Experimental Investigation and Optimization of Drilling Parameters of Hybrid Polymer Matrix composites from Bamboo/sisal and Al_2O_3 Reinforced

Sisay Diriba Bedada

A Thesis Submitted to Department of Mechanical Engineering School of Mechanical, Chemical and Material Engineering

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

Office of Graduate Studies
Adama Science and Technology University

June, 2024

Adama, Ethiopia

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ADVISOR:DR.Moera Gutu (Associate Professor)

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APPROVAL SHEET

I, the advisor of the thesis entitled, the advisors of the thesis entitled" Experimental investigation and optimization of drilling parameters of hybrid polymer matrix composites from bamboo/sisal and Al_2O_3 reinforced "and developed by sisay Diriba Bedada, hereby certify that the recommendation and suggessions made by the board of examiners are appropriately incorprated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Sisay Diriba Bedada have read and evaluated the thesis entitled ''Experimental investigation and optimization of drilling parameters of hybrid polymer matrix composites from bamboo/sisal and Al_2O_3 reinforced '' and examined the candidate during open defense.This is, to certify that the thesis is accepted for partial fulfulliment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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DECLARATION

I hereby declare that this Master thesis entitled ‘‘Experimental investigation and optimization of drilling parameters of hybrid polymer matrix composites from bamboo/sisal and Al_2O_3 reinforced ’’ is my own work and has not been submitted to any university for similar purpose. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION OF ADVISORS

We, the advisors of this thesis hereby certify that we have read the final version of the thesis entitled ‘‘Experimental investigation and optimization of drilling parameters of hybrid polymer matrix composites from bamboo/sisal and Al_2O_3 reinforced ’’ prepared under our guidance by Sisay Diriba Bedada submitted in partial fulfillment of the requirements for the degree of Master’s of the requirements for the degree of Master’s of Science in Manufacturing Engineering. Therefore,we recommended the submission of the final of the revised version of the thesis to the department following the applicable procedures.

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ACKNOWLEDGMENT

First and foremost, praise and thank God, the Almighty, for His abundant blessings during my research work to complete the thesis.

I would like to express my deep and sincere gratitude to my thesis advisor, Dr. Moera Gutu, an assistant professor at Adama Science and Technology University, Adama, for allowing me to do research and providing invaluable guidance throughout this thesis work. His dynamism, vision, sincerity, and motivation have deeply inspired me. It was a great privilege and honor to work and study under his guidance. I am extremely grateful for what he has offered me. The precious advice and help he has given to me in the achievement of this research work. I would also like to thank him for his friendship, empathy, and great sense of humor. I am extending my heartfelt thanks to his family and friends for their acceptance and patience during the discussion I had with him on this thesis work.

I would like to express my sincere gratitude to Adama Science and Technology University for allowing me to fulfill my dream of attending the Technology University, the administration of the school of mechanical, material, and chemical engineering, and the school of research and graduate studies for their kind assistance in pursuing and completing my education. I would also like to thank every one of my teachers.

This thesis is wholeheartedly dedicated to my beloved families who has been my source of inspiration and strength when I give up, and who continually provide their moral, spiritual, emotional, and financial support.

Friends here at Adama Science and Technology University. You all are like relatives to me. Thank you, everybody!

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ACRONOMYS AND ABBREVATIONS

ASTM	American Society for Testing Materials
CNC	Computer numerical control machine
C	Circularity
Df	Delamination factor
Dmax	Maximum diameter
Dmin	Minimum diameter
GA	Genetic Algorithm
HSS	High speed steel
NFC*s*	Natural fiber reinforced composites
OP	Optical Microscope
PM	Polymer matrix
Ra	Surface roughness
RSM	Response surface method
S/N	signal to noise ratio
% Wt.	Weight Percentage

ABSTRACT

Composites made up of heterogeneous (physically and chemically) phases have the potential to be used in the automotive, aerospace, construction, marine, and research industries. Natural fiber composite (NFC) materials are gaining popularity due to their eco-friendliness, lightweight nature, life-cycle superiority, low cost, and acceptable specific strength properties with high toughness. This thesis investigated the optimization of drilling parameters for composites fabricated from bamboo/sisal fibers reinforced with varying concentrations of alumina. The primary objective was to enhance the efficiency and quality of drilling operations by determining the optimal settings for spindle speed, feed rate, and drill diameter using Design Expert software and the Box-Behnken design, a robust response surface methodology (RSM). Composite samples were fabricated with different alumina concentrations, and their mechanical and physical characterizations of the composite material were conducted. For drilling operation experimental trials were conducted at spindle speeds of 500 rpm, 750 rpm, 1250 rpm; feed rates of 0.03 mm/rev, 0.06 mm/rev, 0.12 mm/rev; and drill diameters of 3 mm, 6 mm, 12 mm on the CNC machine . A *Zeta-20, 3D optical surface roughness measuring instrument was used to determine the surface roughness value. Delamination and circularity were measured in Image software. A genetic algorithm was employed using MATLAB, targeting the minimization of surface roughness, delamination and circularity.*

Key word: Hybrid composite, Drilling, Delamination, Surface roughness, RSM, Box-Behnken

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Composite materials, known for their superior mechanical properties and versatility, have revolutionized various industries. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly Tsai and Hahn (2018). Composite materials are replacing the traditional materials in various application, like aerospace, automobile, construction and other, because of their light weight, high modulus, high specific strength, and low thermal expansion. It is economically an alternate material when compared with cast iron and steel (Arun Ramnath et al., 2018). Composite materials are the combination of two or more materials in such a way that certain improved or desired properties are achieved. In a composite, the dispersed phase(s) is distributed in a continuous medium called matrix. The only condition is that the dispersed phase should retain its original identity after processing and/or during service/reprocessing.

The properties of the composites are a function of the properties of the constituents, their relative proportion and the geometry, distribution, and orientation of the dispersed phase (Balasubramanian, 2014).The elements of the composite must not react with one another at high temperatures, which result in early failure of the composite (Sharma et al., 2020). Matrix phase is continuous, homogeneous and monolithic material such as ceramics, metals or polymers used to embed, and transfer load to reinforcement. Reinforcement phase are dispersed part that can be fiber, particulates, and whiskers, harder or softer depend on the application and used to improve characteristic of matrix. Interface is bonding area of matrix and reinforcement. A fundamental requirement for obtaining high-performance composites is the efficiency of the stress transfer which takes place at the fiber/matrix. Fibers support the applied mechanical load while the matrix transfers and redistributes it from one fiber to the other through the interface, provided that the fiber/matrix adherence is good (Le Moigne et al., 2018).

Natural Fiber is any hair like raw material directly obtainable from an animal, plant, or mineral source or an agglomeration of cells in which the diameter is negligible in comparison with the length. Cellulose is main constituent of plant fibers. NFs such as nettle, sisal, baggase, cotton, pineapple, coir, banana, kenaf, and bamboo have benefits in terms of environmental impact such as recyclability, renewability and biodegradability, as well as lower raw material costs and light weight, and are used as reinforcement in composite fabrication (Petroudy, 2017). However natural fibers have disadvantages of being hydrophilic, lower durability and lower impact strength (Zulkafli et al., 2019). Using natural fibers as a single reinforcement is inadequate to satisfy the technical needs of the composite. Methods of using fiber and matrix toughening, interface toughening, through-thickness reinforcement, and hybridizing techniques to improve the impact properties of composites to have high quality of drilled part (Razali et al., 2017). Hybrid composites are the combination of two or more reinforced elements in single matrix or a mixture of different matrices merged with a single reinforcing element. Hybridization of fibers can enhance the properties by taking the advantages of each of the individual fibers. The physical and mechanical properties of the hybrid composites is dependent on the aspect ratio of fiber, properties of individual fiber, orientation of fiber, length of individual fiber, adhesion between fiber and matrix and stacking sequence of both fibers (Karthi et al., 2020).

The natural fiber composite materials (NFCs) have emerged as a replacement to synthetic fiber reinforced composites and other old-style engineering materials (Malviya et al., 2020) **.**However, there are disadvantages of natural fiber reinforced composites such as inadequate adhesion, poor wettability; high level of moisture absorption, and deboning (Jusoh et al., 2016). Machining of NFCs composites creates challenges that do not usually come across in machining of conventional metallic/monolithic material as the composite materials are heterogeneous, anisotropic and abrasive in nature. Several manufacturing and machining defects include matrix imperfection, resin-starved area, resin-rich area, voids, cracks, blisters, deboned, delamination, fiber pull-out and burning (Gohil et al., 2015).

Delamination is the damage stumble in drilling. Delamination of the component surface at entry and exit of the drill was occurred .Elimination rates of up and about to 60% are accounted in case of aircraft assembly. Delamination can significantly lower the performance of the finished part. The different parameters used to measure delamination are delaminated area, crack length, ratios of delaminated areas and delamination factor (Rajmohan et al., 2019**) .**

Peel-up delamination: is observed at the top surface of the composite. When the drill bit comes in contact with the composite, there occurs the cutting force tangential to the periphery of the drill bit. It makes the drill grooves pull the upper laminates and cause the separation of fibrous layers at the surface.

Push-out delamination: It appears at the exit of a hole while drilling FRPCs. When the drill bit approaches the hole exit, it has less thickness of the composite to drill and at some point, when the thrust force exceeds the bonding strength of laminates, then there occurs the layer separation of laminates at the exit. The drill pushes the laminates out, and causes the formation of push-out delamination. Push-out delamination turns out to be more severe than peel-up delamination while drilling FRPCs. The propagation of delamination and the size of the damage are influenced by the drilling thrust force developed during the process. High thrust force results from the use of improper drilling parameters, improper tool geometry and the nature of the material being drilled (Karimi et al., 2018).

The surface roughness mainly depends on the machining parameters while drilling of fiber reinforced polymer composite such as: spindle speed, feed rate, and point angle and drill diameter. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes and aesthetic requirements (Shahabaz et al., 2020)**.**

The drilling of composites becomes vital for manufacturing industries. This proposal deals with the influence of fabrication parameter, on drilling of natural fiber composite and the optimization of drilling parameter to enhance the machining performance. The efficiency of machining is described in terms of tool life, production, quality of machined surface (defect free). In these study the enhancement of interfacial bond strength which cause degradation of physical and mechanical properties is examined. The surface roughness (Ra) and defect of drilled nettle-sisal reinforced epoxy composite with woven sisal and nettle random orientation is analyzed.

