Fabrication and Multi Response Parametric Optimization of False Banana Sisal Glass Fiber Reinforced Composite for Automotive Application

Genet Bekele Alemu

A Thesis submitted to
Department of Mechanical Design and Manufacturing Engineering School of Mechanical Chemical and Material Engineering

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

Office of Graduate Studies

Adama science and Technology University

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December,2021

Adama, Ethiopia

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Main-Adviser: Dr Devendra Kumar Sinha

Co-Adviser: Dr Moera Gutu Jiru

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DECLARATION

I hereby declare that this Master Thesis entitled "Fabrication and Multi Response parametric optimization of False banana Sisal Glass fiber reinforced composite for Automotive Application" 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.

Genet Bekele Alemu	______________________	_______________
Name of the student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Fabrication and Multi Response parametric optimization of False banana Sisal Glass fiber reinforced composite for Automotive Application" prepared under our guidance by Genet Bekele Alemu submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering.

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

Dr Devendra Kumar Sinha	__________________	______________
Main advisor	Signature	Date
Dr. Moera Gutu Jiru	__________________	________________
Co-advisor	Signature	Date

APPROVAL SHEET

We, the advisors of the thesis entitled "Fabrication and Multi Response parametric optimization of False banana Sisal Glass fiber reinforced composite for Automotive Application" and developed by Genet Bekele Alemu hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr Devendra Kumar Sinha	________________	________________
Main advisor	Signature	Date
Dr. Moera Gutu Jiru	________________	________________
Co-advisor	Signature	Date

We, the undersigned, members of the board of examiners of the thesis by Genet Bekele Alemu have read and evaluated the thesis entitled "Fabrication and Multi Response parametric optimization of False banana Sisal Glass fiber reinforced composite for Automotive Application" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

CMC	ceramic Matrix Composites
DAVI	Dejen Aviation Industry
DMA	Dynamic mechanical analysis
FRP	fiber reinforced composite
FAOSTAT=	food and Agricultural organization database
FMOE	flexural modulus of Elastisity
GFRPC	Glass Fiber Reinforced polymer composite
GRA	Grey relational analysis
GRC	Grey relational coefficent
GRG	Grey relational grade
HNFC	Hybrid natural fiber composite
HLU	hand layup method
MEKP	Methyl ethyl ketone peroxide
MMCs	Metal Matrix Composites
OA	Orthogonal array
PMCs	polymer matrix composites
PRP	Particle reinforced composites
PVC	poly vinyl chloride
S/N	Signal to noise ratio
SST	Total sum of squares
SSTR	Sum of squares
TCC	thermal conductivity of composite
TEM	Transition electron microscope
UTM	universal testing machine
VHN	Vickers hardness Number

NOMENCLATURE

M_c	Mass of composite (g)
M_f	Mass of fiber (g)
M_m	Mass of matrix (g)
M_p	Mass of particle (g)
V_F	Volume fraction of fiber
V_M	Volume fraction of matrix
V_c	Volume of composite (mm^3)
V_f	Volume of fiber (mm^3)
V_m	Volume of matrix (mm^3)
$\mathcal{P}_c$	Density of composite (g/cm^3)
$\mathcal{P}_f$	Density of fiber (g/cm3)
$\mathcal{P}_m$	Density of matrix (g/cm3)

ABSTRACT

Over the last decades, concern for replacement of non-biodegradable resources with a biodegradable resource has been attracting the researcher's attention . Composite materials are materials which have attractive properties such as low density, high specific strength, low cost, high toughness, corrosion resistance and eco-friendly. Natural composites have been utilized in many engineering applications including Automotive industry. The reduction of weight for an advantage of reducing fuel consumption for mass transportation increased the replacement of automotive body parts with composites. Due to limitation of high-water absorption property of natural fibers hybridization with synthetic fibers was used for dual benefit. It was noticed that sisal and false banana fibers have enormous possibilities in hybridization with synthetic fibers such as carbon and glass fibers. Each hybridized composite has its own property that depends on the different parameters. For this reason, mechanical characterizations of the composite with parameter optimization methods were used for design of the experiment. In the present work after fabrication mechanical and morphological characterization were conducted for false banana, sisal and glass fiber reinforced composite. Two levels with four factors were considered to optimize the parameters. Hand lay-up method was used for fabrication by considering orientation of natural fiber, NaOH treatment level, weight percentage of fiber and orientation of glass fiber as parameters. The experiment was designed with Taguchi L_8 orthogonal array and grey relational analysis was used in hybrid with Taguchi to predict the optimal parameter combination for best mechanical property, water absorption and void content of the composite. The results showed maximum tensile strength of 185MPa and a compressive strength of 57Mpa and flexural strength of 391MPa.The maximum impact strength of 448KJ/M^2 was measured. The hardness of 119HV was achieved. Water absorption test and void content of fabricated composite were also studied. It was predicted that the composite with 0/90 natural fiber orientation,10% NaOH,10 fb20 s10 g weight percentage of fiber and woven glass fiber orientation had better mechanical property and it also had lowest water absorption property with less void content. Mechanical, physical and morphological property of a composite can be enhanced by using optimal parameters and it was also recommended to study the property by varying other parameters like fabrication method and treatment type.

***Key words**: natural composite, mechanical, physical property, Taguchi, Grey relational analysi*

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The application of composite material was utilized from the time of developing straw clay. A composite material is made of two or more different materials that are mechanically bonded together. They are cohesive structures made by physically combining two or more compatible materials, special in composition, characteristics and sometimes in form. Each of the various components retains its identity in the composite and maintains its characteristic structure and properties. Generally, the structure of a composite contains two phases, matrix and reinforcement. The matrix is a continuous phase that glue all fibers together in shape and transfers stress between the reinforcing fibers .besides, the reinforcement is discontinuous in form. The reinforcements help in achieving strength of the composite and the matrix helps in bonding of the reinforcements (Betelie et al., 2018) .Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, or decrease the product cost (Arpitha et al., 2014).

The reinforcements for composites can be found from different sources. Natural and synthetic sources are the two most common fiber sources. Natural fibers can be derived from plants, animals and minerals. Natural fiber of plant is defined as plant material produced as a result of photosynthesis. These fibers are sometimes called as vegetables, biomass, agro mass and solar mass or photosynthetic fibers (Maurya et al.,2015).

During recent years, Natural fibers have appeared to be the materials which will become a better replacement for non-renewable, abrasive and expensive synthetic fibers. They have been relatively used in different sectors of industrial production (shipbuilding, packaging) and above all, in automotive and civil sectors for non-structural applications where lightness and low cost are lower than those of any composite reinforced by synthetic fibers. In addition to this, natural composites are used for the advantage of good thermal and acoustic insulation capacity, availability in large quantities, bio degradability, low density, recyclability and ease of manufacturing (Zuccarello and Marannano, 2018).

Enset is a natural plant that grows in wide amount in Ethiopia. It has shorter and thicker pseudo stem structure compared to banana Plant. Because of this, Enset plant gave large amount of fiber per single plant than banana. It has a large perennial herb with leaf sheaths that form pseudo stem. The fibers have diameters in the range of 100–400 μm and has more than 1 m long surrounding with 8-1s2 large leaves (Temesgen et al., 2019).Sisal is a natural fiber that yield stiff fiber and it has been traditionally used for making twine and rope. It is a biodegradable and eco-friendly crop. Moreover, sisal is a strong, stable and versatile material which has been recognized as an important source of fiber for composites. Sisal fiber is extracted from the large spear shaped tropical leaves of the Agave Sisalana plant. Now Sisal has been utilized as an environmentally friendly strengthening agent to replace asbestos and fiber glass in composite materials in various cases including the automobile industry.

Hybrid composite materials are made by combining two or more different types of fibers in single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. Normally a high modulus fiber when it combined with low modulus fiber it enhances the high strength. In addition, the expensiveness of preparation of composite material is low. Hybridization of natural fiber with synthetic fiber, for example, glass or carbon fiber, can also improve the stiffness, strength, as well as the moisture resistant behavior of the composite. Hybridization of natural fiber with synthetic glass fiber significantly gives better heat transportability and heat transfer coefficient. Moreover, it enhances crack resistance of the composite (Sanjay and Yogesha, 2017). Due to serious challenges of natural fibers, including sever moisture absorption, weak fire resistance, durability and demanding manufacturing processing the need to hybridization with glass is increasing.

Hybrid composites have their own mechanical property. in order to identify this property, mechanical characterization of hybrid composites must be done. Mechanical characterization includes tensile, compression, flexural, impact strength and hardness testing .these properties are affected by different parameters and conditions. The parameters include fiber orientation, weight percentage of fiber, Alkali treatment, type of fiber and Matrix, fabrication method and so on. When the parameters considered for the study of mechanical property is three or more it is better to apply optimization method in order to investigate the effect of each parameter on the required property.

In the past few years different optimization methods for designing of experiment have been used. Taguchi and grey relational are the most common ones. Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be assessed independently of all the other factors, so the effect of one factor does not affect the estimation of a different factor. This can reduce the time and cost associated with the experiment when fractionated designs were used.

Many researchers are making their effort to use the advantage of hybrid of natural fiber and synthetic fiber. Therefore, fabrication and multi-response parametric optimization of false banana sisal glass fiber reinforced composite has been proposed in the present work. The experiments were designed using L8 orthogonal array and grey relation analysis. morphology of the sample was analyzed using scanning electron microscope.

1.2 Statement of Problem

In the earliest time, the demand for materials with low weight and low cost of raw material for getting highest specific strength was increased in the field of automobile industry. Reduction of weight of the vehicle by utilizing lightweight materials for lessening fuel consumption thereby contamination was a major challenge confronted by vehicle makers. Ethiopia is exceptionally much dependent on importation of body parts either for building the body or to repair the harmed panels. Therefore, there's an urgent to produce light weight composite materials with neighborhood available natural fiber for creation of vehicle body Parts. Ethiopia has a considerable amount of false banana and sisal plants, due to lack of awareness and unavailability of experimental tools, research on the contribution of hybrid of false banana and sisal fiber was rarely done. According to report by FAOSTAT in 2013, Ethiopia stands 11^{th} by sisal production (Meragiaw and Asfaw,2014). even if most part of the country is semi-arid dried and fertile for sisal that account for 71% land coverage from the entire only 46% was reached by sisal (Tekola, 2020). Even though the Enset plant had been cultivated in the country, it is mostly used for human and cattle food.

Now adays there is a dramatic change in design of many engineering fields not only in Automotive industry. In the near periods, automotive assembling industry numbers are expanding in Ethiopia both governmental and private institutions of Ethiopia. It includes assembling of different city Buses including Addis Ababa light weight city bus that is assembled in Bishoftu Automotive and Locomotive industry, Automobile car assembly in Hyundai Marathon motors, AMCE Automotive manufacturing company of Ethiopia, LIfAN motors, Mesfin industrial Engineering and so on . Even though most part are imported from foreign country, Dejen Aviation Industry(DAVI) is trying to manufacture some parts from composite made of imported synthetic fiber. But these imported synthetic fibers can lead Ethiopia to be dependent on other nations to import those engineered fiber and other raw materials for the production of light weight car body parts, subsequently these can lead the company to lose the income, deny the country's asset to be utilized conjointly cause contamination on Environment amid the Disposal of the utilized Composite Fabric. To reduce the above problems, this study dealt with fabrication of composite materials made of false banana sisal and glass reinforced composite through hand layup method. The plan and design of experiment was carried out by Taguchi orthogonal array method. The mechanical, physical and morphological properties of the fabricated specimens were investigated and the optimal process parameter was determined by hybrid taguchi grey relational analysis method.

1.3 Objective

1.3.1 General objective

Fabrication of False Banana Sisal Glass Fiber Reinforced Composite and optimization of its process parameters for optimization of its multi responses including mechanical, physical and morphological properties.

1.3.2 Specific objectives

- ❖ To fabricate false banana sisal glass fiber reinforced polyester composite by conventional hand lay-up method.
- ❖ To investigate mechanical physical and morphological properties like tensile, compression, flexural, impact strength, Hardness, water absorption and void content of the composite.
- ❖ To determine the effect of natural fiber orientation, sodium hydroxide treatment level, weight percentage of fiber and orientation of glass fiber on output characteristics.
- ❖ To predict the optimal process parameters for the best value of mechanical and morphological properties
- ❖ To determine machinability of the composite for easy assembling of parts in Automotive body application.
- ❖ To compare the strength of the material with the existing material.

1.4 Significance and Beneficiaries of the Study

- ❖ Natural fibers possess advantages of lower cost ($200-1000/ton) and energy to produce (4 GJ/ ton) compared to synthetic fibers such as glass fibers (cost: $1200-1800/ton and energy to produce: 30 GJ/ton and for carbon fibers cost: $12500/ton and energy to produce: 130 GJ/ton) (Annandarajah, 2020).
- ❖ False banana fiber and sisal are biodegradable, easily available, low cost and this gives an advantage of utilizing the agricultural product.
- ❖ It helps to develop the economy of the farmers for the reason of cultivating natural plants.

- Since the sisal crop and false banana is very labor intensive, it will offer a great job opportunity for large rural population
- The production of the reinforcement needs relatively small energy compared to that of synthetic fiber.
- Dual advantage from hybridization of synthetic and natural fiber.
- The optimized parameters will be used for fabricating false banana sisal and glass fiber reinforced composite for automotive area.

1.5 Scope of the study

This thesis proposal is delimited to: -

- Fabrication of composite material with varying fiber orientation of sisal and false banana, alkali treatment, weight percentage of fiber and orientation of glass fiber.
- Focusing on testing of mechanical property of false banana sisal glass fiber reinforced composite with polyester resin for Automotive body application.
- Composite testing was done on the available testing facilities as per the standards.
- The optimization of the parameters was done by using hybrid of Taguchi and Grey Relational Analysis method.

1.6 Limitation of the study

For performing the research there were several constraints encountered ; these constraints are described as under.

- Non availability of sisal decortication machine for fiber extraction
- Non availability of compression molding machine for composite fabrication
- The laboratories used in this work is found in different city of the country causing time waste.
- The malfunction of testing machines causing unwanted reptation of the experiment in another machine.
- Un willingness of different authorities for allowing machines to be used by the researcher.

1.7 Research Motivation

The need of transportation system is increasing in a significant manner in our country, Ethiopia. To meet these needs the automotive industries in Ethiopia import the spare parts from abroad. But if these spare parts can be replaced by lightweight, unexpansive and locally available materials, it can improve the vehicle performance and simultaneously save foreign currency for imported one. Thus, sisal and false banana which are the abundant resources in Ethiopia can be the suitable material for the body parts of an automotive.

Public transportation gives better benefit over other mode of transportation in terms of safety, environmental impact and flexibility. Vehicles for public transport buses and mini buses offer extremely high savings with light weighting among the other road vehicles due to highest energy savings is observed for vehicles that employ frequent stops and accelerations. city buses offer high life time energy savings. Therefore, weight reduction is quite important for these vehicles.

Over the near years, the efforts to find more environmentally friendly materials have spurred as a consequence of persistence of plastics in the environment, landfill space shortage and depletion of petroleum resources. Growing environmental problems has become a major influence on government policy in many countries by encouraging “greener” materials research.

1.8 Thesis Organization

The thesis was organized in the five chapters. The first chapter is devoted to Thesis back ground; problem of the statement; general and specific objectives, Significance and beneficiary, delimitation, limitation and motivation of the research. The second chapter presents literature review on composite materials, false banana plants, sisal fiber, Automotive application of composite and optimization of parameters. The third chapter deals with the materials and Methods used in the work. The fourth chapter addresses mechanical and morphological test results and discussion. The last chapter devoted to draw conclusions, recommendations and scope of future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this section different literatures from different sources which are related to the current study were reviewed and from the review research gap was identified.

2.2 Composite Materials

The need of a material with light weight and high performance is increasing in a dramatic way from time to time. The advancement of the execution for a fabric is constrained when there's one composition. Hence, there got to be a modern material with high execution which constitutes two or more customary materials had been obtained. Composite materials are engineering materials in which two or more different materials are combined together but remain uniquely distinguishable in the mixture, having strong fibers surrounded by a weaker matrix material to obtain better properties that are dissimilar from those of the individual components.

The Reinforcing fibers provide the physical and mechanical properties; specifically, to improve the physical and mechanical properties of the matrix and thus add strength and stiffness for the composite. The matrix helps to hold, ensure and convey the fibers, conjointly to transmit and disperse the load to the fibers. A collaboration between these two basic materials produces material properties that are not provided for each material element of origins.

2.2.1 Classification of Composites

A) Based on Matrix Type:- composites based up on matrix are shown in Figure 2.1

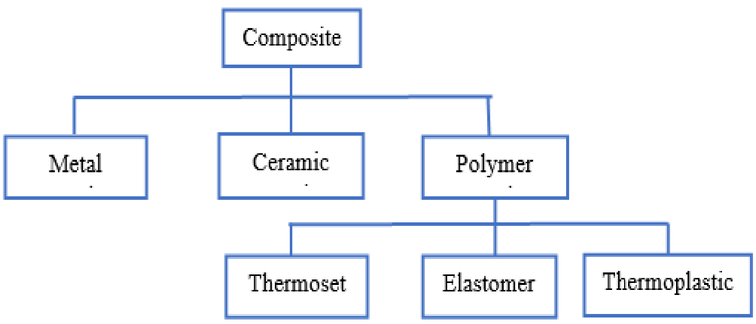


Figure 2.1 Composites based on matrix material

1) Polymer Matrix Composites

From all types of composites, polymer matrix composite is most commonly used composites, because of its advantages such as high strength, low cost and simple manufacturing principle. The requirement of polymer material in this modern dynamic world is increasing day by day because 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 increases in temperatures. Polymer matrices can be either thermoplastic or thermoset according to the effect of heat on their properties. The thermoset polymer is frequently used as the matrix material due to some advantages it has over the thermoplastic one. Table 2.1 compares thermoplastic and thermosetting resins and Table 2.2 depicts properties of thermosetting resins.

Table 2.1 Qualitative Comparisons of Thermoplastic ands Thermosetting Resin (Nguyen et al., 2017)

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

The thermoset polymer matrix materials have overall, better economics and high temperature, good mechanical, wetting and adhesion properties and easiness for disposal. The most commonly used thermoset resin materials are epoxy, polyester ,vinyl ester and phenolic.

Table 2.2 Properties of typical Thermoset Polymers used in Composite Fabrication (Chaudhary and Ahmad, 2020)

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

2) Metal Matrix Composites

The main metal matrix now a day used include metal oxide of Aluminum, magnesium and titanium. metal matrix compsosites are mainly used for the applications of making missile guidance system, for structure of bicycle. an MMC made from silicon carbide fibers in a titanium matrix is currently being developed for use as the skin of the US National Aerospace Plane(A.Haq et al., 2017).

3) Ceramic Matrix Composites

The typical matrix of ceramic is silicon carbide. Ceramic matrix composites are suitable for high temperature resisting components like airplane jet engine. Though, ceramics are known by their resilience to oxidation and deterioration at elevated temperatures, high melting points and high compressive strengths, ceramics suffer from susceptibility to brittle fracture and therefore have relatively low values of fracture toughness (Douglas Kiser et al., 2018).

B) Based on Reinforcement

1) Particulate Composite

Suspending particles of one or more materials in a matrix of another material produces particulate composites. The particles and matrix can be either metallic or non-metallic. The commonly used particulate composites are concrete, solid rocket propellants, carbides etc. Particulate fillers are working to improve high-temperature performance, reduce friction, to increase wear resistance and to reduce shrinkage (Thomas et al., 2012).

2) Fibrous Composites

Fibrous composites are formed by embedding and binding together of fibers by a continuous matrix. fibre is a material in lengthened form such that it has a minimum length to a maximum average transverse dimension of 10:1 and has a maximum cross sectional area of $5.2*10^{4}$ cm^{2} and a maximum transvers dimesnsion of 0.0254 cm

(Aditya et al., 2017). The matrix is meant for bonding the fibers so that they act together. The purpose of the matrix is to support, protect and transfer stress among the fibers. The matrix is usually of much lower strength, stiffness, density and is tougher than the fibers.

3) Structured Compositess

structured composites can be either in laminate form or sandwich form. laminates are sheet developments which are made by stacking layers moreover called handles or laminae and more often than not unidirectional in a specific arrangement. The layers are often in pre-impregnated fiber with partly cured resin in an autoclave. The layer may have more than 3 layers and different angle of orientation can be used for each layer.in addition to this, Fiber orientation of laminate vary from layer to layer in regular way through thickness of the laminate. Figure 2.2 illustrates classification of reinforcement based on reinforcement and Figure 2.3 illustrates based on source.

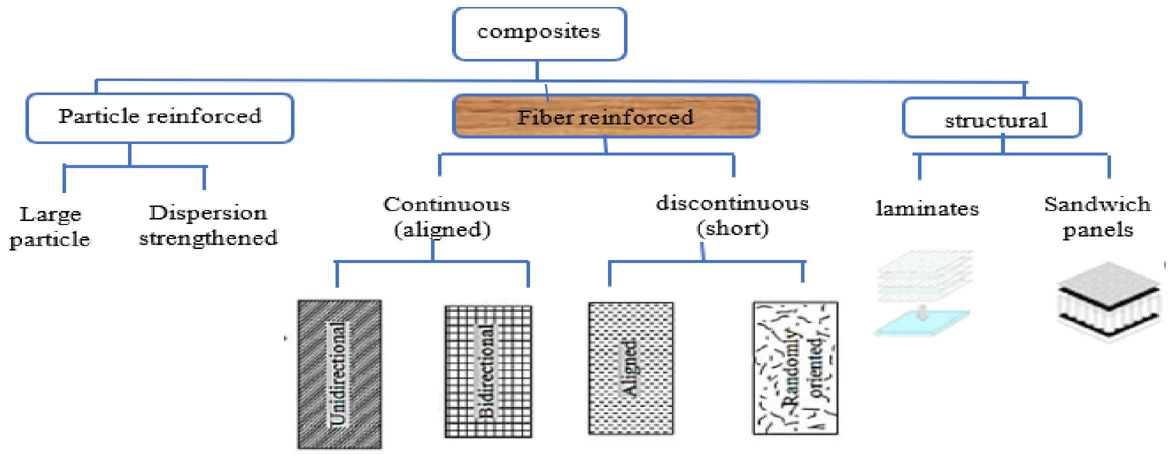


Figure 2.2 Composite based on Reinforcement

C) Based on Source of Reinforcement

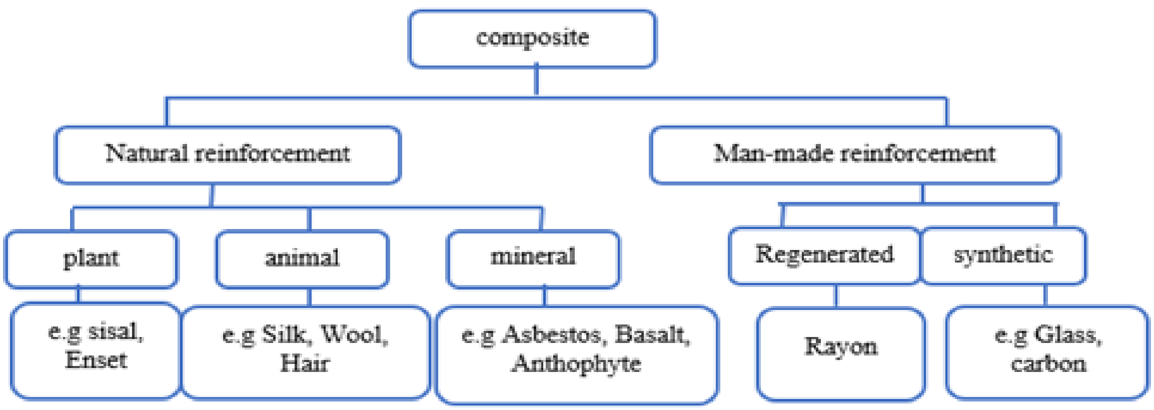


Figure 2.3 Basic constituent of Natural and Man-Made Fiber Reinforced Composites Chaudhary and Ahmad, (2020)

Natural Fiber reinforced composite

Over the past few years, natural fibers as a substitute alternative of reinforcement in polymer composites have attracted the attention of many researchers and scientists due to their better benefit than synthetic glass and carbon fibers (Sanjay et al.,2015).The natural fiber is a type of renewable sources and a new material of reinforcements and dietary support for polymer-primarily based materials.it is a very successful material that replace synthetic substances and its product are relevant for less weight and energy conserving in actively emerging Automotive and aircraft sectors. Natural fibers can be derived from plant, animal and minerals**.** Sisal plant is depicted in figure 2.4

Sisal fiber

Ethiopia and most of African countries cultivate sisal plant for fiber production and cattle feed (Meragiaw and Asfaw., 2014). Ethiopia's sisal production was at level of 756 tons in 2019 up from 740 tons previous year, this is a change of 2.16%.The leaves are cut for fiber between the third and fourth year. The lowest leaves are cut close to the trunk. Each plant yields 250-300 leaves during its lifetime of 7-8 years. A sisal leave weighting about 600gm will yield 20% weight of fiber with each leave containing about 1000 fibers and each leave has 20% fiber,0.75% cuticle,8% dry matter,87.25% water (Tekola, 2020).

Figure 2.4 Sisal Plant

Extraction Methods of Sisal Fiber sisals can be extracted in different ways

a) Chemical Extraction Method

In this method Alkali, more commonly NaOH and acids such as sulfuric acid, oxalic acid, hydrogen per oxide, pectin and sodium citrate can be used for extracting the sisal fiber.

b) Mechanical Extraction Method

The extraction process was done on simple machine in which the rolling element on the machine rolls on fixed support. The roller is provided with horizontal blades with blunt edges. This method can reduce labor work and increase benefit from production.

c) Manual Extraction Method

This method relies on peeling the leave using ribbons or hand. The trunk is pulled apart and sheath is undressed finally the fiber is obtained by removing pulpy part using ribbons (Tekola, 2020).

Enset fiber

Ensete is one of the hopeful substitutes to commonly used hemp, jute and sisal fibers. Ensete is widely cultivated in East Africa and mostly used for food crops. Ensete is a genus with four described species in Africa and Asia (Ensete ventricosum, Ensete Livingston Anum, Ensete homblei, Ensete perrieri).Even though it is first reported by Bruce in 1790 during travels in Ethiopia, it is formally described by Horaninow in 1862 (Borrell et al., 2019).

Ensete plant known as ensete ventricosum (scientific name) is a perennial plant that has leaves, a large underground corm, pseudo stem, moreover it is one of the main food plants grown for traditional diet in Ethiopia (Sgriccia et al., 2008).Decortication of ensete ventricosum's pseudostem (leaf sheaths) gives starchy pulp which along with the corn is mixed and can be consumed as a food product. Ensete ventricosum is the only Ensete species in Ethiopia. It occurs in the South and South-West across the Southern Nations, Nationalities and People's Regional region, as well as the neighboring regions of Oromia sand parts of Benishangul-Gumuz. The distribution of enset is showed in Figure 2.5.

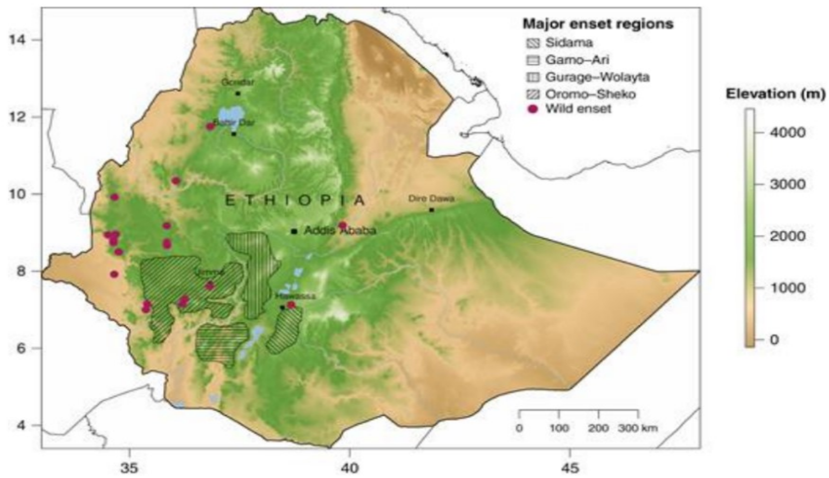
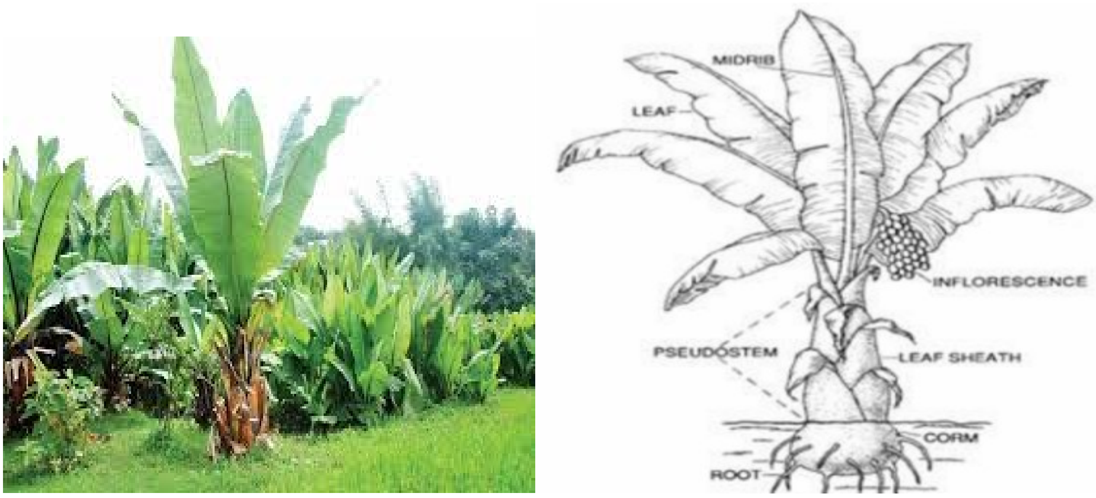


Figure 2.5 Distribution of Enset Plant in Ethiopia (Borrell et al., 2019)

The Enset plant has great ability to withstand environmental stress, including periods of drought. Enset can also be harvested at any time of the year and at any stage over several years including when it is immature. Enset plant constitutes a root system, pseudostem that is dilated at the base and large leaves. The above ground part of Enset pseudo stem is formed by a bundle of clutching and overlying leaf sheaths. As the plant grows older and matures, an inflorescence grows at the apex and a stalk develops along the inner part of the pseudo stem, and the flower emerges at the top and droops out. The plant height may range from 4 to 13 m. The pseudo stem has a circumference ranging from 1.5 to 3.0 m and a length of 2 to 5 m. The leaves are 4 to 6 m long and 0.6 to 0.9 m wide. The corms are 0.7–1.8 m long and 1.5–2.5 m in diameter at maturity. Figure 2.6 illustrates enset fiber and its parts.



a b

Figure 2.6 a) Enset plant at Field b) Parts of Enset Plant. (Berhanu et al., 2018)

As a byproduct ensete fiber is a plant fiber obtained from the pseudostem (leaf) part of ensete plant. Fiber extraction from Ensete stem is economical and as a byproduct it is abundant and easily cultivated in most part of Ethiopian regions (Negawo et al., 2021).Ensete fiber has a tensile strength of 352 MPa, fracture strain of 3.2% and moisture content of 12.2% (Chandrasekar et al., 2017).These properties of ensete fiber indicate its competitive candidate to make natural fiber-based bio composites.

Extraction Process of Enset Fiber

Fiber is extracted from the stalk part of ensete ventricosum plant by using manual scrapping method. The pseudostem is made up of several layers of sheath that is over lapped. The pulpy part is removed by scraping by sharp-edged blade usually bamboo against rectangular flat plate in the fiber length direction. After finishing the scraping process the fibers were washed and dried by sun light.

2) Synthetic Fiber Reinforced Composite

Glass fiber

Research on glass fiber started in the early 1960s by applying on borosilicate glass (E-glass) and soda-lime-silica fiber (A-glass).hybridizing natural fiber with synthetic fibers such as carbon and glass fiber shall be done rather than two or more different natural fibers (Venkateshwaran et al., 2011).The Mechanical properties of naturally obtained fibers are less than synthetic such as glass fibers though the specific properties of the composites from natural fibers were found to be higher when compared with those of glass fiber (Sanjay et al., 2015). Incorporation of fibers manmade or natural into a polymer is known to cause substantial changes in the mechanical properties of composites. mechanical properties of the natural fiber reinforced composites can be improved by hybridizing with high strength man-made fibers. Table 2.3 illustrates physical property of natural and synthetic fibers.

