326045
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 5.00 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 100.00 mm²
TEST RESULTS
Force max Fm 2.85 kN.
Tensil Stress Rm 28.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 0.9 %
Yield Stress Rp[.2%] 27.3 MPa

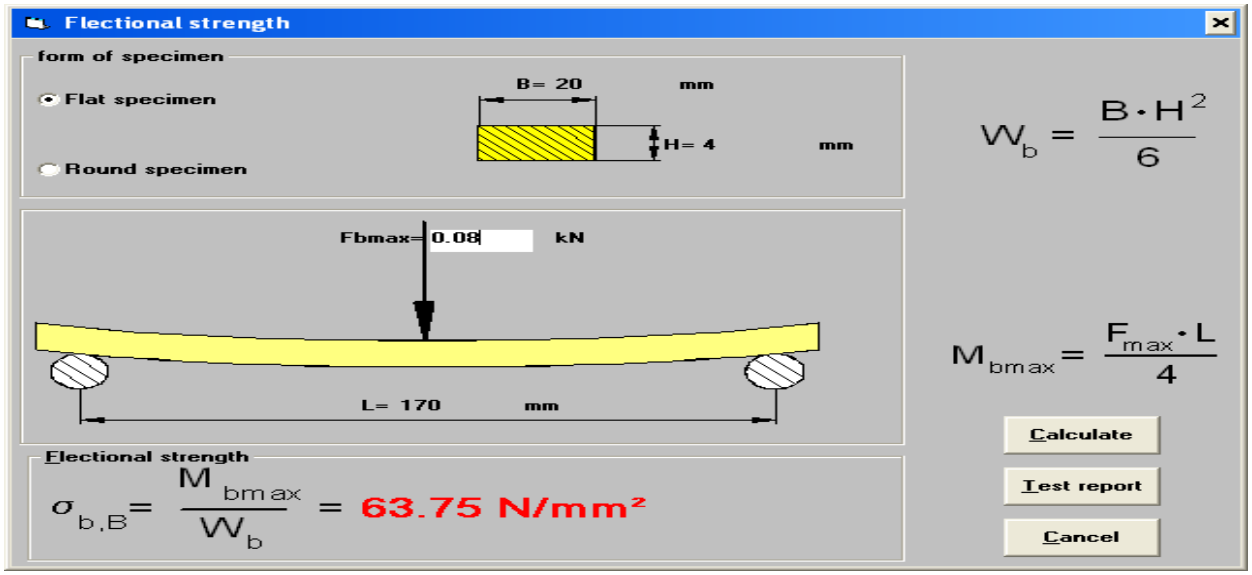

TENSION TEST (ISO 6892-1)
N/mm²
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13326044
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.50 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 90.00 mm²
TEST RESULTS
Force max Fm 4.24 kN.
Tensil Stress Rm 47.1 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 1.6 %
Yield Stress Rp[.2%] 37.6 MPa

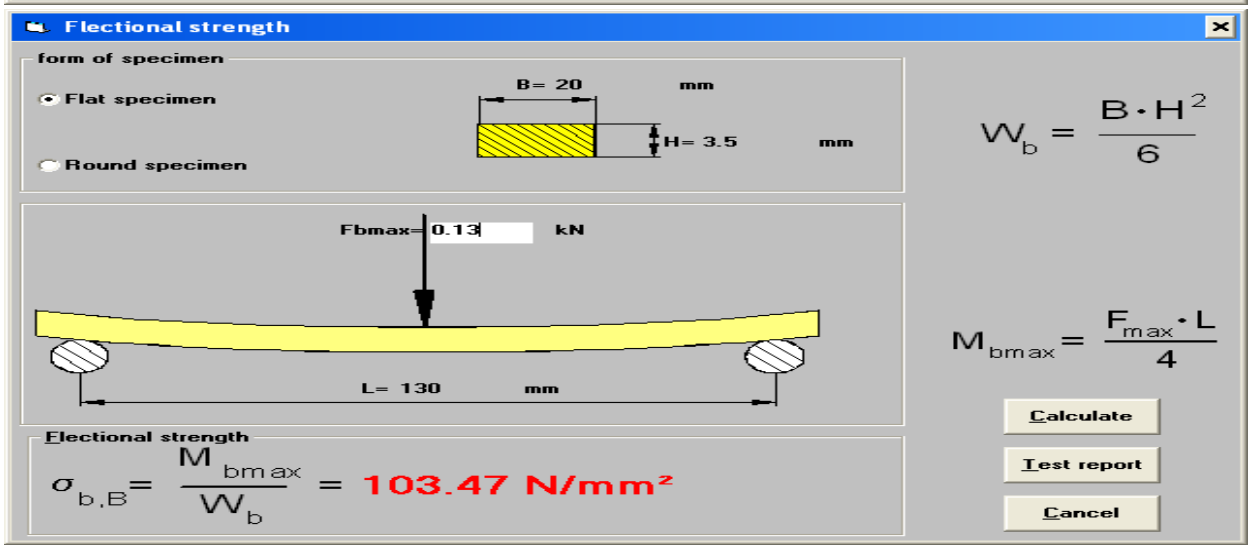

TENSION TEST (ISO 6892-1)
N/mm²
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993
TEST DATA
Test num 13326046
Order num
For students
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.80 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 75.00 mm
Area So 96.00 mm²
TEST RESULTS
Force max Fm 3.10 kN.
Tensil Stress Rm 32.3 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.5 %
Uniform Elong Agt 0.9 %
Yield Stress Rp[.2%] 28.7 MPa