1.2 Problem Statement

Composite materials are highly required in all sector of applications. These materials are replacing conventional materials and particular natural reinforced composite materials are of great interest owing to their eco-friendly nature, lightweight, life-cycle superiority, low cost, and also have acceptable specific strength properties with high toughness. NFRCs are one of them used in structural application, railing and shipping container(Nurazzi et al., 2021) . However, machining of composites creates challenges that do not usually come across in machining of conventional metallic/monolithic material as the composite materials are heterogeneous, anisotropic and abrasive in nature. Most common defects during drilling of composites are peel-up delamination, push-out delamination, geometric defects, matrix degradation, burrs, tearing, thermal damages and also surface roughness effect (Helmi Abdul

Kudus et al., 2021). Among these defects of drilling, delamination and surface roughness effect are considered as the major defect. The defects are depend on various parameter such as work material, cutting tool, drill, material, fiber material ,fiber thickness, fiber orientation fiber matrix deboning and process parameter (feed and speed). Hence, optimization of mechanical property and drilling process parameter have vital role to obtain minimized defect of drillled hole. In this thesis optimization of the drilled part through material property using different alumina fiber Wt%. and drilling process parameter (speed , feed rate and drill diameter) are a major concern to obtain optimum surface roughness and defect free hole.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this thesis work is to investigate drilling and optimization of the process parameters of fabricated natural fiber compsites.

1.3.2 Specific objective

1. Synthesis bamboo-sisal-alumina reinforced composite materials
2. Investigate mechanical and physical properties of developed hybrid composites
3. Investigate damage mechanism during drilling operation
4. Optimize drilling process parameters for optimum responses
5. Fracture analysis of composite failure using optical microscope for delamination factor

1.4 Significance of Study

Hybrid bamboo-sisal- alumina composites have a significant contribution to numerous technical applications. Drilling challenges limit the use of composites in industrial sectors, interior automotive parts, and furniture. Investigation of damage assessment through fabrication and drilling parameter enable the utilization of these composite. Therefore, this study has crucial benefits academically and practically to individual and to other manufacturing sector-for further research findings.

1.5 Scope of Study

The research focuses on the investigation of impact of fabrication parameters on hybrid bamboo-sisal-alumina-reinforced composites during drilling operations, as well as process parameter optimization to improve surface roughness. Fabrication of bamboo-sisal-alumina reinforced polyster hybrid composites with varying fiber weight composition of alumina ; mechanical and physical property investigation; experimental investigation of CNC drilling; and optimization of drilling process parameters for optimum surface roughness are all part of this thesis work.

1.6 Motivation

A lot of researchers have been researching on optimization of drilling parameter without considering fabrication process. Loss of properties during drilling reduces structural strength and lowers assembly tolerance which can be detrimental to the long-term performance of the composite material. By controlling fabrication parameter and machining parameters drilling can be conducted with reduced delamination, required circularity, and surface roughness. Considering the increasing structural application of composite materials, the limitation in their machining performance should be envisaged in a detailed and systematic way for producing quality holes with reduced damage should be identified.

CHAPTER TWO

LITREATURE REVIEW

2.1 Introduction

This chapter provides a review of the published literature on introduction to composite materials, reinforcement effects on mechanical properties, drilling of composites, the effect of drilling parameters on surface finish, delamination, and optimization of process parameters of hybrid natural fiber polymer composites to place the research problem in perspective. From the summary of this literature review, the gaps are identified and also discussed for further investigations and studies.

2.2 Composite Materials

Composites are defined as a material combination of two or more materials that produces better properties than the individual components used alone. Unlike metallic alloys, each material retains its distinct chemical, physical, and mechanical properties .A reinforcement and a matrix are the two components. When compared to bulk materials, the main advantages of composite materials are their high strength and stiffness combined with low density, allowing for weight reduction in the finished part.

2.3 Characteristic of Composite Materials

Composite properties are heavily influenced by the properties of their constituent materials (both continuous phase and discontinuous phase), their distribution, and their interaction. The weight percentage of reinforcement constituents in the matrix material also influences composite properties. Aside from the nature of the primary material properties, the geometry of the reinforcement (shape, size, and distribution) has a significant impact on the composite's properties. The orientation of the reinforcement influences the properties of composites as well. The interfacial area is determined by the volume fraction, which is important in determining the extent of the interaction between the reinforcement and the matrix (Hoa, 2017). Proper selection of factors influence the characteristic of composites like, density, tensile strength and modulus, compressive strength and fatigue failure of part.

2.4 Classification of Composites

Based on the type of matrix material used, synthetically made type of composite can be classified as metal matrix composites (MMCs), polymer matrix composites (PMCs) and ceramic matrix composites (CMCs). Man-made composite materials can also be classified as Particulate Composites, Fibrous Composites and Laminate Composites based on the reinforcing material structure (Callister Jr & Rethwisch, 2020).

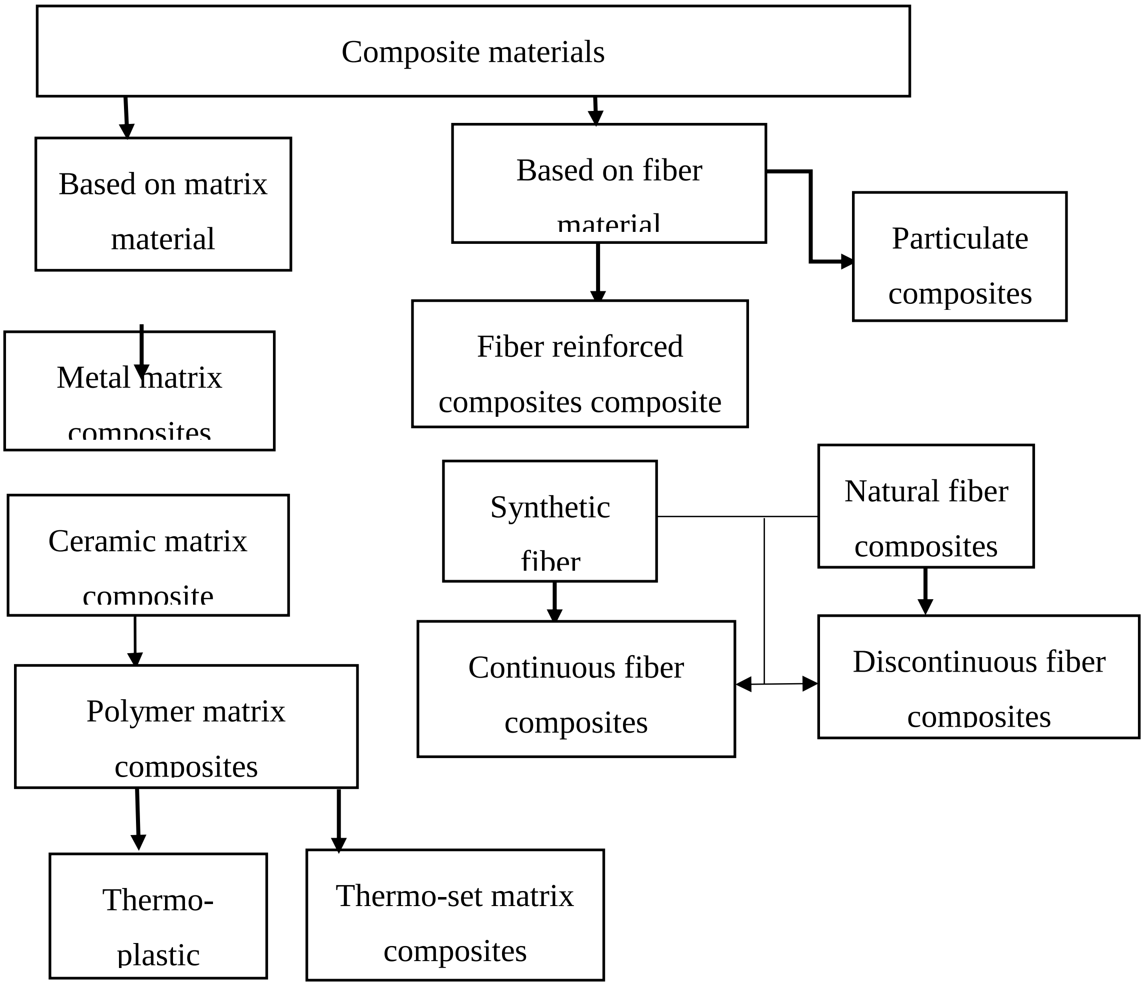


Figure 2.1 Classification of Composites

2.5 Polymer Matrix Composites

Polymer-matrix composites (PMCs) are made up of a polymer resin matrix and fiber reinforcement. PM are a collection of molecules that resemble long chains and are made up of several little repeating units by covalent bond. Because of their room-temperature properties, ease of fabrication, and low cost, these materials are used in the widest range of composite applications and in the greatest quantities. However, compared to ceramic and metal, they have low strength and are less rigid, making them unsuitable for structural use. To compensate for this effect, PM is reinforced with fiber, either natural or synthetic. Polymer matrices can be thermoplastic or thermoset depending on how heat affects their properties (Jawaid et al., 2017). Because of some advantages over thermoplastic polymers, thermoset polymers are frequently used as matrix materials. The thermoset polymer matrix materials are polymers that are cured into a solid form and cannot be returned to their unusual uncured form and also have better overall economics, a high temperature, good mechanical, wetting, and adhesion properties, and are easier to dispose. The transformation from the liquid state to the solid state involves a chemical reaction that takes place mostly during the composite part manufacturing stage. Catalysts or other reactive molecules may be needed to initiate and/or accelerate the chemical reaction. As curing proceeds, pre-polymer molecules become chemically linked with each other to form a 3D molecular mass with viscosity approaching infinity (Mallick, 2017). Epoxy, polyester, vinyl ester, and phenolic are the most common thermoset resin materials. Reinforcing fibers modify the characteristics of PMC such as fracture toughness, tensile strength and stiffness (Asghar et al., 2021).

2.5.1. Fiber reinforced composites

Synthetic fibers and natural fibers are the two types of fibers used in the manufacturing of composite materials. Natural fiber is like bamboo, sisal, and flax, banana, and jute preferred over synthetic fiber due to benefits such as biodegradability, environmental friendliness, and renewable nature. Natural fiber reinforced composites have the potential to minimize component cost and material waste in automotive applications. The rising need for lighter, safer, and more fuel-efficient automobiles has led to the increased use of natural fiber composite materials in automotive applications (Naik & Kumar, 2021).However, due to its cellulosic component, it has low mechanical strength, high water absorption, and thermal degradation at low temperatures.