Table 2.3 Physical Property of Some Natural and Synthetic Fibers (Teli and Terega, 2017) (Sanjay and Yogesha, 2018)

Fiber	Cellulose (%)	Hemi cellulose (%)	Lignin (%)	Elongation (%)	Tensile strength (MPa)	Density (g/cm^3)
Banana	57.6-62.5	19-29.1	5-13.3	5.9	180-914	1.32
Sisal	47.6-78	10-17	10-14	3-7	317.5	1.33
False banana (Ensete)	64.46	22.47	6.88	3.2	351.7	1.31
E-glass	-	-	-	3		2.54

2.2.2 Composite Manufacturing Methods

1) **Open Molding**

It is a low-cost process used in composite manufacturing . The mold is first treated with a release agent and gel before the fabrication begins. Hand lay-Up is most popular fabrication method for thermoset composite. prepreg plies are laid up on a tool by hand to create a laminate stack. After laying the plies resin is applied. After this compacting the laminate using hand roller (Zeleke and Rotich, 2021).

2) **Resin Transfer Method**

For fast fabrication of composite materials resin transfer method is used.in this method dry reinforcement is putted on the mold then after mixture of resin and catalyst is pumped by high pressure (Tempelman et al., 2014). The resin used in this method must have low viscosity for applying the preform before it cures.

3) **Vacuum Assisted Resin Transfer Molding**

This composite manufacturing method does not need heat or pressure rather it draws the resin and catalyst mixture by using vacuum into the preform (Hsiao et al., 2000).

4) **Compression molding**

This method is applied for high-volume thermoset composite production (Faruk et al., 2012).

5) **Injection Molding**

It is a low pressure for fabricating thermoplastics. This method is fast with injection speed between one to five seconds (Faruk et al., 2012).

2.2.3 Advantages of Composites

Composites offer many advantages compared to traditional materials (Degefe, 2015).

1.Weight Reduction

FRP composites are typically 25-35% slighter than steel parts of equal strength. Fiber reinforced composite parts can be designed to carry the same loads as steel Parts are for the most part molded at least thickness to diminish weight and minimize molding cycle time. Table 2.4 illustrates comparison of Al, Mg and glass fiber.

Table 2.4 Comparison of Aluminum and Magnesium sheet with glass fiber reinforced composite (Rosato, 2014)

Material	Mass(kg)	Weight Saving(%)
Steel	6.54	-
Aluminum sheet(5182)	3.38	48%
Polyamide glass fiber	2.87	56%
Polypropylene glass fiber	2.35	64%

2. Lower Manufacturing Complexity

Finished assemblies with fewer parts reduce manufacturing costs and often shorten time required for design completion and model introduction (Rajak et al., 2019).

3. Corrosion Resistance

FRP composites are superior in corrosion resistance for many applications. Composites do not rust nor corrode when exposed to moisture and will literally out last most of the steel components on a vehicle (Michelle Kopier, 2011). Their inherent chemical resistance and dimensional stability makes them well suited for engine components such as valve covers and oil pans. The natural fiber reinforced composite has low maintenance requirements, high stress to weight ratio, high corrosion and impact resistance, non-conductive, less electrical hazards, reduced cost, easy installation due to light weight and fire retardant. These composites are used in aerospace industry tails, wings, propellers, bicycle frames, boat hulls, fishing rods, storage tanks, baseball bats, ice skating boards, door panels and automobile industry (Jarukumjorn and Suppakarn, 2009).

2.3 Previous Works on Composites

2.3.1 Effect of different Parameters on Composites

1) Fiber Orientation

Saxena and Chawla., (2021) prepared composites by using three distinct fibers of banana sisal and one synthetic-glass fiber. Fiber orientation of 90^0, 45^0,-45^0 and 0^0 were used. The specimens were examined for directional deformations, stresses, and rotations using ANSYS the result showed that the arrangement of fibers in the sequence sisal-banana-glass-sisal (S-B-G-S) at different orientations was superior in terms of toughness and distortion resistance.

Alemayehu et al., (2020) prepared sisal fiber as a reinforcement material with the fiber orientation of 0^0, 45^0, 0^0 & 90^0 by using hand layup fabrication technique. From the test result it was observed that different orientation of fiber had shown enhanced mechanical properties of sisal fiber reinforced composite material.

Batu and Lemu., (2020)investigated mechanical property of false banana E-glass fiber reinforced composite by considering effect of fiber orientation and volume fraction. It was found from the experimental result that fiber orientation of 0^0 direction give better mechanical properties than other designed composite directions.

Adekomaya and Adama., (2017) developed a composite sheet of three different fiber loading of glass10,20,and 30 wt.% with 0^0 orientation and the glass fibers were arranged in two different fiber orientations with respect to the reinforcing base fiber ($30^0$and 60^0) which were also represented by $G_{20}E_{30}$ and $G_{20}E_{60}$.the weight percentage of fiber at 30^0 and 60^0 orientations in the composites were 10 and 20% weights respectively. composite with 60^o fibre orientation exhibited better tensile strength when compressed with the neat resin and other oriented ($G_{10}E_{30}$) fibre reinforced composite.

2) Weight Percentage of Fiber

Too little fiber reinforcement in the composite showed to deteriorate the properties of the material. Too plentiful fiber volume may also decrease the strength of the composite due to the lack of space for the matrix to fully exploit the uniform load transfer between fibers. Gupta et al., (2021) investigated the effect of different fractional level of sisal and banana fiber and the specimen failure was analyzed with ANSYS software and from experimental result it was concluded that with increase in total fiber volume percentage the flexural and the tensile strength of the composite also increased.

Demissie et al., (2019) fabricated false banana fiber reinforced composite with epoxy resin. ASTM standards were followed to investigate the increase of mechanical properties, surface finish and water absorption property.it was shown that 30% fiber to 70% Epoxy had greater tensile strength of 42Mpa and impact strength of 3.2J.

Mesfen Kebede, (2015) fabricated specimen of sisal reinforced composite by using epoxy as a matrix and sisal fiber as a reinforcement material with the15%,25% and35% fiber weight fraction and concluded from the result that sisal reinforced composite was suited for Automotive body application.

Negawo et al., (2021) used 4 layers of carded Woven ensete and glass fabric to fabricate the composite by Vacuum-assisted resin transfer molding method. Mechanical and dynamic mechanical properties of hybrid composites were characterized. The test results showed that hybridization of ensete woven with glass woven fabrics enhanced the mechanical properties of ensete composites.

3) Fiber Treatment

Jamil and Hasan, (2021) reported that banana fiber was frequently chemically treated to increase the adhesion between banana fiber and polymer matrix. The treatments include Alkali treatment, sodium lauryl sulfate treatment and maleic anhydride treatment.it was conclude that Chemical treatment of banana fiber generally increases the properties of resultant polymer composites.

Abraham et al., (2020) used sisal and banana fiber to prepare the composite by treating both fibers equally with 0.5% of sodium oxidanide and 0.5% potassium permanganate by soaking in this solution and distilled water for 240 min and then the washing and drying from 8 AM to 10AM was done. The experiment showed that treated sisal and banana fiber-based composite performed better than un treated fiber.

Dinesh et al., (2020) prepared a composite by hybridizing S2 glass and banana fiber. The sample were prepared and tested by using 5% NaOH treated and untreated banana fiber. The treated fiber was immersed in the Alkali for 24 hours. The results have proven that the Hybrid natural fiber composite of NaOH treated offered superior performance at taking the tensile test and flexural strength of the NaOH treated composite was very high when compared with Untreated banana fiber composite.

Karthick et al., (2020) used sisal and banana fiber to hybrid with glass fiber. The banana fiber was treated with specific concentration of 2-Hydroxysuccinic Acid in the distilled water. The bio epoxy was employed as matrix material with mix of hardener. The prepared composite was characterized by water absorbability and also characterized by tensile properties, flexural properties and shock absorption capacities in wet condition. It was experimentally proved that the proposed treated banana fiber-based composite performed well than untreated banana fiber-based hybrid composite.

Phani Sushma et al., (2018) composite of polyester resin and sisal fiber was fabricated. 20 grams each of the extracted sisal fibers was soaked in 2, 6 and 10 % NaOH solution for 2, 3 and 5 hours each at a temperature of 65^{o}C under constant stirring. The fibers were then rinsed with distilled water followed by neutralization in 2% acetic acid solution to remove the residual NaOH solution. A final rinse in distilled water till the fibers was neutral to litmus paper and then dried in open air for 4 to 5 days. From the results of the mechanical test, it was observed that, concentrations of 10% NaOH at 2 & 5 hours ,6% NaOH at 5 hours and 2 % NaOH at 5 hours show prodigious improvement of the mechanical performance for tensile, flexural and impact test respectively than the other various concentrations of NaOH at different time intervals. This illustrates that, the extent of surface modification depends on the concentration of NaOH solution and time of treatment.

Prasad et al., (2017) conduct experiment on both treated and un treated sisal polyester composites to study its impact strength characteristics. ASTM D256 standards were followed to conduct the impact test on the specimens of 2 mm, 3 mm, 4 mm, 5 mm and 6 mm thicknesses for fiber volume of 10 %, 15 %, 20 %, 25 % and 30 %. Length of fibers used in casting the specimen was 10 mm. The obtained results indicate that impact strength increases with increase in the thickness. Untreated sisal polyester composite yielded its peak impact strength of 3.581 N-m at its 30 % fiber volume fraction. Treated sisal polyester composite has shown highest impact strength of 1.962 N-m at its 30 % fiber volume fraction.

Gupta and Srivastava, (2016) treated the fiber with 5%NaOH for 30 minutes. After this the fiber was washed with water for several times with distilled water followed by immersing the fibers in very dilute HCl for proper removing of the NaOH adhering to the fibers. Finally, the fiber was washed several times with distilled water and dried in an oven at 70^{0} C. The result showed that the Alkali treatment enhanced tensile and flexural property of the composite by 46% and 65% respectively.

4) Hybridization with Glass fiber

Hybridizing natural fiber with synthetic fiber helps in enhancing the mechanical property of the composites.

Nayak et al., (2021) used synthetic glass fiber to study the effect of hybridization and the effect of the mechanical property of natural fiber composite material due to water diffusion was also evaluated. In addition to this, mechanical characterization by hardness and impact tests were carried out and impact strength of 87KJ/m^2 and Barcol hardness number of 33BHN was obtained.

Ratna Kumari et al., (2021) fabricated sisal fiber-reinforced poly lactic acid and sisal/polyester composites by using compression molding and hand lay-up techniques, respectively. The effect of fiber loading 10%, 20%, 30% weight on water absorption behavior of sisal/ polyester and sisal/PLA composites at room temperature was investigated.

Logendran et al., (2020) used sisal, banana and glass fiber for preparing hybrid composite. The banana fiber was treated with specific concentration of 2 Hydroxy succinic Acid in the distilled water. Then two composites were formed one is treated and the other untreated one. The fiber orientation in the vertical direction and horizontal direction was followed. The prepared composite was characterized by water absorbability and also characterized by tensile properties, flexural properties and shock absorption capacities in wet condition.

Pani et al., (2019) considered three stacking variety of hybrid composite of jute, bamboo and glass fiber reinforced composite. The considered stalking sequence were GJB, GBJ, JBG. The hybrid was also produced by keeping the weight fraction of each fiber to 35% and epoxy polymer was 65%. It was found that GBJ hybrid composite absorb more amount of seawater than the other two type of sequencing. This sea water absorption leads to degradation of flexural strength by 42% and modulus by 33%.In addition to this the GBJ showed minimum specific wear rate.

Kumar et al., (2018) fabricated three different laminate of glass/sisal/banana fiber reinforced hybrid composite by hand layup method and the standard testing method was followed to study mechanical properties such as tensile strength, impact strength and flexural strength of a composite. The result showed that glass-sisal-banana fiber reinforced hybrid composite have superior property.

Ravalika et al., (2017) fabricated a hybrid of sisal jute banana and glass reinforced composite and evaluated the mechanical properties such as tensile, impact, hardness and flexural strength and the obtained result from the experiment was compared in ANSYS software. The samples that consisted glass, sisal, Banana and Jute fibers had greater strength than others.

Daniel Redda and Abiy Alene, (2016) investigated performance of bamboo and E-glass fiber reinforced epoxy hybrid composite. The specimen was fabricated with 45% fiber volume fraction and the mechanical property testing tensile, compressive, in plane shear and flexural showed that 50:50 bamboo to E-glass fiber ratio had high elastic modulus and compressive strength.

Arthanarieswaran et al., (2014) studied effect of woven glass fiber hybridization with the randomly oriented chopped natural fiber of banana and sisal with the use of epoxy matrix. The result shows that the addition of two and three layer of glass fiber can improve tensile strength by a factor of 2.34 and 4.13 respectively. The modulus of elasticity of short fiber composite material was increased by 28%.Enset Fibers as the filler modulus of elasticity of long fiber composite material was increased by 46%.

Arthanarieswaran et al., (2014) analyzed the hybridization of glass fiber with randomly oriented chopped banana and sisal fibers with woven E-glass effect of synthetic fibers. Nine different kinds of laminate were prepared in the staking sequence of B, S, BS, G/B/G, G/S/G, G/BS/G, G/B/G/B/G, G/S/G/S/G and G/BS/G/BS/G. Mechanical properties like tensile strength, flexural strength and impact strength were evaluated and compared. Interfacial analysis was also carried out with the help of Scanning Electron Microscope (SEM) to study the microstructural behavior of the tested specimen. It was observed that the addition of two and three layer of glass fiber can improve the tensile strength by a factor of 2.34 and 4.13 respectively. The flexural properties were enhanced on banana–sisal fiber with two layers of glass fibers rather than three layers and the laminate with sisal and three glass ply offers better impact strength.

Reddy and Sreedhar., (2011) used S-Glass fiber and It has been concluded that the S-glass fiber coating over the surfaces of hybrid fiber improves the mechanical properties tremendously and the chemical treatment of the natural fiber increased adhesion between the fibers. The hybrid fiber coated with glass fiber in this composite plays a tremendous role in determining the mechanical properties.

5) Polyester based Composites

Venkata Deepthi et al., (2019) dynamic mechanical analysis of banana, pineapple leaf and glass fibre reinforced polyester composites was fabricated to determine storage modulus(E_0), loss modulus (E_{00}), damping and glass transition temperature (Tg) with the effect of fibre content. The factors considered was 30%,20% and 10% fiber loading and 1Hz,2Hz,5Hz,7Hz and 10Hz frequencies.

Negera et al., (2019) conducted an experiment to obtain water absorption property, physical and mechanical property of hybrid composite made from false banana fiber and sisal fiber with general purpose polyester resin. The false banana to sisal fiber ratio considered was 1:1, 3:1 and 1:3 respectively. The water absorption tap water and rain water for hybrid composite of 1:3 FB: S ratio exhibit excellent tensile strength and flexural strength. The false banana to sisal ratio of 3:1 showed highest value of compression strength.

Gupta and Singh, (2018) studied the effect of reinforcement of PLA coated sisal fiber in polyester resin. The composite was fabricated by Hand layup method followed by compression molding. Flexural analysis was carried out in terms of breaking force, elongation (%), flexural strength and modulus whereas DMA were carried out in terms of storage modulus (E'), damping ($Tan\ \delta$) and glass transition temperature (T_g). Incorporation of PLA coated sisal fibers into polyester matrix has a significant influence on flexural and dynamic mechanical properties.

Prasad et al., (2017) studied the water absorbability property of sisal polyester composite. The composites were produced with different volume fraction of fiber 5%,10%, 20%,25%,30% and for two different thickness of 3mm and 5mm. The moisture test was done as per ASTM D 570-98 standards and moisture absorption increase with increase of volume fraction.

Kejariwal and Keerthi Gowda, (2017) after extracting the banana fiber and chopping it to 10 mm length, Polyester resin, catalyst and hardener were mixed in the proportion of 100:2:2.the composite was produced by varying Volume fraction as 5%,10%,15%,17.5% and 20% by compression molding theqnique.it was shown that percentage of water absorption of banana fibre reinforced polyester composite specimen was found to increase with increase in fibre volume fraction because of high cellulose content of the natural fibre. (Muktha and Keerthi Gowda, 2017) characterize short raw banana fiber with polyester matrix. the banana fiber was randomly oriented by varying the volume fraction as 5%,10%,15%,17.5% and 20% and by varying the thickness of the composite to 5mm and 3mm.ASTM D3039,ASTM D7264 and ASTM D256 standards were followed to investigate flexural, tensile and impact strength property of the composite respectively. The result proved that 20% fiber volume fraction has increased mechanical property for both 3mm and 5mm thickness composites.

6) Automotive application of Natural fiber reinforced composites

Germany made the first leading point in taking the initiative to use natural composite for interior and exterior car body applications. Composites of natural fibers provides the chance for extensive applications in fields such as automobile, aerospace and for many other common applications where the prohibitive cost of reinforcement at show limits the utilize of ordinary lightweight strengthened plastics.

The use of natural fibers is improved remarkably due to the fact that the field of application is improved day by day especially in automotive industries (Texas, 2018). Hybridization of natural fiber composite by another natural fiber does not yield superior mechanical properties as hybridization by synthetic fiber like glass fiber (Ramesh et al., 2013). and hence this kind of hybrid composite are suitable for low-cost applications and this kind of materials are very popular in engineering market such as automotive and aerospace industries.

Liu et al., (2012) Designed as multi scale approach for predicting three-dimensional elastic model of carbon twill weave fabric composite for the application of body structure of electric vehicle. The numerical results of property were compared with those from uniaxial tensile and three- point bending tests. Finally, the constitutive model of such composite was employed to crash worthiness analysis for electric vehicle body structure under the roof crash and side pole impact. The whole weight of fabricated composite was 1080 kg which was lighter in weight compared to Nissan LEAF(1521 kg) and Renault Fluence ZE(1543 kg).
Mistry et al., (2021) identified the important component of rail vehicles for light weighting by fiber reinforced comsposite.5 parts of rail a cantilever seat bracket ,luggage rack module inter-mediate end structure, body side structure and roof structure were identified. it was determined that car body structural component intermediate end, body side and roof structure were most optimal components to be replaced by composites. From the result it was estimated that a composite redesign with fiber reinforced component results in mass saving of 57% for intermediate end structure,47% for body structure and 51% for roof structures.

2.3.2 Taguchi Grey Relational Optimization Method

Sampath et al., (2021) examined mechanical property of hybrid banana glass fiber reinforced composite. The tensile and flexural strength was examined by considering thickness, length, and percentage of fiber volume fraction as process parameters. The experiments were conducted using Taguchi L9 orthogonal array. The analysis of variations was conducted to find the significant parameters and contribution of parameter. from the result it was found that volume fraction of fiber with matrix polyester has a higher contribution than other factors.
Jaysukhlal, (2020) fabricated banana-coir fiber reinforced composite with different combinations and caried outs the analysis of variance for proving the homogeneity of

prepared sample. In addition to this, Gray relational analysis was proposed for ranking of mechanical properties and obtaining best combination of input variable.

Ribeiro Filho et al., (2018) investigated the physical and mechanical properties of hybrid composite made of sisal /glass fibers and Portland cement inclusions. The effect of stacking sequence and cement particles on the flexural strength, stiffness, apparent density, apparent porosity and water absorption of composite was identified by generating a full factorial design. Interaction and contribution of main factors were determined by applying design of experiment DOE and ANOVA. The inclusion of cement micro particles increased apparent porosity. The 98% indicate the fiber staking sequence was the most relevant factor that determined the mechanical property and damage mechanism of bio-composite. The failure mode of the hybrid composites consists of cracks in the matrix and fiber pullout effects, especially when the natural fibers were incorporated.

Sailesh et al., (2015) fabricated a banana glass fiber reinforced composite by hand layup method with variable fiber orientation and conducted a test for flexural strength and identified best flexural strength by Taguchi method. The combination of 0^0 glass, 0^0 Bamboo, 45^0 banana, 0^0glass fiber orientation with 10:1 mixing ratio and 30minute curing time provided the best flexural strength.

Mosisa and Sirhabizu, (2019**)** conducted the experiment based on Taguchi experimental method. The research considered weight fraction, fiber orientation of sisal and bamboo fiber and curing temperature as controlling parameters. The result illustrated bamboo-sisal fiber reinforced composite with 25/25 weight percentage of sisal to bamboo fiber unidirectionally stacked at curing time of 25^0C had high tensile and bending strength of 103.611 and 137.633 MPa.

2.4 Other Literatures

The various authors have carried out research work related to the development of composite material based on natural fibers. However, some of the details of research works carried out in the recent past were as follows

Kumari et al., (2021) used conventional hand layup method to fabricate composite from banana sisal and saw dust with different compositions. The specimens were made with proper composition of 20 wt% of reinforcing materials and 80 wt% of the matrix material. The tensile strength, compressive, flexural, and impact strength, as well as Brinell hardness of the prepared NFCs, were found to increase with the increase in sawdust content in the epoxy matrix.

Batu and Lemu., (2020) used false banana and glass fiber for reinforcing the epoxy matrix and fabricated the composite using conventional hand layup method and compression molding technique. It was concluded that the fiber orientation of 0^0 and fiber volume fraction of false banana to glass of 10/40 has better mechanical property.

Karthick et al., (2020) characterize the prepared sisal and textile-grade glass composite by water absorbability, tensile properties, flexural properties and shock absorption capacities. The sisal was treated with specific concentration of sodium hydrate and potassium permanganate in the distilled water. The composite synthesized were with treated and un treated sisal fiber. It was experimentally proved that the proposed treated Sisal fiber-based composite performed well and its cost were also reduced.

Logendran et al., (2020) for fabricating the composite, two natural fibers (banana and sisal) and synthetic glass fiber was used. The banana fiber was treated with specific concentration of Hydroxy butane dioic Acid in the distilled water. The composites were synthesized with treated and untreated banana fibers. Fiber orientation of vertical and horizontal were followed. The bio epoxy is employed as matrix material with mix of hardener. The prepared composite was characterized by water absorbability, tensile properties, flexural properties and shock absorption capacities. The synthesized composites were also characterized for dry and wet applications. The synthesized composite tested under the tensile load proved its ability is better in wet condition than its dry condition.

Raghul et al., (2020) investigated the effect of the addition of silica nano particles content in the sisal-palm-glass fiber-reinforced composite. The composite was fabricated by hand lay-up method followed by hot press molding and their mechanical behaviors like tensile strength, flexural strength and impact strength were evaluated. The results showed that maximum tensile and flexural strength were achieved when 2% Nano-silica added to the sisal-palm-glass fiber and the result showed that the incorporation of 1% of Nano-silica has significant effects on the Charpy impact behavior.

R.Siva et al., (2020) Investigated mechanical properties of sisal, kenaf Aloe vera hybrid composites of epoxy resin. Three different arrangements of hybrid composites were prepared (1) Sisal + Kenaf + Aloes vera + Epoxy (2) Kenaf + Aloe vera + Sisal + Epoxy and (3) Kenaf + Sisal + Aloe vera + Epoxy by hand lay-up method and their tensile strength, flexural strength, impact strength and hardness were examined. The study revealed that higher property values of tensile strength, flexural strength, impact energy were obtained for Kenaf + Sisal + Aloe vera + Epoxy arrangement compared to the other two arrangements; higher hardness characteristics were obtained for Sisal + Kenaf + Aloe vera + Epoxy matrix than the other two arrangements.

Samal and Pradhan, (2020) performed comparison of sisal-jute with jute-banana hybrid composite. The fiber composition in each specimen was 1:1 while the resin and hardener composition 10:1 respectively. The mechanical properties were compared with calculated values according to the rule of hybrid mixing. The flexural quality and modulus were higher incentive than elasticity and modulus of composite.

Siva et al., (2020) fabricated composite of sisal, kenaf Aloe vera hybrid with epoxy resin by hand lay-up method and their tensile strength, flexural strength, impact strength, hardness was examined. The study reveals that higher property values of tensile strength, flexural strength, impact energy was obtained for Kenaf + Sisal + Aloe vera + Epoxy arrangement compared to the other two arrangements; higher hardness characteristics are obtained for Sisal + Kenaf + Aloe vera + Epoxy matrix than the other two arrangements.

Yorseng et al., (2020) The bio epoxy resin and kenaf/sisal fiber fabrics were used for making hybrid bio-based composites and manufactured composite laminates using a compression molding method. For comparison purpose, a neat bio epoxy thermo set was fabricated by casting mold technique. To promote the accelerated weathering of composites, the samples were exposed to environmental conditions such as ultraviolet radiation, extreme temperature and humidity conditions in accelerated weathering tester machine according to ASTM G155-13 cycle 1. The tensile, impact, morphology, thermo gravimetric analysis, dynamic mechanical analysis, and water absorption test were performed for both before and after weathering test samples according to international standards. The results indicated that the manufactured fully bio-based kenaf/sisal fiber reinforced hybrid bio epoxy composites showed moderate properties when compared to the neat bio epoxy composite at both before and after weathering conditions.

Ansari et al., (2019**)** investigate mechanical properties of sisal fiber and human hair reinforced epoxy composite. The Tensile, Flexural, Impact and hardness tests were conducted on specimens with different weight percentage combinations of sisal and hair reinforced epoxy . Results indicate that the tensile strength of the composite increased with fiber percentage loading, ultimate tensile strength was maximum in case of epoxy (95% weight composition) and less in epoxy (85%weight) composition. While Impact energy of the sisal fiber and human hair hybrid composite also increased with increased in fiber percentage loading .Flexural modulus of Elasticity was maximum for Epoxy (85% weight) composition and minimum in case of Epoxy (95% of weight)composition .The Flexural modulus of rupture was found to be more for Epoxy (85% of weight) composition and minimum in case of Epoxy (95% of weight) samples respectively.

Thiagamani et al., (2019) used a green epoxy as the matrix material for fabrication of hybrid bio composite of sisal/hemp composite by hand layup method followed by hot pressing with different stacking sequence. The inter laminar shear strength, hardness, tensile strength, compressive strength were measured. Physical properties such as density, void content, water absorption and thickness swelling were also analyzed. When the stalking sequence was varied there had been small change in tensile strength. The hybrid composite with the intercalated arrangement (HSHS) exhibited the highest tensile modulus when compared with the other hybrid counterparts.

Abuye, (2017) carried out an experimental investigation on false banana reinforced gypsum resin with fabricating it by hand layup method. To find the effect of false banana at different weight % of 5, 20, 30 mechanical tests were carried out with ASTM standards, It was shown from the result that addition of false banana with 20% weight ratio improved tensile, flexural, impact property and water absorption property of gypsum resin.

Kumre et al., (2017) Glass fiber reinforced polymers were mixed with sisal of various fiber lengths (5, 10, and 15, 20 mm) for increasing many Engineering and Technology applications. It was shown that variation of fiber length of sisal gives insufficient transfer of force from epoxy to the fiber. The reason for this was of poor adhesion between fiber and matrix. The incorporation of glass fiber into sisal greatly enhanced the mechanical property of composite and moisture resistance of sisal fiber.

Raj et al., (2016) fabricated and evaluated mechanical property of Ethiopian banana fiber reinforced composite. The fabricated samples were cut as per ASTM standard using water jet machining and subjected to mechanical testing of tensile strength, flexural strength and impact loading resistance. The test reveals that tensile strength of 5% banana with 90^0 orientations of fiber has 67.5 MPa higher tensile strength than 20% banana bi directional fiber and also impact test showed that 5% and 10% banana bidirectional fiber possess higher impact strength than other samples. The morphological study revealed that fiber pullout occurred on various percentage of bidirectional fiber. The epoxy resins were well bonded than bidirectional fiber which results in weak interfacial bonding on fiber percentage of 5% banana with 90^0 orientations of fiber.

Krishnan K et al., (2015) extracted cellulose fibers from sisal leaves using steam explosion technique. The progressive removal of non-cellulosic constituents was confirmed by FTIR studies. X-ray diffraction reveals that crystallinity increased with successive chemical treatments. Characterization of the fibers by SEM and TEM gives indication for the formation of cellulose nano fibers. TGA results show that the cellulose nano fibers exhibit enhanced thermal properties over the untreated fibers. Water transmission data shows that the addition of 0.5 Wt.% CNF decreased the transmission rate in the composite. Mechanical properties improve with the incorporation of cellulose nano fiber.

Mizera et al., (2015) studied deformation property of Enset reinforced epoxy composite. Enset fiber was cut to length of 2,3,5,6,7and 8mm for the short fiber and for the long fiber it was cut in to 10,15,20,25,30 and 35 mm length. Filler of 2wt% was used. The modulus of elasticity of the short-fibre composite material was increased of 28 ± 12% by Enset fibers as the filler. The modulus of elasticity of the long-fibre composite material was increased of 46 ± 14%.

Maurya et al., (2015) used epoxy matrix and tensile, flexural and impact properties of randomly oriented short sisal fiber reinforced composite. Hand lay-up method was used to fabricate the composite with fiber length of 5,10,15 and 20 mm. fiber content of 30wt% sisal was used. The result offered that tensile strength was not increased by reinforcing sisal but flexural strength was improved 25% by 15mm sisal fibre and large improvement was observed in impact properties by 20 mm sisal fibre.

Kimutai et al., (2014) collected waste plastics and the polyethylene plastics melted and the ensete false banana fibers were prepared by means of compression molding. The percentage of fiber were varied between 0 to 40% and then the effect of fiber loading on mechanical properties such as impact strength, flexural strength, wear resistance and water up take was studied. The study demonstrated that the optimum fiber loading for the best performance of the composite achieved was 30wt%.

2.4.1 Taguchi Gray Relational Method

Taguchi's technique has been used to find optimum process parameters at optimal cost (Hussain et al., 2020).This method has restraint to optimization of single response problems. To increase the usefulness of this technique for multi-response optimization problems, Grey relational analysis (GRA) proposed by Deng Julong can be incorporated with Taguchi method (Liu and Lin, 2010). In GRA, the multi- response problem is converted in to a single response problem and then optimal solutions are evaluated. The GRG is used to optimize process parameters and the optimal process parameters setting can be evaluated by the Taguchi method using GRG as sa measure of performance index. Selection of Orthogonal array provide that all controlled variables are equally considered in experiments. The minimum number of trial run must be more than or equal to the total degrees of freedom. Each row of orthogonal array represents different combination of level parameters (Hussain et al., 2020).

Signal to Noise Ratio (S/N)

Signal to noise ratio was employed to performance characteristic to measure process robustness and to evaluate deviation from desired values. The noise traits to the uncontrollable factors associated with the experiment, which has to be eliminated to reduce the noise, thereby reducing the variance that exists in the experimental or actual process variables. The noise attributes to the uncontrollable factors associated with the experiment, which has to be eliminated to reduce the noise, thereby reducing the variance that exists in the experimental or actual process variables.

ANOVA

It was used when multiple cases were involved. It is a procedure for testing the difference among different groups of data for homogeneity. Two estimations of population variance (between samples and within samples variance) are required and then compared with F-test. ANOVA was carried out to find out that there is no level of significance in selecting the samples for different mechanical properties (Hussain et al., 2020).

2.4.2 Data Analysis of Responses

The data from experimentation were 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. There are 3 types of quality indicative, namely larger is better, smaller is better and nominal is best.

$$S/N = -10\log\left(\text{sum}\left(\frac{Y^2}{n}\right)\right) \quad (2.1)$$

$$.S/N = 10\log \text{sum}\left(\frac{\frac{1}{y^2}}{n}\right) \quad (2.2)$$

where y = number of factors

N= number of observations

After the execution of the design of the experiment the experimental response was changed into the S/N ratio and using grey relational analysis, the S/N ratio of several factors were changed into one row of grey relational grade response. Using the grey relational grade Taguchi analysis was take place. from the Taguchi analysis of the main effect plot for signal to noise ratio the optimal condition was predicted.

2.4.3 Optimization of Parameters

Optimization of parameters were done by utilizing minitab16 statistical software. Frist the response parameters were converted into S/N ratio. The S/N ratio was cooperated in to grey relational analysis and converted into the normalizing sequence, the deviation sequence which was used to calculate the grey relational coefficient, was calculated from the normalizing sequence. Finally, the GRG value which is used on the taguchi optimization for optimization purpose was calculated from the gray relation coefficient.

The Grey Relational Method based on Taguchi grey relational technique consist of following steps

Step-1: Identification of process parameters and their levels

Step-2: Selection of appropriate orthogonal array.

Step-3: Perform experimental trial runs and evaluate responses.