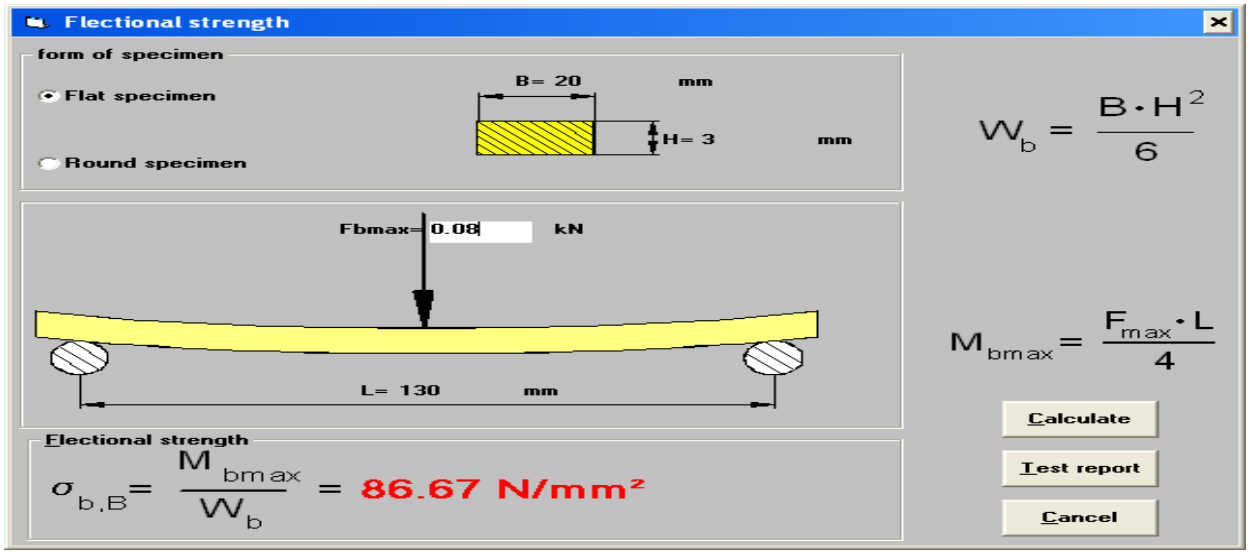


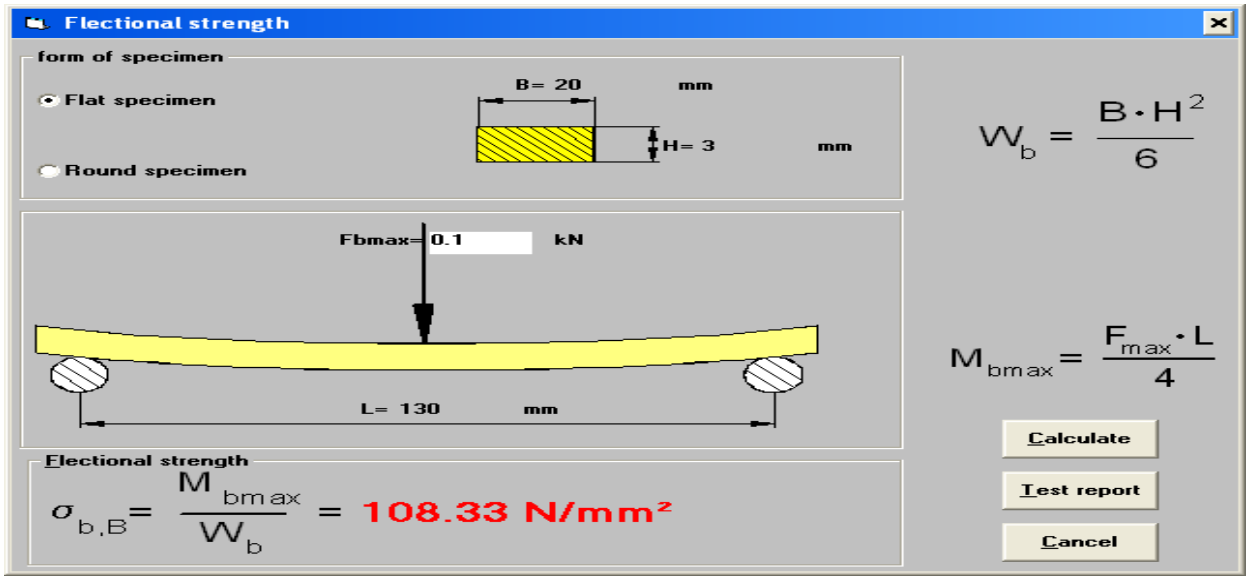
Appendix B

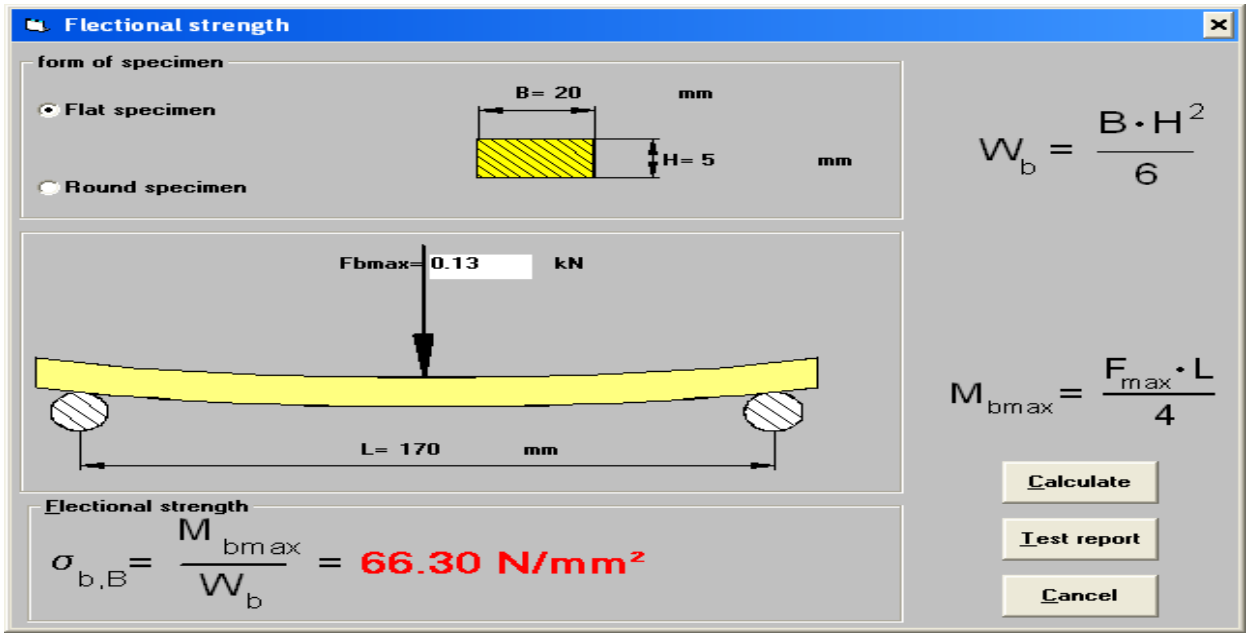
Flexural strength

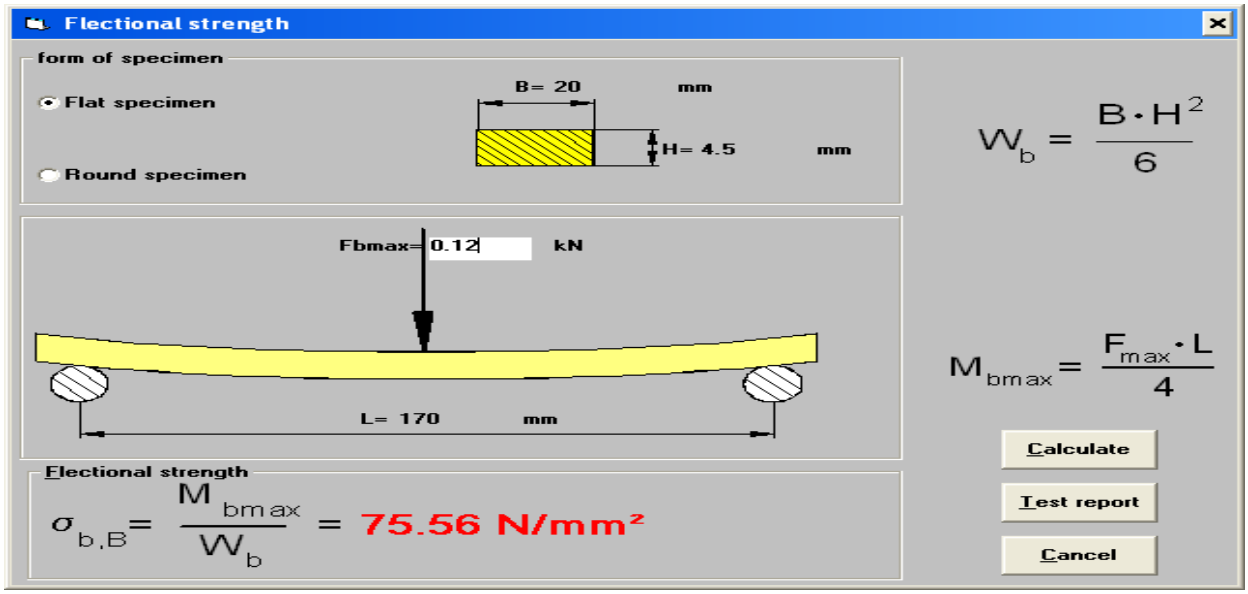


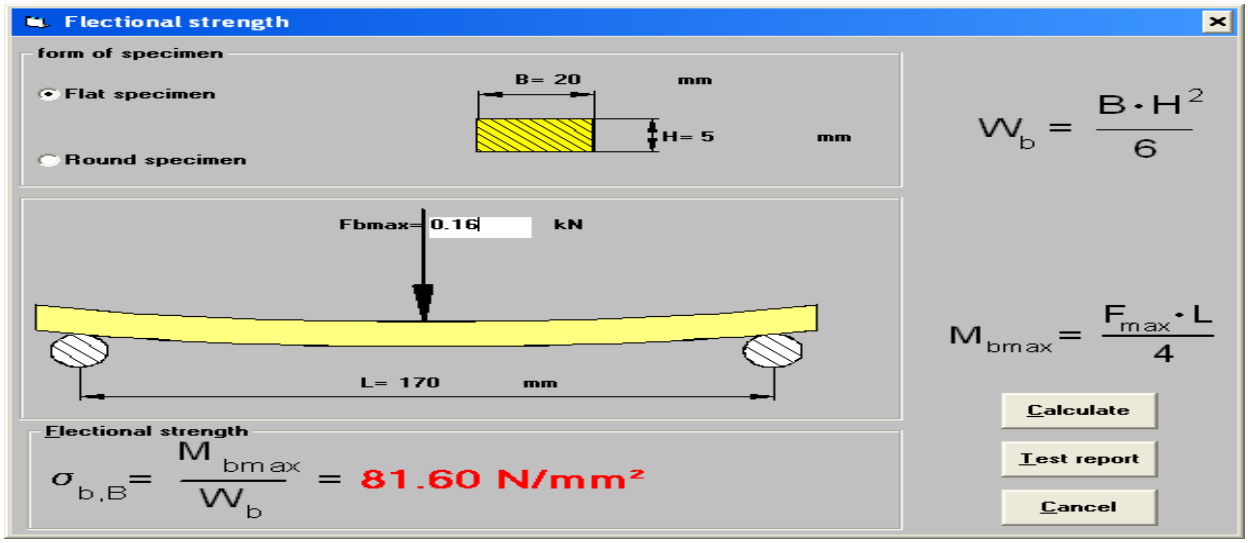


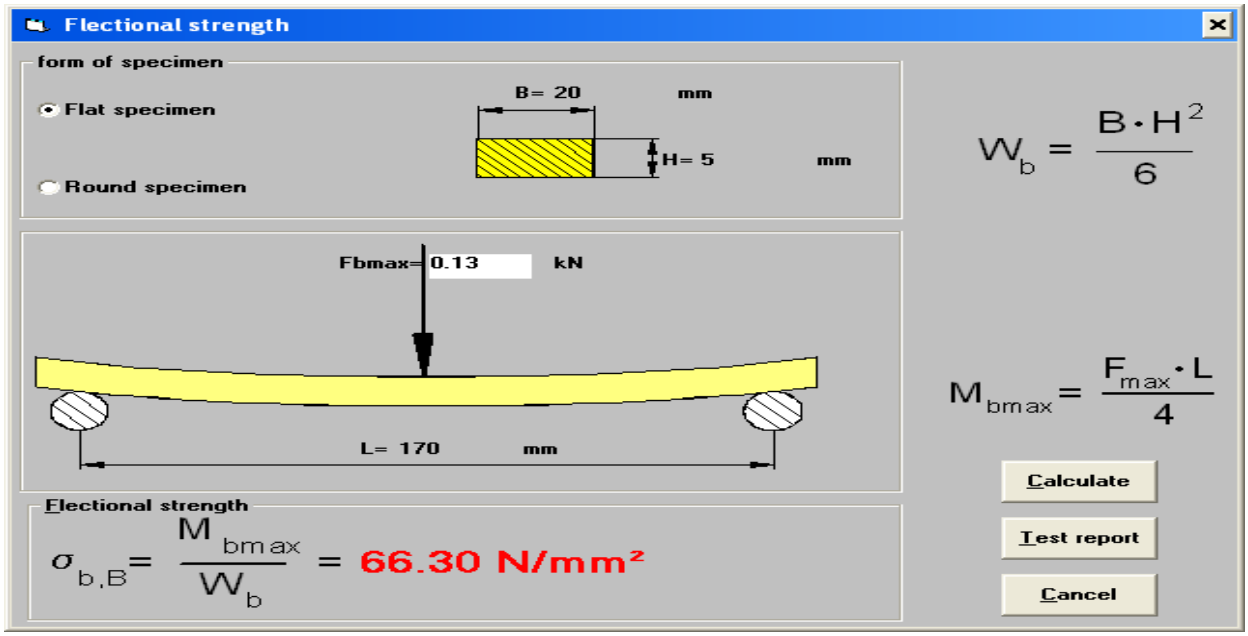

Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 3 mm
Fbmax= 0.08 kN
L= 130 mm
Flectional strength
$\sigma_{b,B} = \frac{M_{bmax}}{W_b}$ = 86.67 N/mm²
$W_b = \frac{B \cdot H^2}{6}$
$M_{bmax} = \frac{F_{max} \cdot L}{4}$
Calculate
Test report
Cancel

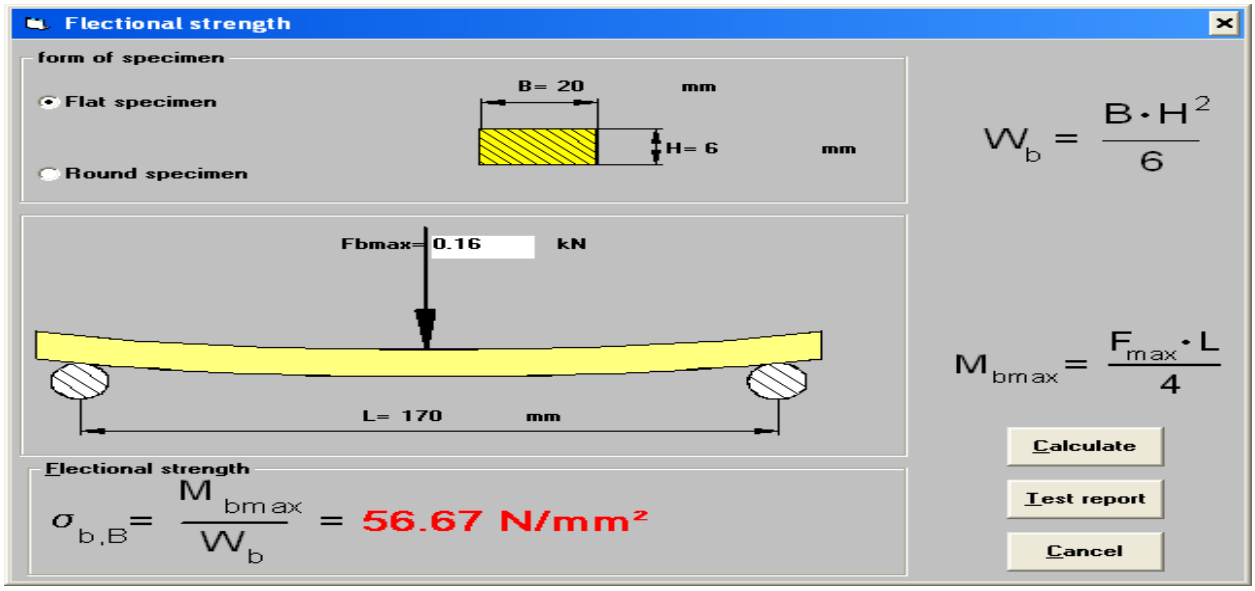

Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 3 mm
Fbmax= 0.1 kN
L= 130 mm
Flectional strength
$\sigma_{b,B} = \frac{M_{bmax}}{W_b}$ = 108.33 N/mm²
$W_b = \frac{B \cdot H^2}{6}$
$M_{bmax} = \frac{F_{max} \cdot L}{4}$
Calculate
Test report
Cancel