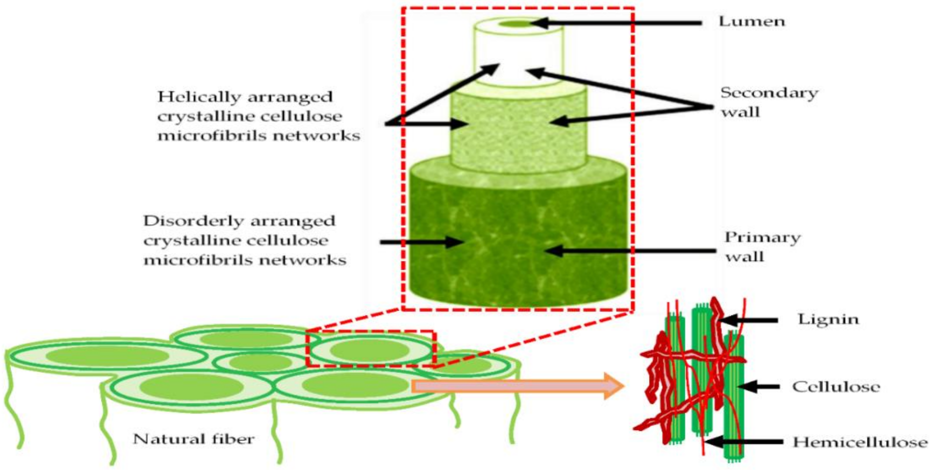


Figure 2.2 Structure of natural fiber (Thapliyal et al., 2023)

2.5.1.1. Bamboo and sisal fiber as polymer reinforcement

Bamboo plant are grasses, versatile renewable resources, with a high potential for socioeconomic development and for environmental improvement. Ethiopia has greatest bamboo resources (Yushania alpine and Oxytenantheria abyssinica) in Africa representing a significant proportion of Africa's total bamboo resources (Kassahun, 2014).Because of high fiber content and easier method of extraction fiber from hollow type highland bamboo (Yushania Alpina), is used for reinforcement as fiber in a polymer (Mohammed, 2021). Chemical composition of bamboo fibers are Cellulose, hemicellulose and lignin which contributes more than 95% of the bamboo total mass. Naturally bamboo is unidirectional fiber reinforced composite comprising long and parallel cellulose fibers surrounded by ligneous matrix (Chokshi et al., 2020). The bamboo plants are short life cycle to grow, and its fibers have higher strength to weight ratio comparatively to conventional metallic fibers and good amount of availability (Jena, 2018).

Sisal plant is a plant in the same family as aloe vera. It resembles a vast aloe vera plant, with very coarse leaves that are pointy on the ends, and it can grow to be six feet tall. It produces a rigid fibre that is used as fiber in a mixture of different products. Sisal fiber is a kind of natural fiber, which retains high specific strength and modulus, low cost, recyclability, easy availability (Sisal Initiative – Ethiopia). The chemical composition of sisal fiber depends on the location, age factor, and like other natural fibers, sisal fiber contains cellulose, lignin, and hemicellulose. The physical and mechanical behaviors of sisal fiber depend on their source, age, and location, their fiber diameter, experimental temperature, gauge length, and strain rate (Naveen et al., 2019).

Figure 2.3 sisal plant

Sisal fiber is a potential reinforcement for polymer composites. As high temperatures are encountered during the thermosets' curing step, sisal fiber's thermal resilience is essential in the production of composite materials. The walls of the sisal fiber undergo pyrolysis during high-temperature processing, resulting in the formation of charred layers. To prevent further degradation, the charred layers will form a protective layer around the lignocellulose. Thus, the thermal stability of the fiber, the bonding behavior of sisal, and the distribution of the fiber in the composites are important factors in the fabrication of sisal-reinforced composites (Baloyi et al., 2021).Sisal is a strong and eco-friendly material that can be used to replace asbestos and fiberglass in composite materials (Ribeiro Filho et al., 2018) for various uses, including the automobile industry. It is commonly used for mooring small craft, lashing cargo, and handling cargo. It has several advantages in terms of product design flexibility, insulation, noise absorption, and impact resistance. Due to these properties, sisal reinforced composite is used in building materials like roofing sheets, locomotives (like gear case, and main doors), automobiles like the German automotive industry, the door panel of an E-class Mercedes, and military applications like transportation vehicles and safety equipment (Mamo & Subramanian, 2019).

Filler materials are particles that are added to resin or binders (plastics, composites, and concrete) to enhance certain qualities, reduce cost, or achieve a combination of the two (Pelzl et al., 2018). They are naturally occurring or synthetically made and can affect tensile strength, toughness, heat resistance, and clarity. There is a common factor influencing natural fiber-reinforced polymer composite materials. These are:

Fiber content: Yang et al. (2020) found that improved flexural strength, tensile property, reduced weight loss, as well as improved thermal stability and degradability of the matrix were obtained with the incorporation of bamboo fiber. Furthermore, it has been shown that adding bamboo material to polypropylene enhanced its mechanical properties by up to 50% when measured by the weight of the matrix.

Fiber orientation: Rao et al. (2020) observed that the best mechanical strength can be found for fiber parallelly aligned to the applied load direction. Concluded that within composite materials, fiber orientation can greatly impact a part's strength.

Size /length of fiber: Datta et al. (2022) concluded that the length of the fiber perception in terms of "critical" length determines the need for pre-treatment processes of natural fibers to improve shear stress at the interface for various matrices. Experimentation revealed the suitability of bamboo fiber as an effective reinforcement in an epoxy matrix for improved mechanical properties at optimum fiber length. Long fiber offers better impact resistance and rigidity properties than short fiber. The large-size fiber is not easily interlocked in a matrix compared to the small size fiber (Giridharan et al., 2019).

Treatment: Manalo et al. (2015) reported chemical treatment with a 5 percent NaOH solution successfully changed the surface roughness of bamboo fiber by rising the accessibility of polymer matrix for mechanical interlocking. As a result, mechanical characteristics was enhanced. Chemical treatments have been found as a critical measurement in decreasing the aqueous solubility of natural reinforcement and enhancing the interfacial adhesion created between the hydrophilic matrix and reinforcement (Reddy et al., 2020). Alkalization, benzoylation, flame retardant treatment, silane, and acrylation are method of chemical treatments that have been often used to overcome the drawbacks of natural fiber. Chemical treatments have improved the surface properties of natural fibers and increased the fibers' adhesive bonding ability with the matrix. (Sekaran et al., 2015)

Interfacial strength - Fang et al. (2022) reported improved interfacial strength through surface modification of natural fibers, which involved using the deep eutectic solvent system and successfully depositing a layer of lignin on the surface of the bamboo fibers for good adhesion to polylactic acid. The decline in mechanical properties of natural fiber reinforced polymers is due to poor interlocking between fibers and matrix. Factors affecting the bond between fibers and matrix are molecular attractive forces, mechanical interlocking, and chemical bonds.

Hybridization: - according to Dong (2018) the general purpose of making natural fiber hybridization with other synthetic fibers is to enhance the weakness of both fibers. Hybridized composites of synthetic with natural fiber in a composite resulted in better mechanical characteristics than hybridizing natural with natural fiber composite. Natural fiber hybrid composites are cost effective and possess impressive mechanical and thermal stability and might partially replace and reduce the utilization of synthetic fibers as reinforcements of polymeric composites .When lightweight composite materials made of hybrid natural fibers like bamboo-sisal fibers were used in automotive applications, the fuel economy of the vehicle improved, reducing the related harmful emissions. (Getu et al., 2021).

2.5.1.2 Effect of hybridization on mechanical properties of composites

Nagaraja et al. (2021) studied the effect of hybridization to enhance the mechanical properties. The addition of the secondary reinforcements greatly reduce the crack growth and increase the fatigue life of the composites. Tensile, hardness and flexural tests were performed on the sisal/periwinkle hybrid composite and the results showed that the addition of periwinkle shell particles improved the mechanical properties of sisal fiber reinforced composites.

2.6 Drilling of Hybrid Composites

Mechanical fastening, in which the components are joined using bolts, rivets or screws, is the dominant way of joining composites. Because of several advantages over adhesive bonding: fastened joints do not require special surface preparation, permit disassembly for inspection or maintenance and are not greatly affected by thermal or humidity degradation (Arhamnamazi et al., 2021).Drilling is a frequent resulting machining operation for making easy assembling of parts prepared for fiber-reinforced material. In the view of the growing engineering applications of NFRCs, a thorough and efficient study of their drilling characteristics is needed. It is a cutting process in which a drill bit is spun to cut a circular cross section hole in solid materials. The drill bit is typically a multi-point rotary cutting tool. The bit is pressed against the work piece and rotated at speeds ranging from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work piece, removing swarf from the hole as it is drilled. The efficient and economic drilling of NFRCs are essential for the required dimensions and surface finish .However drilling may affect the mechanical properties of the work piece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface and makes the work piece more prone to corrosion and crack propagation at the stressed surface.

In drilling operation, drill bit is rotated relative to work piece and may produce coarse, helical feed marks on the work piece depend on the machining parameters such as feed rate, speed, tool geometry and coolant (Raj et al., 2021). The fiber breakage, matrix breakage and fiber matrix deboning are the major factors to decide the finishing of the drilled holes in fiber reinforced polymer composites .The defect acts as a stress concentrator and localized crack propagation and failure occurs at these sites (Kant & Jawalkar, 2022).

2.6.1 Drilling process parameter

The factors that affect drilling performance can be divided into two categories: Those related to composite manufacturing and others related to the drilling operation with regard to the geometry of the drill bit used or the modes in which it is operated in terms of velocity, feeding rate, and tool diameter.

Malik et al. (2022) studied main drilling input parameters such as drill bit geometry, tool diameter, cutting speed, and feed rate, when the output parameters were the delamination factor, thrust force, tool wear, roughness, and torque. Reported that process parameters were essential for the drilling of NFRCs because the selection of the parameters affected the drilling performance. Yallew et al. (2016) reported that the tool point angle is an important factor in deciding the delamination and hole quality in natural fibre reinforced composites and that the drilling quality of natural fibre composites can be increased through chemical treatment of fibre.