Step-4: Normalizing response data .the normalization of the data was conducted according to the criteria

$$\text{for Larger the better } X_{ij} = \frac{Y_{ij} - \min Y_{ij}}{\text{Max}Y_{ij} - \min Y_{ij}} \quad (2.3)$$

$$\text{for smaller is the betters} X_{ij} = \frac{\max Y_{ij} - Y_{ij}}{\max Y_{ij} - \min Y_{ij}} \quad (2.4)$$

Step-5: Generate Grey relational coefficient(GRC) and calculate Grey relational grade(GRD).

$$\mathrm{GRC_{ij}} = \frac{\Delta_{\min}+\psi_{\Delta\max}}{\Delta_{ij}+\psi\Delta_{\max}} \quad (2.5)$$

$$GRD_i = 1\sum_{j=1}^{m} GC_{ij} \quad (2.6)$$

Step-6: Evaluate optimal level of parameters setting through main effects table.

Step-7: Identification of most influential parameters through Analysis of Variance.

Step-8: prediction of optimal process parameters

2.5 Research Gap

Even though Several research has been done on mechanical and morphological characterization of false banana reinforced composite, sisal reinforced composite and glass hybridized composite was not yet done. more over characterization with varying natural fiber orientation ,Alkali treatment level , weight percentage of natural fiber and glass fiber orientation was less done. In addition to this design of experiment for optimizing the mechanical and physical property of the composite with finding best parameters combination was done mainly for single response optimization but for multi response optimization it was rarelydone.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this section the materials and equipment's used in the study and machines for testing different samples were presented.in addition to these methodologies used conducting the research was also presented.

3.2 Materials

Materials used in the study is illustrated in table 3.1

Table 3.1 materials used in the study

Materials Used	Sisal fiber	False banana fiber	Glass fiber	General purpose resin	Catalyst	wax	Sodium Hydroxide
Amount	1Kg	1Kg	2Kg	4Kg	0.25L	1pack	500g

1) False Banana Fiber

Enset fiber was collected from the market in Addis Ababa town called merkato

2) Sisal Fiber

Ethiopia is a very rich suitable country for harvesting sisal fiber. Ethiopian sisal leaves is 500mm long and it vary in its length depending on its age and location (Samal and Pradhan, 2020).More often plants are harvested after 24-36 months. About 50 leaves, each weighing up to 1 kg may be cut per plant per year. In this research sisal plant was taken from Oromia regional area called ambo and typical view of sisal plant is shown in figure 3.1

Figure 3.1 Collection of Sisal Plant

3) Glass fiber E-glass fiber with random orientation and Woven type was used in this study for hybridization with natural fiber. It was bought from World glass fiber organization. glass fiber used is shown in Figure 3.2

Figure 3.2 Random and Woven Glass Fiber

4) **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 (Demissie et al., 2019). Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and absorbs moisture and carbon dioxide in air. Although molten sodium hydroxide possesses properties similar to those of the other forms its high temperature comparatively limits its applications. 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. Sodium hydroxide that was used in this research is shown in Figure 3.3a

a b c d

Figure 3.3 a) NaOH in pallet form, b) Wax c) Polyester resin d) Distilled Water

5) General Purpose Polyester Resin

In this experiment general purpose polyester was bought from local market of Addis Ababa called World Glass fiber organization.it has density of 1.29g/cm^3 and it is shown in fig 3.3c

6) Catalyst

catalyst used for polyester resin was methyl ethyl ketone per oxide (MEKP). it helps the resin to solidify. The ratio of polyester to hardener was 3g of hardener to 1 kg of polyester.

7) Wax

Honey wax was used for easy removal of the fabricated composite from the mold.it is shown in fig 3.3 b

8) Distilled Water

Is a water in which the contaminants are removed. In this study it was used in fiber treatment, water absorption and void content testing. It is illustrated in figure 3.3 d.

3.3 Methods

Different methods used in the study include fiber extraction, design of experiment, fiber treatment, composite fabrication, specimen preparation and testing.

1) Sisal Fiber Extraction

The required amount of sisal plant leaves for this thesis work was collected from Oromia region of Ethiopia. after cutting at their base from the field the fibers were extracted from the given plant manually with the help of knife and scraping wood. Initially the leaves trimmed in longitudinal direction into strips for ease of fiber extraction. The peel was clamped between the wood plank and scraping wood, and one should hand-pulled through in longitudinal direction gently, removing the resinous material as shown in the Figure 3.4.for final neat removing of the resinous material knife was used. After performing the extraction process, the extracted fiber was washed with pure water in order to remove and separate unwanted dusts from the fiber and it was dried with sun and eventually the required fine fibers were obtained.

Figure 3.4 Fiber Etraction of Sisal Plant

2) Design of Experiment and Orthogonal Array Selection

In performing this experiment,4 factors at two levels were considered giving total of 8 experimental runs. Table 3.2 and Table 3.3 illustrates parameter levels and orthogonal array respectively.

Table 3.2 Process Parameters and Levels

Process Parameters	**Notations**	**Level 1**	**Level 2**
Fiber orientation of false banana and sisal	A	0/90	-45/45
NaOH treatment	B	5%	10%
Weight percentage of false banana, sisal fiber and glass fiber	C	20:10:10	10:20:10
Glass fiber orientation	D	Random	Wave

Table 3.3 L_8 Orthogonal Array

Test Runs	**Fiber orientation (A)**	**Alkali treatment (B)**	**Weight percentage (%)**	**Glass fiber orientation(D)**
1	0/90	5%	20:10:10	Random
2	-45/45	10%	20:10:10	Woven
3	0/90	10%	10:20:10	Woven
4	-45/45	5%	10:20:10	Random
5	0/90	5%	20:10:10	Woven
6	-45/45	10%	20:10:10	Random
7	0/90	10%	10:20:10	Random
8	-45/45	5%	10:20:10	Woven

3) Alkali treatment

Alkaline treatment with NaOH, known as mercerization, extracts lignin sand hemicelluloses, increasing the strength and the elongation at break of the composite (Mesfen Kebede, 2015).as it is suggested in (Malaiah et al., 2013),both sisal and false banana was treated at two level of 10% and 5% NaOH concentration. The fibers were soaked in distilled water for 12 hour and after that it was continuously and repeatedly washed with water. After this the fiber was dried in sun light for two days. Figure 3.5 shows fiber treatment steps.

Figure 3.5 Treatment of fiber

4) Weight and Volume Fraction Calculation

In several literatures (Mann et al., 2019) 25-50% volume fraction of natural fibers was used. Weight fraction of fiber is calculated as (Maurya et al.,2015).

$$W_f = \frac{w_f}{w_f + w_m} \tag{3.1}$$

Weight fraction of Matrix is given by

$$W_m = \frac{w_m}{(w_f + w_m)} \tag{3.2}$$

where Wf= weight fraction of fiber

Wm=weight fraction of matrix

Total fiber volume fraction is calculated by using the following equation

$$(V_f) = \frac{(\frac{w_s}{\rho_s} + \left(\frac{w_{fb}}{\rho_{fb}}\right) + (\frac{w_g}{\rho_g})}{\left(\frac{w_s}{\rho_s}\right) + \left(\frac{w_{fb}}{\rho_{fb}}\right) + \left(\frac{w_g}{\rho_g}\right) + \left(\frac{w_m}{\rho_m}\right)} \tag{3.3}$$

where Vf =volume fraction of fiber

Wfb=weight of false banana fiber ρfb=density of false banana fiber

Ws=weight of sisal fiber ρs=density of sisal fiber

Wg= weight of glass fiber ρg=density of glass fiber

Volume of mold (V_c) = 300 mm * 300 mm * 4 mm = 360000 mm^3 = 360 cm^3

density of polyester = 1.29g/$cm^{3,}$ false banana fiber =1.31g/$cm^{3,}$ sisal fiber=1.33g/cm^3

E-glass fiber =2.54g/cm^3, Vcomp = Vf+ Vm

$$\frac{1}{\rho c} = \left(\frac{1}{\rho f}\right)\left(\frac{Wf}{Wc}\right) + \left(\frac{1}{\rho m}\right)\left(\frac{Wm}{Wc}\right) \quad (3.4)$$

By substituting the density of fibers and matrix listed above in to equation 3.4 and considering weight fraction of fiber(W_f) to be 40% and weight fraction of Matrix(W_m) to be 60%, weight fraction of each fiber is tabulated in Table 3.4.

$\boldsymbol{\rho}_c$=1.8438g/cm^3

$$W_c = V_c \times \rho_c = 774.427\text{g} \quad (3.5)$$

For level 1

W_{fb}=20%Wc , W_s=10%Wc ,W_G =10%Wc

For level 2

W_{fb}=10%W_c , W_s=20%W_c ,W_G=10%W_c

Table 3.4 Weight Fraction of Fiber

Fiber type	Mass(g) for level 1	Mass(g) for level 2
False banana fiber	154	77.44
Sisal fiber	77.44	154
Glass fiber	77.44	77.44

5) Weighting of Fiber

The mass of each fiber type and polyester were measured with a balance

4) Woven Making

Fiber of false banana and sisal were weighted and then woven into two type orientation of 0/90 and -45/45 degree by hand and it is illustrated in Figure 3.6

Figure 3.6 Woven Making at 0/90 and -45/45 degree

5) Pattern Preparation

The pattern was designed by as per ASTM standard. The pattern was made up of MDF wood. The pattern Size is 350 × 350 mm. The pattern consists of two parts. Upper Plate and lower plate.

6) Preparation of Polyester Resin

The most commonly used thermoset resins are epoxy, Vinyl ester, polyester and phenolic. The resin and hardener (catalyst) were mixed slowly by stirring with a stick by hand for 5 minutes. The ratio of resin to catalyst was 1:3.

7) Fabrication of Composite by Hand Lay-Up Method

According to (Betelie et al., 2018) hand lay-up method is the oldest simplest, and the most commonly used method for the manufacture of both small and large reinforced products. This technique is shown in figure 3.7 flat surface made from wood with C clamp for tithing and applying of equal load was used for fabricating the composite. This process requires less capital investment and expertise and it was therefore easy to use.

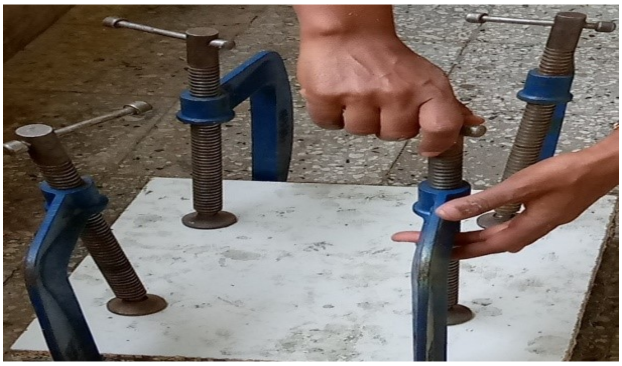


Figure 3.7 Fabrications of Composites with Tightening by C-clamp

8) Cutting of Specimens with Hand jigsaw

The specimens used for different testing's were cut with different sizes and shapes by hand jigsaw machine.

9) Testing of Specimens

Mechanical, Physical and morphological testing of specimen of 8 samples were conducted in different machines.

The different methodologies followed in performing this study was summarized and presented in the activity flow chart in figure 3.8

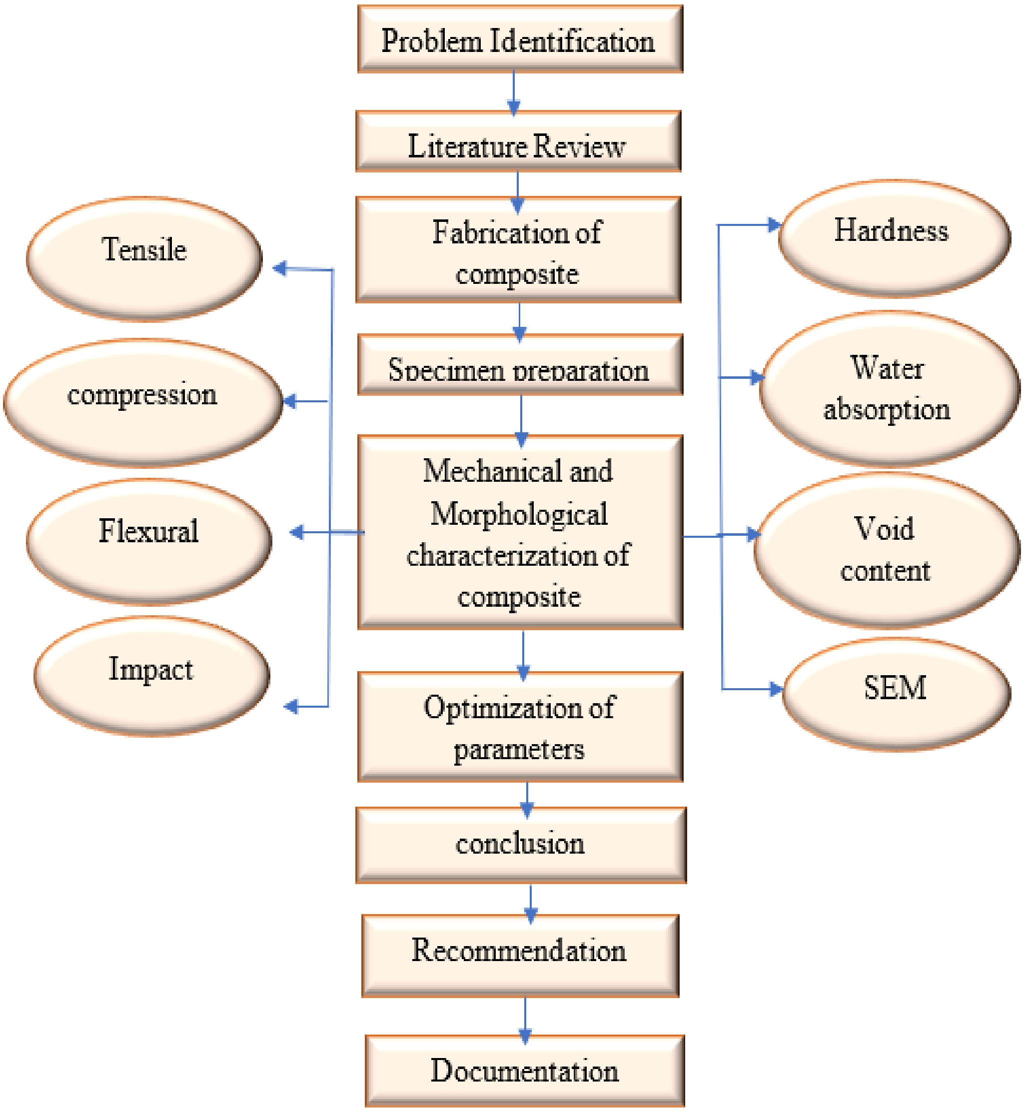


Figure 3.8 Activity flow chart

3.4 Equipment and Machines used for the Study

The equipment used for studying the mechanical property and morphology of the composite are presented in this section. Figure 3.9 shows mass balance and jigsaw cutting machine.

a b

Figure 3.9 a) Electronic balance b) Jigsaw machine

1) Electronic Mass Balance

Electronic mass balance was used for measuring the weight of the fiber, sodium hydroxide and polyester.

2) Jig Saw Cutting Machine

was used for cutting the fabricated composite into different sizes and shapes.

3) Universal Testing Machine

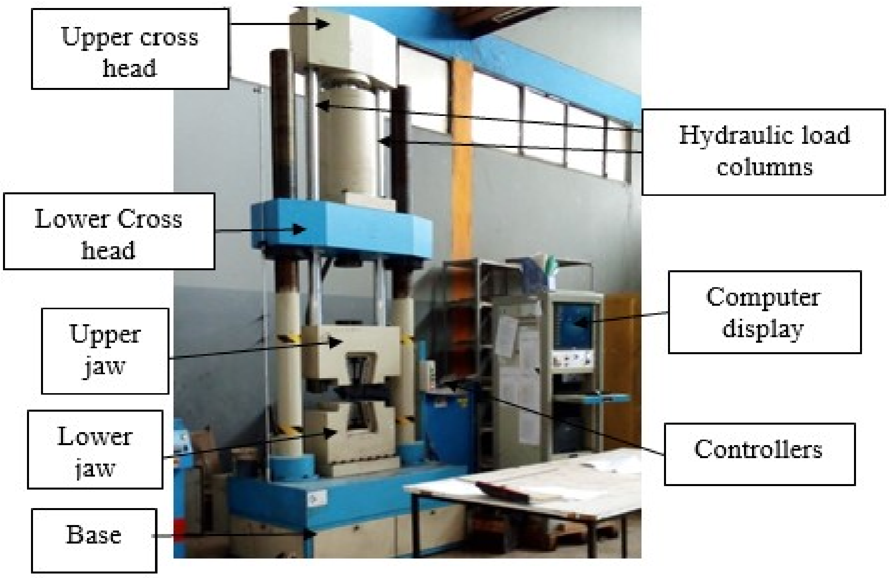


Figure 3.10 Universal testing machine

Universal testing machine illustrated in figure 3.10 was used for conducting tensile test, three point bending test and compressive test for studying mechanical property of the composite. The universal testing machine has controller's unit for adjusting speed and load of the machine. In this study three universal testing machine were used.

Flexural (three-point bending) test was carid out using electro-hydraulic universal testing machine(WP310) in national defense collage of bishoftu. Tensile test was conducted at Ethiopian Conformity Assessment Enterprise universal testing machine (MTL/013) and compressive test was caried at Adama Science and technology university mechanical lab.

Tensile, compressive and flexural tests were conducted at constant strain rate value in quasi-static condition and at room temperature. Three point bending test was conducted at cross head speed of 1.5 mm/min. During the test, load is continuously applied for all the specimens from dynamometer load cell until the specimen fails.

4) Vickers Hardness Machine

Vickers hardness testing machine in adama science and technology university of material science laboratory was used. The specimen was placed in the table and then the light source was adjusted to reveal the deformed area of the composite. The load was applied by diamond shaped indenter and the hardness values were displayed in the computer display. vicker hardness machine used in the study is shown in Figure 3.11

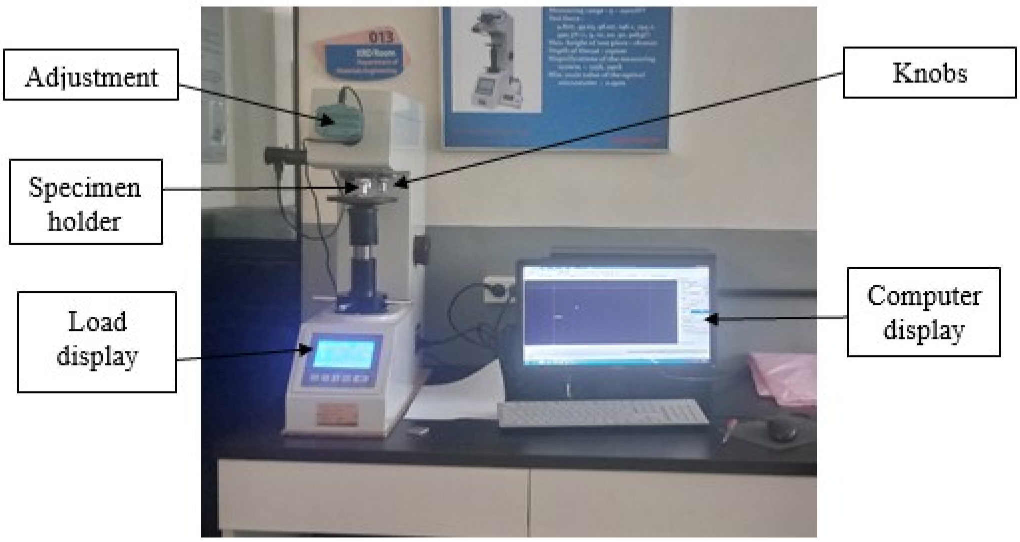


Figure 3.11 Vickers hardness testing machine

5) Charpy Impact Testing Machine

Impact strength of a material was recorded by Charpy impact testing machine at Bishoftu Defense engineering collage that is illustrated in figure 3.12. The striking hammer was lifted up to the maximum position and then the specimen was placed in center. after releasing the striker and hitting the specimen the reading by the pointer was recorded.

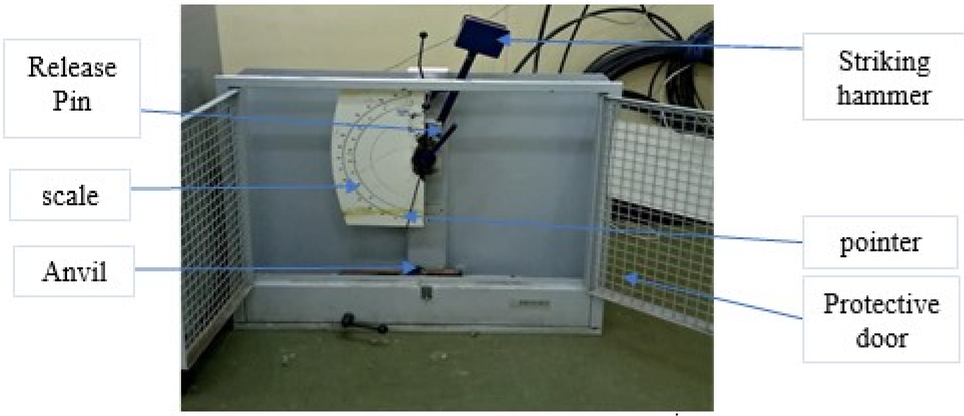


Figure 3.12 Charpy Impact testing machine

7) Vertical Drill Machine

Vertical drill machine constitutes diferent parts as shown in figure 3.13.the spindle is the rotating part of the drill machine that holds the drill chuck useed in holding of cutting tool.the hand feed helps to in feed the drill bit into the composite.

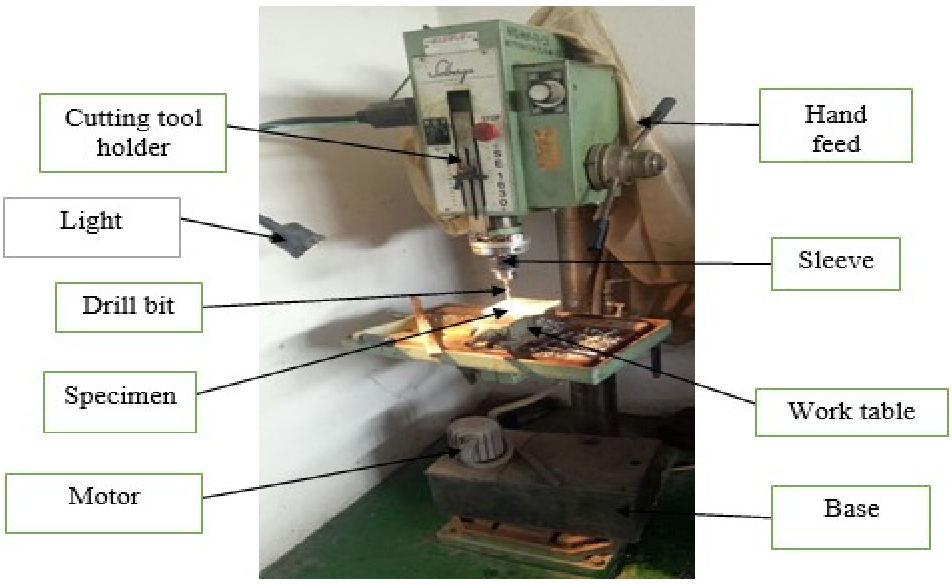


Figure 3.13 Vertical drilling machine

6) Scanning Electron Microscope

The specimen was cut and it was placed in the sample chamber and then the magnification level was adjusted and the image was generated and displayed in the computer screen. The scanning microscope used is illustrated in figure 3.14.

Figure 3.14 Scanning Electron Microscope

3.5 Composite Characterization

Mechanical, Physical and Morphological characterization of a composite were performed according to ASTM standard and at room temperature.

1) Tensile testing

The mechanical behavior of the composites prepared with the fabricated samples were tested in the Universal Tensile testing machine with testing load range of Maximum 2000 KN with gear rotation speed of 2.5 mm/min. The experiments were conducted at room temperature .The test specimens were cut as per ASTM D3039 standards using hand jigsaw machine. During tensile testing the samples were placed vertically in the grip appropriately to prevent slipping. The speed and load applied were adjusted in the controller unit. Then load was applied up to breaking of the composite and the data was recorded and saved in the computer attached to the machine. The prepared specimen for tensile test is shown in Figure 3.15.

$$Tensile\ Strength = \frac{Breaking\ load\ (KN)}{orginal\ Crossectional\ Area(m^2)} \qquad (3.6)$$

Percent Elongation

It is the increase in percent of length of specimen at its breaking point.it can be calculated from the equation 3.7 (Sanjay and Yogesha, 2017).

$$percent\ elongation = \frac{(elongation\ at\ rupture) \times 100}{initilal\ gage\ length} \quad (3.7)$$

$$\%\ elongation = \frac{L - L_0}{L_0} \times 100 \quad (3.8)$$

Where Lo = original length L= final length after failure

Figure 3.15 Tensile test specimens

2) Compression Test

compression test was conducted to determine the materials resistance to a crushing force by applying a compressive pressure to a specimen. The compressive force pushed inward the specimen causing it to shorten in the direction of applied load and expanding in perpendicular direction to the force. ASTM D3410 was followed to prepare the specimen for the compression test. composite was tested at Adama science and technology university mechanical lab. Figure 3.16 shows composite on compression testing.

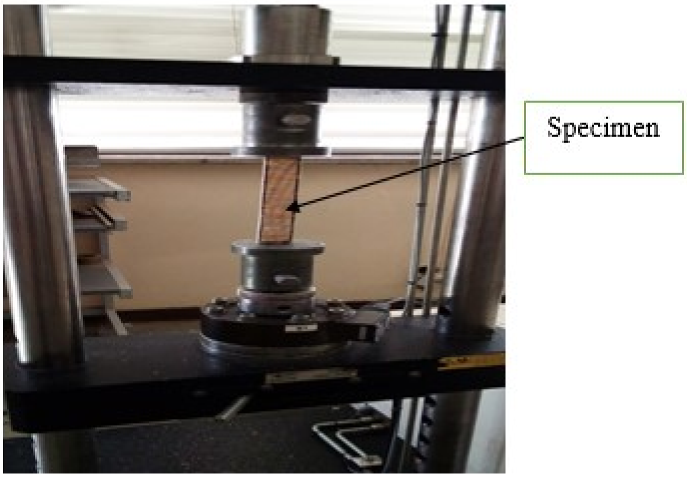


Figure 3.16 Compression strength testing of composite

3) Flexural test

The flexural test measures the force required to bend a beam under three- point loading situations. The three- point bending test was performed in accordance with ASTM D790 standards .The samples were cut into 110*20*3 mm respectively. The specimen was laid horizontally over three point of contact and then a force was applied to the top of the material through point of contact until the sample fails. Figure 3.17 shows bending strength testing.

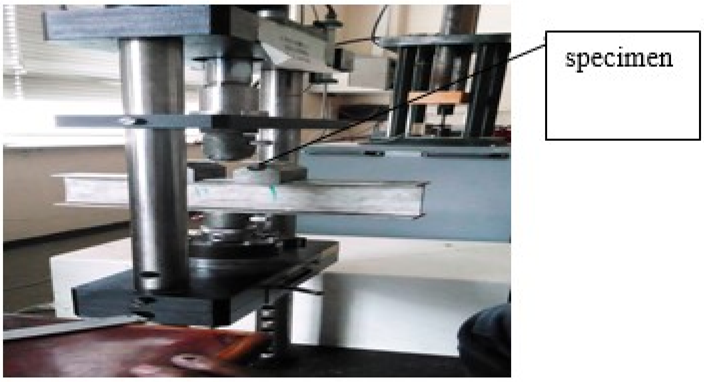


Figure 3.17 Bending strength testing

4) Impact test

Charpy impact test was used for studying the toughness of material. Generally synthetic fibers produce interface having lower strength with matrix due to which energy absorption increases at these interfaces. Impact strength of the composite specimens was carried out in Charpy impact testing machine according to ASTM D256 standard. The specimen size was 65mm*13mm*3 mm with depth under notch of 2.5mm.The Charpy impact test, is a standardized high strain rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent, ductile-brittle transition (Aditya et al., 2017).according to (Uzay et al., 2016) impact strength is given by eqn 3.9 and prepared specimen for impact test is shown in Figure 3.18.

$$\sigma = \frac{E}{t * b} \tag{3.9}$$

where σ = impact strength, E = absorbed energy by the specimen tested ,t = thickness and b = width of specimen.

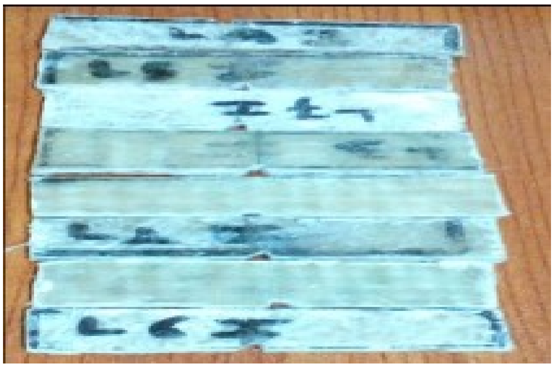


Figure 3.18 Impact testing specimen

5) Hardness test

hardness is the resistance of a material to indentation load.it is determined by depth of indentation. When the material is indented into smaller extent then the material is harder. Vickers hardness testing relies on the use of optical measurement. Microhardness test procedure, ASTM E-384, specifies different of loads using a diamond indenter to make an indentation which is then measured and converted to a hardness value. this Study used Vicker hardness testing machine (HVS-50 Buehler,USA) with test force of 10kgf and dwelling time of 10 sec. The indenter is dymond pyramid shape with square base having an included angle of 136^0 ±0.5.the indenter was forced into the samples surface at constant load of 10 Kgf with dwell time of 10s. The surface-projected diagonal lengths of the resulting impression of each sample were then measured immediately after unloading using an upright optical. The flat surface was indented at two different locations and the average of the mean diagonal lengths of two indentations were calculated using the expression below.

$$HV = \frac{Constant \times Test\ force}{Surface\ area\ of\ indentation} \qquad (3.10)$$

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

Where, F = force , d = diagonal of indentation , 136^0 = angle between the opposite surface at vertex.

6) Water absorption test

Water absorption test was carried out in accordance to ASTM D 570.The samples were immersed into distilled water and rain water. The weight of the specimen was taken and recorded as initial weight. The specimen was placed in a container of distilled water and rain water which rested on its edge and entirely immersed. At the end of 24 hour, the specimen was removed from water one at a time. The water on the surface was wiped off with a dry cloth and weighed immediately and recorded as final weight and then the percentage increase in weight was calculated. Figure 3.19 illustrates rain and distilled water absorption.

Figure 3.19 Rain water and distilled water absorption testing

The percentage of water absorbed by the composites was determined by finding the weight difference between samples, immersed in water and dry samples using eqn 3.11 (Sahu and Gupta, 2018).

$$W(\%) = \left(\frac{W_f - W_i}{W_i}\right) \times 100\% \qquad (3.11)$$

where $W(\%)$ = Moisture content in percentage, W_f = weight of Wet samples, W_i = initial weight of samples.

7) Density and Void Fraction Studies

Voids are one of the most common manufacturing-induced defects during the fabrication of composites. Higher voids content leads to low resistance to water penetration in addition to both increased variation and poor strength properties of composites. In particular, a good composite should have less than 1.5% voids, but composite can have up to 5% void content (Zhang and Peijs., 2010).In order to determine void content of the composite theoretical and experimental density of the composite must be determined. For determination of voids in composites, ASTM D2734-94 method was used. Theoretical density of fabricated sample is calculated by using the mixture rule (Bindal et al., 2013).

$$\rho_{Th} = \rho_m V_m + \rho_{fb} V_{fb} + \rho_s V_s + \rho_G V_G \quad (3.12)$$

Where V_m = Volume fraction of Matrix, V_{fb} = Volume fraction of False banana , V_s = Volume fraction of Sisal , V_G = Volume fraction of Glass , ρ_m = density of matrix, ρ_{fb} = density of false banana , ρ_s = density of sisal and ρ_G = density of glass fiber.

The experimental densities (ρ_{exp}) of the composites were measured using a simple water immersion method. The samples were weighted by suspending in distilled water and measuring its density (Ww) then after measuring its density in air (Wa) after drying it. Then actual density is calculated according to eqn3.13.

$$\rho_a = \frac{W_a}{W_a - W_w} \rho_w \quad (3.13)$$

The volume of void content is determined from the theoretical and experimental densities of the composites by equation 3.14.

$$(Vv) = \frac{\rho_{th} - \rho_a}{\rho_{th}} \quad (3.14)$$

Where ρ_a = actual density, W_a = weight in air, W_w = weight in water , ρ_w = density of water , (Vv) = Volume of void content, ρ_{th} = theoretical density and ρ_a = actual density.