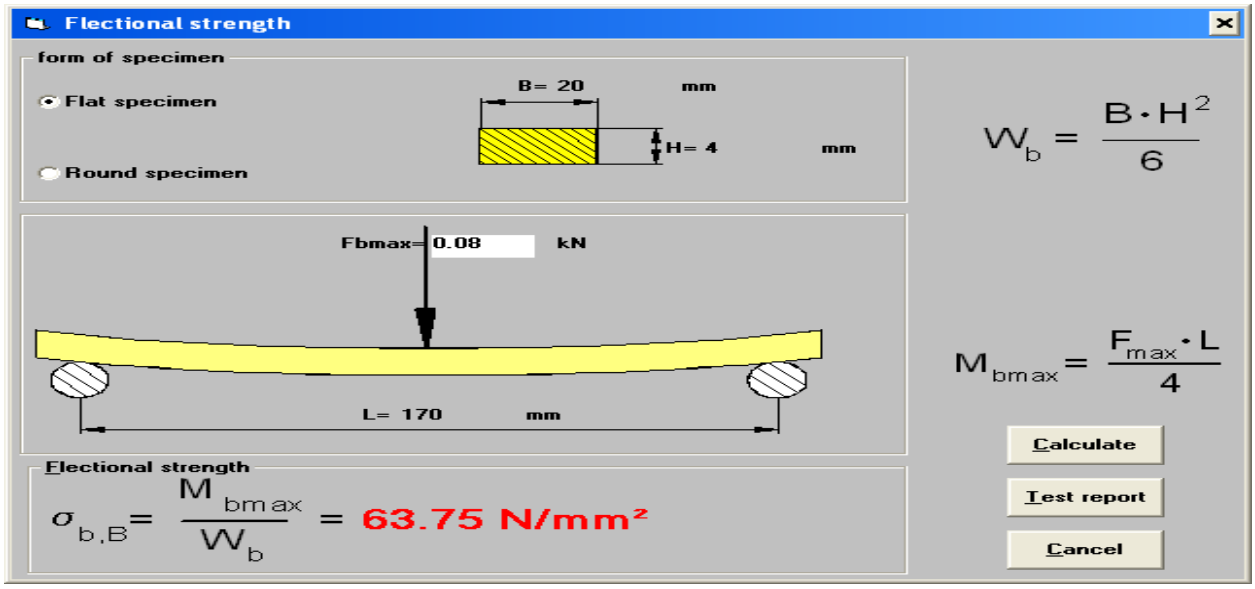

Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 5 mm
Fbmax= 0.13 kN
L= 170 mm
Flectional strength
$\sigma_{b,B} = \frac{M_{bmax}}{W_b}$ = 66.30 N/mm²
$W_b = \frac{B \cdot H^2}{6}$
$M_{bmax} = \frac{F_{max} \cdot L}{4}$
Calculate
Test report
Cancel


Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 4.5 mm
Fbmax= 0.12 kN
L= 170 mm
Flectional strength
σb,B = Mbmax / Wb = 75.56 N/mm²
Wb = B·H²/6
Mbmax = Fmax·L/4
Calculate
Test report
Cancel


Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 5 mm
Fbmax= 0.16 kN
L= 170 mm
Flectional strength
σb,B = Mbmax / Wb = 81.60 N/mm²
Wb = B·H²/6
Mbmax = Fmax·L/4
Calculate
Test report
Cancel

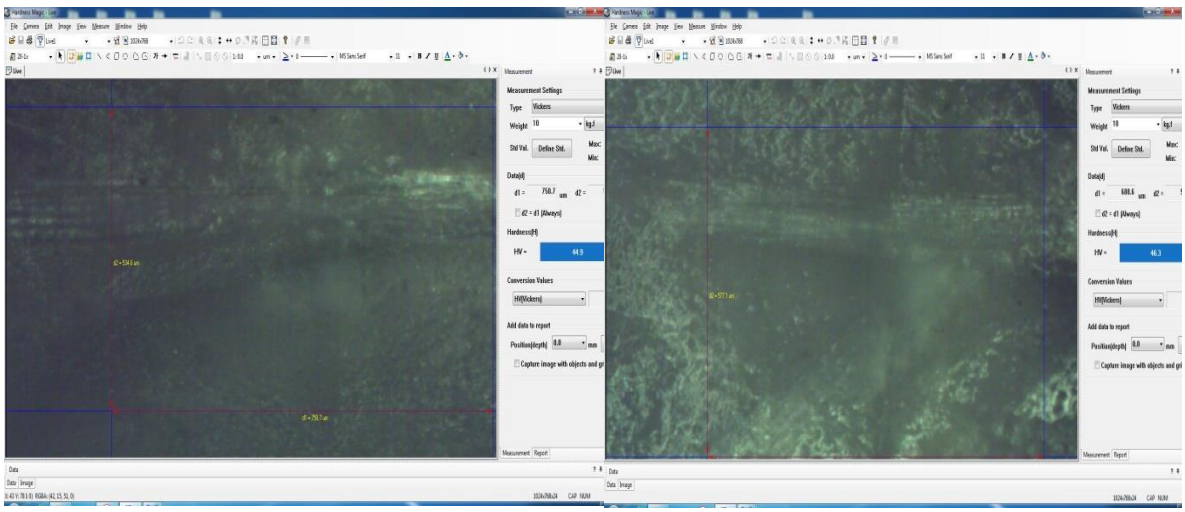

Flectional strength
form of specimen
Flat specimen
Round specimen
B= 20 mm
H= 5 mm
Fbmax= 0.13 kN
L= 170 mm
Flectional strength
σb,B = Mbmax / Wb = 66.30 N/mm²
Wb = B·H²/6
Mbmax = Fmax·L/4
Calculate
Test report
Cancel