Chegdani et al. (2020) studied the impact of the orientation of fibers in natural fiber reinforced polymer composites during machining. Concluded that fiber orientation affects the cutting characteristics and chip formations during the machining of the composites.The particular structure of natural fibers, including their hierarchized geometry, which potentially causes fibrillation, can result in an increased chance of irregularity of the hole and a more complex mode of delamination damage to the composite (Jagadeesh et al., 2023) .

The variation in tensile strength, stiffness, and strain propagation due to the presence of open holes of various sizes, the number of holes, the holes' patterns, the effect of the type of fiber of the notches, the fiber architecture, and the fibers' stacking sequence in bio composites.

2.7 Mechanical property of composite

Natural fiber polymer composite properties are influenced by manufacturing method, fiber orientation, fiber volume fraction, matrix type, and fiber length.

Tensile strength: refers to the amount of load or stress that a material can withstand before stretching or breaking and is affected by the nature of the fiber and matrix. Alovera in woven form is tested with hybridization of sisal and kenaf fibers and found that the sisal-kenaf combination has good tensile properties (Kumar et al., 2017). The impact strength of a composite material refers to its ability to absorb shock. The impact test of hybrid composites (sisal and glass) used for two wheeler side boxes revealed that the weight of the product was reduced by 50% when compared to the existing product and the impact strength increased from 35 to 40 J. The ability to withstand compression loads is referred to as compression strength (BELAY, 2021). The compressive strength of unidirectional composites is strongly influenced by the elastic and strength properties of the fiber and matrix phases, as well as by local geometrical properties such as fiber volume fraction, misalignment, and waviness of fibers. (Petroudy, 2017).

2.8 Related Work on Machinability of Natural Fiber Reinforced Composite

Mazumder et al. (2016) studied the influence of process parameters on the performance characteristics of bamboo fiber-reinforced polymer composites during drilling using an HSS twist drill. The experiments were conducted according to Taguchi's L16 orthogonal array with input parameters for cutting speed (500, 1000, 1500, and 2000) rpm, feed rate (0.02, 0.04, 0.06, and 0.08) mm/rev, and point angle (103, 108, 113, and 118) in degrees. The result of the ANOVA showed that for a lower thrust force, point angle had the highest percentage contribution (49.58%), followed by feed rate (22.15%), and cutting speed (13.88%).

Vinayagamoorthy et al. (2016) investigated the damages that occurs during drilling of randomly oriented steel wool and woven jute as reinforcements and polyester as the matrix resin by adopting Box-Behnken methodology. Input factors, Speed (500 1250 2000) rpm, feed rate (0.1 0.2 0.3) mm/rev, point angle (90,120,150) and tool diameter (8, 10, 12) mm were taken and the damage at entrance and exit surfaces have been measured as output responses. Result revealed that good bonding strength of woven jute was at speed 500 rpm-970 rpm, feed of 0.1 mm/rev, a tool angle of 900-1200, and selection of 8 mm and 10 mm as tool diameter were be the optimum input for obtaining high quality drilled part.

Bajpai et al. (2017) paper presented on experimental investigation, of natural fiber (sisal and Grewia optiva fiber)-reinforced polylactic acid-based green composite laminates developed using hot compression through film stacking method. For each type of drill geometry, drilling was carried out for three different levels of cutting speeds (900, 1800, and 2800 r/min) and feed rates (0.05, 0.12, and 0.19 mm/r). Response surface methodology (RSM) and the regression equations has been used to model thrust force generated during drilling of PLA/G and PLA/S composite laminates. The thrust force and torque decrease with increase in the cutting speed and increase with increase in feed rate during drilling of developed composite laminates. The drilling-induced damage was decrease trend with cutting speed and it increases with increase in feed rate.

Suhaily et al. (2018) Investigated the influence of drilling parameters such as cutting speed, feed rate and drill sizes on the delamination produced when drilling woven kenaf reinforced epoxy composite using the non-coated carbide drill bits. It was observed that the upper delamination factor of woven kenaf/epoxy composite laminates, increases with increase in feed rate and decreases with increase in cutting speed. when using the drill size of 6 mm of the non-coated carbide drill bit at the respective cutting speed of 20 m/min with a feed rate of 0.2 mm/rev. when using a 12 mm drill bit of the non-coated carbide drill bit at the particular same cutting parameters (cutting speed:20 m/min; feed rate: 0.2 mm/rev).

Rezghi Maleki et al. (2019) delamination behavior and whole quality of flax/epoxy composite laminates were investigated in response to feed, spindle speed, and different drill bit types. The results revealed that the drill bit used has a significant impact on the delamination factor (67.27%) and surface roughness (74.44%).Jayaprakash et al. (2020) studied the effect of rice husk addition to glass fiber epoxy based composite plates on the drilling parameters. The experiments were conducted with three rotational speeds namely 500, 800 and1250 rpm and feed of 0.02, 0.04 and 0.06 mm/rev using Taguchi technique. The optimization result proved that at feed rate of 0.06 mm/rev and speed of 1250 RPM the minimum thrust force of 217.23 N and torque of 0.83 Nm was obtained.

Singh et al. (2021) the effect of drill geometry configuration and drilling parameters such as speed (500, 1000, 1500) rpm and feed rate (0.01 0.06 0.12) mm/rev on drilling-induced force and damages (delamination and surface roughness) in hybrid sisal-jute fiber composite drilling was investigated. Drilling forces, drilling-induced damages, and whole quality attributes were investigated experimentally for the drill geometries (Twist, Step and Core). Microscopic analysis using a scanning electron microscope revealed that delamination and surface roughness type damages (SEM). According to the findings, a twist drill, spindle speeds of 1500 rpm and feed rate of 0.01–0.06 mm/rev was best suited for minimum hole- and force-induced damages.

Mohammed and Wolla (2022) Conducted an experiment on Optimization of machining parameters in drilling hybrid sisal-cotton fibers reinforced polyester composite for better hole roundness accuracy and surface finish using Taguchi's L_{16} orthogonal array method. The effect of machining parameters including spindle speed (600,900, 1200, 1600 rpm), feed rate (10, 15, 20, 25 mm/min) and drill diameter (6, 7, 8, 10 mm) on drill hole accuracy (roundness error) and surface-roughness of the was evaluated. Whole roundness error and surface-roughness are determined using ABC digital caliper and Zeta 20 profilometer, respectively. Optimum machining condition for drilling hybrid composite material (speed: 1600 rpm, feed rate: 25 mm/min and drill diameter: 6 mm) was determined.

Raja et al. (2022) studied influence of drilling parameters such as speed, feed, and drill point angle on the quality of drilling of chopped sisal fiber and human hair of 30 mm length mixed with epoxy resin. The experiment was designed using high-speed steel (HSS) drills and three factors with three levels. For delamination reduction, the drilling parameters were optimized using Grey Relational Analysis and the Taguchi method. A cutting speed of 2500 rpm and a feed rate of 50 m/min result in higher quality holes.

2.9 Optimization Techniques

Optimization techniques have been applied across different studies to identify the right mix of variables to produce the most efficient results for any given process (Neggaz et al., 2020). The use of modelling and optimization methods in drilling process is used to minimize the experimental runs and to get best cutting condition. In modelling technique, a mathematical equation-based model is developed based on input and response parameter relationship to get optimum cutting condition. In optimization technique an objective function is formulated with or without mathematical model to get the drilling condition.

Taguchi method

It is one of the easiest statistical approaches to optimization of input parameters for the determination of the optimum outputs Taguchi design of experiments converts the usual design into a robust design This design allows to understand and provide the interaction of factors affecting the output parameters. Taguchi analysis uses orthogonal array (OA) of experiments that give set of appropriate number of experimentt trials. These orthogonal arrays reduce the number of trial experiments (Gope & Goel, 2021)

Response Surface Methodology

RSM is a dynamic, important tool of the design of experiment (DOE) and is based on fitting empirical models with experimental data. These data are obtained from the relationship between responses and input decision variables to maximize or minimize response properties. RSM is a set of statistical techniques that employ linear or square polynomial functions to describe and explore experimental conditions of a studied system until its optimization.

2.10 Research gap

The literatures provided the drilling of various materials and the influence of drilling parameters such as cutting speed,feed rate ,tool geometry and tool material on the quality of drilled holes and drilling-induced damages. As tried to be specified in the literature review, majority of studies focused on optimizing drilling process parameters (speed, feed, and drill diameter) to achieve a defect-free hole. Drill ability of NFR composite refers to the material's ability to withstand drilling force and produce high-quality drilled holes with lower defects, lower surface roughness, better circularity, and the required surface finish. furthermore,most of the reviewed studies focuses on investigating the performance characteristics or quality attributes of drilled holes,such as thrust force,torque,delamination ,surface roghness and hole roundness accuracy. However,there is a gap in research that comprehensively examines the interaction effects of multiple parameters and optimization strategies for achieving desired machining outcomes. Future studies could explore the influence of drilling parameters on the performance characteristics and fabrication quality of hybrid bamboo/sisal-alumina reinforced polymer composites,filling this gap in the existing literature,indicating a need for targeted research that address the unique machining challenges and optimization opportunities associated with this particular composite composition.

2.11 Literature summary

Table 2.1 Parameter used in Drilling of composite materials

s.no	Author and year	Material used	Parameter used	Conclusion
1.	(Shanmugam et al., 2021)	- Redmond as filler and sisal fiber as reinforcement in polyester matrix.	Drill tool point angle 90°, 118°, 135°. - Cutting speed = 1000, 1500, and 2000rpm -Feed rate = 100, 150, and 200 mm/min.	- speed contributed 39% in affecting the thrust force -feed rate had the maximum influence of ca. 38% in affecting delamination. - Drill tool with 118°-point angle generated lower thrust force.