8) Morphology under SEM

Scanning electron microscope observation was undertaken in order to investigate the morphology of composite .The air bubbles and voids was also investigated by examining the surface of composite with higher mechanical and physical value. figure 3.20 illustrates scanning electron microscope specimen.

Figure 3.20 Scanning Electron Microscope Specimen

9) Drilling of Composite Drilling is a process in which a rotating cutting tool was used to remove unwanted materials to produce a specific size hole. Testing the drill ability of the composite is a mandatory for assembling and joining of the parts. The drilling operation was conducted using the vertical drill machine located in mechanical engineering work shop at ASTU.

The operation was performed with cutting speed of 2 mm/se, spindle speed of 200 rev/min and feed rate of 0.5mm.Figure 3.21 shows drill bit used for the study.

Figure 3.21 Drill bit for Composite drilling

3.6 Optimization of Parameters

In order to optimize the process parameters of multi response experiment Taguchi gray relation method was followed. Experimental design is verily required to know the total degree of freedom for proper selection of suitable orthogonal array. The degree of freedom is the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is (Wennberg, 2013).

For tensile, compression, flexural, impact tests and hardness tests ”larger is better” quality exhibitive was used. For water absorption and void study “Smaller is better ” quality exhibitive was used.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Introduction

In this chapter the result and discussion of the performed experiments (Tensile, compressive, flexural, impact, hardness, rainwater absorption, distilled water absorption and void content) were briefly discussed and the results were interpreted.

4.2 Tensile Test

For tensile strength evaluation ,8 samples were prepared varying in fiber orientation of false banana and sisal fiber, NaOH treatment level, weight percentage of false banana sisal fiber and by varying glass fiber orientation. The fractured specimens after tensile test were shown in figure 4.1 and the typical stress strain graph for those 8 samples were shown in figure 4.2.Table 4.1 indicates the tensile test result.

Table 4.1 Tensile test result

Test runs	Fiber Orientation (a)	NaOH treatment (b)	Weight Percentage (c)	Glass Fiber Orientation (d)	Tensile Strength (MPa)	Elongation at break (%)
1	0/90	5%	20fb,10s,10G	Random	119.2	10.437
2	-45/45	10%	20fb,10s,10G	Woven	163.2	5.8786
3	0/90	10%	10fb,20s,10G	Woven	184.6	6.31356
4	-45/45	5%	10fb,20s,10G	Random	68.5	2.7031
5	0/90	5%	20fb,10s,10G	Woven	185.5	8.9479
6	-45/45	10%	20fb,10s,10G	Random	68.7	5.6027
7	0/90	10%	10fb,20s,10G	Random	156.2	13.9744
8	-45/45	5%	10fb,20s,10G	Woven	157.5	15.3544

Figure 4.1 Fractured samples in tensile test

The axial load was applied for all the specimen and it leads the specimen to fracture as shown in Figure 4.1.The steep part of the curve represent elastic property and elastic modulus is defined as the slope of the curve. This value represents the ultimate point at which the material was stretching but not deformed.

Youngs modulus (modulus of elasticity) is given by

$$Modulus(Mpa) = \frac{\Delta\, stress(MPa)}{\Delta strain} \qquad (4.1)$$

The higher the Youngs modulus the higher is the stiffness. stiffness is the tendency of an element to return to its original length after the applied load.

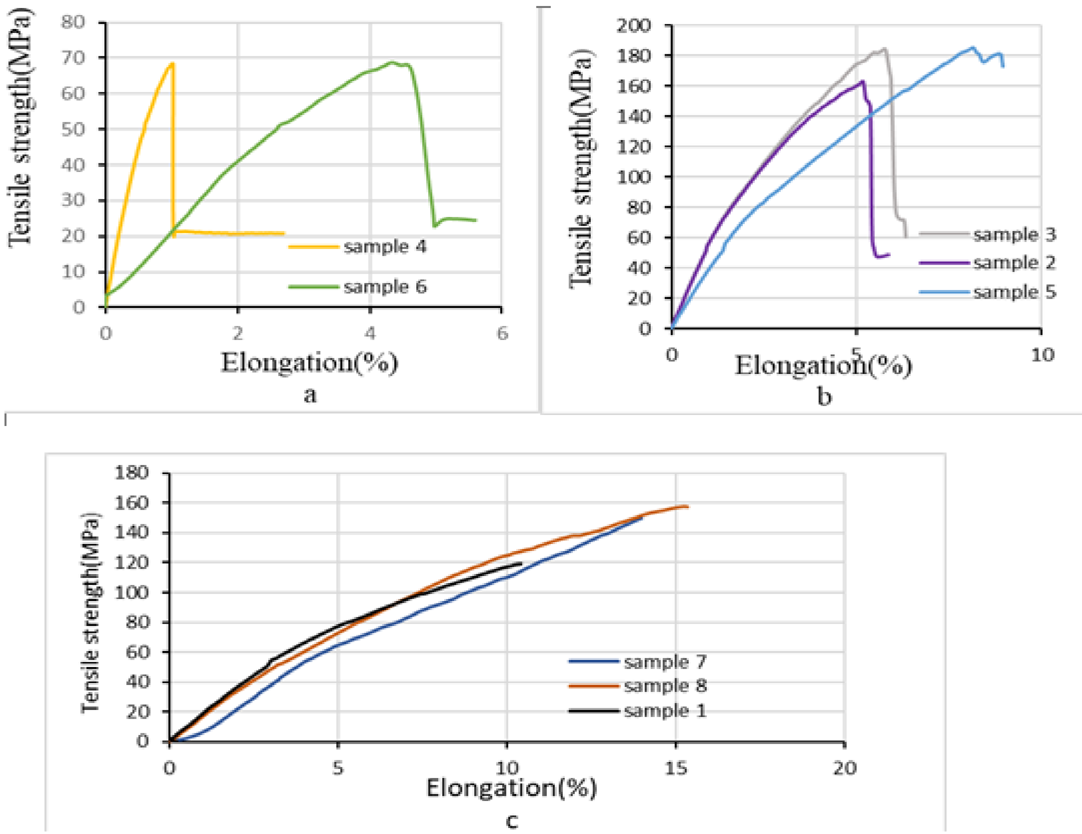


Figure 4.2 Tensile strength of samples a) elongation>5 b) >10 c) elongation<10

The tensile strength of false banana sisal glass fiber reinforced composite is depicted in Fig 4.2.It is observed from figure 4.2 that the composite of sample 5 (0/90, 5%,20fb20s10g, Woven) and sample 3 (0/90,10%,10fb10s10g,Woven) had highest tensile strength than the other composites. Samples 5 has tensile strength of 185MPa and sample 3 had tensile strength of 184MPa.When the composites with woven glass fiber orientation type was compared with that of random glass fiber type, the woven type had higher tensile strength of 184MPa,185MPa, 163MPa and 157MPa respectively for sample number 3, 5, 2 and 8.besides this, the composite with random glass fiber type have tensile strength of 119MPa, 156MPa, 68MPa and 68MPa respectively for sample number 1, 7, 4 and 6.

The reason for this variation was due to equal distribution of load in equal proportion in the entire fiber in woven fiber format. Aside from this, when random glass fiber type was used there was a grate probability for fiber agglomeration in one place. This could be during the fabrication process when the composite was rolled with a roller. consequently, this produced a void space in one area and unequal distribution of load on the composite during testing. moreover, tensile result showed that the false banana sisal glass fiber reinforced composites have better adhesion with the polyester matrix, which happened to give good interfacial bonding of fiber and matrix, which was responsible for increasing tensile strength of composites (R Siva et al., 2020).

In addition to glass fiber orientation, natural fiber orientation was the other parameter that affect the tensile strength of the composite. When the composite with woven glass type but with $0^0/90^0$ and -45/45 natural fiber orientation was compared, the $0^0/90^0$ fiber-oriented composite have higher tensile strength of 184MPa and 185MPa respectively. On the other hand, composite with $-45^0/45^0$ had tensile strength of 163 and 157MPa respectively. This difference was shown also for random glass fiber type with $0^0/90^0$ and $-45^0/45^0$ natural fiber orientation. Tensile strength of 119MPa and 156MPa was recorded for composite with $0^0/90^0$ however composite with $-45^0/45^0$ has tensile strength of 68.5MPa and 68.7MPa.since the load was applied parallel to the sisal fiber or perpendicular to the false banana fiber for $0/90^0$ fiber orientation, and at a slanted angel for $-45/45^0$ orientation (Hayashi et al., 1978) and (Malaiah et al., 2013) showed the same result that $0/90^0$ fiber orientation exhibited higher tensile strength than $-45/45^0$ orientation.

The additional parameter that determines tensile strength was alkali treatment level. It was shown from the tensile test result that a composite treated at 10% NaOH had 7.2% greater tensile strength than fiber with 5% alkali treatment. The value indicates that 10% treated fiber exhibited tensile strength of 163,184,156 and 68.7 MPa. on the other hand,5%NaOH treated fiber exhibited tensile strength of 185,157,119 and 68.5 MPa.it was calculated that average tensile strength for 10% NaOH treated fiber was 143 whereas for 5% it was 132MPa.

The amount of fiber used for reinforcement was the other parameter that must be considered in the fabrication design of a composite. For this study composite was fabricated with (20% false banana, 10% sisal, 10% glass fiber) and (10% false banana,20% sisal,10% glass fiber) varied combination.in tensile test result, composite of the second combination level (10% false banana,20% sisal, 10% glass fiber) has 5% higher strength than the former combination.

This investigation revealed that when the sisal fiber weight percentage amount was greater (double) than the false banana fiber, 10% NaOH treatment level yields better tensile strength result.

As it is shown in Figure 4.3 the sample number 4 and 6 has elongation percent of 2 and 5. In addition to this sample number 3, 2 and 5 has elongation value of 6, 5and 8. moreover, sample number 1, 7 and 8 had elongation number of 10 ,13 and 15. Elongation value is related to the ductile property of the material. The material that has higher elongation is more ductile. therefore, it was seen from the result that sample number 7 and 8 were more ductile. both the samples were reinforced with 10 false banana 20 sisal and 10 glass fiber weight percentage. on the other hand, sample number 6 and 4 with 45/45-degree orientation and random glass fiber reinforcement were more brittle composites. The result revealed that double number of sisal fiber to that of false banana fiber leads to more ductility and random glass fiber leads to more brittle composite.

4.2.1 Analysis of main effect plot of tensile test

The signal to noise ratio of tensile test is displayed in table 4.2 and from this value main effect of the factors were obtained.

Table 4.2 computed S/N ratio for tensile test

Sample no	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
S/Nratio	41.5255	44.2544	45.3246	36.7138	45.3762	36.7391	43.8736	43.9456

As it can be interpreted from fig 4.3 the optimum tensile sttrength was found from the composite compbination with 0/90^0 natural fiber orientation,10% NaOH treatment and 10fb20s10G weight percentage of false banana sisal and woven type glass fiber orientation. this was comparable with the result obtained form tensile test in which the second higher tensile strength was achieved in sample no 3 that has (0/90, 10%, 10f20s, woven) composite combination.

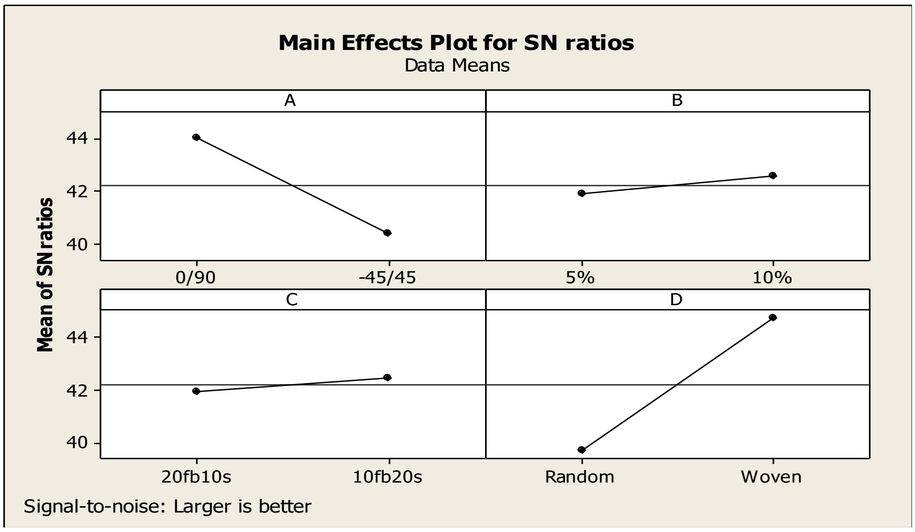


Figure 4.3 Main effect plot of signal to noise ratio of tensile test

4.2.2 Analysis of Response table for signal to noise ratio of tensile test

The response of signal to noise ratio of Table 4.3 for tensile test indicates that glass fiber orientation type had highest contribution in increasing tensile strength of the composite with delta number 5.01. while natural fiber orientation was the second factor that had significance in increasing the tensile strength with delta number 3.61. NaOH treatment level and fiber weight percentage were the third and fourth contributing factor with delta number 0.66 and 0.49.`

Table 4.3 Response Table for Signal to Noise Ratios of Tensile test

Level	A	B	C	D
1	44.03	41.89	41.97	39.71
2	40.41	42.55	42.46	44.72
Delta	3.61	0.66	0.49	5.01
Rank	2	3	4	1

4.2.3 Analysis of Variance for tensile test

ANOVA was used to identify the effect of parameters on multi-responses. the last column in table 4.4 indicates the percentage of contribution. It was obtained by dividing the Seq SS(sum of squares) by total and multiply it by 100%.According to this table glass fiber orientation type has highest contribution factor of 55.63% because of the amount of distribution of force in the fiber. Table 4.4 shows ANOVA of tensile test.

Table 4.4 Analysis of Variance for SN ratios of tensile test

Source	**Df**	**Seq ss**	**Adj ss**	**Adj ms**	**F**	**P**	**Pc**
A	1	26.056	26.056	26.056	6.19	0.089	28.870
B	1	0.871	0.871	0.871	0.21	0.680	0.9655
C	1	0.486	0.486	0.486	0.12	0.756	0.5386
D	1	50.197	50.197	50.197	11.93	0.041	55.63
Residual error	3	12.622	12.622	4.207			
Total	7	90.232					

4.2.4 Comparison with previous works on tensile strength of the composite

Comparison of the tensile strength of composite with other literature is shown in Table 4.5 .

Table 4.5 Comparison of tensile strength

Fiber	Matrix	Fiber orientation	Fiber/matrix weight ratio	Fiber treatment NaOH	Tensile strength (MPa)	References
False banana ,sisal and e-glass	polyester	0/90, woven	40/60	5%	185.5	Current work
Glass	epoxy	0/90	-	-	120	Hadi and Trisolicha , (2016)
Banana, sisal, e-glass	epoxy	Chopped , Woven	40/60	-	104	Arthanarieswaran et al, (2014)

4.3 Compression test

For studying the compression strength of the false banana sisal glass fiber reinforced composite,8 specimens were tested representing the 8 samples. The result depicted in Table 4.6 from the compression test gives the maximum compression strength and elongation of the specimen at break.

Table 4.6 Compression test result

Test Runs	Fiber orientation (A)	Alkali Treatment (B)	Weight percentage (C)	Glass fiber Orientation (D)	Compression Strength (MPa)	Maximum Elongation (%)
1	0/90	5%	20fb,10s,10G	Random	47.67	16.9
2	-45/45	10%	20fb,10s,10G	Woven	48.78	7.64
3	0/90	10%	10fb,20s,10G	Woven	57.22	17.24
4	-45/45	5%	10fb,20s,10G	Random	33.67	8.74
5	0/90	5%	20fb,10s,10G	Woven	56	19.59
6	-45/45	10%	20fb,10s,10G	Random	11.4	20.41
7	0/90	10%	10fb,20s,10G	Random	20.67	12.81
8	-45/45	5%	10fb,20s,10G	Woven	56.67	15.4

Figure 4.4 Compressed specimens in compression test

Crushing Load was applied in the axial direction to the composite. The applied force tries to compress the specimen and undergo deformation. The compression test helps to determine the materials property under the crushing force and to investigate the plastic flow of a material and ductile fracture limit. The fractured specimens after compressive test were illustrated in Figure 4.4 The compressive strength of 8 specimen tested in this study was depicted in Figure 4.5

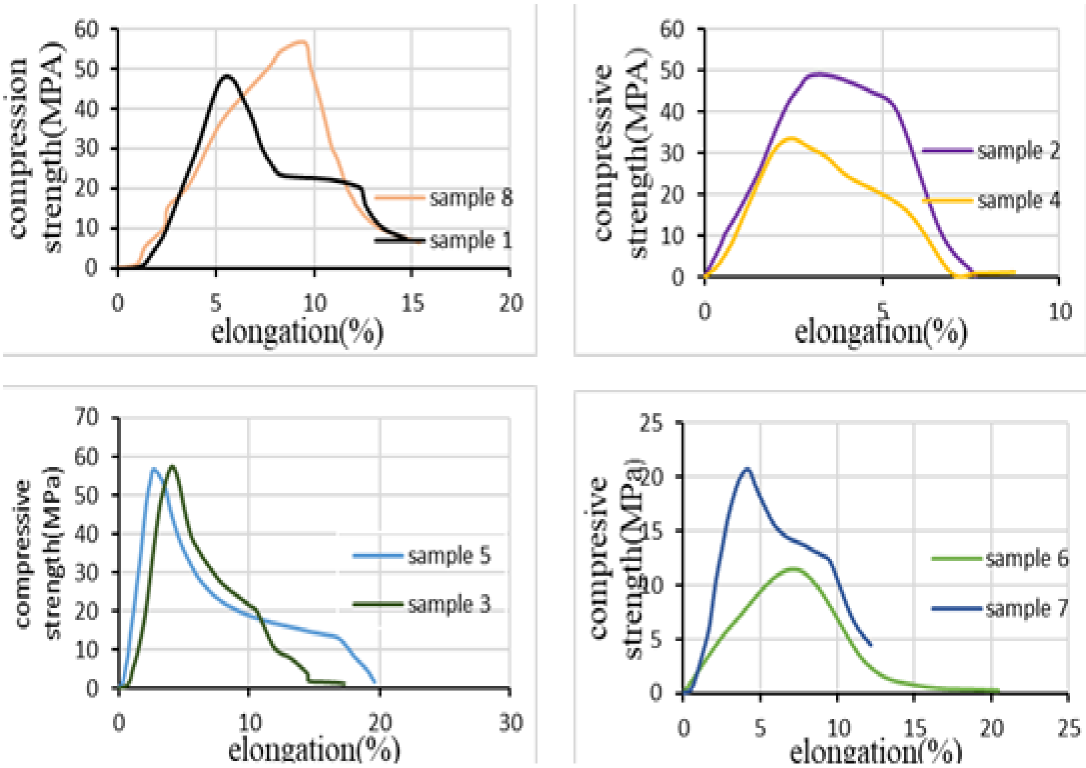


Figure 4.5 Compression strength of samples

As it is illustrated in Figure 4.5 composite sample number 3,8 and 5 had higher compressive strength of 57,56.67 and 56 MPa. As it was shown in tensile test result, in compression test also the composite with Woven type glass fiber had the higher compressive strength than randomly oriented glass fiber reinforced composite.

The composite with woven type glass fiber illustrated compressive strength of 57,56.67,56 and 48MPa.This gives the average compressive strength of 54MPa for Woven type glass fiber. on the other hand, composite with randomly oriented glass fiber type have compressive strength of 47,33,20 and 11Mpa.This gives the average compressive strength of 28MPa for randomly oriented glass. Therefore, woven glass reinforced composite strength was 48% greater than randomly oriented glass fiber reinforced composite. Since composite with randomly oriented glass fiber were more exposed to unequal distribution of load, it will more initiates buckling of composite than woven type. Buckling is a phenomenon of instability and it results in sudden collapsing of specimen prior to desired failure mode in small load increase.

Natural fiber orientation also influences compression strength of composite. composite of 0/90 fiber orientation have shown 17% higher compression strength than -45/45 fiber orientation. Composite with the 0/90 orientation exhibited compressive strength of 57,56,47and 20MPa.beside this, composite with -45/45 orientation have compressive strength of 56.67,48,11and 33MPa.From this result it was calculated that average compressive strength for 0/90 and -45/45 fiber-oriented composite were 45 and 37respectively. The uniform distribution of load in both transvers and axial direction played a valuable role for increased compressive strength in the case of 0/90 fiber reinforced composite. Hossain et al, (2013) also concluded that there was not much difference in load distribution in longitudinal and transverse direction in 0/90 orientation mean while the load was more concentrated in longitudinal direction when it was applied in 0^0 orientation.

When the alkali treatment level is considered, composite with 5% NaOH level was greater by 28.83% than 10%NaOH treated fiber reinforced composite. composite of 5% treatment exhibited compressive strength 56.67,56,47 and 33MPa whereas, composite with 10% NaOH exhibits compressive strength of 57,48,20 and 11MPa. since 5% and 10% concentration levels have average compressive strength of 48 and 34 MPa respectively. The result revealed that when the fiber was treated up to 5% NaOH level the compression strength increases.

Strength of Composites with 10fb 20s 10g weight percentage was 16.2% greater than composite of 20fb10s10g.The compressive strength exhibited in the former composite were 57.22, 56, 20, 33MPa and the second combination composites have compressive strength of56, 48, 47 and11MPa.The findings was that when the ratio of false banana to sisal fiber in weight percentage was 1:2 the compression strength increased.

4.3.1 Analysis of main effect plot for compression test

Signal to noise ratio of compression test is displayed in table 4.7 and main effect of the factors were obtained from it.

Table 4.7 Signal to noise ratio of compression test

Sample no	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
S/Nratio	33.56 49	33.764 8	35.151 0	30.544 9	34.963 8	21.138 1	26.306 8	35.067 1

One could see from the Figure 4.6 that the optimum factor combinations for compression test was 0/90 natural fiber orientation, 5% NaOH treatment level, 10 false banana 20 sisal 10 Glass weight percentage and woven type glass fiber orientation.

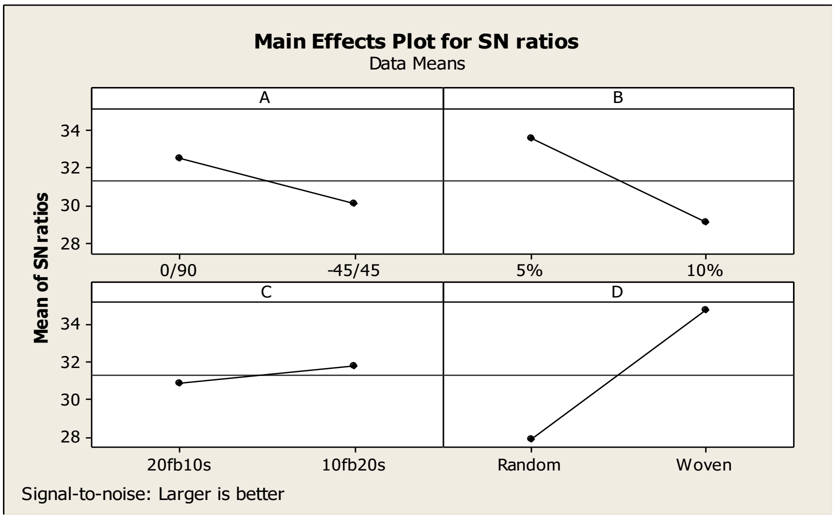


Figure 4.6 Main effects of signal to noise ratio of compression test

4.3.2 Response for signal to noise ratio of compression test

From the response table 4.8 it was obtained that woven glass fiber type had the highest rank in affecting the compressive strength of the composite with delta number 6.85 .the sodium hydroxide treatment level and orientation of natural fiber were the second and third ranked factors with delta number of 4.44 and 2.37 respectively. The weight percentage level of natural fiber was the lastly ranked factor with delta number 6.85.

Table 4.8 Response table of signal to noise ratio of compression test.

Level	**A**	**B**	**C**	**D**
1	32.50	33.54	30.86	27.89
2	30.13	29.09	31.77	34.74
Delta	2.37	4.44	0.91	6.85
Rank	3	2	4	1

4.3.3 Analysis of signal to noise ratio of compression test

From the percentage contribution (Pc) value it was obtained that glass fiber type had contribution level of 51.416% and alkali treatment level has 6.1475% contribution. natural fiber orientation had 6.1475% contribution and weight percentage of natural fiber has 0.9067%.Table 4.9 shows the analysis of signal to noise ratio of compression test.

Table 4.9 Analysis of Variance for signal to noise ratio of compression test

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc
A	1	11.214	11.214	11.214	0.93	0.406	6.1475
B	1	39.516	39.516	39.516	3.27	0.168	21.66
C	1	1.654	1.654	1.654	0.14	0.736	0.90672
D	1	93.790	93.790	93.790	7.76	0.069	51.416
Residual Error	3	36.240	36.240	12.080			
Total	7	182.414					

4.3.4 comparison with previous works on compressive strength of the composite

Comparison of compressive strength of composite with other literatures is shown in table 4.10.

Table 4.10 Comparison of compressive strength

Fiber	Matrix	Fiber orientation	Fiber/Matrix weight ratio	Fiber treatment	compressive strength (MPa)	References
False banana, sisal and glass	Polyester	0/90,woven	40/60	5% NaOH	56.68	Current work
Sisal, glass	polyester	0,woven	-	2% NaOH	45	Srinivasan, (2014)
Sisal	epoxy	random	30/70	-	42	Olusegun et al., (2012)

4.4 Flexural test

flexural bending strength is the ability of material to resist deformation under applied load. The test was performed under three-point loading condition. When the load was applied at mid span of a sample between two rollers the maximum bending stress and force found is depicted on figure 4.7 for sample 3 and the flexural test result is depicted in table 4.11.fractured specimens are shown in figure 4.8.

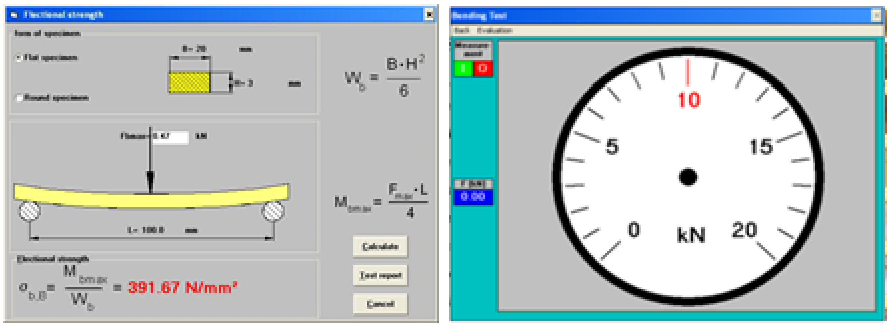


Figure 4.7 Flexural bending test loading

The maximum flexural strength obtained from three point bending test was portrayed in table4.11

Table 4.11 Flexural test results

Test Runs	Fiber orientation (A)	Alkali treatment (B)	Weight percentage (C)	Glass fiber orientation (D)	Maximum flexural strength(MPa)
1	0/90	5%	20fb,10s,10G	Random	375
2	-45/45	10%	20fb,10s,10G	Woven	300
3	0/90	10%	10fb,20s,10G	Woven	391.67
4	-45/45	5%	10fb,20s,10G	Random	225
5	0/90	5%	20fb,10s,10G	Woven	383
6	-45/45	10%	20fb,10s,10G	Random	191
7	0/90	10%	10fb,20s,10G	Random	358
8	-45/45	5%	10fb,20s,10G	Woven	300

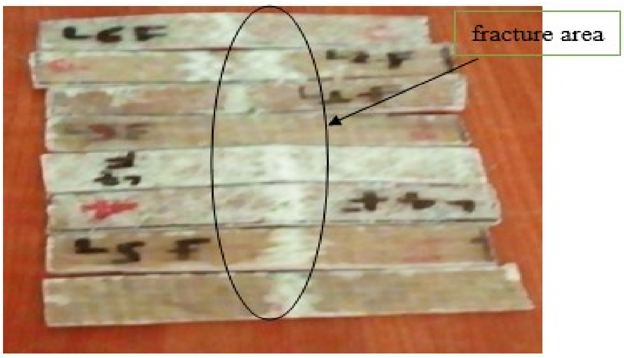


Figure 4.8 Fractured specimens in three point bending test

According to Bindal et al, (2013)

$$\text{Flexural strength}(\sigma_b) = \frac{3FL}{2bd^2} \tag{4.2}$$

$$\text{Flexural modulus} = \frac{mL^3}{4bd^3} \tag{4.3}$$

$$M_{bmax} = \frac{F_{max}L}{4} \tag{4.4}$$

$$W = \frac{bh^2}{6} \tag{4.5}$$

Where b = width of specimen, h = thickness of specimen, F = load ,L = support spam(mm), b = width of beam tested (mm) , d = depth of beam(mm), m= slope of a load deflection curve. Flexural modulus is used as an indication of a material's stiffness when inflection.it is a material property for resistance to bending action.

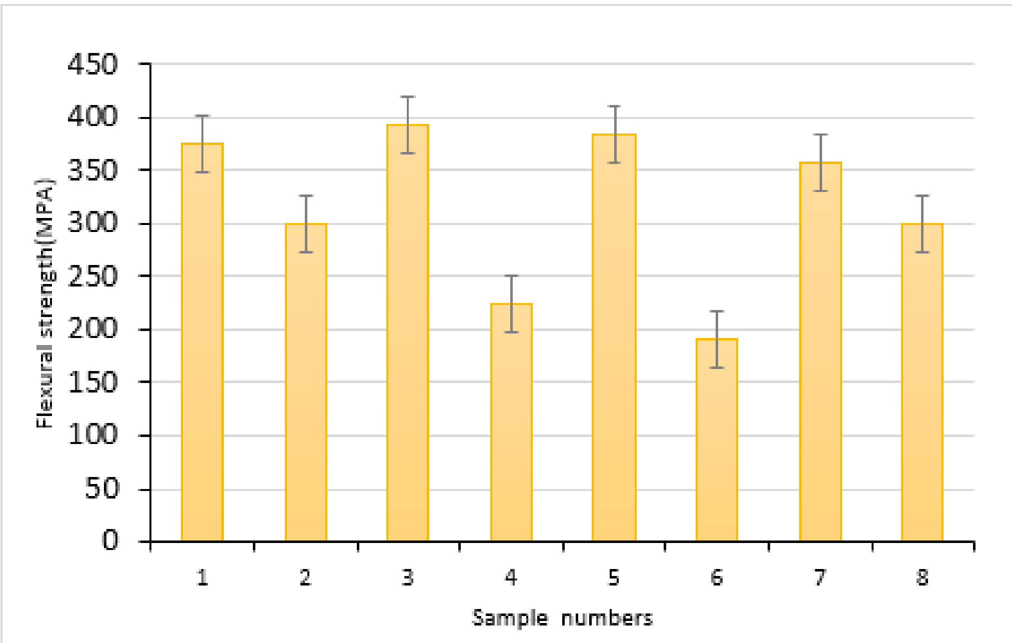


Figure 4.9 Flexural strength of different samples

The flexural stiffness of a structure is a function based upon two essential properties. The first is the elastic modulus of the material that composes it and the second is the moment of inertia, a function of the cross-sectional geometry. It was shown from the test that composite with woven type glass fiber had flexural strength of 391,383,300 and 300MPa.on the other hand composite with random glass fiber type showed flexural strength of 375,358,225 and 191MPa.so when average strength was compared, composite with woven type glass fiber was 16% greater than random glass fiber type. Sakin et al, (2008) also reported that flexural strength was increased in woven type glass fiber than random glass fiber type.

As it was shown in Figure 4.9 the composite sample number 3 had the highest flexural strength of 391MPa and the second flexural strength was recorded in sample number 5.The third and fourth results are also recorded for sample number 7 and 1 respectively. From this result it can be seen that composites with 0/90 natural fiber orientation has higher flexural strength than -45/45 fiber-oriented composites. This difference in flexural strength of $0/90^0$ and $-45/45^0$ orientation was also shown in investigation reported by (F.Suhad D. et al., 2016). when the material has different properties in different directions, it is called anisotropic material and at a microscopic level, the characteristics of these composites are determined by the orientation and distribution of the fibers, as well as by the properties of the fiber and matrix materials.

The composite with 5% NaOH treatment level had revealed more flexural strength than 10%NaOH.the composite with 5% NaOH had shown flexural strength of 383,375,300 and 225MPa.beside this 10% NaOH composites had flexural strength of 391.67,358,300 and 191MPa.(Wijianto et al., 2019) also investigated that 5% NaOH treatment level had higher bending strength than 10% NaOH.

4.4.1 Analysis of main effect for flexural test

The signal to noise ratio of flexural bending test was depicted in Table 4.12.the main effect was plotted from it. Table 4.12 shows the signal to noise ratio of bending test.