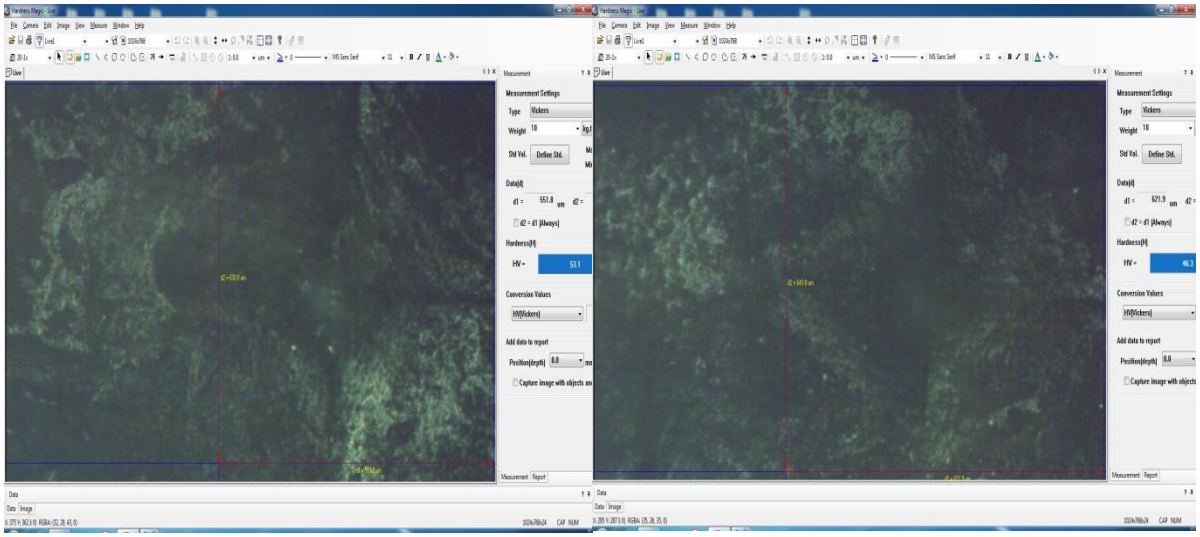


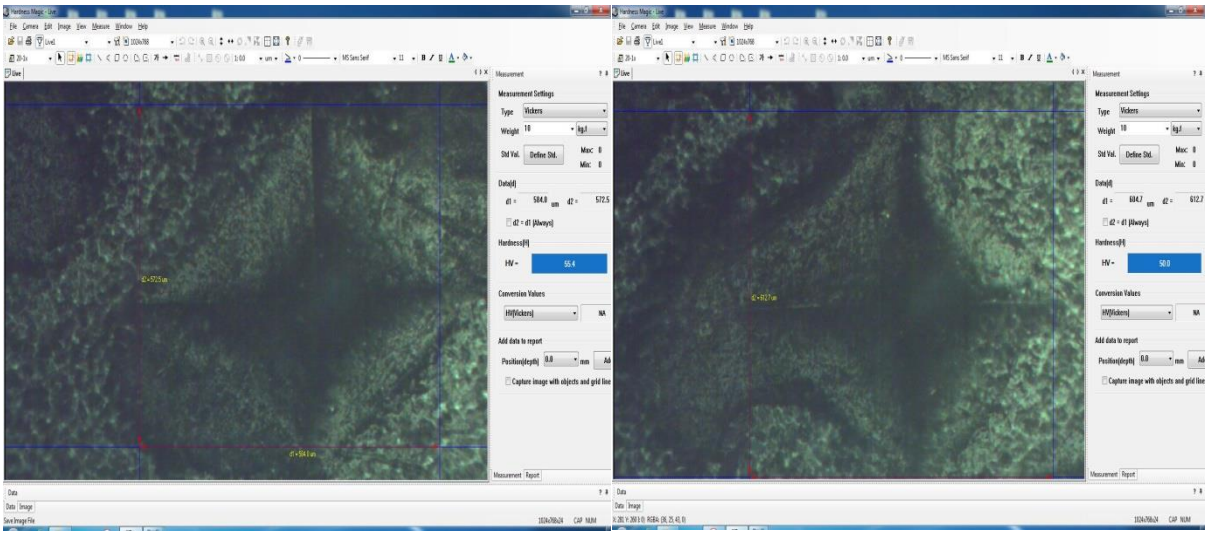


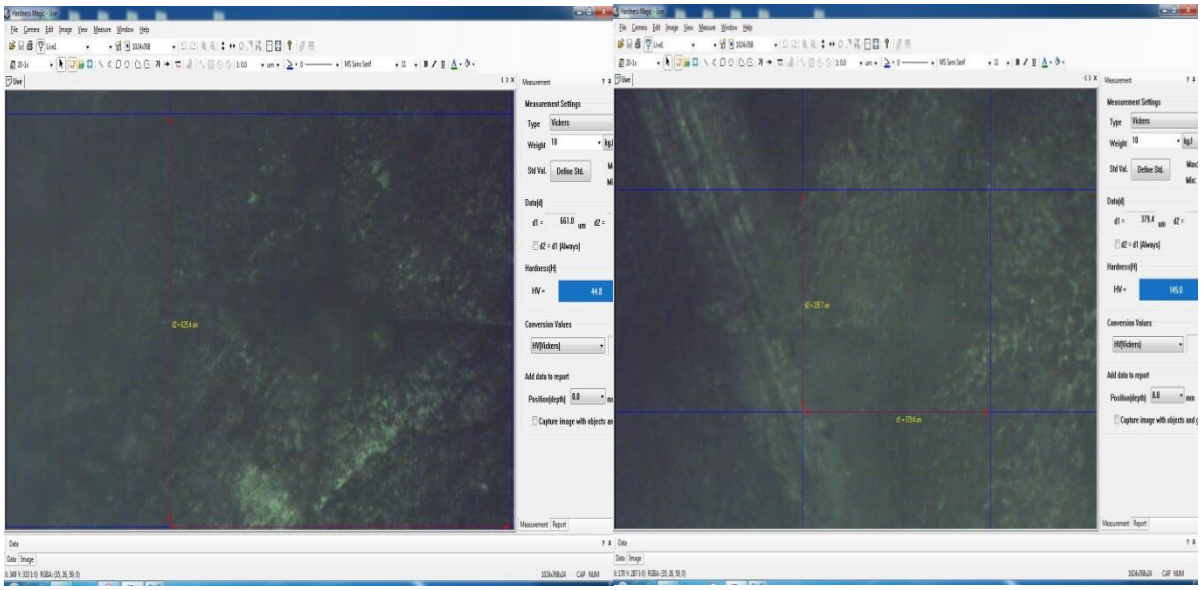
Appendix C