2.	(Singh et al., 2021)	-Sisal and jute hybrid natural fibers as reinforcement. Epoxy resin (LY 556) and hardener (HY 951), having a mixture ratio of 10:1, were used as the matrix materials. Solid HSS drill bit geometry of (Twist, Step, and Core).	-The hand lay up method was used - The thickness of composite = 6 mm. Spindle speed (N) = 500, 1000, and 1500 rpm. Feed rate (f) = 0.01, 0.06, 0.12 mm/rev	- As feed rate increased, both thrust force and torque increased. Twist drill is best suited for the hole- and force-induced damages. The uncut fiber damages occurred at lower feed rates and cutting speeds, whereas higher burr formation was observed at higher feeds and lower cutting speeds. From the tensile strength of the joint. Hole drilled by the twist drill sample has a greater amount of tensile strength, and the core drilled sample has the lowest tensile strength. With an increase in spindle speed, both delamination and surface roughness decrease.
3.	(M Ramesh et al., 2014)	- Glass, Sisal, and Jute fiber. Drilling is carried out in using a coated	- Feed Rate = 0.04, 0.06, and 0.08 mm/rev.	- The delamination increases when the feed rate and drill diameter increase, and it decreases

		carbide drill (brad and spur) drill. Hand molding technique With applied pressure. The drilling induced damage is analyzed with the help of the profile projector.	Spindle speed 1000,2000,300 rpm Drill Diameter = 6, 9, and 12mm. Thickness = 5mm.	with an increase in the spindle speed. - The thrust force decreases when the spindle speed increases. - The torque at a higher feed rate is greater than that at lower feed rates. - Lower feed rates and moderate speed were more suitable for drilling hybrid composites.

4.	(Abilash & Sivapragash, 2016)	Reinforcement= Bamboo. Matrix= polyester resin. Prepared using hand layup and compression molding technique. Cutting edges of the drilled holes was examined using scanning electron	-SMT radial drilling machine was used. -Speed ranges of 500, 860, and 1360 rpm. -Feed ranges of 18, 26, and 34 mm/min. Drill tool diameter ranges from 4, 6, and 8 mm.	-Delamination optimized were found different for inlet and outlet holes where the highest hole Delamination was found at hole two for the inlet part and hole eleven for the outlet part. - It was found that feed rate and drill diameter have the highest effect from ANOVA analysis - recommended to use small feed and drill diameter to ate optimized hole

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The study was conducted to investigate the damage occur during drilling of hybrid bamboo-sisal-alumina composites and optimizing the drilling parameters to obtain high quality drilled hole. The material and method used to fabricate the composites samples and the machines used for testing and drilling operation was explained in the section. The selection of materials were depend on application, availability and cost consideration.

3.2 Experimental Design for Composite Fabrication

3.2.1 Materials

3.2.1.1 General Purpose Polyster resin

Among the main matrix materials, thermosetting resin includes epoxies, vinyl ester, polyster, and polyvinyl ethylene. In this study, the matrix material used was polyster resin which was purchased from world fiber glass and water proofing enterprise, Addis Ababa, Ethiopia. Having low viscosity for fast wet out, low density, low cost, and capability for the hand layup method of composite fabrication were advantages of unsaturated polyster compared to other thermosetting resins (Fasil, 2020). The mechanical properties of polyster are improved by the incorporation of filler and fiber material.

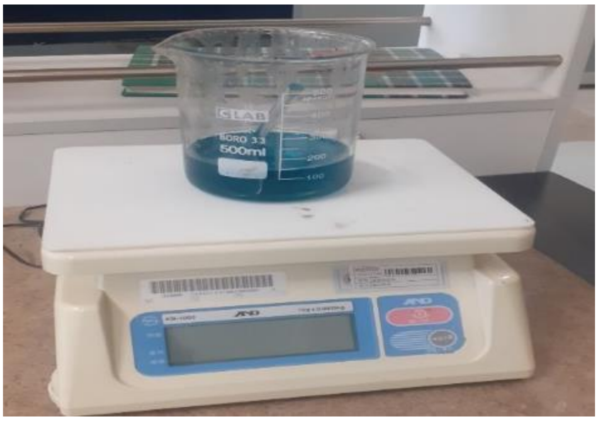


Figure 3.1 Polyster

3.2.1.2 Hardener

The hardener is used as a curing agent for matrix, which causes the chemical reaction of polyster resin and monomer ingredients from liquid to solid state. In this work, a catalyst with a brand name called methyl ethyl ketone peroxide hardener was used. The matrix for this study was prepared by mixing 20:1 polyster with hardener after mixing with alumina powder used as filler (Rajamurugan et al., 2020).

3.2.1.3 Alumina

Aluminum oxide is a chemical compound obtain from aluminum and oxygen with the chemical formula of Al_2O_3. Alumina is the most commonly used filler material for polymer matrix composites due to its relatively high hardness, good oxidation resistance, chemical stability, electrical resistance and make it the most extensively used material in many applications including polymer matrix composite,(Britannica, 2020). The limitation of the application of alumina was due to its low fracture toughness as studied by (Kiran et al., 2018).Alumina used as filler material in the present study were purchased from chirkos,Addis Ababa ,Ethiopia. Its property was listed in table 3.1. Alumina (Al_2O_3) is selected in the fabrication of natural fiber-reinforced composites (BSFRCs) due to its combination of high hardness, strength, and thermal stability, which significantly enhance the mechanical properties of the composite(Escandon & Uribe).

Table 3.1 Properties of alumina (Lindsay & Lavoie, 2022)

Description	Al_2O_3
Density (g/cm^3)	3.95
Tensile strength (MPa)	200–660
Young’s modulus (GPa)	380
Bending strength (MPa)	200–600
Compressive strength (MPa)	1900–200
Poison’s ratio	0.25–0.30
Coefficient of thermal expansion (/°C)	7.39×10^{-6}