Table 4.12 Signal to noise ratio of flexural bending test

Sample no	1	2	3	4	5	6	7	8
S/Nratio	51.48	49.5424	51.8584	47.0434	51.664	45.6207	51.077	49.5424

It is can be seen from Figure 4.10 that the optimum parameter combination for obtaining optimal flexural strength was composite with 0/90 natural fiber orientation, woven type glass fiber, 5% NaOH treatment level and 10 false banana 20 sisal 10 glass fiber weight percentage.

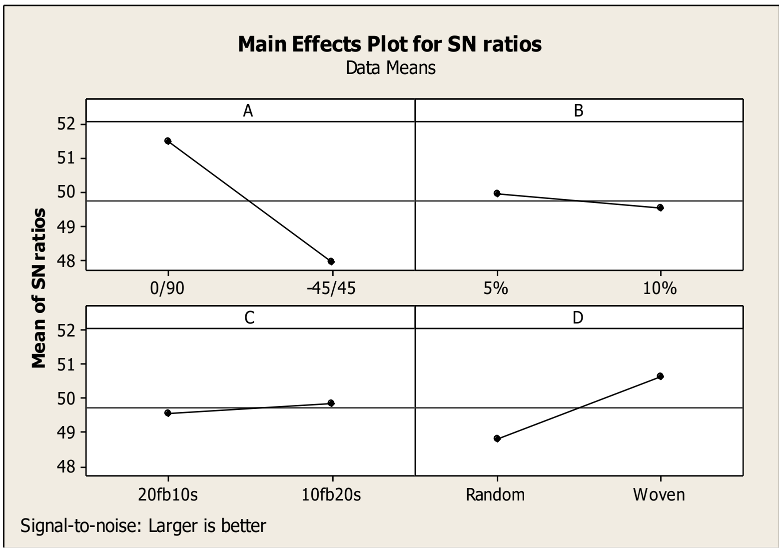


Figure 4.10 Main effect plot of signal to noise ratio of flexural test

4.4.2 Response table of signal to noise ratio of flexural test

Response table 4.13 for signal to noise ratio with larger is better indicates that orientation of natural fiber was the first parameter that affect the flexural strength of the composite with delta number 3.58. Moreover, orientation of glass fiber and alkali treatment level constituent the second and third rank followed by weight percentage of fiber with delta number 1.85,0.41 and 0.30 respectively.

Table 4.13 Response table of signal to noise ratio of flexural test

Level	A	B	C	D
1	51.52	49.93	49.58	48.81
2	47.94	49.52	49.88	50.65
Delta	3.58	0.41	0.30	1.85
Rank	1	3	4	2

4.4.3 Analysis of Variance of signal to noise ratio of flexural test

From the analysis of variance in table 4.14, it could be understood that natural fiber orientation constituted higher percent of contribution of 68.78% in affecting the flexural strength of the composite and it was followed by 18.2% contribution of glass fiber orientation. The alkali treatment level and weight percentage of fiber constitutes 0.8913 and 0.494% in affecting the flexural strength of the composite.

Table 4.14 Analysis of Variance of signal to noise ratio of flexural test

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc(%)
A	1	25.6740	25.6740	25.6740	17.84	0.024	68.78
B	1	0.3327	0.3327	0.3327	0.23	0.664	0.8913
C	1	0.1844	0.1844	0.1844	0.13	0.744	0.494
D	1	6.8166	6.8166	6.8166	4.74	0.118	18.262
Residual Error	3	4.3170	4.3170	1.4390			
Total	7	37.3247					

4.4.4 Comparison with previous works on flexural strength of the composite

comparison of flexural strength of composite with other literatures is shown in table 4.15.

Table 4.15 Comparison of flexural strength

Fiber	Matrix	Fiber orientation	Fiber/Matrix weight ratio	Fiber treatment	Flexural strength (MPa)	References
False banana, sisal and glass	polyester	0/90	40/60	5% NaOH	391	Current work
sisal	Epoxy	-	20/80	6% NaOH	122.27	Mittal and Sinha, (2017)
Glass	polyester	0/90	-	Un treated	375.199	Sakin et al., (2008)

4.5 Impact test

Charpy impact test was performed on 8 specimens and the energy absorbed from the test was recorded then the impact strength was calculated from it and it was summarized in Table 4.16.The fractured specimens after impact test are shown in figure 4.11

Table 4.16 Impact test result

Test Runs	Fiber orientation (A)	Alkali treatment (B)	Fiber weight percentage (C)	Glass fiber orientation (D)	Impact energy(J)	Impact strength (KJ/mm²)
1	0/90	5%	20fb,10s,10G	Random	7	179
2	-45/45	10%	20fb,10s,10G	Woven	19	487.17
3	0/90	10%	10fb,20s,10G	Woven	16	410.25
4	-45/45	5%	10fb,20s,10G	Random	7	282.05
5	0/90	5%	20fb,10s,10G	Woven	15	384.61
6	-45/45	10%	20fb,10s,10G	Random	9	230.76
7	0/90	10%	10fb,20s,10G	Random	11	179.48
8	-45/45	5%	10fb,20s,10G	Woven	17.5	448.71

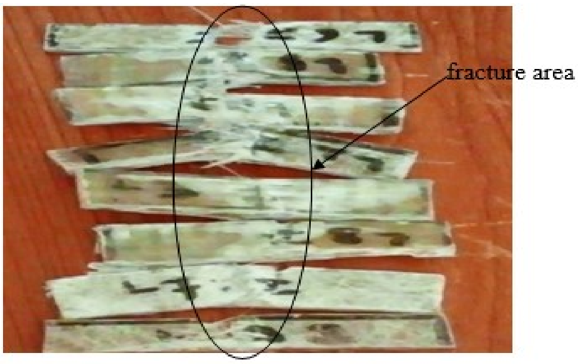


Figure 4.11 Fractured specimens in impact test

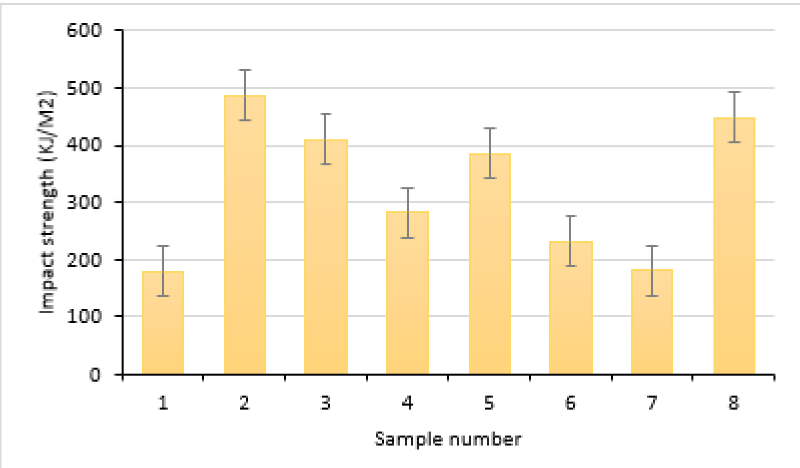


Figure 4.12 Comparison of Impact Strength of different samples

Toughness is the ability of a material to withstand a suddenly applied load or it is the energy absorbed by a material before its failure. The impact failure of a composite occurs with factors including matrix fracture, fiber/ matrix debonding, and fiber pull-out. Among these, fiber pull–out is found to be an important energy dissipation mechanism in fiber reinforced composites. Fiber-matrix debonding occurs when the applied load transferred by shear to fibers exceeded the fiber/matrix interfacial bond strength. When the stress level exceeds the fiber strength, fiber fracture occurs. The fractured fibers may be pulled out of the matrix, which involves energy dissipation.

The composite with woven glass fiber type was 49% greater than random glass fiber type. As it is illustrated in fig 4.12 the composite with woven glass fiber type has Charpy impact strength of 487.17, 448.71, 410.25 and 384.61 KJ/m^2 on the other hand, composite with random glass fiber type have impact strength of 282.05, 230.76, 179.48 and 179KJ/m^2 From this results one can understood that woven type glass fiber reinforced composite has better fiber matrix adhesion than random glass fiber reinforced composite. Similarly, (Alavudeen et al., 2015) have concluded that Woven glass fiber had higher impact strength. and it was observed that interfacial strength between fiber and matrix solely decides impact strength in the case of random orientation. However, with composites reinforced with a weaving pattern, the effect of interlaminar delimitation also imparts impact strength in addition to interfacial strength.

In addition to the orientation of glass fiber, orientation of natural fiber also influences impact strength of a material. It was shown from the result that -45/45 fiber orientation exhibited 20.38% better mechanical impact strength than 0/90 fiber orientation. The higher averages impact strength of 487.17 KJ/m2 was shown for 45/45 fiber orientation besides, it was 410.25 KJ/m2 for 0/90 fiber orientation. The same result was obtained in (Dress et al., 2021) that -45/45 woven natural fiber shown higher impact strength of 20KJ/m2. According to (Aljibori , 2009) 0/90 failed by fiber fracture while -45/45 composite failed by combination of fiber pullout and fiber fracture.

The 5% NaOH treatment level also given 1.016% higher impact strength than 10% NaOH treated fiber. The reason for this was toughness property also lies on the matrix and fiber quality. The other parameter that affects the impact strength property was fiber weight percentage. In this test also 10 false banana 20 sisal 10 glass fiber reinforced composite has shown better strength than 20 false banana 20 sisal 10 glass fiber reinforced composite. It might be concluded that when the amount of sisal fiber was double than the weight percentage of false banana fiber the impact strength was better.

4.5.1 Analysis of main effect for impact test

The signal to noise ratio of the impact test is depicted in table 4.17 and the response table and graph was plotted from it.

Table 4.17 Signals to noise ratio of impact test

Sample no	1	2	3	4	5	6	7	8
S/Nratio	45.0571	53.7536	52.2610	49.0065	51.7004	47.2632	45.0803	53.0393

As it is illustrated in figure 4.13 the optimum parameter for better impact strength was found with parametric combination of -45/45 natural fiber orientation, 5% NaOH treatment level,10 false banana, 20 sisal 10 glass fiber weight percentage and woven type glass fiber.

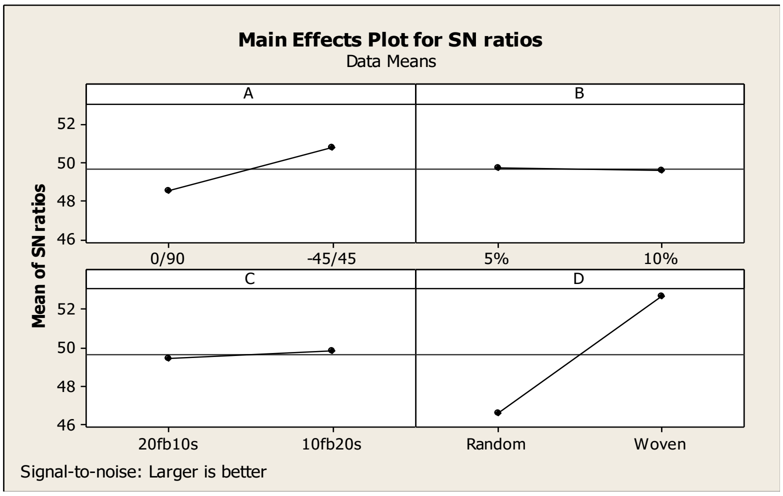


Figure 4.13 Main effect plots of signal to noise ratio of impact test

4.5.2 Response table of Impact test

It was shown from the response table 4.18 it is shown that the main parameter that affect the impact strength of the composite was the type of glass fiber orientation with delta number 6.09.the second parameter that affect the impact strength was the type of natural fiber orientation with delta number 2.24. The weight percentage level of natural fiber and sodium hydroxide treatment level proceed with delta number 0.40 and 0.11.

Table 4.18 Response table for signal to noise ratio of impact test

Level	A	B	C	D
1	48.52	49.70	49.44	46.60
2	50.77	49.59	49.85	52.69
Delta	2.24	0.11	0.40	6.09
Rank	2	4	3	1

4.5.3 Analysis of variance for impact test

It could be understood from the Pc value that the type of glass fiber orientation affected the impact property of the material in a highest percentage contribution of 84.745%. The second higher contributing parameter was the natural fiber orientation type.it has second percentage contribution of 11.48 %. The third and fourth contributing factors were weight percentage of natural fiber and NaOH treatment level with percentage contribution of 0.3719% and 0.02836%. Table 4.19 shows the analysis of variance for impact test.

Table 4.19 Analysis of variance for impact test

Source	DF	Seq SS	Adj	Adj MS	F	P	Pc(%)
A	1	10.044	10.043	10.043	10.23	0.049	11.480
B	1	0.024	0.024	0.024	0.03	0.884	0.028
C	1	0.325	0.325	0.325	0.33	0.605	0.371
D	1	74.098	74.098	74.098	75.51	0.003	84.745
Residual error	3	2.944	2.944	0.981			
Total	7	87.436					

4.5.4 comparison with previous works on Impact strength of the composite

Comparison of impact strength with other literatures is shown in table 4.20

Table 4.20 Comparison of Impact strength

Fiber	Matrix	Fiber orientation	Fiber/ Matrix weight ratio	Fiber treatment	Impact energy (J)	Impact strength (KJ/m2)	References
False banana, sisal and E-glass	Polyester	0/90,woven	40/60	5% NaOH	19	487.17	Current work
E-glass, jute	Polyester	-	40/60	10% NaOH	-	235.46	Bindal et al., (2013)
Banana, sisal, E-glass	Epoxy	Chopped, woven	40/60	-	13.3		Arthanarieswaran et al., (2014)
Banana, sisal, Ground nut shell	Epoxy	random	40/60	1		256	Ash, (2020)

4.6 Hardness test

In order to investigate the hardness of a material 8 specimens were selected and tested two times and then the average of the two trials were recorded and summarized in table 4.21. the Vickers hardness indentation area is also shown in figure 4.14 and figure 4.15 shows hardness of different samples.

Table 4.21 Vickers hardness result

Test Runs	Fiber orientation (A)	Alkali treatment (B)	Fiber weight percentage(%)	Glass fiber orientation	Hardness (HV)		
					Trial 1	Trial 2	Average
1	0/90	5%	20fb,10s,10G	Random	70.7	61.8	66.25
2	-45/45	10%	20fb,10s,10G	Woven	107.4	125	116.2
3	0/90	10%	10fb,20s,10G	Woven	78.6	96.6	87.60
4	-45/45	5%	10fb,20s,10G	Random	86.2	102.8	94.5
5	0/90	5%	20fb,10s,10G	Woven	106.2	91.8	99
6	-45/45	10%	20fb,10s,10G	Random	69.4	72.6	71
7	0/90	10%	10fb,20s,10G	Random	117.2	111.6	114.4
8	-45/45	5%	10fb,20s,10G	Woven	142.3	96.1	119.2

In performing the hardness test the diamond shape indenter was pressed into the surface of the composite creating a deformed area. This resistance of a material to indentation(penetration) was recorded for each sample and the value was displayed with a unit of HV(Vickers hardness number).

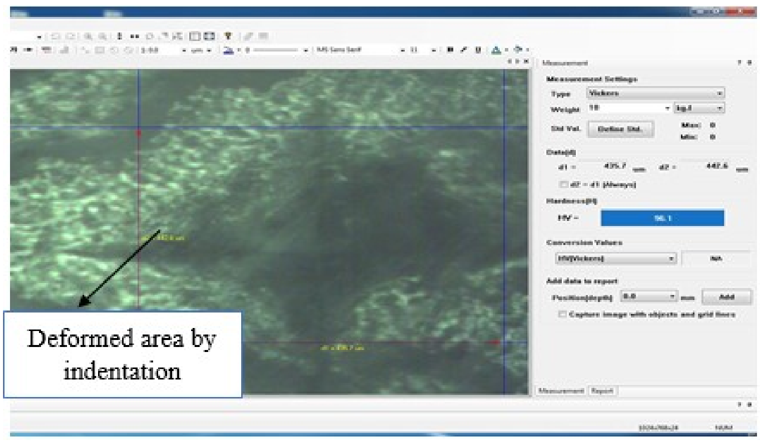


Figure 4.14 Vickers hardness\ indentation area and result

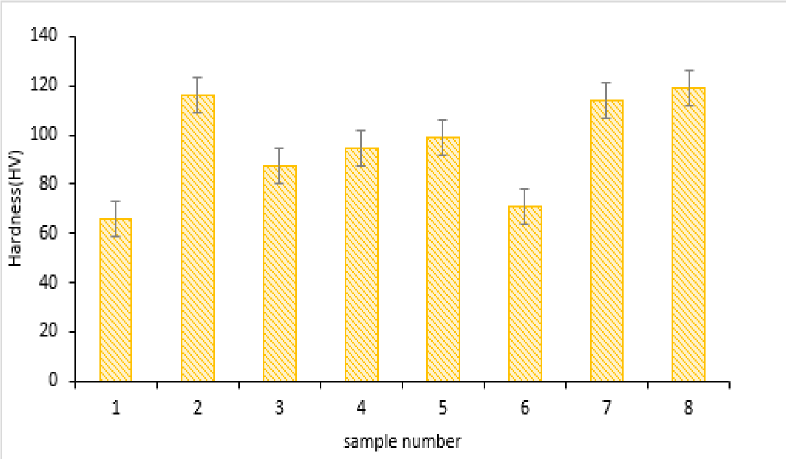


Figure 4.15 Comparison of hardness of different samples.

Hardness measures a materials resistance to surface indentation. The result from the Vickers hardness test told that a considerable hardness change was shown based on the variation of different parameters. Higher hardness was observed in sample number 8 with parametric combination of -45/45 natural fiber orientation,5% NaOH ,10fb 20s 10G weight percentage of fiber and woven glass fiber type. The lowest hardness value was exhibited by sample number 1with parametric combination of (0/90 natural fiber orientation,5% NaOH, 20fb 10s 10G weight percentage and random glass fiber orientation).

In continues glass fiber type, the woven structure produces pockets from matrix in the cross-over points which show a substantial role in improving the hardness values (Nassar and Nassar, 2020). On the contrary, in composites with random fibers, there was a poor distribution of fibers inside the resin. This poor distribution could result from the gap between fibers itself and inclusions resulted during resin drying. Consequently, this reduces the hardness of the composite. On the other hand, fiber orientation showed variation in Hardness value. As it was shown in this study and in (Sharan Gupta et al., 2021) hardness measurement ,composite with -45/45^0 orientation had best result than 0/90^0 fiber orientation.

The amount of sodium hydroxide treatment level also impacted the resistance of the material to penetration or indentation.5% NaOH treatment level has shown hardness values of 99, 119, 66 and 94 HV. Beside this,10% NaOH value showed hardness value of 87,116,114 and 71 HV. It was concluded that 10% NaOH treatment level increased the hardness of a material. When the fiber was treated with appropriate level of alkali the strength of the surface to resist the penetrating load had increased.

The weight percentage of the fiber was the other parameter that determines hardness property of the material.10 false banana 20 sisal 10 glass fiber had showed increased hardness value of 99, 116, 66 and 71 HV. from the result it was concluded that when the amount of sisal fiber was two times that of false banana the hardness value will increase by 15.2% than composites reinforced with 20 false banana 10 sisal 10 glass fiber.

4.6.1 Analysis of main effect plot

The average hardness value and signal to noise ratio of each run was displayed in table 4.22

Table 4.22 Signal to noise ratio of hardness test

Sample no	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
S/Nratio	36.4257	41.3041	38.8501	39.5036	39.9127	37.0252	41.685	41.5255

From figure 4.16 it was seen that the optimum condition for having better surface hardness was with parametric combination of 45/45 natural fiber orientation,10% NaOH fiber treatment,10 false banana 20 sisal, 10 glass fiber content in weight percentage and woven type glass fiber.

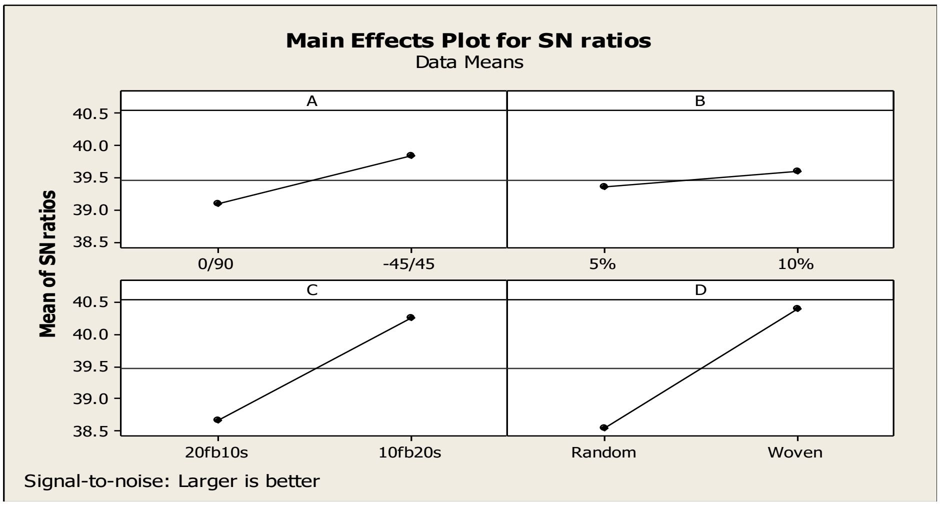


Figure 4.16 Main effect plot of signal to noise ratio of hardness test

4.6.2 Analysis of response table for signal to noise ratio of Hardness test

From the response table of signal to noise ratio of hardness test in table 4.23, one could understood that the type of glass fiber orientation had the highest effect on the hardness value of the composite with delta number of 1.87.In addition to this, weight percentage and orientation of natural fiber constitutes the second and third rank in affecting the hardness property of the composite with delta number 1.6 and 0.75.The last parameter was the level of sodium hydroxide treatment with delta number 0.24.

Table 4.23 Response table of signal to noise ratio of hardness test

Level	A	B	C	D
1	39.09	39.34	38.67	38.53
2	39.84	39.59	40.26	40.40
Delta	0.75	0.24	1.60	1.87
Rank	3	4	2	1

4.6.3 Analysis of Variance for Signal to Noise ratio of Hardness Test

The Analysis of signal to noise ratio values in Table 4.24 demonstrates that the type of glass fiber orientation had highest contribution number of 26.482% and the weight percentage and orientation of natural fiber had second and third percentage contribution of 19.37 and 4.299. The last contributing factor was the level of Alkali treatment.

Table 4.24 Analysis of Variance of signal to noise ratio of Hardness test

Source	DF	Seq SS	Adj MS	F	P	Pc(%)
A	1.131	1.131	1.131	0.26	0.645	4.299
B	0.119	0.119	0.119	0.03	0.879	0.453
C	5.099	5.099	5.099	1.18	0.357	19.379
D	6.968	6.968	6.968	1.61	0.294	26.482
Residual error	12.994	12.994	4.331			
Total	26.312					

4.6.4 comparison with previous works on Hardness of the composite

Comparison of Hardness of the composite with other literatures is shown in table 4.25 and it was shown that the fabricated composite has better hardness.

Table 4.25 Comparisons of Hardness of composite

Fiber	Matrix	Fiber orientation	Fiber/Matrix Weight ratio	Fiber treatment	Hardness (HV)	References
False banana, sisal and glass	polyester	0/90	40/60	5% NaOH	119.20	Current work
Banana, sisal	epoxy	random	-	5% NaOH	97.45	Patel et al., (2016)

4.7 Water absorption

4.7.1 Water absorption in rain water

Specimens were weighted for 7 days up to obtaining stabilized water absorption level. The maximum water absorption of the composite is shown in table 4.26 and figure 4.17. water absorption level is calculated by the equation 4.6 given below

$$W(\%) = \left(\frac{W_f - W_i}{W_i}\right) \times 100\% \qquad (4.6)$$

Table 4.26 Water absorption of composite in rain water

Sample No	1	2	3	4	5	6	7	8
Maximum Rain water absorption (%)	4.27	2.24	1.65	3.92	3.25	3.8	3.66	3.1
S/N ratio	-12.606	-7.005	-4.349	-11.8	-10.237	-11.595	-11.263	-9.827

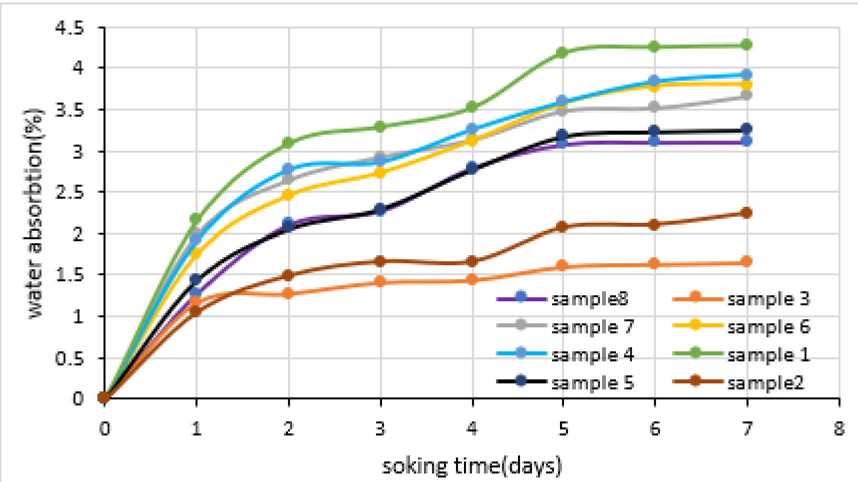


Figure 4.17 water absorption of samples in rain water

As it was depicted in Figure 4.17 the water absorbtion in sample number 1 was greater than the other samples.This sample had parametric combination of 0/90 natural fiber orientation, 5% NaOH treatment level, 20 false banana 10 sisal 10 glass fiber content in weight percentage and random glass fiber type.the second higher water absorbing sample was sample nuber 4 that has parametric combination of 45/45 natural fiber orientation, 5%NaOH treatment level, 10 false banana, 20 sial 10 glass fiber content in weight percentage and random glass fiber type.

On the other hand,the lowest water absorbing sample was sample number 3 that has parametric combination of 0/90 natural fiber orientation, 10% NaOH,10false banana, 20 sisal 10 glass fiber content in weight percentage and Woven type glass fiber.the second less water absorbing sample was sample number 2 with parametric combination of 45/45 natural fiber orientation,10% NaOH treatment level,20 flase banana 10 sisal 10 glass fiber content in weigth percentage and Woven glass fiber type.

From the result it can be concluded that glass fiber type had the highest effect on influencing the water absorbtion property of the composite.the composite with woven glass fiber has the lowest water absorbing property.this proeprty was connected to the reduced number of void spaces between fibers in woven type glass fiber than random glass fiber oriented composite.

In addition to glass fiber orintation,The composites with 10% NaOH treatment level also showed less water absorbtion property than 5% NaOH treated composite.it was seen from the result that water absorbtion for sample number 3, 2, 7 and 6 are 1.65%, 2.24%, 3.66% and 3.8%.on the other hand,composite that are treated with 5% NaOH in sample number 5, 8, 4and 1 showed water absorbtion of 3.25%, 3.1%, 3.92% and 4.27%.mercerization improve fiber surface adhesion property by removing impurirties from the surface and causing better fiber interloking with matrix (Bisanda, 2000).from this it can be concluded that 10 % treatment given better fiber matrix adhesion than 5% NaOH treatment level.

Composites with 10 false banana 20 sisal 10 glass fiber showed less water absorbtion property than 20 false banana 10 sisal 10 glass fiber reinforced composite.The former composite with weigth percentage showed water absorbtion of 1.65, 3.1, 3.66 and 3.92 in sample number 3, 8, 7 and 4.on the contorary composite with 20 false banana 10 sisal 10 glass fiber exhibited water absorbtion of 3.25, 2.24, 3.8 and 4.27 for sample number 5, 2, 6 and 1. This implies that composites reinfroced with double number of sisal fiber than false banana fiber has lower hydrophilic nature.

4.7.2 Analysis of main effect plot of signal to noise ratio of rain water absorption

As it is shown in figure 4.18 the optimum condition for lower water absorption of the composite was 0/90 natural fiber orientation, 10% NaOH treatment level, 10 false banana 20 sisal 10 glass fiber content in weight percentage and woven type glass fiber orientation.

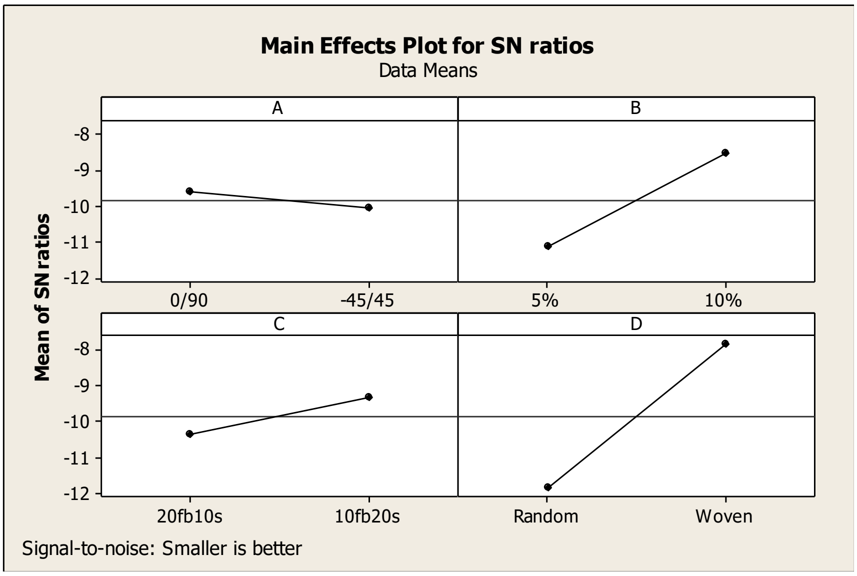


Figure 4.18 main effect plots of signal to noise ratio of rain water absorption

4.7.3 Analysis of Response table of signal to noise ratio of rain water absorption

The type of glass fiber had shown higher rank in affecting the water absorption property of the composite with delta number of 3.980 and alkali treatment level was the second ranked parameter with delta number of 2.58.The weight percentage of natural fiber and orientation also affect the rain water absorption property of the composite with delta number of 1.034 and 0.457 respectively. Table 4.27 shows the response table of signal to noise ratio of rain water absorption.

Table 4.27 Response table of signal to noise ratio of rain water absorption

level	A	B	C	D
1	-9.616	-11.135	-10.362	-11.835
2	-10.073	-8.555	-9.328	-7.855
Delta	0.457	2.580	1.034	3.980
Rank	4	2	3	1

4.7.4 Analysis of Variance of signal to Noise ratio of rain water absorption

From the Analysis of Variance table, it was seen that the type of glass fiber orientation had highest percentage of contribution of 57.357% and alkali treatment level had second percent of contribution of 24.099%.the weight percentage of natural fiber and orientation of natural fiber were the third and fourth contributing factors with contribution percent of 3.8688 and 0.7562. Table 4.28 shows the analysis of variance of signal to noise ratio of rain water absorption.

Table 4.28 Analysis of Variance of signal to noise ratio of rain water absorption

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc
A	1	0.417	0.417	0.417	0.16	0.713	0.756
B	1	13.310	13.310	13.310	5.19	0.107	24.099
C	1	2.136	2.136	2.136	0.83	0.428	3.868
D	1	31.680	31.680	31.680	12.36	0.039	57.357
Residual Error	3	7.687	7.687	2.562			
Total	7	55.2338					

4.7.5 Water absorption in distilled water

Eight samples were immersed in distilled water for fixed time of 24hr interval and then after the samples were dried with towel, weight change was measured by electrical balance. The maximum water absorption for each sample is given in table 4.29 and figure 4.19 shows the progress of water absorption in 8 samples.