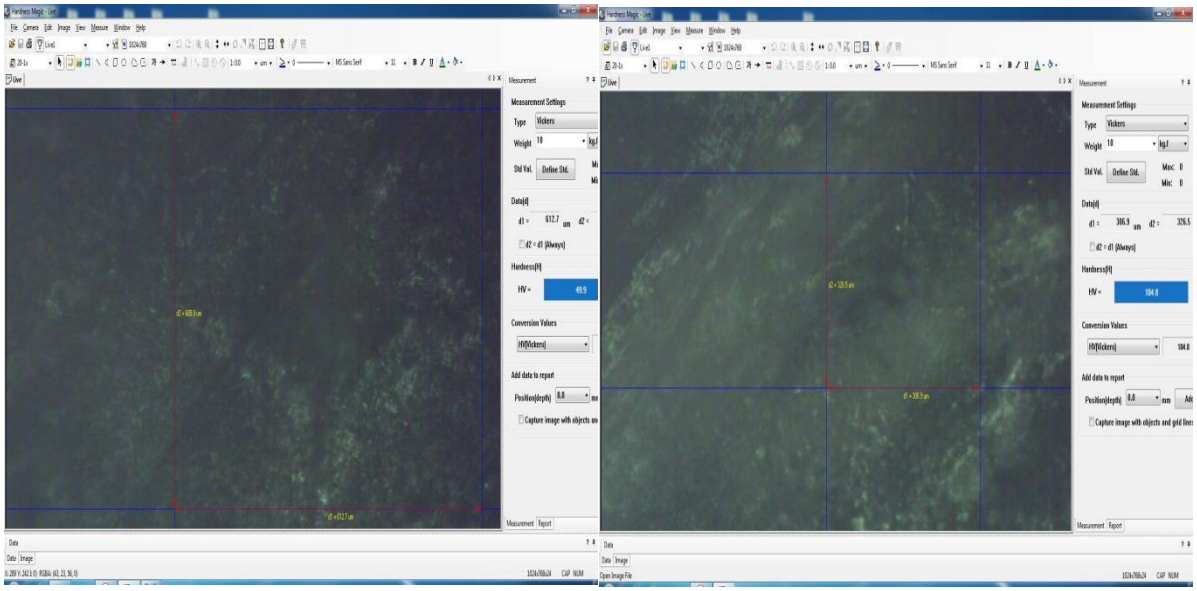
Hardness test

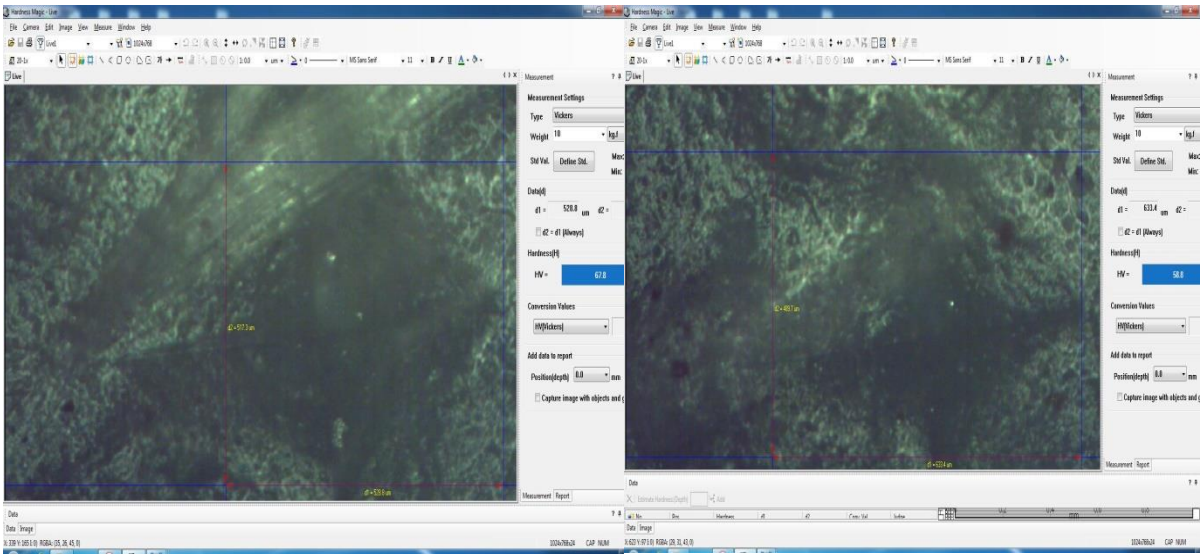


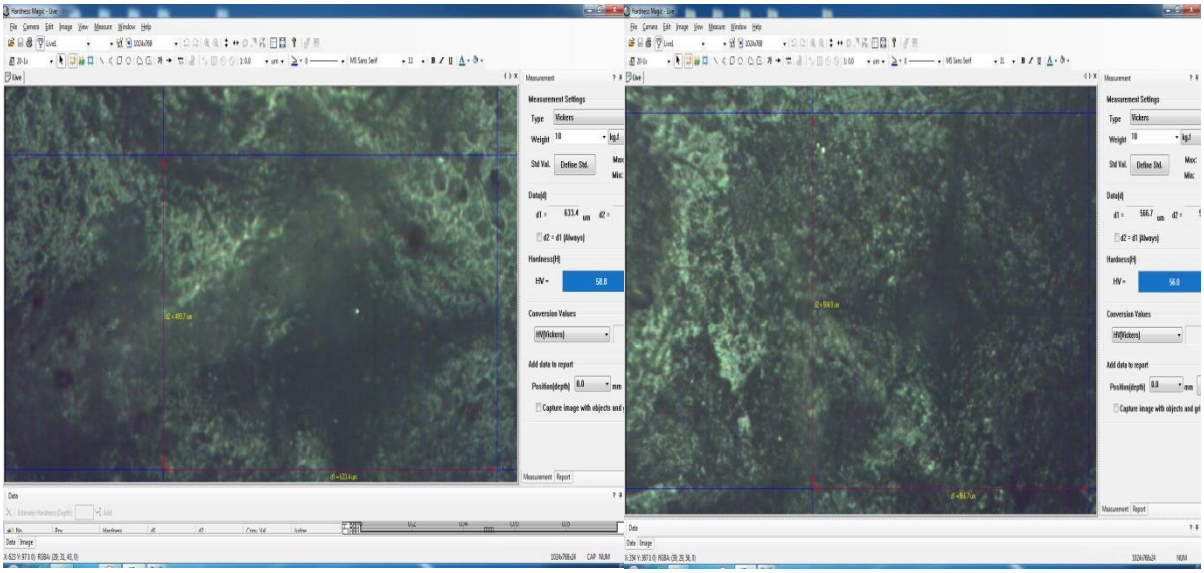