(a) (b

Figure 3.2 Aluminum oxide (a) packed (b) powder

3.3 Research Methodology Flow Chart

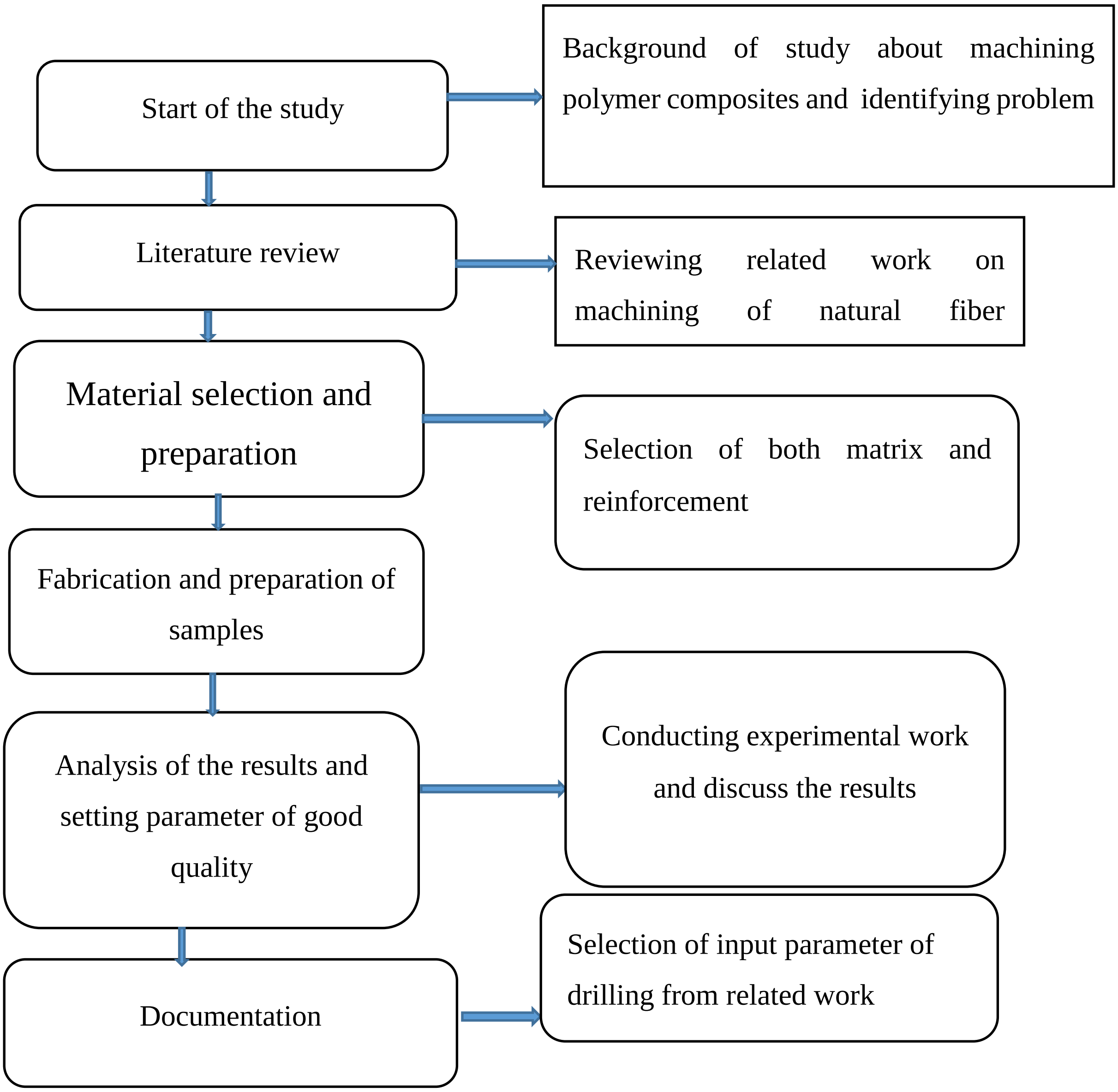


Figure 3.3 Research methodology

3.4 Sisal Fiber and its Extraction Method

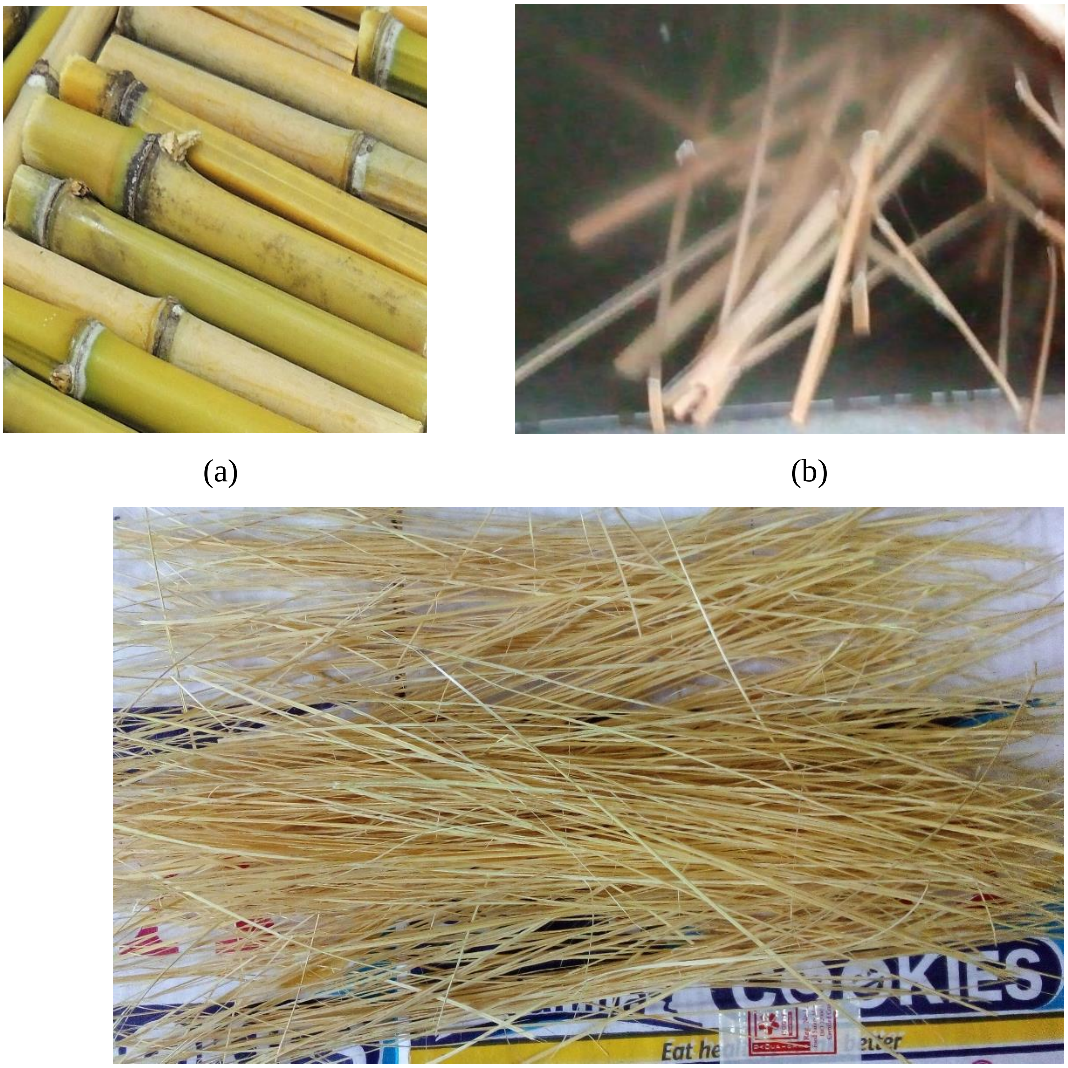
Sisal fiber is produced from the leaves of the sisal plant, technically known as Agave sisalana.It has various benefits in terms of product design freedom, insulation and non oise absorption and impact resistance and has also been used as potential reinforcement in synthesis of polymer composite. Due to these properties, sisal reinforced composite is used in building materials like roofing sheets, locomotives like gear case, and main doors (Olhan et al., 2019). The sisal fibers were extracted manually using a knife with length between 1m-1.35m and diameter of $50\mu m - 150\mu m$ after collection of sisal plant from Arsi, Ethiopia. In the development of composite both random oriented and chopped form was used.

a) b)

Figure 3.4 sisal plant (a) Extracted with knife (b) sisal fiber

3.4.1 Bamboo fiber and its extraction method

Bamboo plant have high fiber content which used as reinforcement for polymer composite fabrication. Munde et al. (2022); Pulikkalparambil et al. (2023) studied bamboo fiber reinforced epoxy composites as competitive material for conventional construction in semi structural, nonstructural, and interiors of automobile application. The fiber was extracted by a mechanical method called retting. The process includes harvesting matured bamboo stalks, remove the leaves and branches and cutting it into its nodes and drying it. Then, scrape the outer cover of the cylindrical part of the bamboo culm and peel to obtain the strip. Submerged bundles of strips completely in water for 7 days to soften and separate the non-cellulose parts. The wetted strips were beaten slowly with a rubber hammer to isolate fiber, then the fiber was scraped with a comb to obtain individual fiber.



(a) (b)

(c)

Figure 3.5 Bamboo stalk (b) soaked bamboo strips (c) extracted bamboo fiber

3.4.2 Surface modification of bamboo and sisal fiber

Sodium hydroxide is a strongly alkaline white deliquescent with chemical formula NaOH. It is a highly corrosive base and alkali that decomposes protein at room temperatures which cause chemical burns. It used as surface treatment of natural fiber in area of composite fabrication industry. NaOH is soluble in water, ethanol, methanol and it is found in different forms, like pallet, flakes and granules. For this study alkaline treatment technique was used, which involves the immersion of natural fibers in concentrated sodium hydroxide (NaOH) solution. The solution cause the reaction with the hydroxyl group of natural fibers to remove the cementing materials,including hemicellulose,lignin wax and oils that surround the external surface of the fiber leading to an increase in the surface roughness and fiber –matrix bonding interactionsManalo et al. (2015) reported that chemical treatment with a 5 percent

NaOH solution successfully changed the surface roughness of bamboo fiber by rising the accessibility of polymer matrix for mechanical interlocking. For this reason 5% NaOH in the form of a pallet purchased from local supplies was used for both bamboo and sisal fiber of 15g .in the solution fibers were soaked for at room temperature for a day and at a temperature of 80 °C for an hour. Eq (1) below shows the reaction between bamboo, sisal and sodium hydroxide solution. Then the soaked fiber was washed with distilled water and dried for 2 days.

$$\text{FIBER–OH} + \text{NaOH} \longrightarrow \text{FIBER–O-Na+} + \text{H2O} \quad (3.1)$$

Figure 3.6 Fiber preparation process

3.5 Experimental design for the Preparation of composite specimen

Composite fabrication is the process of creating composite materials by combining two or more components for intended properties and performance. The fabrication way may poses many challenges and requires careful consideration to synthesis specimen with required characteristic. There are many method for fabricating composites. Among them hand lay-up is the simplest and widely used method to fabricate composites (Meenakshi &

Krishnamoorthy, 2018). To fabricate the samples hybridization of natural fiber with synthetic fiber was held. The hybridization brings out various appealing properties of both natural and synthetic fiber, resulting in attractive properties at an affordable price for the finished product. In this study chopped bamboo and sisal fiber were hybridized with different concentration of alumina for synthesizing of composites samples.

3.5.1 Weight (in mass) estimation for matrix and reinforcements

Total mass of matrix and reinforcement required for fabrication hybrid bamboo-sisal polyster composite is calculated depend on the required test. Since the test dimension of the specimen is limited by size of the produced sample. All samples were manufactured on $180mm \times 150mm \times 5mm$ mold size. The mechanical and physical properties of the natural fiber composites samples are largely depend on the inclusion of synthetic reinforcement. The weight percentage(Wt.%) of both matrix and the reinforcements used in this research work was determined based on a literature survey (Gupta, 2020).The Wt.% composition of any reinforcement addition should not exceed 35% for minimized defect. Weight fraction of matrix and fibers are calculated as the equation given below.

$$WF + WM + Wf = Wcomposite \quad (3.\ 2)$$

$$weight\ fraction\ of\ matrix = {}^{weightof\ fiber}/_{total\ weight}$$

$$\%WM = {}^{wm}/_{wm + wf}$$

$$\%WF = {}^{Wf}/_{wm + wf}$$

$$wm + wf + wF = wc$$

$$\rho c = mc/vc \quad (3.\ 3)$$

(Gupta et al., 2020)

Where:

ρc = density of composites

mc=mass of composites

vc=volume of composites

Volume of composites are calculated based on mold size and thickness of fabricated samples. By using the above equations for individual samples weight were calculated and listed in the table 3.2. During the fabrication process the catalyst was mixed with resin and air bubble is removed by degassing or mix slowly and carefully. The fabrication process was conducted at room temperature. The dimension of the mold was $1800mm \times 150mm \times 5mm$ stainless steel. The mold surface was covered with release gel to keep the polymer from sticking to it and fibers were placed in the mold and the mixture of alumina powder with polyster and hardener were poured into the mold plate. Brushes are used to evenly apply the resin to the fibers, while rollers are used to work air bubbles out of the reinforcement and ensure complete wet out. Then using roller to distribute the mixture finely over the fiber and level the mixture for uniform thickness. Finally closed the mold plate by applying the upper plate and fixed the two plate with C-clamp. The sample cured for 24 hr. For post curing samples were kept in an oven at 50℃ where high bonding appears between fiber and matrix thereby delaminating tendency to reduce and it was left for cooling for few hours. After that the specimens of required dimensions was prepared for testing and drilling.

Table 3.2 Weight of fibers and polyster for different sample

No. sample	Weight of BF (g)	Weight of SF (g)	Weight of Al2O3(9)	Weight of polyster(g)	Total g of sample	Total weight %of fiber
S1	31.2	33.5	30	172	266.7	35
S2	18.69	41.4	30	175	265.09	35
S3	34.3	36.65	0	172	242.95	35
S4	38.4	21.38	7	169	235.78	35
S5	12.3	18.4	15	153.4	198.7	35
S6	16	14.33	12.09	170.45	212.87	35

3.5.2 Tools and equipment

Table 3.3 Tools and machines

S.no	Tools /Machines	Functions
1.	Hand lay	To fabrication composite samples
2.	Hack saw and grinder	To prepare samples for testing according to ASTM standard
3.	Universal testing machine	To determine, flexural, and impact strength
4.	Vickery hardness machine	To determine the hardness of composite’s
5.	CNC machine	To drill composite sample
6.	Profilometer Zeta-20	To measure surface roughness of the drilled hole wall
7.	ImageJ software	For measurement of circularity and delamination
8.	SEM	To characterize morphology of produced composite
9.	Minitab 21 software	Used for data analysis and optimization through its tools like S/N ration, and ANOVA