Table 4.29 Water absorption of composite in distilled water and signal to noise ratio

Sample No	1	2	3	4	5	6	7	8
Maximum distilled water absorption (%)	2.00	1.12	1.003	1.91	1.29	1.52	1.49	1.15
S/N ratio	-6.04	-0.98	-0.026	-5.62	-2.21	-3.63	-3.463	-1.2139

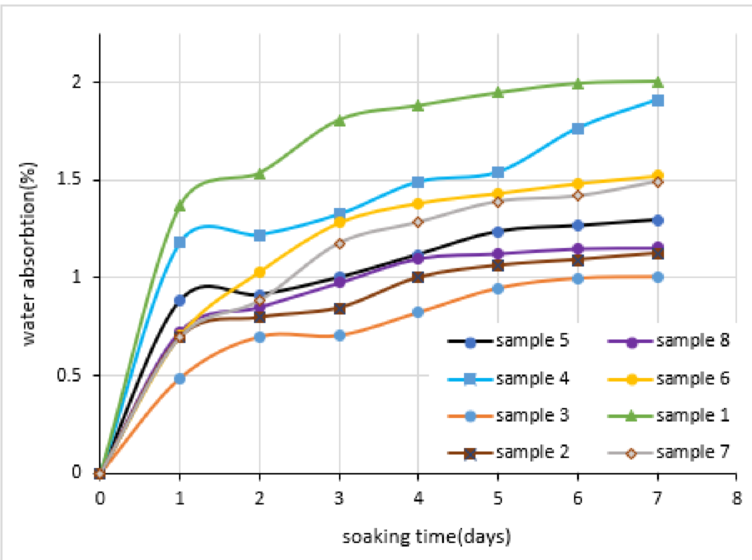


Figure 4.19 Water absorption of samples in distilled water

The composite soaked in distilled water for 7 consecutive days with 24-hour interval showed that the considered parameters have effects on water absorption property of the composite. The composites with woven type glass fiber have lower water absorption in sample number 3, 8, 2 and 5 with absorbing percent of 1.003%, 1.15%, 1.12% and 1.29%.beside this, randomly oriented glass fiber reinforced composites exhibit water absorption level of 2.005%, 1.91%, 1.52% and 1.4% in sample number 1, 4, 6and 7.Therefore as the case for rain water absorption, the more void space created during fabrication process of the composite in random glass fiber reinforced composite caused to absorb more distilled water than woven glass fiber reinforced composite.

The sodium hydroxide treatment level also affected the water absorption property of the material. Composites with 10% NaOH treatment level showed lower water absorption level than 5% NaOH treated composite. The higher content of cellulose in the composite leads to higher water absorption of the composite.

In addition to the fiber treatment, fiber content also contributed to variation of water absorption level of the composite. Composites with 10 false banana 20 sisal 10 glass fiber reinforced composite has shown lower amount of water absorption than 20 false banana 10 sisal 10 glass fiber reinforced composite. (Badyankal et al., 2020) also obtained the same result that for 15 Banana : 25 Sisal weight percentage the water absorption was lower.

4.7.6 Analysis of main effect plot of signal to noise ratio of distilled water absorption

From Figure 4.20 the optimum condition for obtaining lower amount of water absorption was woven type glass fiber, 10% NaOH fiber treatment, 10false banana 20 sisal 10 glass fiber content in weight percentage and -45/45 natural fiber orientation.

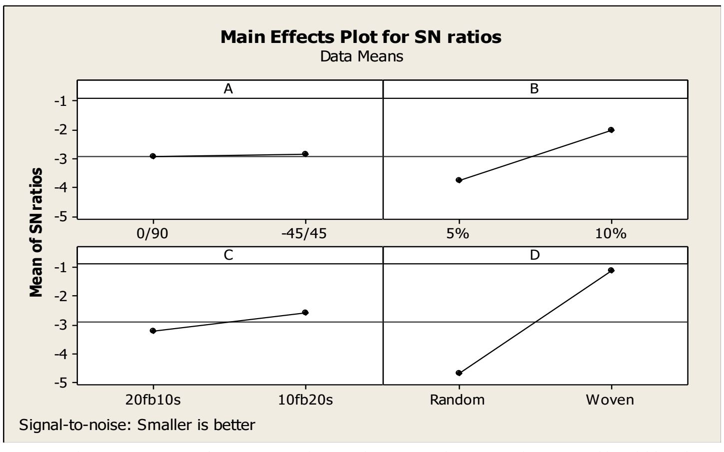


Figure 4.20 Main effect plots of signal to noise ratio of distilled water absorption

4.7.7 Analysis of response table of signal to noise ratio of distilled water absorption

Response table for distilled water absorption indicates that the type of glass fiber was the first ranked parameter in affecting the absorbing property of the composite with delta number 3.582 and alkali treatment level of fiber followed it with delta number of 1.744. Amount of fiber in weight percentage and natural fiber orientation were the third and fourth ranked parameter. Table 4.30 shows the response able for signal to noise ratio of distilled water absorption test.

Table 4.30 Response table for signal to noise ratio of distilled water absorption test

Level	A	B	C	D
1	-2.936	-3.772	-3.219	-4.691
2	-2.864	-2.028	-2.581	-1.109
Delta	0.072	1.744	0.638	3.582
Rank	4	2	3	1

4.7.8 Analysis of variance of signal to noise ratio of distilled water absorption

The percentage of contribution value indicated that glass fiber orientation type has higher contribution of 76.86% and NaOH treatment level has percentage contribution of 18.231 %.The fiber content also has contribution percent of 2.43% and natural fiber orientation had contribution of 0.0311%.Table 4.31 shows the analysis of variance of signal to noise ratio of distilled water absorption.

Table 4.31 Analysis of Variance of signal to noise ratio of distilled water absorption

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc
A	1	0.010	0.010	0.010	0.04	0.857	0.031
B	1	6.086	6.086	6.086	22.45	0.018	18.231
C	1	0.813	0.813	0.813	3.00	0.182	2.436
D	1	25.659	25.659	25.659	94.65	0.002	76.864
Residual Error	3	0.813	0.813	0.271			
Total	7	33.382					

4.7.9 Comparison with previous works on water absorption of the composite

Table 4.32 shows the comparison of water absorption of samples.

Table 4.32 Comparison of water absorptions

Fiber	Matrix	Fiber orientation	Fiber/Matrix weight ratio	Fiber treatment	Water absorption (%)	References
False banana, sisal and glass	polyester	0/90	40/60	5% NaOH	4.27 (rain) 2.005(distilled)	Current work
Banana, sisal	Epoxy	Random	40/60	**5%** NaOH	18	Badyankal et al., (2020)
Banana, E-glass	polyester	Random	-	-	6.75	Arpitha and Yogesha, (2016)

4.8 Void content of composite

4.8.1 Void determination

The actual and theoretical density of the composite were measured by using Archimedes principle. ASTM D 792-08 were followed to determine the density of the composite.

For theoretical density calculation volume was measured by digital caliper. The actual density was measured by suspending the specimen in the air and then in the water then after measuring its weight.

$$\rho_{ex} = \frac{W_a}{W_a - W_w}\rho_w \tag{4.7}$$

where ρ_{ex}= experimental density, W_a= weight in air , W_w= weight in water

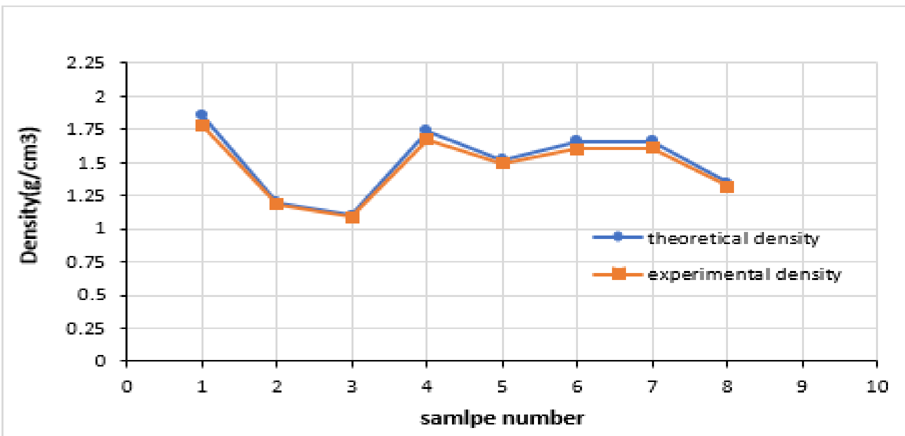


Figure 4.21 Experimental and theoretical density

From Figure 4.21 it can be seen that, the theoretical density was higher than the experimental density the reason for this was in experimental density, it is assumed that all atomic positions is occupied with an atom of the material but in experimental density the values will decrease by the existence of void and impurities in the composite.

void content of the composite was determined by eqn4.8 and is summarized in Table 4.33

$$void = \frac{(\rho th - \rho ex)}{\rho th} \times 100\% \qquad (4.8)$$

where ρth is theoretical density, ρex experimental density

Table 4.33 Density and void content of composites

Sample number	Theoretical density	Experimental density	Void(%)	S/N ratio
1	1.856	1.7804	4.07	-12.191
2	1.1957	1.1824	1.14	-1.138
3	1.09822	1.08734	0.99	0.087
4	1.739	1.6708	3.92	-11.865
5	1.5201	1.4895	2.01	-6.063
6	1.662	1.6003	3.71	-11.387
7	1.6604	1.61008	3.03	-9.628
8	1.344	1.32074	1.73	-4.760

From Table 4.33 it can be seen that the composite with lower void content was sample number 3 with parametric combination of (0/90, 10% NaOH, 10 false banana 20 sisal 10 glass content and woven glass fiber).on the other hand, composite with higher void content was found in sample number 1 with parametric combination of 0/90, 5% NaOH, 20 false banana 10 sisal 10 glass content and random glass fiber type.

The composite with woven type glass fiber exhibited lower amount of void content than random glass fiber reinforced composites. sample number 3,2,8,5 all with woven glass fiber constitutes void amount of 0.99, 1.14, 1.73 and 2.01%.on the other hand, composites with random orientation of glass fiber constitutes void content of 4.07,3.92,3.71and 3.03%.This was due to the amount of fiber agglomeration in one area in random orientation was greater than woven orientation and this leads to the void formation in the other area.

The fiber treatment at 10% NaOH also leads to 24% decrease of void content in the composite than 5%NaOH treated composite. The reason for this could be as the fiber was treated at 10%NaOH level the fiber matrix adhesion of the fiber increase and this leads to reduction of unfulfilled space by the fiber and matrix. In addition to this, the composite with double number of sisal fiber exhibited reduced amount of void content than the composite with double number of false bananas. It was concluded from this that the sisal fiber has strong fiber matrix adhesion than false banana fiber.

4.8.2 Analysis of main effect plot of signal to noise ratio of void content

From Figure 4.22 the optimum condition for minimization of void content was obtained with parametric combination of $A_1B_2C_2D_2$ or 0/90 natural fiber orientation,10% NaOH treatment of fiber, 10 false banana 20 sisal 10 glass fiber content and woven glass fiber orientation.

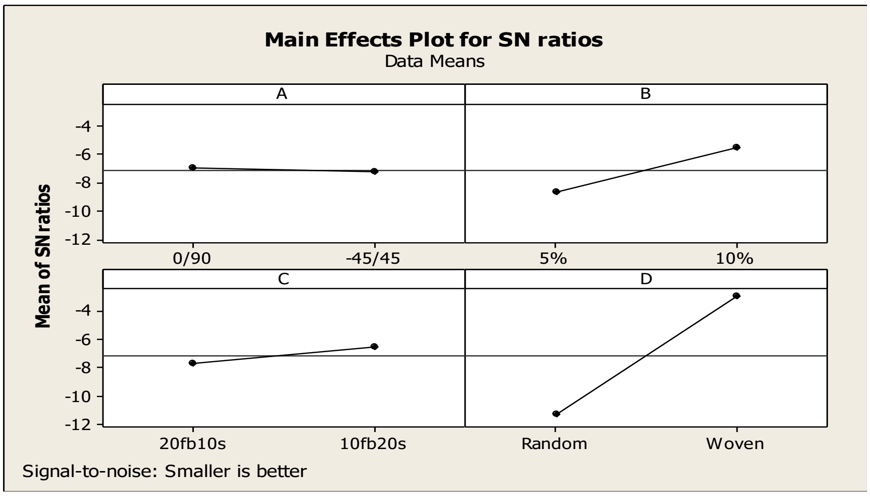


Figure 4.22 Main effect plots of signal to noise ratio of void content

4.8.3 Analysis of response table for signal to noise ratio of void content

From Table 4.34 it can be observed that the type of glass fiber orientation is the first ranked parameter in affecting the void content of the composite with delta number 8.300.the fiber treatment level and the weight percentage of fiber are the second and third parameter in affecting the void content with delta number 3.204 and 1.153 . Orientation of natural fiber was the list affecting parameter with delta number 0.339.Table 4.34 illustrates response for void content of the composite.

Table 4.34 Response table for signal to noise ratio of void content

Level	A	B	C	D
1	-6.949	-8.721	-7.695	-11.268
2	-7.288	-5.517	-6.542	-2.969
Delta	0.339	3.204	1.153	8.300
Rank	4	2	3	1

4.8.4 Analysis of Variance of signal to noise ratio of void content

The value of percent of contribution indicated that the type of glass fiber was the first contributing factor with percent contribution of 82.415% and alkali treatment level and weight percentage of fiber was the second and third contributing factors with contribution number of 12.281 and 1.5912%.The last contribution was by natural fiber orientation with contributing number of 0.1369%.Table 4.35 illustrates ANOVA of void content.

Table 4.35 Analysis of variance of signal to noise ratio of void content

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc(%)
A	1	0.229	0.229	0.229	0.12	0.757	0.136
B	1	20.529	20.529	20.529	10.31	0.049	12.281
C	1	2.660	2.660	2.660	1.34	0.332	1.591
D	1	137.766	137.766	137.766	69.16	0.004	82.415
Residual Error	3	5.976	5.976	1.992			
Total	7	167.160					

4.8.5 Comparison of void content of the composite

The result of void content of the composite is compared with other literatures in table 4.36

Table 4.36 Comparison of void content of the composite

Fiber	Matrix	Fiber orientation	Fiber/Matrix weight ratio	Fiber treatment	Void content(%)	References
False banana, sisal and glass	Polyester	0/90	40/60	5% NaOH	4.07	Current work
Banana, E-glass	Polyester	Random	-	-	7.027	Arpitha and Yogesha, (2016)

4.9 Analysis of grey relational analysis of mechanical and Physical tests

The data obtained from signal to noise ratio of tensile, compressive, flexural, impact Hardness, water absorption and void content tests were compiled in to one to predict the optimal parameter combination for best mechanical and physical property of the composite.

The obtained S/N ratio was normalized and then the normalizing sequence value deviation was calculated from it. The grey relational coefficient for all parameters was calculated using the deviation sequence values. at the end the grey relational grade was developed from grey relational coefficient. by analyzing the main effect of the grey relational grade value in Minitab 16 software, the optimal parameter was predicted for the best value of mechanical and physical property. The response of all tests was illustrated in table 4.37 with there SN ratio in table 4.38. from those tables normalization was done in table 4.39 then deviation sequence was calculated from it in table 4.40 then, the grey relational grade was depicted in table 4.41.

Table 4.37 Response of mechanical and physical tests

Exp no	Tensile (Mpa)	Compression (Mpa)	Flexural (Mpa)	Impact (KJ/m^2)	Hardness (HV)	Rain water absorption (%)	Distilled water absorption (%)	Void content (%)
1	119.2	47.67	375	179	66.25	4.27	2.005	4.07
2	163.2	48.78	300	487.17	116.2	2.24	1.12	1.14
3	184.6	57.22	391.67	410.25	87.60	1.65	1.003	0.99
4	68.5	33.67	225	282.05	94.5	3.92	1.91	3.92
5	185.5	56	383	384.61	99	3.25	1.29	2.01
6	68.7	11.4	191	230.76	71	3.8	1.52	3.71
7	156.2	20.67	358	179.48	114.4	3.66	1.49	3.03
8	157.5	56.67	300	448.71	119.2	3.1	1.15	1.73

Table 4.38 S/N ratio values of all responses

Exp no	Tensile (MPa)	Compression (MPa)	Flexural (MPa)	Impact (KJ/m^2)	Hardness (HV)	Rain water absorption	Distilled water absorption	Void content
1	41.525	33.56	51.48	45.057	36.425	-12.606	-6.042	-12.191
2	44.254	33.764	49.54	53.753	41.304	-7.005	-0.984	-1.138
3	45.324	35.151	51.85	52.261	38.850	-4.349	-0.026	0.087
4	36.713	30.544	47.043	49.006	39.503	-11.86	-5.62	-11.865
5	45.376	34.963	51.664	51.7	39.912	-10.237	-2.21	-6.063
6	36.739	21.138	45.620	47.263	37.025	-11.595	-3.636	-11.387
7	43.873	26.306	51.077	45.08	41.685	-11.263	-3.463	-9.628
8	43.945	35.067	49.542	53.039	41.525	-9.8272	-1.213	-4.760

Table 4.39 Normalization of all responses

Exp no	tensile	comp	Flexural	Impact	Hardness	Rain water absorption	Distilled water absorption	Void content
1	0.555	0.886	0.940	0.000	0.000	0.000	0.000	0.000
2	0.870	0.901	0.629	1.000	0.927	0.678	0.840	0.902
3	0.994	1.000	1.000	0.828	0.461	1.000	1.000	1.000
4	0.000	0.671	0.228	0.454	0.585	0.090	0.070	0.026
5	1.000	0.986	0.970	0.763	0.663	0.286	0.637	0.499
6	0.002	0.000	0.000	0.253	0.114	0.122	0.400	0.065
7	0.826	0.368	0.875	0.002	1.000	0.162	0.428	0.208
8	0.834	0.994	0.629	0.917	0.969	0.336	0.802	0.605

Table 4.40 Deviation sequence of all responses

Exp no	Hardness	Tensile	Comp	Flexural	Impact	Hardness	Rain water absorption	Distilled water absorption	Void content
1	0.444	0.113	0.059	1.000	1.000	1.000	1.000	1.000	0.444
2	0.129	0.099	0.370	0.000	0.072	0.321	0.159	0.098	0.123
3	0.006	0.000	0.000	0.171	0.539	0.000	0.000	0.000	0.006
4	1.000	0.328	0.771	0.545	0.414	0.909	0.929	0.973	1.000
5	0.000	0.013	0.029	0.236	0.337	0.713	0.363	0.501	0.000
6	0.997	1.000	1.000	0.746	0.886	0.877	0.600	0.934	0.997
7	0.173	0.631	0.124	0.997	0.000	0.837	0.571	0.791	0.173
8	0.165	0.006	0.370	0.082	0.030	0.663	0.197	0.394	0.165

Table 4.41 Grey relational coefficient and Grey relational grade of all responses

	Grey relational coefficient (GRC)								
Exp no	Tensile	Comp	flexural	Impact	Hardness	Rain water absorption	Distilled water absorption	Void content	Gray relational grade (GRD)
1	0.529	0.814	0.893	0.333	0.333	0.333	0.333	0.333	0.488
2	0.794	0.834	0.574	1.000	0.873	0.608	0.758	0.833	0.785
3	0.988	1.000	1.000	0.744	0.481	1.000	1.000	1.000	0.902
4	0.333	0.603	0.393	0.478	0.546	0.354	0.349	0.339	0.425
5	1.000	0.974	0.943	0.679	0.597	0.412	0.579	0.499	0.711
6	0.334	0.333	0.333	0.401	0.360	0.363	0.454	0.348	0.366
7	0.742	0.442	0.801	0.339	1.000	0.373	0.466	0.387	0.568
8	0.751	0.988	0.574	0.859	0.942	0.429	0.716	0.558	0.728

4.9.1 Analysis of GRG of Mechanical and Physical tests

From main effect plot of signal to noise ratio of tensile, compressive, flexural, impact strength, hardness, water absorption and void content of the composite,the optimal parametric combination was predicted to be 0/90 natural fiber orientation,10% NaOH treatment level,10 false banana 20 sisal 10 glass fiber weight percentage and woven type glass fiber (A1B2C2D2).

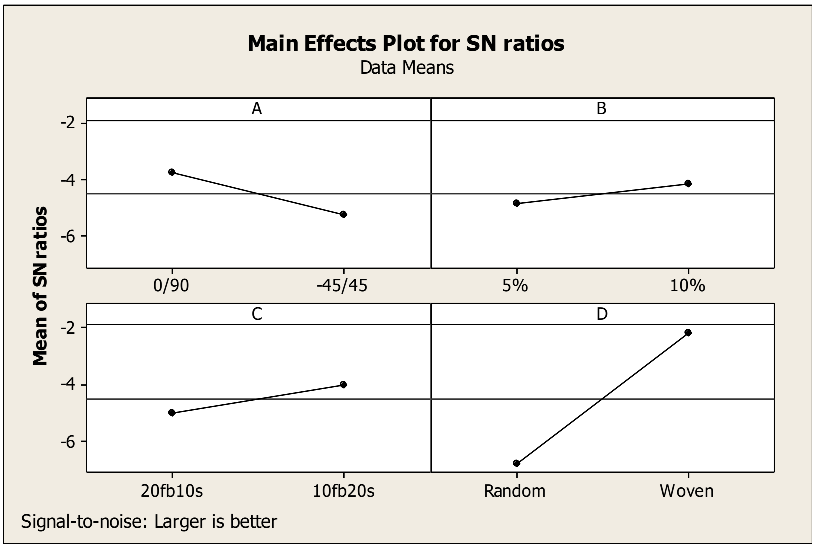


Figure 4.23 Main effect plot of signal to noise ratio of all responses

4.9.2 Response table for means of GRG of Mechanical and Physical tests

The response table analysis of tensile compressive flexural, impact strength, hardness, water absorption and void content of the composite indicated that the type of glass fiber was the first ranked parameter with delta number 4.642 and the orientation of natural fiber was the second ranked parameter with delta number of 1.508.weight percentage and Alkali treatment of natural fiber were the third and fourth ranked parameter with delta number 1.007 and 0.689.Table 4.42 represents response table of all responses of all tests.

Table 4.42 Response table of signal to noise ratio of all responses

Level	A	B	C	D
1	-3.750	-4.849	-5.008	-6.825
2	-5.258	-4.160	-4.001	-2.183
Delta	1.508	0.689	1.007	4.642
Rank	2	4	3	1

4.9.3 Analysis of Variance for signal to noise ratio of GRG of mechanical and physical tests

From the last column of ANOVA table, it was seen that the type of glass fiber was the highest contributing factor with percentage contribution of 80.2%. The second contributing factor was the orientation of natural fiber with percentage contribution of 8.5024%. Weight percentage and NaOH treatment of natural fiber were the third and fourth contributing factor in affecting tensile, compressive, flexural, impact strength, hardness, water absorption and void content of the composite with contribution factor of 3.77 and 1.7654.Table 4.43 illustrates ANOVA of all responses.

Table 4.43 Analysis of variance of signal to noise ratio of all responses

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pc
A	1	4.546	4.546	4.546	4.38	0.127	8.502
B	1	0.948	0.948	0.948	0.91	0.410	1.765
C	1	2.028	2.028	2.028	1.96	0.256	3.770
D	1	43.100	43.100	43.100	41.54	0.008	80.205
Residual Error	3	3.112	3.112	1.037			
Total	7	53.737					

4.10 Confirmation experiment

After obtaining the optimal process parameters and levels the next step was to verify that the predicted result was against experimental results. If the combination of optimal process parameters level coincides with that of any experimental trial in the orthogonal array these will be no need of confirmation test. In thisstudies the optimal process parameter coincided with sample number 3.

4.11 Comparison of fabricated composite with current automotive door panels

After the analysis of different mechanical strength tests the composite is compared with the current available door panels used in different automotive companies in table 4.44.

Table 4.44 Comparison of door panel strength with the fabricated composite (Pradeep et al., 2017).

Materials	Fabricated composite	Long glass fiber	Jute-epoxy-pp	Kenaf-pp	Flax-hemp-pp	Flax-sisal-pp
Tensile Strength (MPa)	185	151	110	58	60	50
Auto maker	-	Ford	Mercedes-Benz	VW	Daimler Chrysler	Audi

4.12 Machinability test by Drilling of composites

The drilling operation was performed with high-speed steel cutting tool of diameter of 6mm, 8mm and 10 mm. The composite of sample number 3 which was the sample with best mechanical strength achieved was drilled and it is shown in figure 4.24 the drilled section was cut into two parts to see the inner drilled part clearly. From the visiual inspection of each composite, it was seen that the fiber pullout occur around the bottom part of the drilled composite and round the drilled hole delamination had also occurred more in 6 diameter hole.The delamination and fiber pullout could be occur from the less fiber matrix adhesion.

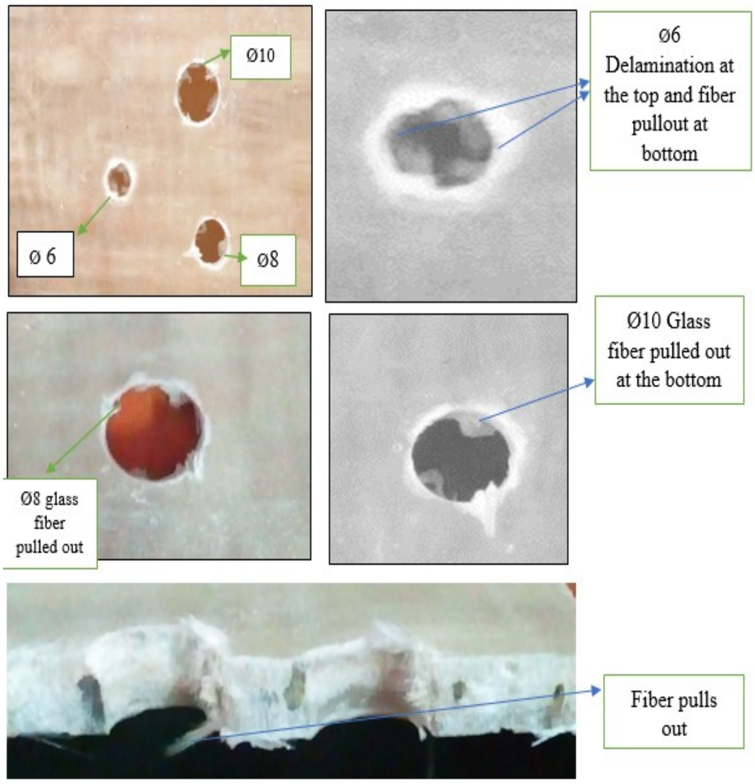


Figure 4.24 Drilling specimens

4.13 Scanning Electron Microscope Test

The morphological analysis of the composite was undertaken at different magnification of 20,50,200 and 500 micrometer at different locations of the composite surface and it is illustrated in figure 4.25. The result from the scanning electron microscope indicated that the composite contains air bubbles, voids and rough surfaces. The morphology of the composite was affected by fabrication technique of the composite. Since it was fabricated by hand layup open molding, it was more exposed to formation of air bubbles on the surface and void spaces.

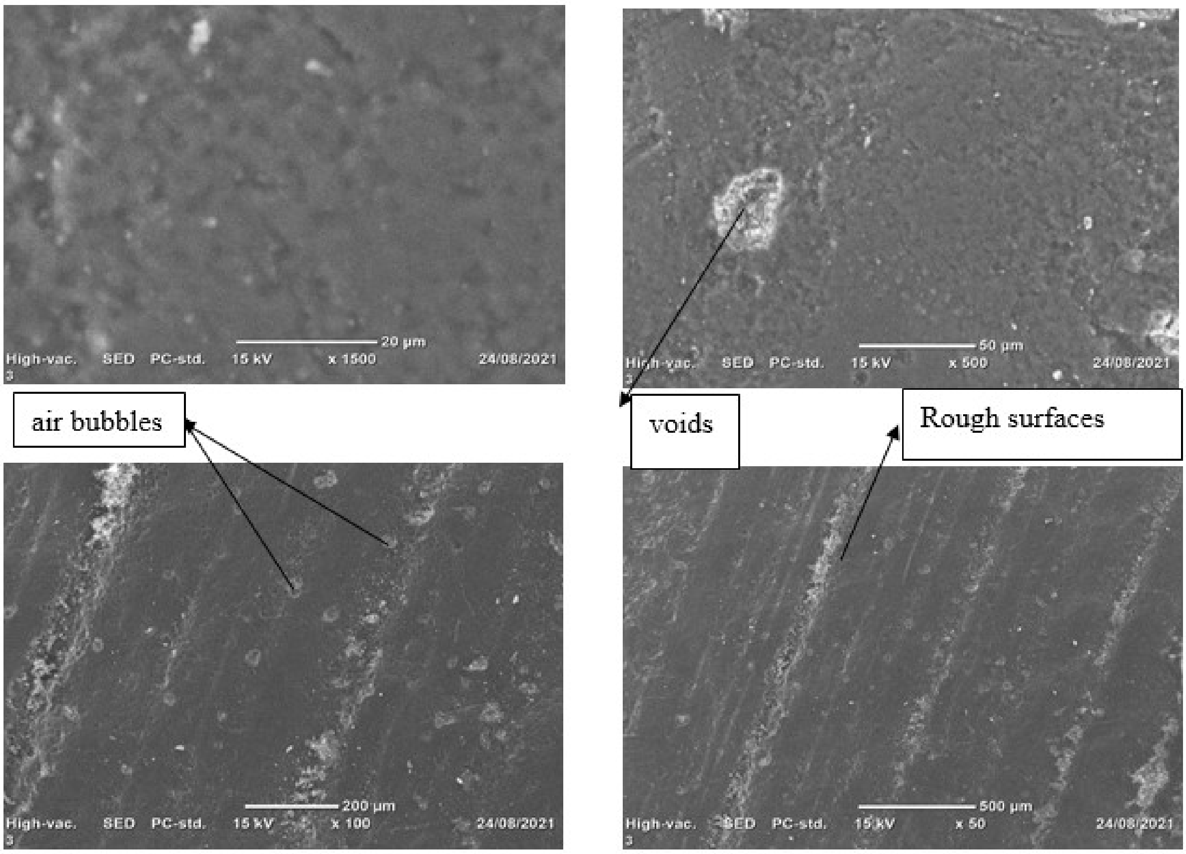


Figure 4.25 Scanning microscope morphological analysis of the composite

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this section conclusions from results and recommendation and future work for better improvement was presented

5.2 CONCLUSION

In this study, hybrid polymer material made from false banana, sisal and glass fiber reinforced composite was fabricated by hand layup method. Mechanical, physical and morphological characterization including tensile, compressive, flexural, impact and hardness property were performed according to ASTM standard. The optimal parametric combination was predicted by hybrid of Taguchi and grey relational analysis method. From the characterization and optimization of the composite the following conclusions were drawn

- Mechanical, physical and morphological properties of composite was studied and it was found that the properties were enhanced due to the hybridization of the natural fiber with glass fiber.
- In characterization of the composite, Maximum tensile strength of 185.5Mpa was achieved in sample number 5 and 10%NaOH fiber treatment level showed 7.2 % greater tensile strength than 5% NaOH treated fiber.
- Uniform distribution of load in both transverse and axial direction causes to increasing of compressive strength in 0/90 fiber reinforced composites. Maximum compression strength of 57.22Mpa was achieved in sample number 3 moreover, the maximum flexural strength of 391.67Mpa was achieved in the same sample.
- The impact strength of the composite was also affected by fiber orientation and -45/45 fiber oriented composite 20.38% better impact strength than 0/90 fiber reinforced composite. Maximum impact strength of 448 KJ/m^2 .was achieved in sample number 8.In addition to this, Maximum hardness of 119.2 HV was also achieved for the same sample number and it was concluded that in woven type reinforced composite the hardness values was more improved than random fiber-oriented composite.
- The higher rain and distilled water absorption and void content was seen in sample number 1 with 4.27%, 2% and 4.07% value.
- The effect of each parameter was investigated and the variation of parameters resulted in change of property and according to ANOVA result the most significant factor in

affecting the mechanical ,physical and morphological property of the composite was found to be glass fiber orientation type.

- The experimental design by Taguchi method gives a simple, systematic and effective methodologies for the optimization of mechanical and physical property test parameters.
- From the Grey relation Grade(GRG) analysis, it was predicted that the optimal process parameters for the best mechanical property was found with 0/90 natural fiber orientation,10% NaOH, 10 fb 20 s10 G weight percentage and Woven glass fiber type.
- The machinability test with drilling operation at three drill bit size showed that the predicted and fabricated composite was suitable for Automotive body part assembling with slight additional failing.
- The scanning electron microscope analysis of the composite illustrates that the composite with highest mechanical strength has been also exposed to air bubbles and voids.

5.3 Recommendation

For better property and application of the composite, it is recommended:-

- To use fiber extracting machines rather than using traditional hand scraping method
- To fabricate the composite with compression molding or vacuum assisted method for reduction of air bubbles trapping into the composite.
- To use better matrix material such as pure high-quality epoxy for the fabrication of the composite.
- To treat the natural fibers with Acids and other Alkali treatments like potassium hydroxide
- To fabricate the composite for other applications in addition to Automotive industry.

5.4 Scope of future researches

From different direction of observations, working on natural composite has several benefits. regarding the scope of future research based on works of material from false banana, sisal and glass fiber reinforced composite future scope for interested researchers will be;

- To study thermal and fire resistance property of the composite at different parametric combination.
- To study wear behavior of the composite at different conditions.
- To conduct finite element analysis of the test by using software's like ANSYS or Deform 3D.