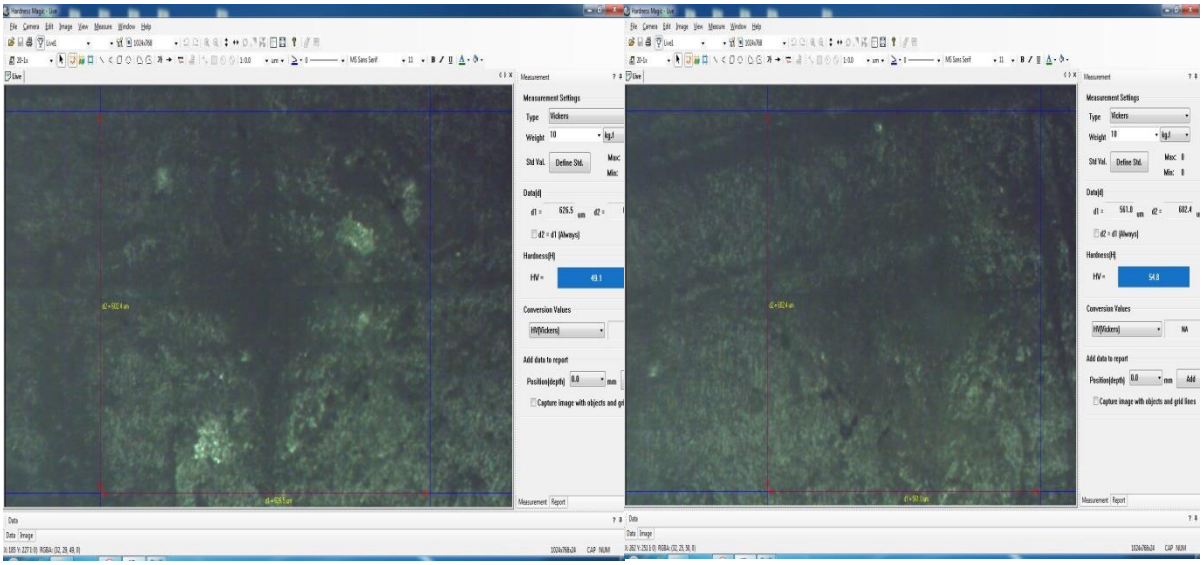


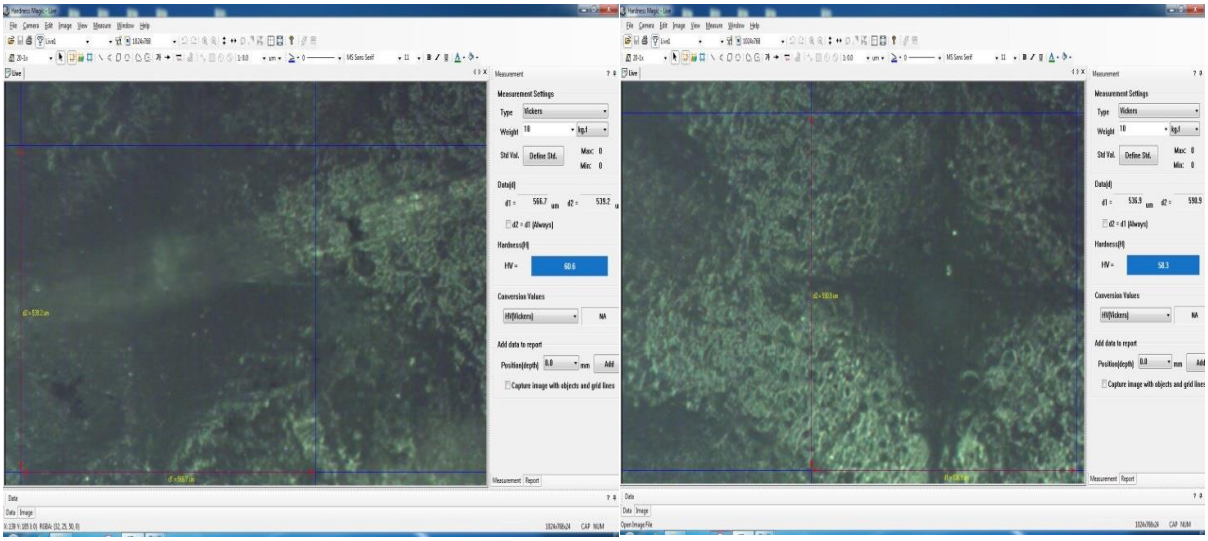


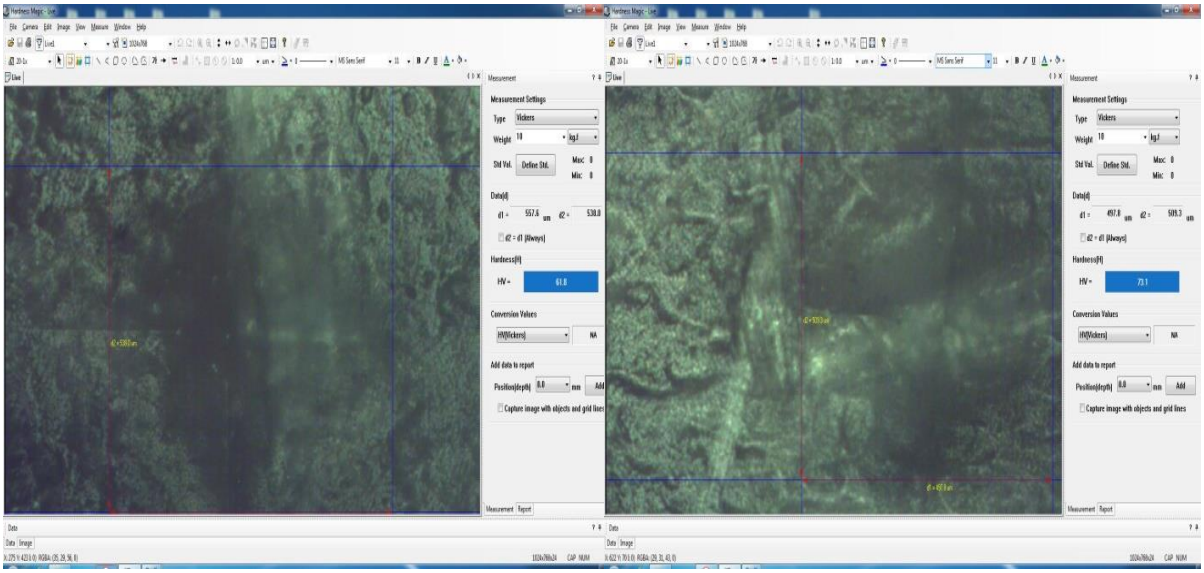












Appendix D

Morphology