3.5.3 Flow diagram of composite fabrication

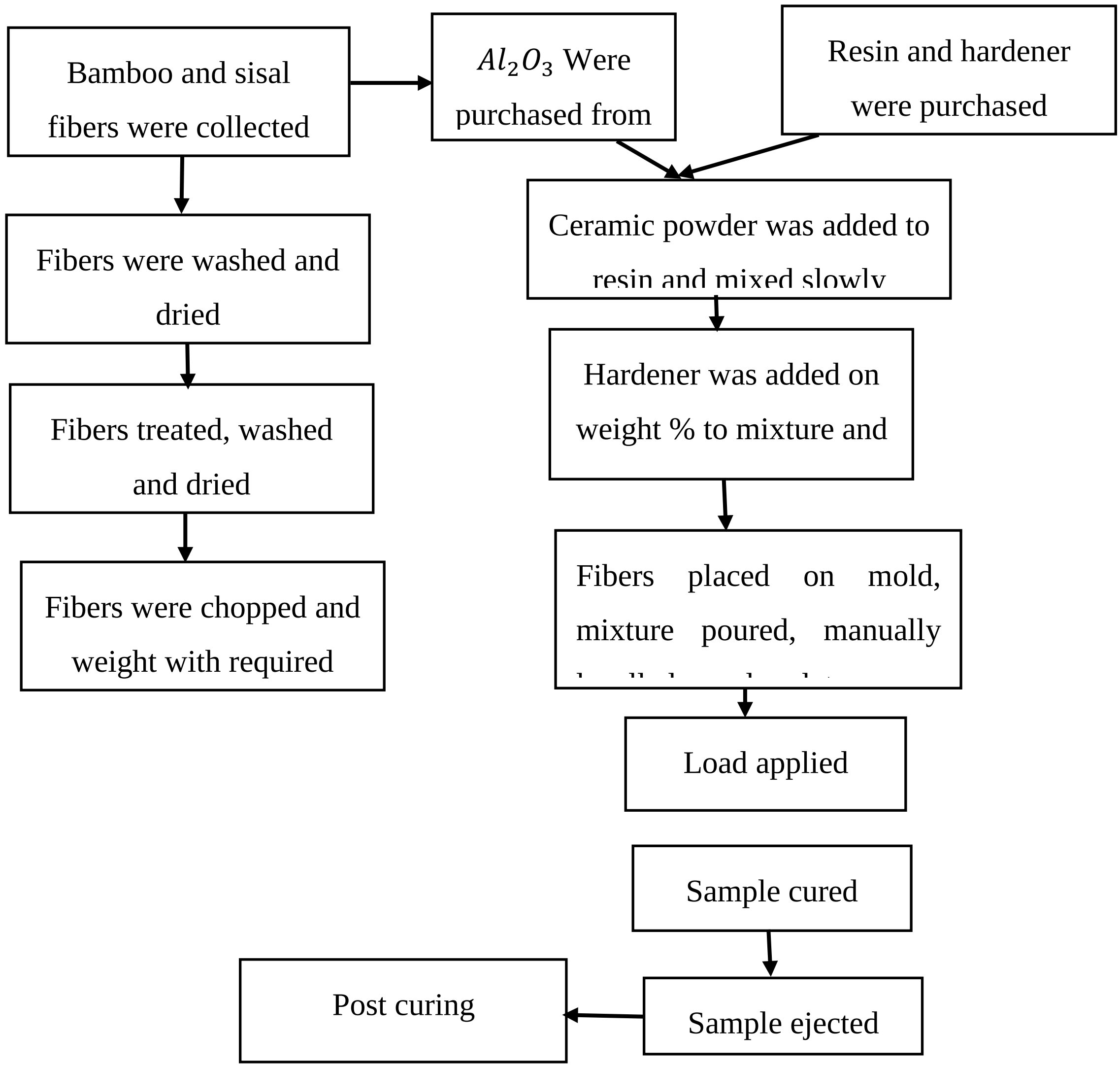


Figure 3.7 Flow diagram of fabrication process

3.6 Composite Characterization

Composite characterizations involves both mechanical testing and physical characterization of prepared samples. These characterizations were performed according to ASTM standards and at room temperature.

3.6.1 Mechanical characterization

These tests included tensile strength, flexural strength, impact strength, and hardness.

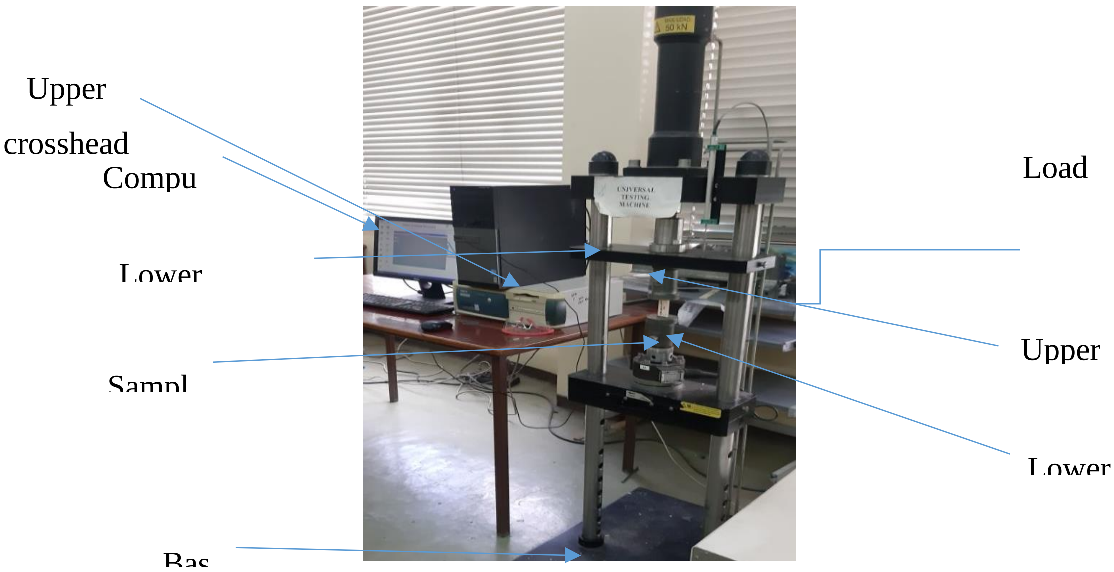
3.6.1.1 Tensile strength testing

Tensile strength is measurement of ability of to withstand force that tend to pull it apart. It is the maximum stress that a material can withstand before breaking when stretched or pulled. It determines the amount of force required to break a composite specimen, as well as the extent to which the specimen stretches or elongates to that breaking point. It's required to investigate mechanical performance of samples. The strength of the composites is determined by factors such as matrix, the strength of the layer arrangement, fibers, weight percentage of the fibers, and bonding properties between the, matrix, and fiber. Hybridizing natural fiber reinforcement with synthetic fiber reinforcement improves the tensile properties of the composites due to the increased stiffness and strength of the fibers. Six samples was tested on universal testing machine according to ASTM D 3039 with trial and then mean value reported as best value. During the test uniaxial load was applied through both end of sample. Then grips were tightened evenly and firmly to prevent any slippage.as the test started, the specimen elongates; the resistance of specimen increases and the resistance was detected by load cell, and then load was recorded until the rupture of sample. The tensile test was conducted in Ethiopian Defense Engineering University College, Bishoftu. The universal testing machine with maximum loading capacity of 30KN and $250mm \times 25mm \times 5mm$ size of samples was used for tensile test. The tensile strength of the composites was investigated as follows:

$$\sigma_t = {}^{p}/_{w \times t} \qquad (3.\ 4)$$ (Hariprasad & Megalingam, 2022)

Where, σ_t= tensile strength $({}^{N}/_{mm^2})$, p=applied load (N), w =width (mm), t =thickness (mm)

$A = w \times t$, A= cross-sectional area of samples



b

c

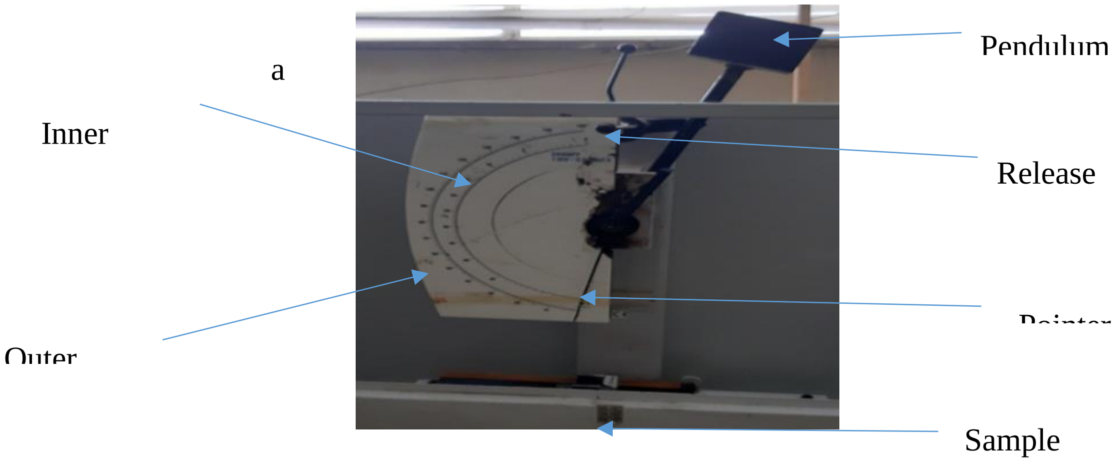
Figure 3.8 a, Tensile testing machine b, samples c, tasted sample

3.6.1.2 Impact strength testing

The Impact strength of material refers to its ability to absorb shock and energy required to break a specimen of a given dimension to resist sudden impact (Kumar & Kumar, 2022). Impact strength testing determines the fracture characteristics of samples. The charpy impact machine was used for test. It is a standardized high stress-strain test that determines the amount of energy absorbed by specimen under test during fracture. For test machine at Ethiopian defense engineering college, Bishoftu was used. The samples was prepared as per the ASTM D256 of Model IT-30 standards with $55mm \times 10mm$ dimensions x. The V-notch bar-shaped specimen is loaded into the testing machine and struck with a weighted pendulum hammer. That causes the specimen to deform, crack, and fracture at the notch. The amount of energy absorbed in the fracture is then used to calculate a sample impact strength. The formula used to calculate the impact strength is (Kumar & Kumar, 2022)

$$Impact\ strength = Energy\ absorbe\ \ in\ joule/Damaged\ area \qquad (3.5)$$

a



b)

Figure 3.9 a) Impact testing machine b) Tested samples

3.6.1.3 Hardness Testing

Hardness is a measure of how it is difficult to deform materials by scratching and indenting. The size of depth of indentation indicated how the material are responded to scratching or indenting force depending on their composition and structure. The test was conducted at Adama science and Technology University by using Vickers scale which depend on optical measurement. The Vickers hardness testing machine HVS-50 Buehler, USA and the dimension of sample $30mm \times 20mmx5mm$ was used according to ASTM E-50.The indenter was the diamond pyramid shaped indenter with square base having an included angle of $136° \pm 0.5$.A load of 10kgf was applied to indenter with dwell time of 15s and the size of indentation left on the surface of sample was observed. The flat surface indented at different three location and the average of measurement was taken. Then the indentation was converted to hardness value. The equation which used during the calculation of HV is :

$$HV = \frac{con\, xtest\ \ force}{surface\ area\ of\ indenter} \tag{3. 6}$$

$$0.102 \times 2F(sin\frac{136/_{2}}{d^2} \tag{3. 7}$$

(Gogolinskii et al., 2019)

Where:

F =force, d=diagonal of indentation and 136° is the angle between the opposite surface at vertex.