REFERENCES

Abraham Eben Andrews, A., P. Karthick, Velugoti Pavan Kalyan, Chavva Brahma Teja, Mogallapalli Anirudh, and Grandhi Venakata Naga Sudheer. 2020. 'Synthesize and Exploration of Wet Strength of Fiberglass/Hydroxysuccinic Acid Treated Banana and Sisal Fibers Hybrid Composite'. *Materials Today: Proceedings* 33:2814–17. doi: 10.1016/j.matpr.2020.02.701.

Abuye, Ashenafi. 2017. 'Fabrication and Characterization of False Banana Fiber Reinforced Gypsum Composite'. Addis Ababa University Addis Ababa Institute of Technology.

Adekomaya, O., and K. Adama. 2017. 'Glass-Fibre Reinforced Composites: The Effect of Fibre Loading and Orientation on Tensile and Impact Strength'. *Nigerian Journal of Technology* 36(3):782–87. doi: 10.4314/NJT.363.1391.

Aditya, P., K. Kishore, and D. Prasad. 2017. 'Characterization of Natural Fiber Reinforced Composites'. *International Journal of Engineering and Applied Sciences* 4(6):257446.

Alavudeen, A., N. Rajini, S. Karthikeyan, M. Thiruchitrambalam, and N. Venkateshwaren. 2015. 'Mechanical Properties of Banana/Kenaf Fiber-Reinforced Hybrid Polyester Composites: Effect of Woven Fabric and Random Orientation'. *Materials and Design* 66(PA):246–57. doi: 10.1016/j.matdes.2014.10.067.

Alemayehu, Zewdie, Ramesh Babu Nallamothu, Mekonnen Liben, Seshu Kishan Nallamothu, and Anantha Kamal Nallamothu. 2020. 'Experimental Investigation on Characteristics of Sisal Fiber as Composite Material for Light Vehicle Body Applications'. *Materials Today: Proceedings* 38:2439–44. doi: 10.1016/j.matpr.2020.07.386.

Aljibori, Hakim S. Sultan. 2009. 'Quasi-Static Axial Crushing of a ± 45 ° Fiber Orientation Angle with a Different Number of Layers : Part 1 , Experimental Study'. *Test* 4(4):72–84.

Annandarajah, Cindu. 2020. 'Manufacture and Characterization of Natural Fiber Biocomposites for Automotive Application'.

Ansari, Anas Ahmed, S. K. Dhakad, and Pankaj Agarwal. 2019. 'Investigation of Mechanical Properties of Sisal Fibre and Human Hair Reinforced with Epoxy Resin Hybrid Polymer Composite'. *Materials Today: Proceedings* 26:2400–2404. doi: 10.1016/j.matpr.2020.02.513.

Arpitha, G. R., M. R. Sanjay, L. Laxmana Naik, and B. Yogesha. 2014. 'Mechanical Properties of Epoxy Based Hybrid Composites Reinforced with Sisal / SIC / Glass

Fibers'. *Ijergs* 2(5):398–405.

Arthanarieswaran, V. P., A. Kumaravel, and M. Kathirselvam. 2014. 'Evaluation of Mechanical Properties of Banana and Sisal Fiber Reinforced Epoxy Composites: Influence of Glass Fiber Hybridization'. *Materials and Design* 64:194–202. doi: 10.1016/j.matdes.2014.07.058.

Badyankal, Pramod V, T. S. Manjunatha, Gurushanth B. Vaggar, and K. C. Praveen. 2020. 'Compression and Water Absorption Behaviour of Banana and Sisal Hybrid Fiber Polymer Composites Materials Today : Proceedings Compression and Water Absorption Behaviour of Banana and Sisal Hybrid Fiber Polymer Composites'. *Materials Today: Proceedings* (March):2–6. doi: 10.1016/j.matpr.2020.02.695.

Batu, Temesgen, and Hirpa G. Lemu. 2020. 'Investigation of Mechanical Properties of False Banana/Glass Fiber Reinforced Hybrid Composite Materials'. *Results in Materials* 8(October):100152. doi: 10.1016/j.rinma.2020.100152.

Berhanu, Hanna, Zebene Kiflie, Isabel Miranda, Ana Lourenço, Joana Ferreira, Sisay Feleke, Abubeker Yimam, and Helena Pereira. 2018. 'Characterization of Crop Residues from False Banana /Ensete Ventricosum/ in Ethiopia in View of a Full-Resource Valorization'. *PLOS ONE* 13(7):e0199422. doi: 10.1371/JOURNAL.PONE.0199422.

Betelie, Araya Abera, Yonas Tsegaye Megera, Daniel Telahun Redda, and Antony Sinclair. 2018. 'Experimental Investigation of Fracture Toughness for Treated Sisal Epoxy Composite'. *AIMS Materials Science* 5(1):93–104. doi: 10.3934/matersci.2018.1.93.

Bindal, Amit, Satnam Singh, N. K. Batra, and Rajesh Khanna. 2013. 'Development of Glass/Jute Fibers Reinforced Polyester Composite'. *Indian Journal of Materials Science* 2013:1–6. doi: 10.1155/2013/675264.

Bisanda, E. T. N. 2000. 'Effect of Alkali Treatment on the Adhesion Characteristics of Sisal Fibres'. *Applied Composite Materials* 7(5–6):331–39. doi: 10.1023/A:1026586023129.

Borrell, James S., Manosh K. Biswas, Mark Goodwin, Guy Blomme, Trude Schwarzacher, J. S. Heslop-Harrison, Abebe M. Wendawek, Admas Berhanu, Simon Kallow, Steven Janssens, Ermias L. Molla, Aaron P. Davis, Feleke Woldeyes, Kathy Willis, Sebsebe Demissew, and Paul Wilkin. 2019. 'Enset in Ethiopia: A Poorly Characterized but Resilient Starch Staple'. *Annals of Botany* 123:747–66. doi: 10.1093/aob/mcy214.

Chandrasekar, M., M. R. Ishak, S. M. Sapuan, Z. Leman, and M. Jawaid. 2017. 'A Review on the Characterisation of Natural Fibres and Their Composites after Alkali Treatment and Water Absorption'. *Plastics, Rubber and Composites* 46(3):119–36. doi: 10.1080/14658011.2017.1298550.

Chaudhary, Vijay, and Furkan Ahmad. 2020. 'A Review on Plant Fiber Reinforced Thermoset Polymers for Structural and Frictional Composites'. *Polymer Testing* 91(May):106792. doi: 10.1016/j.polymertesting.2020.106792.

Daniel Redda, and Abiy Alene. 2016. 'Experimental Analysis of Bamboo and E-Glass Fiber Reinforced Epoxy Hybrid Composite'. *Journal of Materials Science and Engineering B* 6(3):153–60. doi: 10.17265/2161-6221/2016.5-6.005.

Degefe, Samson Yohannes. 2015. 'Finite Element Analysis of E-Glass / Epoxy Composite for Automotive Structures'. 1–81.

Demissie, Lemi, Araya Abera, and Daniel Telahun. 2019. 'Development of Minibus Interior Wall Panel Using Hybrid Sisal and False Banana Fiber Reinforced Epoxy Composite'. 10(11):569–79.

Dinesh, S., C. Elanchezhian, A. Devaraju, Siva Kumar Sivalingam, and V. Velmurugan. 2020. 'Comparative Study of Mechanical and Morphological Analysis of NaOH Treated and Untreated Banana Fiber Reinforced with Epoxy Hybrid Composite'. in *Materials Today: Proceedings*. Vol. 39.

Douglas Kiser, J., Kaia E. David, Curtis Davies, Rachael Andrulonis, and Cindy Ashforth. 2018. 'Updating Composite Materials Handbook-17 Volume 5— Ceramic Matrix Composites'. *Ceramic Transactions* 263(June):413–23. doi: 10.1002/9781119407270.ch39.

Dress, Genetu A., M. H. Woldemariam, and D. T. Redda. 2021. 'Influence of Fiber Orientation on Impact Resistance Behavior of Woven Sisal Fiber Reinforced Polyester Composite'. *Advances in Materials Science and Engineering* 2021:1–11. doi: 10.1155/2021/6669600.

Faruk, Omar, Andrzej K. Bledzki, Hans Peter Fink, and Mohini Sain. 2012. 'Biocomposites Reinforced with Natural Fibers: 2000-2010'. *Progress in Polymer Science* 37(11):1552–96. doi: 10.1016/j.progpolymsci.2012.04.003.

Gupta, M. K., and Rohit Singh. 2018. 'Flexural and Dynamic Mechanical Analysis (DMA) of Polylactic Acid (PLA) Coated Sisal Fibre Reinforced Polyester Composite'. *Materials Today: Proceedings* 5(2):6109–14. doi: 10.1016/j.matpr.2017.12.216.

Gupta, M. K., and R. K. Srivastava. 2016. 'Tribological and Dynamic Mechanical Analysis of Epoxy Based Hybrid Sisal/Jute Composite'. *Indian Journal of Engineering and Materials Sciences* 23(1):17–44.

Gupta, Upendra Sharan, Amit Dharkar, Mohit Dhamarikar, Aayush Kumrawat, Nitin Giri, Aditya Raj Singh Chauhan, Ayush Giri, Sudhir Tiwari, and Rajeev Namdeo. 2021.

‘Investigation on Effects of Fiber Loading of Mechanical Properties of Banana/Sisal Hybrid Composite’. *Materials Today: Proceedings* 45:7829–37. doi: 10.1016/J.MATPR.2020.12.213.

Haq, A. Noorul, P. Marimuthu, and R. Jeyapaul. n.d. ‘Multi Response Optimization of Machining Parameters of Drilling Al/SiC Metal Matrix Composite Using Grey Relational Analysis in the Taguchi Method’. doi: 10.1007/s00170-007-0981-4.

Hayashi, Ikuhiko, Katsuhiko Mori, Shigeru Kaneko, and Tadashi Mogi. 1978. ‘Effect of Fiber Orientation on Mechanical Properties of Short Fiber Reinforced Composite Materials.’ 1(5):287–92.

Hossain, M. R., M. A. Islam, A. V Vuurea, and I. Verpoest. 2013. ‘Effect of Fiber Orientation on the Tensile Properties of Jute Epoxy Laminated Composite’.

Hsiao, K. T., R. Mathur, S. G. Advani, , J. W. Gillespie, and B. K. Fink. 2000. ‘A Closed Form Solution for Flow During the Vacuum Assisted Resin Transfer Molding Process’. *Journal of Manufacturing Science and Engineering* 122(3):463–75. doi: 10.1115/1.1285907.

Hussain, Md Zakir, Sabah Khan, and Pranjal Sarmah. 2020. ‘Optimization of Powder Metallurgy Processing Parameters of Al2O3/Cu Composite through Taguchi Method with Grey Relational Analysis’. *Journal of King Saud University - Engineering Sciences* 32(4):274–86. doi: 10.1016/j.jksues.2019.01.003.

Jamil, Mahbub, and Mahbub Hasan. 2021. ‘Effect of Chemical Treatment on the Properties of Banana Fiber Reinforced Polymer Composites’. *Reference Module in Materials Science and Materials Engineering*. doi: 10.1016/B978-0-12-820352-1.00115-2.

Jarukumjorn, Kasama, and Nitinat Suppakarn. 2009. ‘Effect of Glass Fiber Hybridization on Properties of Sisal Fiber-Polypropylene Composites’. *Composites Part B: Engineering* 40(7):623–27. doi: 10.1016/j.compositesb.2009.04.007.

Jaysukhlal, Pandya Vishal. 2020. ‘“ Characterization and Optimization of Mechanical Performance of Natural Fiber Composites for Automobile Applications ” Title of the Thesis’. (149997119022).

Karthick, P., A. Abraham Eben Andrews, Gunji Srinath, Najana Tejesh, Katikareddy Arvindnath Reddy, and Volet Nagavenkatasai Umamaheswara Rao. 2020. ‘Persuade of Sodium Hydrate and Potassium Permanganate Treated Sisal/Textile-Grade Glass Fibers Hybrid Composite’. *Materials Today: Proceedings* 33:2818–21. doi: 10.1016/j.matpr.2020.02.702.

Kejariwal, Roshan K., and B. S. Keerthi Gowda. 2017. ‘Flammability and Moisture

Absorption Behavior of Sisal-Polyester Composites’. *Materials Today: Proceedings* 4(8):8040–44. doi: 10.1016/j.matpr.2017.07.142.

Kimutai, S. K., Z. O. Siagi, J. J. Kiptarus, and A. D. Kibet. 2014. ‘*Comparative Study of Composite Made from Ensete False Banana Fibres and Polyethylene with Block Board’. *Journal of Energy Technologies and Policy* 4(12):48–53.

Krishnan K, Asha, Cintil Jose, K. R. Rohith, and K. E. George. 2015. ‘Sisal Nanofibril Reinforced Polypropylene/Polystyrene Blends: Morphology, Mechanical, Dynamic Mechanical and Water Transmission Studies’. *Industrial Crops and Products* 71:173–84. doi: 10.1016/j.indcrop.2015.03.076.

Kumar, V. Krishna, K. J. Gokuleshwar, S. Ranganathan, and C. Thiagarajan. 2018. ‘Fabrication and Mechanical Property Study on Glass / Sisal / Banana Natural Fibres’. 119(12):15637–45.

Kumari, Niharika, Manikant Paswan, and K. Prasad. 2021. ‘Effect of Sawdust Addition on the Mechanical and Water Absorption Properties of Banana-Sisal/Epoxy Natural Fiber Composites’. *Materials Today: Proceedings*. doi: 10.1016/J.MATPR.2021.07.489.

Kumre, Ashish, R. S. Rana, and Rajesh Purohit. 2017. ‘A Review on Mechanical Property of Sisal Glass Fiber Reinforced Polymer Composites’. *Materials Today: Proceedings* 4(2):3466–76. doi: 10.1016/j.matpr.2017.02.236.

Liu, Lei, Xiaobo Wang, Xiao Li, Xiaojun Xu, and Zongfu Jiang. 2012. ‘Thermal-Induced Dephasing in Mid-Infrared Continuous-Wave Singly Resonant Optical Parametric Oscillator’. *Qiangjiguang Yu Lizishu/High Power Laser and Particle Beams* 24(1):24–28. doi: 10.3788/HPLPB20122401.0024.

Liu, Sifeng, and Yi Lin. 2010. ‘Introduction to Grey Systems Theory’. *Understanding Complex Systems* 68:1–399. doi: 10.1007/978-3-642-16158-2_1.

Logendran, D., D. Muruganandam, J. Arunarasi, P. Karthick, A. Abraham Eben Andrews, and Raghuram Pradhan. 2020. ‘Experimental Investigation on Inherent Properties of Hydroxybutanedioic Acid Treated Banana/Sisal Fibers Based Hybrid Composite’. *Materials Today: Proceedings* 33:2842–45. doi: 10.1016/j.matpr.2020.02.708.

Malaiah, Sripathy, Krishna Vinayak Sharma, and M. Krishna. 2013. ‘Investigation on Effect of Fiber and Orientation on the Properties of Bio-Fibre Reinforced Laminates’. *International Journal of Engineering Inventions* 2(2):65–70.

Mann, Guravtar Singh, Lakhwinder Pal Singh, and Pramod Kumar. 2019. ‘Effect of Volume Fraction and Heating Temperature on Hybrid Natural Fibre Composites Developed through the Die Moulding Process’. *International Journal of Engineering and Advanced*

Technology 9(1):2988–94. doi: 10.35940/ijeat.A1359.109119.

Maurya, Hari Om, M. K. Gupta, R. K. Srivastava, and H. Singh. 2015. 'Study on the Mechanical Properties of Epoxy Composite Using Short Sisal Fibre'. *Materials Today: Proceedings* 2(4–5):1347–55. doi: 10.1016/j.matpr.2015.07.053.

Meragiaw, Misganaw, and Zemede Asfaw. 2014. 'Review of Antimalarial, Pesticidal and Repellent Plants in the Ethiopian Traditional Herbal Medicine'. *Research & Reviews: Journal of Herbal Science (RRJoHS)* (January).

Mesfen Kebede. 2015. 'Fabrication and Mechanical Property Characterization of Sisal Fiber Reinforced Epoxy Resin Composite Material for Automotive Body Application Addis Ababa University Addis Ababa Institute of Te'.

Michelle Kopier. 2011. 'Composite Materials and Components | OEM Off-Highway'. Retrieved 29 September 2021 (https://www.oemoffhighway.com/engineering-manufacturing/article/10451450/composite-materials-and-components).

Mistry, P. J., M. S. Johnson, and U. I. K. Galappaththi. 2021. 'Selection and Ranking of Rail Vehicle Components for Optimal Lightweighting Using Composite Materials'. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 235(3):390–402. doi: 10.1177/0954409720925685.

Mizera, D. Herák, M. Müller, and P. Hrabě. 2015. 'Mechanical Behaviour of Polymeric Composite with Fibres of False Banana (Ensete Ventricosum)'. *Agronomy Research* 13(3):680–89.

Mosisa, Sheleme, and Belete Sirhabizu. 2019. 'Study and Characterization of Flexural and Tensile Properties of Hybrid Bamboo / Sisal Fiber Reinforced Epoxy Composite'. *Journal of Material Sciences & Engineering* 8(5):0–7.

Muktha, K., and B. S. Keerthi Gowda. 2017. 'Investigation of Water Absorption and Fire Resistance of Untreated Banana Fibre Reinforced Polyester Composites'. *Materials Today: Proceedings* 4(8):8307–12. doi: 10.1016/j.matpr.2017.07.173.

Nassar, Amal, and Eman Nassar. 2020. 'Effect of Fiber Orientation on the Mechanical Properties of Multi Layers Laminate Nanocomposites'. *Heliyon* 6(August 2019):e03167. doi: 10.1016/j.heliyon.2020.e03167.

Nayak, Smaranika, Dipak Kumar Jesthi, Subhrajyoti Saroj, and Jatin Sadarang. 2021. 'Assessment of Impact and Hardness Property of Natural Fiber and Glass Fiber Hybrid Polymer Composite'. *Materials Today: Proceedings*. doi: 10.1016/J.MATPR.2021.03.079.

Negawo, Tolera A., Yusuf Polat, Yasin Akgul, Ali Kilic, and M. Jawaid. 2021. 'Mechanical and Dynamic Mechanical Thermal Properties of Ensete Fiber/Woven Glass Fiber Fabric Hybrid Composites'. *Composite Structures* 259(November 2020):113221. doi: 10.1016/j.compstruct.2020.113221.

Negera, Dawit Wami, J. Bhaskaran, Idiris Ilmi, and Ramesh Babu Nallamothu. 2019. 'Characterization of Hybrid Composite Made of False Banana Fiber and Sisal Fiber'. *International Journal of Engineering and Advanced Technology* 9(2):3220–26. doi: 10.35940/ijeat.b3604.129219.

Nguyen, Hai, Wael Zatar, and Hiroshi Mutsuyoshi. 2017. *Mechanical Properties of Hybrid Polymer Composite*. Elsevier Ltd.

Olusegun David Samuel1, Stephen Agbo2, Timothy Adesoye Adekanye. 2012. 'Assessing Mechanical Properties of Natural Fibre Reinforced Composites for Engineering Applications'.

Pani, Preeti Ranjan, R. K. Nayak, B. C. Routara, and P. C. Sekhar. 2019. 'Flexural and Specific Wear Rate of Seawater Aged Bamboo, Jute and Glass Fiber Reinforced Polymer Hybrid Composites'. *Materials Today: Proceedings* 18:3409–14. doi: 10.1016/j.matpr.2019.07.268.

Phani Sushma, I. S., B. Vasundhar, and N. V. Jagadeesh Varma. 2018. 'Fabrication and Experimental Evaluation of Properties with Reinforcement of Polyester Resin with Sisal Fibre'. *Materials Today: Proceedings* 5(13):27081–87. doi: 10.1016/j.matpr.2018.09.013.

Pradeep, Sai Aditya, Rakesh K. Iyer, Hakan Kazan, and Srikanth Pilla. 2017. 'Automotive Applications of Plastics: Past, Present, and Future'. *Applied Plastics Engineering Handbook: Processing, Materials, and Applications: Second Edition* 651–73. doi: 10.1016/B978-0-323-39040-8.00031-6.

Prasad, G. L. Easwar., B. S. Keerth. Gowda, and R. Velmurugan. 2017a. 'A Study on Impact Strength Characteristics of Coir Polyester Composites'. *Procedia Engineering* 173:771–77. doi: 10.1016/j.proeng.2016.12.091.

Prasad, G. L. Easwar., B. S. Keerth. Gowda, and R. Velmurugan. 2017b. 'Comparative Study of Impact Strength Characteristics of Treated and Untreated Sisal Polyester Composites'. *Procedia Engineering* 173:778–85. doi: 10.1016/j.proeng.2016.12.096.

Raghul, K. S., M. Logesh, R. Kiran Kisshore, P. Muhila Ramanan, and G. Muralitharan. 2020. 'Mechanical Behaviour of Sisal Palm Glass Fiber Reinforced Composite with Addition of Nano Silica'. *Materials Today: Proceedings* 37(Part 2):1427–31. doi: 10.1016/j.matpr.2020.07.063.

Raj, Jegan, Thomas Gebre, Idiris Mehamud, and Cheru Zeleka. 2016. 'Mechanical Property Evaluation of Bi- Directional Ethiopian Banana Fiber Epoxy Composites'. *Ijarse* 5(5):514–21.

Rajak, Dipen Kumar, Durgesh D. Pagar, Pradeep L. Menezes, and Emanoil Linul. 2019. 'Fiber-Reinforced Polymer Composites: Manufacturing, Properties, and Applications'. *Polymers* 11(10). doi: 10.3390/polym11101667.

Ramesh, M., K. Palanikumar, and K. Hemachandra Reddy. 2013. 'Comparative Evaluation on Properties of Hybrid Glass Fiber-Sisal/Jute Reinforced Epoxy Composites'. *Procedia Engineering* 51(NUiCONE 2012):745–50. doi: 10.1016/j.proeng.2013.01.106.

Ratna Kumari, Y., K. Ramanaiah, A. V. Ratna Prasad, K. Hemachandra Reddy, Srinivas Prasad Sanaka, and A. Kalyan Prudhvi. 2021. 'Experimental Investigation of Water Absorption Behaviour of Sisal Fiber Reinforced Polyester and Sisal Fiber Reinforced Poly Lactic Acid Composites'. *Materials Today: Proceedings* 44(xxxx):935–40. doi: 10.1016/j.matpr.2020.11.002.

Ravalika, Ayla, Suresh Nalla, and E. Surendar. 2017. 'Fabrication and Comparative Analysis of Mechanical Properties of Reinforced Sisal Fibre and Jute , Banana , Glass Fibre Composite Materials'. *International Journal of Innovative Science, Engineering & Technology* 4(10):147–53.

Reddy, K. Srinivasulu, and D. Sreedhar. 2011. 'Thermal Conductivity of Natural Fiber, Glass Fiber & CNTs Reinforced Epoxy Composites'. *International Journal of Current Engineering and Technology* 6(4):1196–98. doi: 10.14741/ijcet/22774106/6.4.2016.18.

Ribeiro Filho, Sergio Luiz Moni, Pablo Resende Oliveira, Luciano Machado Gomes Vieira, Tulio Hallak Panzera, Rodrigo Teixeira Santos Freire, and Fabrizio Scarpa. 2018. 'Hybrid Bio-Composites Reinforced with Sisal-Glass Fibres and Portland Cement Particles: A Statistical Approach'. *Composites Part B: Engineering* 149(May):58–65. doi: 10.1016/j.compositesb.2018.05.019.

Rosato, Don. 2014. 'Automotive Lightweighting with Alternative Materials'.

Sahu, Parul, and M. K. Gupta. 2018. 'PLA Coated Sisal Fibre Reinforced Polyester Composite: Static and Dynamic Mechanical Properties'. *Materials Today: Proceedings* 5(9):19799–807. doi: 10.1016/j.matpr.2018.06.343.

Sailesh, Ashwin, K. Palanikumar, R. Arunkumar, P. Ramu, A. Maxwell Briston, and E. Vija. Chandrakanth. 2015. 'Predicting the Best Flexural Strength of Banana-Bamboo-Glass Fiber Reinforced Natural Fiber Composites Using Taguchi Method'. *Applied Mechanics and Materials* 766–767(February):162–66. doi: 10.4028/www.scientific.net/amm.766-

767.162.

Sakin, Raif, Irfan Ay, and Ramazan Yaman. 2008. 'An Investigation of Bending Fatigue Behavior for Glass-Fiber Reinforced Polyester Composite Materials'. *Materials and Design* 29(1):212–17. doi: 10.1016/j.matdes.2006.11.006.

Samal, Arpita, and Shashwati Soumya Pradhan. 2020. 'Comparison Study of Mechanical Properties of Sisal-Jute and Jute-Banana Hybrid Composite'. *Materials Today: Proceedings* 21:1234–38. doi: 10.1016/j.matpr.2020.01.075.

Sampath, Boopathi, N. Naveenkumar, P. Sampathkumar, P. Silambarasan, A. Venkadesh, and M.Sakthivel. 2021. 'Experimental Comparative Study of Banana Fiber Composite with Glass Fiber Composite Material Using Taguchi Method'. *Materials Today: Proceedings* (xxxx). doi: 10.1016/j.matpr.2021.07.232.

Sanjay, M. R., G. R. Arpitha, and B. Yogesha. 2015. 'Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review'. Pp. 2959–67 in *Materials Today: Proceedings*. Vol. 2. Elsevier Ltd.

Sanjay, M. R., and B. Yogesha. 2018. 'Studies on Hybridization Effect of Jute/Kenaf/E-Glass Woven Fabric Epoxy Composites for Potential Applications: Effect of Laminate Stacking Sequences'. *Journal of Industrial Textiles* 47(7):1830–48. doi: 10.1177/1528083717710713.

Sanjay, Mr, and B. Yogesha. 2017. 'Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution'. *Materials Today: Proceedings* 4(2):2739–47. doi: 10.1016/j.matpr.2017.02.151.

Saxena, Tanvi, and V. K. Chawla. 2021. 'Effect of Fiber Orientations and Their Weight Percentage on Banana Fiber-Based Hybrid Composite'. *Materials Today: Proceedings*. doi: 10.1016/J.MATPR.2021.08.149.

Sgriccia, N., M. C. Hawley, and M. Misra. 2008. 'Characterization of Natural Fiber Surfaces and Natural Fiber Composites'. *Composites Part A: Applied Science and Manufacturing* 39(10):1632–37. doi: 10.1016/j.compositesa.2008.07.007.

Sharan Gupta, Upendra, Amit Dharkar, Mohit Dhamarikar, Arpit Choudhary, Dipanshu Wasnik, Pankaj Chouhan, Sudhir Tiwari, and Rajeev Namdeo. 2021. 'Study on the Effects of Fiber Orientation on the Mechanical Properties of Natural Fiber Reinforced Epoxy Composite by Finite Element Method'. *Materials Today: Proceedings* 45(February):7885–93. doi: 10.1016/j.matpr.2020.12.614.

Siva, R, B. Kesavaram, J. Jones Martin, G. Mathiselvan, Kaja Bantha, and M. Sangeetha. 2020. 'Mechanical Behavior of Sisal and Banana Fiber Reinforced Hybrid Epoxy

Composites Materials Today : Proceedings Mechanical Behavior of Sisal and Banana Fiber Reinforced Hybrid Epoxy Composites'. *Materials Today: Proceedings* (July 2021). doi: 10.1016/j.matpr.2020.10.805.

Siva, R., Snehith Reddy, K. Aditya, M. Sangeetha, N. Karthik, and Nivin Joy. 2020. 'Investigation of Mechanical Properties of Different Arrangement on Sisal/Kenaf/Aloe Vera Hybrid Composites'. *Materials Today: Proceedings* 44(xxxx):3557–63. doi: 10.1016/j.matpr.2020.09.407.

Srinivasan, Dharun Vadugappatty. 2014. 'Sisal Fiber / Glass Fiber Hybrid Nano Composite : The Tensile and Compressive Properties'. *5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India* (Aimtdr):1–6.

Suhad D. Salman, Zulkiflle Leman, Mohamed T. H. Sultan, Mohamad R. Ishak, Francisco Cardona. 2016. 'The Effects of Orientation on the Mechanical and Morphological Properties of Woven Kenaf-Reinforced Poly Vinyl Butyral Film'. Pp. 1176–88 in *Bio Resources*. Vol. 11.

Tekola, By Daniel Tasew Advisor :. Dr .. Beteley. 2020. 'Investigation the Physical Properties and Optimization the Process Parameters Of the Bio Composite Synthesized from Recycled Polyethylene Tere Phatalate (Pet) And Agave Sisalina (Sisal) Plant Fiber for House Celling Applications'. Addis Ababa Institute of Technology.

Teli, Mangesh D., and Jelalu M. Terega. 2017. 'Chemical , Physical and Thermal Characterization of Ensete Ventricosum Plant Fibre'. *International Research Journal of Engineering and Technology* 04(12):67–75.

Temesgen, A. G., Eren, R., & Aykut, Y. 2019. 'Investigation and Characterization of Fine Fiber from Enset Plant for Biodegradable Composites'. P. pp.978-605 in *In 17th National 3rd International the Recent Progress Symposium on Textile Technology and Chemistry*.

Tempelman, Erik, Hugh Shercliff, and Bruno Ninaber van Eyben. 2014. 'Resin Transfer Molding'. *Manufacturing and Design* 171–86. doi: 10.1016/B978-0-08-099922-7.00010-X.

Texas, Mfg. 2018. 'Technical Design Guide for FRP Composite Products and Parts : Techniques & Technologies for Cost Effectiveness'. 25.

Thiagamani, Senthil Muthu Kumar, Senthilkumar Krishnasamy, Chandrasekar Muthukumar, Jiratti Tengsuthiwat, Rajini Nagarajan, Suchart Siengchin, and Sikiru O. Ismail. 2019. 'Investigation into Mechanical, Absorption and Swelling Behaviour of Hemp/Sisal Fibre

Reinforced Bioepoxy Hybrid Composites: Effects of Stacking Sequences’. *International Journal of Biological Macromolecules* 140:637–46. doi: 10.1016/j.ijbiomac.2019.08.166.

Thomas, Sabu, Joseph Kuruvilla, Sant Kumar Malhotra, Koichi Goda, and Meyyarappallil Sadasivan Sreekala. 2012. ‘Polymer Composites’. *Polymer Composites* 1. doi: 10.1002/9783527645213.

Uzay, Cagri, Mete Han Boztepe, and Necdet Geren. 2016. ‘Impact Energy Absorption Capacity of Fiber Reinforced Polymer Matrix (FRP) Composites’. *Conference of the International Journal of Arts & Sciences* 09(June):211–20.

Venkata Deepthi, P., K. Sita Rama Raju, and M. Indra Reddy. 2019. ‘Dynamic Mechanical Analysis of Banana, Pineapple Leaf and Glass Fibre Reinforced Hybrid Polyester Composites’. *Materials Today: Proceedings* 18:2114–17. doi: 10.1016/j.matpr.2019.06.484.

Venkateshwaran, N., A. ElayaPerumal, A. Alavudeen, and M. Thiruchitrambalam. 2011. ‘Mechanical and Water Absorption Behaviour of Banana/Sisal Reinforced Hybrid Composites’. *Materials and Design* 32(7):4017–21. doi: 10.1016/j.matdes.2011.03.002.

Wennberg, David. 2013. *Multi-Functional Composite Design Concepts for Rail Vehicle Car Bodies*.

Wijianto, Rijal Muhamad Diar Ibnu, and H. Adityarini. 2019. ‘Effect of Naoh Concentration Treatment on Tensile Strength, Flexure Strength and Elasticity Modulus of Banana Fiber Reinforced Polyester Resin’. *Materials Science Forum* 961 MSF:10–15. doi: 10.4028/www.scientific.net/MSF.961.10.

Yorseng, Krittirash, Sanjay Mavinkere Rangappa, Harikrishnan Pulikkalparambil, Suchart Siengchin, and Jyotishkumar Parameswaranpillai. 2020. ‘Accelerated Weathering Studies of Kenaf/Sisal Fiber Fabric Reinforced Fully Biobased Hybrid Bioepoxy Composites for Semi-Structural Applications: Morphology, Thermo-Mechanical, Water Absorption Behavior and Surface Hydrophobicity’. *Construction and Building Materials* 235:117464. doi: 10.1016/j.conbuildmat.2019.117464.

Zeleke, Yerdawu, and Gideon K. Rotich. 2021. ‘Design and Development of False Ceiling Board Using Polyvinyl Acetate (PVAc) Composite Reinforced with False Banana Fibres and Filled with Sawdust’. *International Journal of Polymer Science* 2021. doi: 10.1155/2021/5542329.

Zhang, Jian Min, and Ton Peijs. 2010. ‘Self-Reinforced Poly(Ethylene Terephthalate) Composites by Hot Consolidation of Bi-Component PET Yarns’. *Composites Part A:*

Applied Science and Manufacturing 41(8):964–72. doi: 10.1016/j.compositesa.2010.03.012.

Zuccarello, Bernardo, and Giuseppe Marannano. 2018. ‘Random Short Sisal Fiber Biocomposites: Optimal Manufacturing Process and Reliable Theoretical Models’. *Materials and Design* 149:87–100. doi: 10.1016/j.matdes.2018.03.070.

APPENDIXES

Appendix A

Tensile test

የኢትዮጵያ የተስማሚነት ምዘና ድርጅት
Ethiopian Conformity Assessment Enterprise

ቁጥር (No) 2/22/2-1/3887/ለ
ቀን (Date) [illegible] 3 በ 2013

ስንት በቀለ
አዳማ

ሐምሌ 15 ቀን 2013 ዓ.ም በቁጥር 7/2.-1-3/TM80/0327/13 በተፃፈ ደብዳቤ የComposite ናሙናዎች እንዲፈተሽላችሁ መጠየቃችሁ ይታወሳል።

ስለሆነም በጥያቄው መሠረት ፍተሻው ተካሂዶ 8 ገጽ የፍተሻ ውጤት በዚህ ደብዳቤ ሸኝነት የላክን መሆኑን እንገልፃለን።

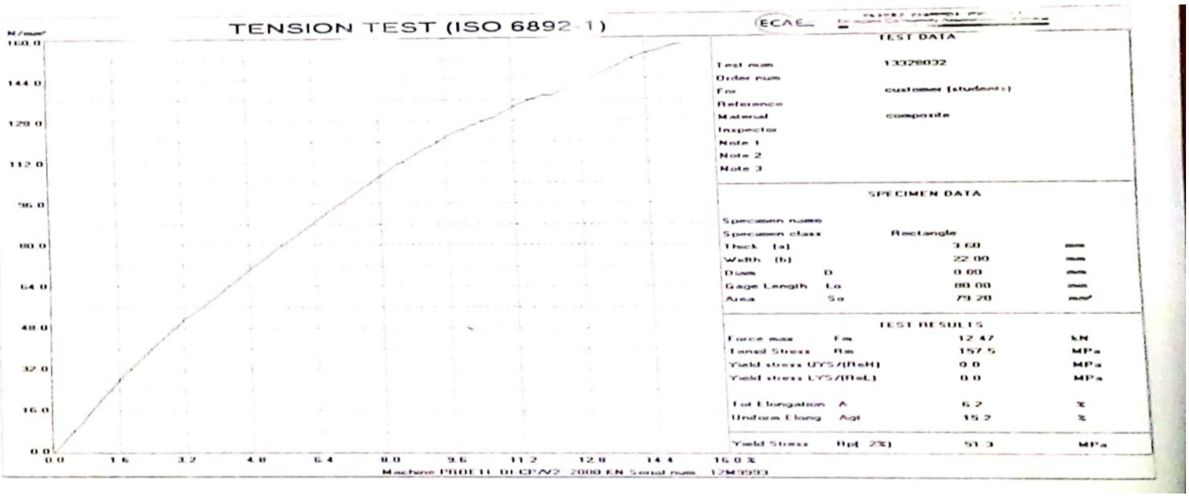
ከሠላምታ ጋር

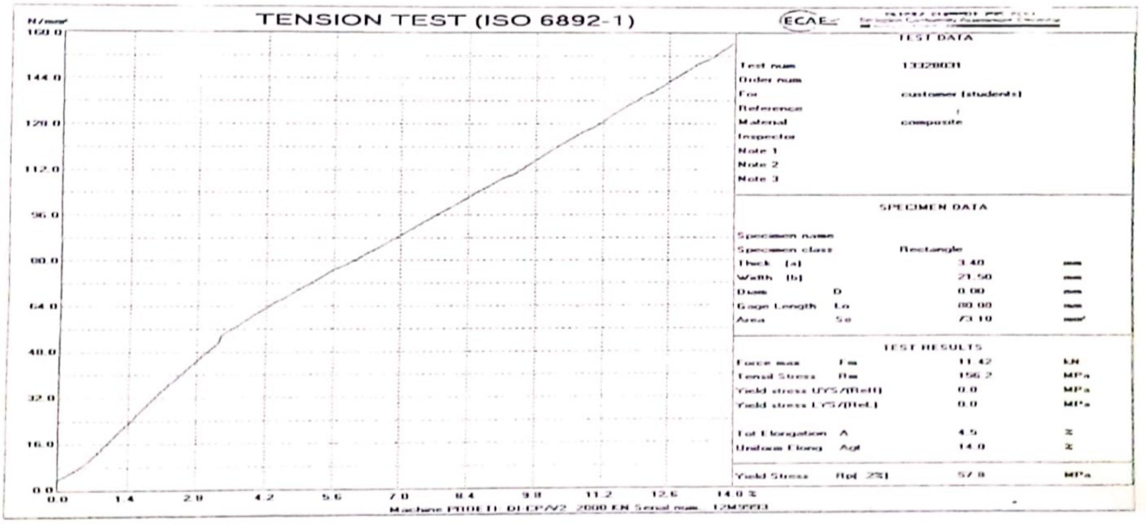
ሰለሞን ሙሉብርሃን
የደንበኞች አገልግሎት ሥራ አስኪያጅ

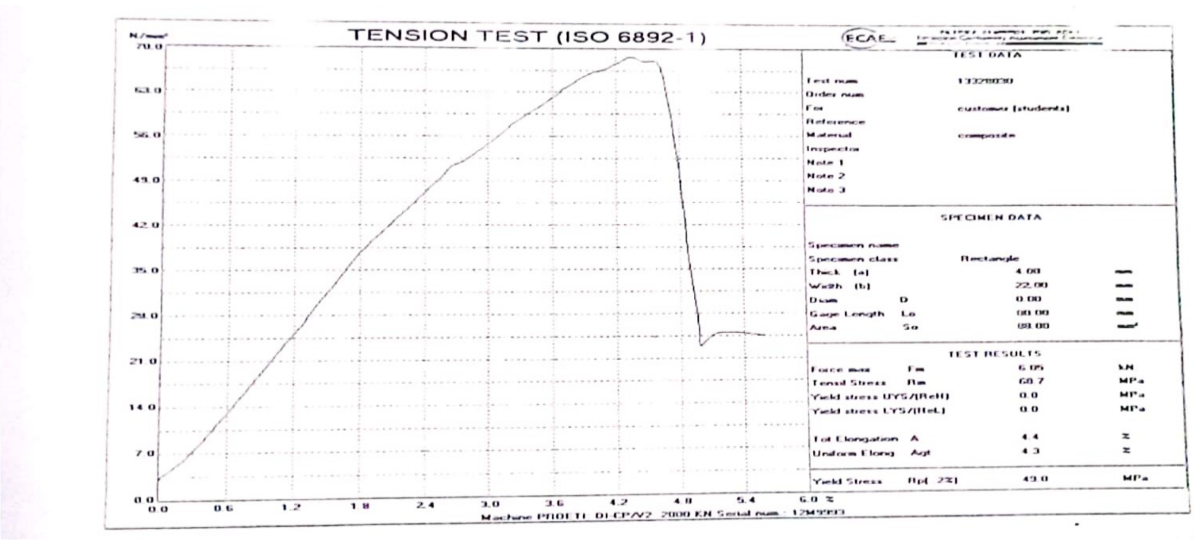
አባሪ፡ 8 ገጽ የፍተሻ ውጤት TLTR/0021-28/14

ግልባጭ፤
በኢትዮጵያ የተስማሚነት ምዘና ድርጅት
- ለደንበኞች አገልግሎት
  አዲስ አበባ

ወደ ላቀ ብቃት የሚያደርስ!
Moving you forward!


TENSION TEST (ISO 6892-1)
N/mm²
160.0
144.0
128.0
112.0
96.0
80.0
64.0
48.0
32.0
16.0
0.0
0.0 1.6 3.2 4.8 6.4 8.0 9.6 11.2 12.8 14.4 16.0 %
Machine PROETI DI CP/V2 2000 KN Serial num. 12M9993
ECAE
TEST DATA
Test num 13328032
Order num
For customer [students]
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.60 mm
Width (b) 22.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 79.20 mm²
TEST RESULTS
Force max Fm 12.47 kN
Tensil Stress Rm 157.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 6.2 %
Uniform Elong Agt 15.2 %
Yield Stress Rp(2%) 51.3 MPa


TENSION TEST (ISO 6892-1)
N/mm²
160.0
144.0
128.0
112.0
96.0
80.0
64.0
48.0
32.0
16.0
0.0
0.0 1.4 2.8 4.2 5.6 7.0 8.4 9.8 11.2 12.6 14.0 %
Machine PROETI DI CP/V2 2000 KN Serial num. 12M9993
ECAE
TEST DATA
Test num 13328031
Order num
For customer [students]
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.40 mm
Width (b) 21.50 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 73.10 mm²
TEST RESULTS
Force max Fm 11.42 kN
Tensil Stress Rm 156.2 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 4.5 %
Uniform Elong Agt 14.0 %
Yield Stress Rp(2%) 57.8 MPa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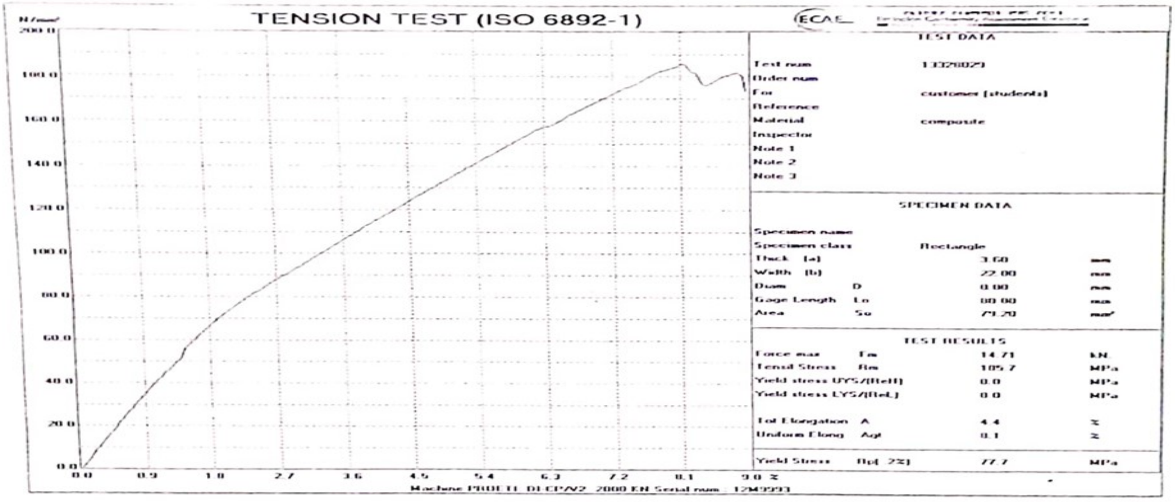
N/mm²
70.0
63.0
56.0
49.0
42.0
35.0
28.0
21.0
14.0
7.0
0.0
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0 %
Machine PROETI DI CP/V2 2000 KN Serial num. 12M9993
ECAE
TEST DATA
Test num 13328030
Order num
For customer [students]
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.00 mm
Width (b) 22.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 88.00 mm²
TEST RESULTS
Force max Fm 6.05 kN
Tensil Stress Rm 68.7 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 4.4 %
Uniform Elong Agt 4.3 %
Yield Stress Rp(2%) 49.0 MPa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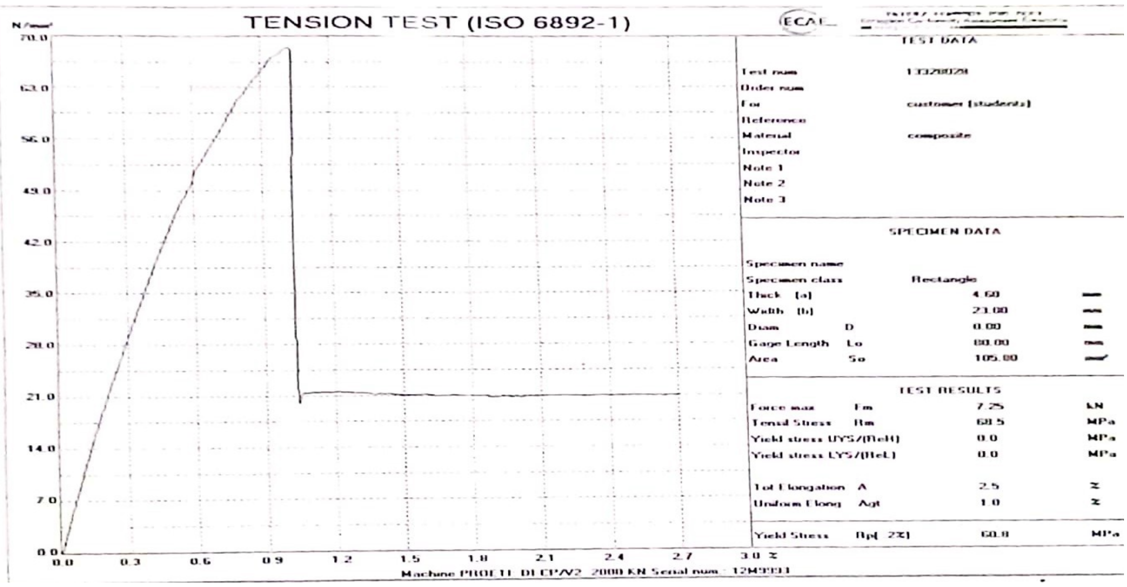
N/mm²
TEST DATA
Test num 13328029
For customer (students)
Material composite
SPECIMEN DATA
Specimen class Rectangle
Thick (a) 3.60 mm
Width (b) 22.00 mm
Gage Length Lo 80.00 mm
Area So 79.20 mm²
TEST RESULTS
Force max Fm 14.71 kN
Tensil Stress Rm 185.7 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 4.4 %
Uniform Elong Agt 8.1 %
Yield Stress Rp(.2%) 77.7 MPa
Machine PROETI DECP/V2 2000 KN Serial num : 12M9993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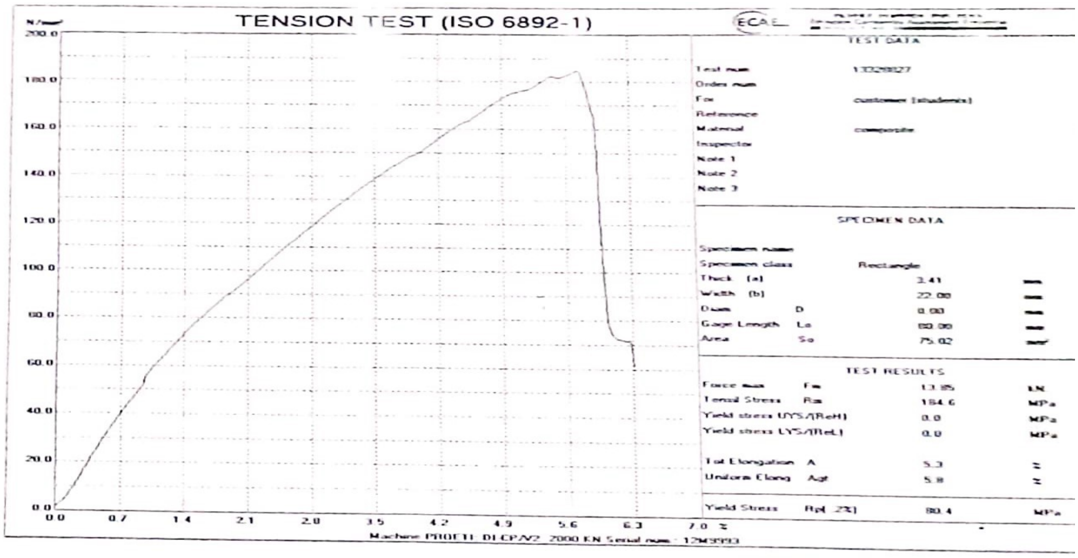
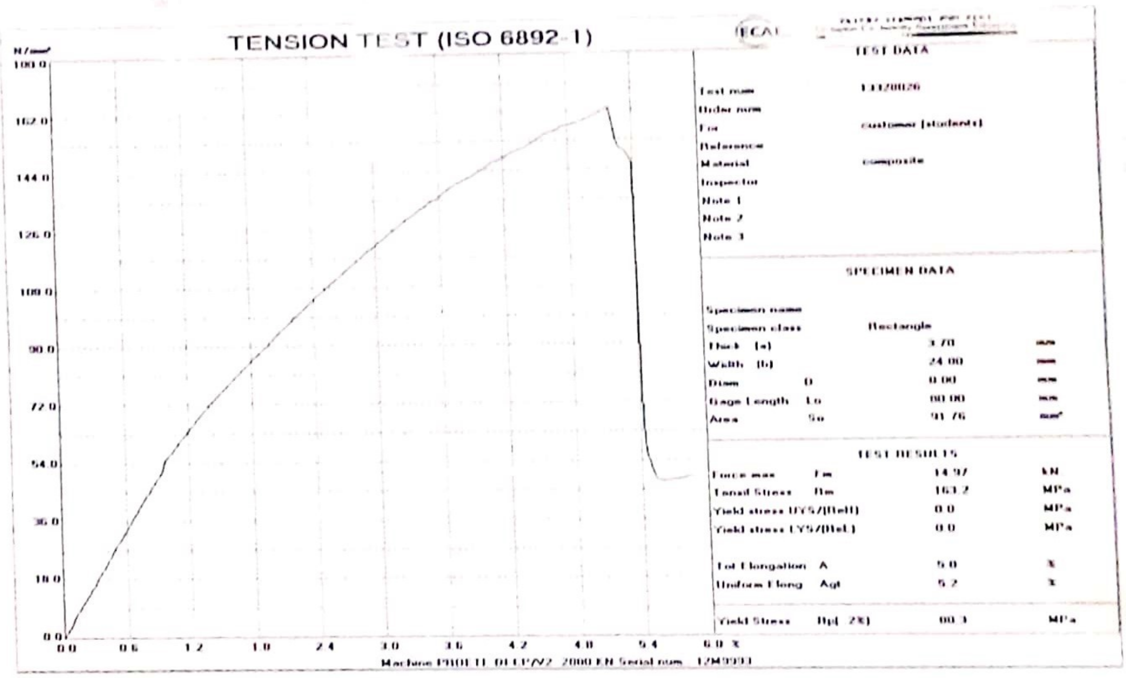
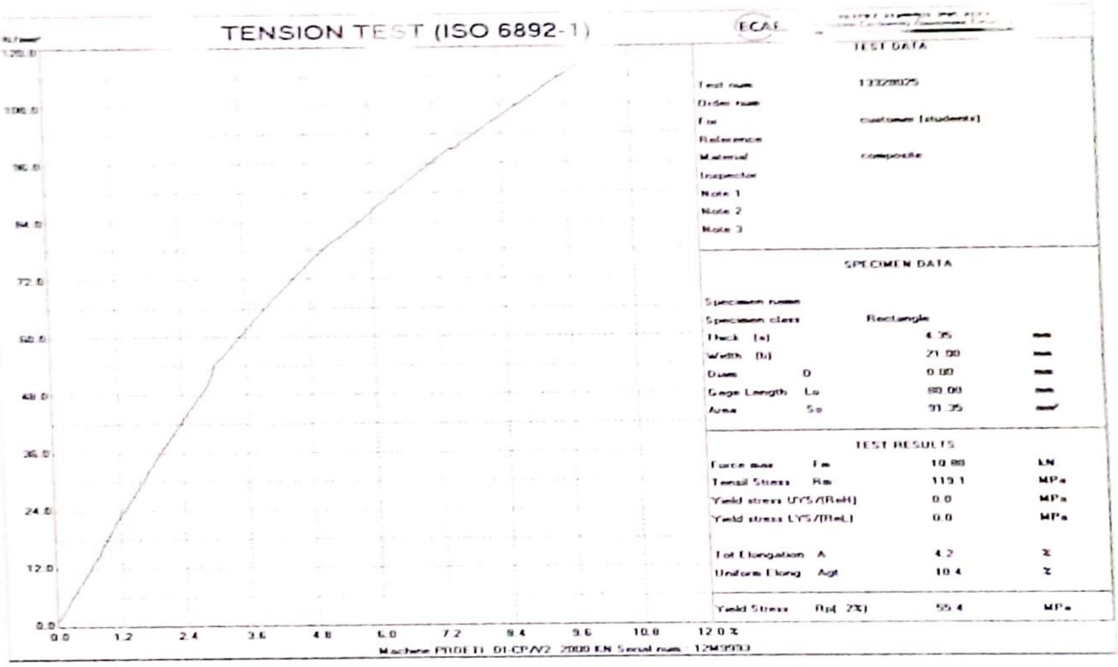
N/mm²
TEST DATA
Test num 13328028
For customer (students)
Material composite
SPECIMEN DATA
Specimen class Rectangle
Thick (a) 4.60
Width (b) 23.00
Gage Length Lo 80.00
Area So 105.80 mm²
TEST RESULTS
Force max Fm 7.25 kN
Tensil Stress Rm 68.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 2.5 %
Uniform Elong Agt 1.0 %
Yield Stress Rp(.2%) 60.8 MPa
Machine PROETI DECP/V2 2000 KN Serial num : 12M9993

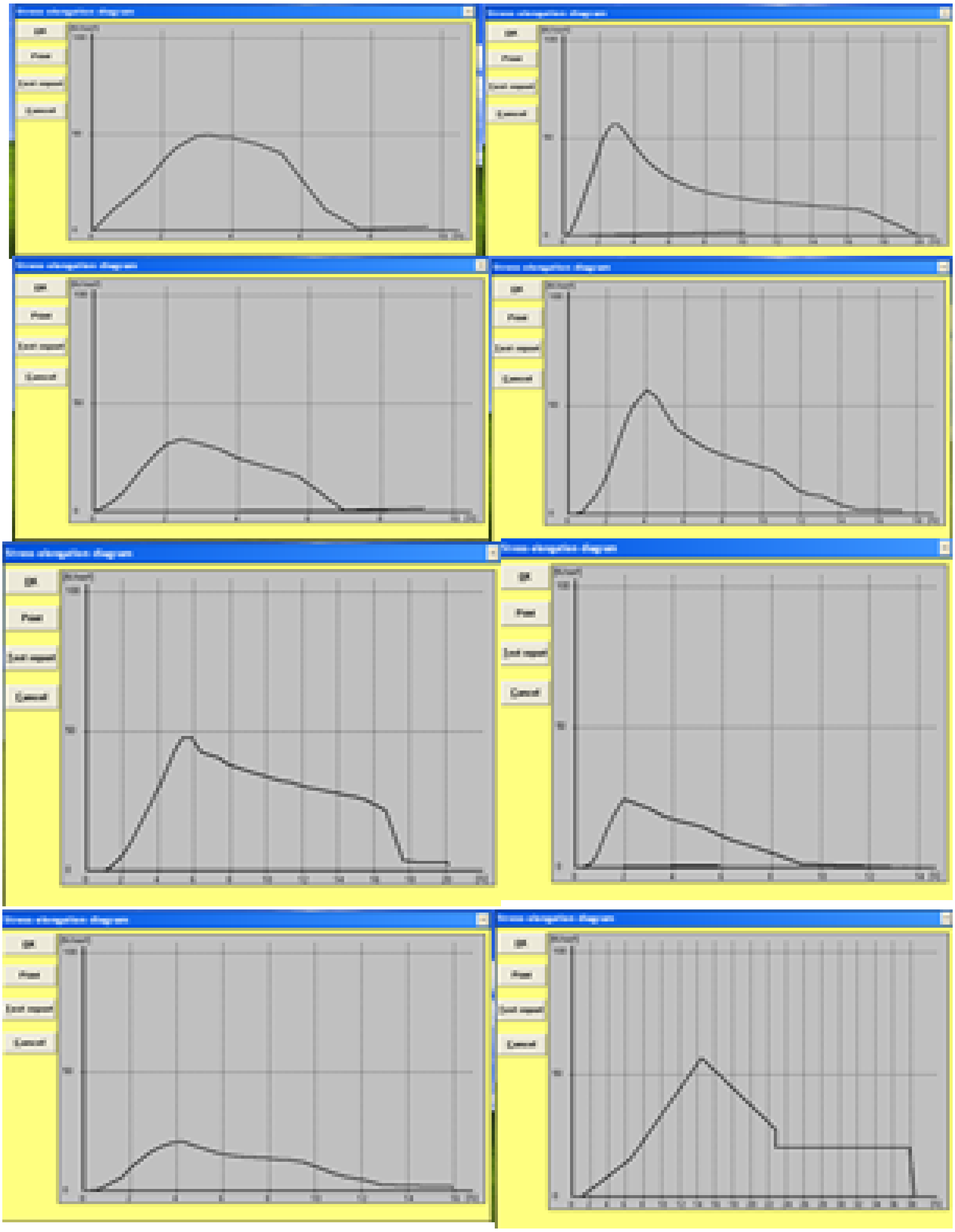

TENSION TEST (ISO 6892-1)
N/mm²
TEST DATA
Test num 13328027
For customer (students)
Material composite
SPECIMEN DATA
Specimen class Rectangle
Thick (a) 3.41
Width (b) 22.00
Gage Length Lo 80.00
Area So 75.02 mm²
TEST RESULTS
Force max Fm 13.85 kN
Tensil Stress Rm 184.6 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 5.3 %
Uniform Elong Agt 5.8 %
Yield Stress Rp(.2%) 80.4 MPa
Machine PROETI DECP/V2 2000 KN Serial num : 12M9993


TENSION TEST (ISO 6892-1)
N/mm²
180.0
162.0
144.0
126.0
108.0
90.0
72.0
54.0
36.0
18.0
0.0
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0 %
Machine PROETI DI-CP/V2 2000 KN Serial num 12M9993
ECAL
TEST DATA
Test num 13120026
Order num
For customer [students]
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 3.70 mm
Width (b) 24.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 91.76 mm²
TEST RESULTS
Force max Fm 14.97 kN
Tensil Stress Rm 163.2 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 5.0 %
Uniform Elong Agt 5.2 %
Yield Stress Rp(.2%) 80.3 MPa


TENSION TEST (ISO 6892-1)
N/mm²
120.0
108.0
96.0
84.0
72.0
60.0
48.0
36.0
24.0
12.0
0.0
0.0 1.2 2.4 3.6 4.8 6.0 7.2 8.4 9.6 10.8 12.0 %
Machine PROETI DI-CP/V2 2000 KN Serial num 12M9993
ECAL
TEST DATA
Test num 13328025
Order num
For customer [students]
Reference
Material composite
Inspector
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.35 mm
Width (b) 21.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 91.35 mm²
TEST RESULTS
Force max Fm 10.88 kN
Tensil Stress Rm 119.1 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 4.2 %
Uniform Elong Agt 10.4 %
Yield Stress Rp(.2%) 55.4 MPa

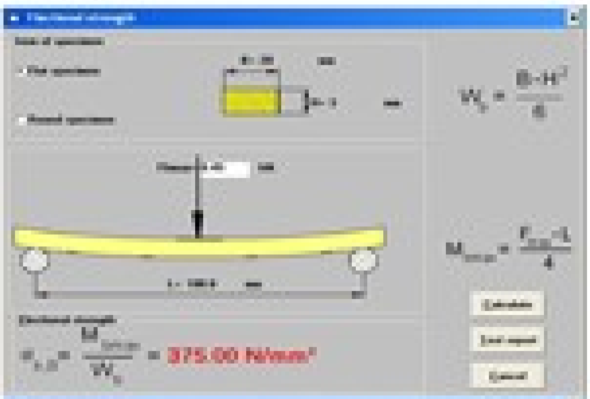
Appendix B

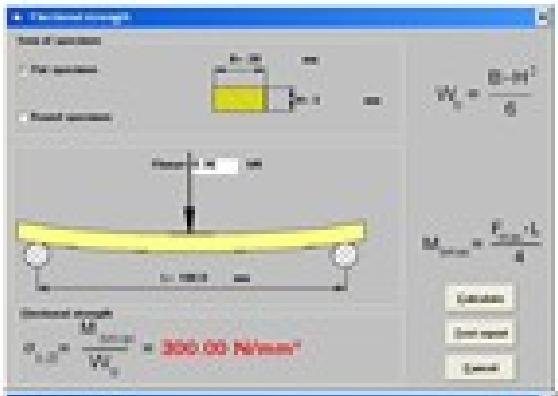
Compression Test

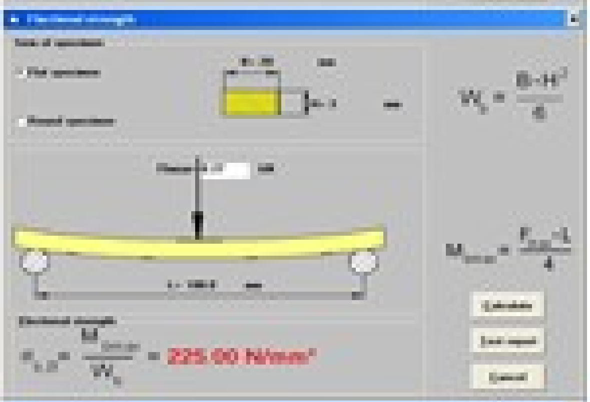


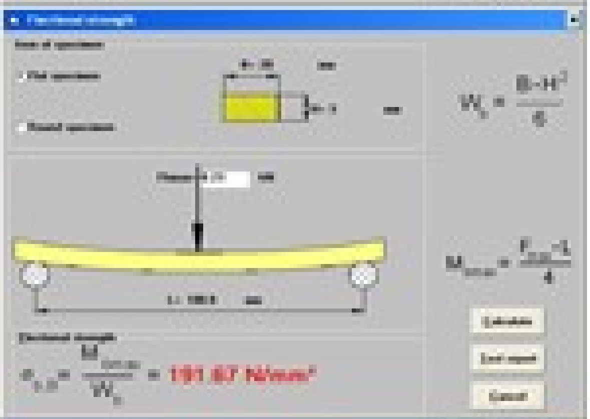
Appendix C

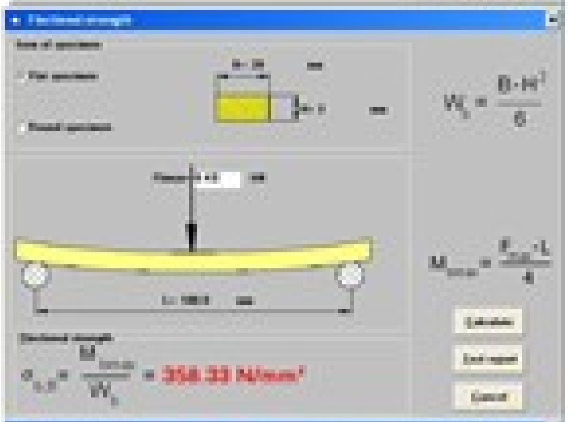
Flexural Test

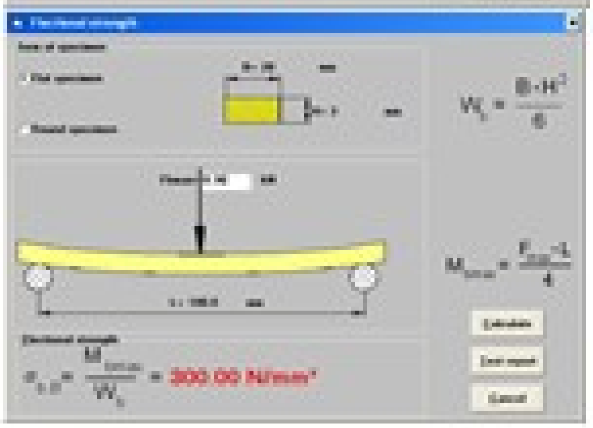


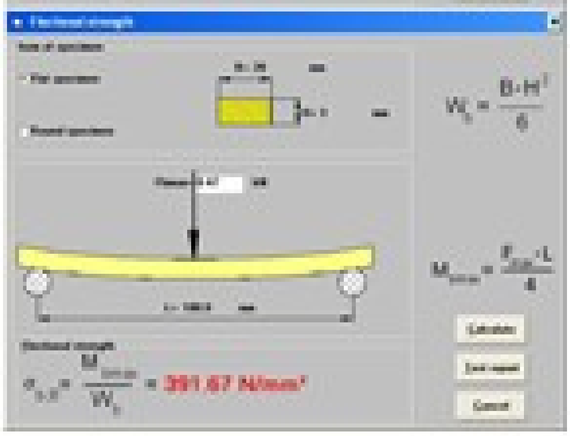












Appendix D

Hardness Test