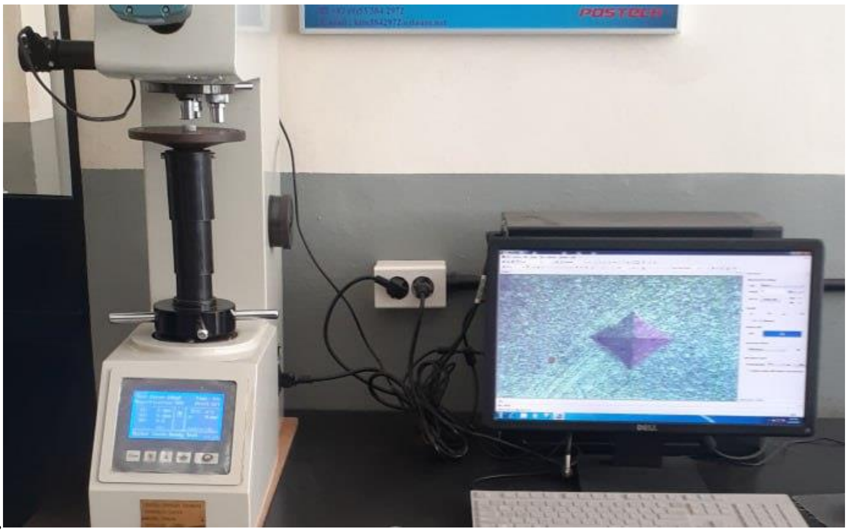


Figure 3.10 Vickers hardness test machine setup

3.6.1.4 Flexural strength analysis

Flexural testing provides information about materials resistant ability to bending, fracture toughness, interlaminar shear strength and failure modes (Saba et al., 2019). Universal testing machine (UTM) Model of Instron 5966 at Adama science and Technology University was used. The experiment was performed at room temperature at crosshead rate of 5mm/min .The three-point bending was applied at the middle of the span for bamboo-sisal fiber reinforced polyster with alumina powder. The dimension of the test sample was according to ASTMD 790 with sample specification$250mm \times 20mm \times 5mm$. The specimen is supported at two points near the ends and loaded at one or two points between the supports. The load is increased until the specimen fails, and the flexural strength was calculated from maximum load, span length and cross sectional of the specimen. The equation used for calculation of flexural strength is:

$$\sigma = \frac{3\mathrm{FL}}{2\mathrm{wd}^2} \tag{3. 8}$$

Where;

F=maximum load, L = length between supports, w=width and d=thickness

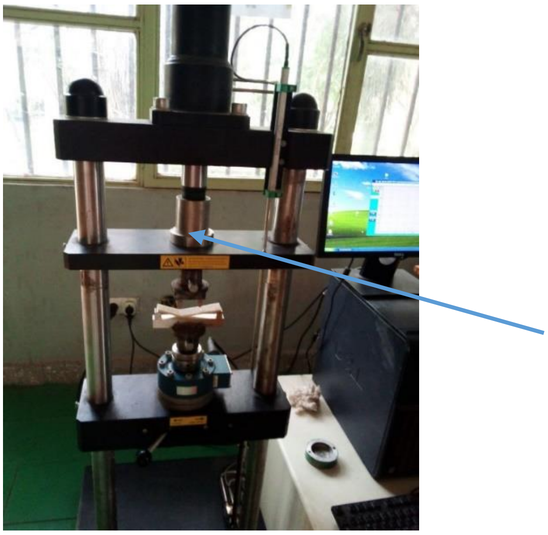


Figure 3.11 Flexular strength testing

3.7 Physical Characterization

3.7.1 Water absorption testing

Water absorption was major concern in determining the application of composites sample in outdoor services. It affect the physical, mechanical properties and dimensional stability .The test was performed as per ASTM 570.The water absorption tests of hybrid composite made of bamboo-sisal –alumina reinforced polyster were done with specimens dimensions $20mm \times 20mm \times 5mm$ by inserting the sample into distilled water for a day at room temperature. The samples were taken out periodically after wiping out the water from the body of sample weighted immediately using digital mass balance to find out the content of water absorbed or volume of water absorbed under specified condition. The weight of the samples before immersion is shown in the below table. The percentage weight gained by the samples was calculated using the following equation:

$$\text{Water absorption } \% = \frac{w2 - w1}{w1} \times 100\% \qquad (3.9)$$

Where w1 and w2 are the weight of dry and wet samples.

Table 3.4 Average weight of the samples

Sample	S1	S2	S3	S4	S5	56
Average weight of the sample before immersion	12.44	11.01	13.86	14.16	12.67	12.61

3.8 Selection of samples steps used in Grey Relation Analysis in Selection of samples

The procedure used in selection of the samples fabricated by handlayup method hybrid bamboo-sisal polyster composites was the following:

Step 1: Based on the type of quality characteristic, transform original response data to S/N ratio using related formula stated in eq (3.10-3.12)

Signal-Noise-Ratio Analysis

Signal- to noise ratio(S/N) is the measurement of the variation of a process for investigating how well the process can resist the effect of the noise factors. It is given as ratio of the mean to the standard deviation of the output. For optimum drilling parameters, the Taguchi methods requires assessing Signal-to-noise ratio of each drilling parameter level for each output function. S/N ratio has performance characteristics expressed as lower-the-better, nominal- the –better and higher -the –better. In the Taguchi optimization, the mean response of the experimental data was evaluated by transforming the output data into S/N ratio. The S/N ratio represents a measure of quality features and is calculated as follows for three condition of performance characteristic (Bhat et al., 2020; N S & AS, 2019)

Condition 1. Larger - the- better

$$\frac{S}{N} = -= -10\, log_{10}(\frac{1}{n}) \sum_{1}^{n} \frac{1}{Yij^2} \cdots \quad (3.\ 10)$$

Where: n is the number of replications,Yij^2 observation response value for i =1, 2, 3…n and j=1, 2, 3…m, this equation is applied where maximization of the quality is point of interest. It is referred to the larger -the –better type of the problem.

Condition 2.Nominal –the- better

$$\frac{S}{N} = 10\, log_{10} \frac{\mu^2}{\sigma^2} \quad (3.\ 11)$$

Where $\mu = \frac{y_{1+}y_{2+}y_{3+\cdots+}y_n}{n}$ and $\sigma^2 = \sum_{i}^{n-1} \frac{(yi-y)^2}{n-1}$ is suitable for normalizing problem.

Condition 3. Smaller –the-better

$$\frac{S}{N} = -10\, log_{10}(\frac{1}{n} \sum_{1}^{n} Yij^2) \quad (3.\ 12)$$

Where: n is the number of replications, ${Y_{ij}}^2$is the observation response value

The drilling effect would be minimized for quality product (Shilpa & Yendapalli, 2022).In this paper, since surface roughness, hole roundness and delamination has to be minimized the smaller-the-better characteristic was selected to yield the optimum results. Thus, the S/N ratio condition was expressed in the logarithmic transformation of the loss function

Step 2: Normalize the data to minimize variability and the effect of using numerous units to make comparability easy. Normalize Y_{ij} as $Z_{ij}(0\_Z_{ij}\_1)$ using eq (3.14) where, Z_{ij} represents the normalized for ith experimental/trial and the jth dependent variable/response. For normalizing S/N ratio with larger-the-better performance characteristic and small-the-better the following equation is used respectively (James et al., 2023).

$$Z_{ij} = \frac{Yij-Ymin}{Ymax-ymin} \tag{3. 13}$$

$$Z_{ij} = \frac{Ymax-Yij}{Ymax-ymin} \tag{3. 14}$$

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

$$GRC_{ij} = \frac{\Delta_{min} + \delta\Delta max}{\Delta ij_{ij} + \delta\Delta max} \tag{3. 15}$$

Where i=1,2,3…,n is number of experiments and j=1,2,3,…,m is the responses.

GRC_{ij} =GRC for ith trial,Δ=absolute difference between Y_{oj} and Y_{ij} ,Δ_{max}=maximum value of Δ,Δ_{min}=minimum value of Δ,δ=is the distinguishing coefficient ($0 \leq \delta \leq 1$)

Y_{0j}=optimum performance value or the ideal normalized value of jth response

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

Step 4: calculate the grey analysis grade ($GRGi$)

$$GRGi = \frac{1}{m}\sum GRCi \tag{3. 16}$$

Where m is the number of responses

Step 5: select optimal levels for the factors based on the maximum average GRGi value using ANOVA.

3.8.1 Secondary Operation Process

The drilling operation is one of secondary operation in which functionality of object enhanced. Drilling of NFRCs is critical machining operation which play a vital role to facilitate parts assembly. The quality of drilled hole is major concern for determining application and duration of assembled parts due to rigid tolerance dimensions. The drilling experiment was performed at Shager city steel manufacturing and flexible engineering S.C. with high precision computer numerical control (CNC) machine. The experiments were performed for different diameter of high speed-steel (HSS) cutting tool of having point angle 135°, Helix angle 33° and chisel edge angle 129°,speed and feed rate as suggested (Malik, Ahmad, & Gunister, 2022; Mohd-Lair et al., 2019).

3.8.2 Experimental Design for Secondary Operations

The fabricated bamboo-sisal –polyster composite was drilled using CNC machine with an experimental design constructed on controlled input variable parameter (spindle speed, feed rate and drill bit diameter) for each sample at room temperature. In this experimental design fabrication factor was also considered as a parameter due to the fact that the first operation has its own effect on the following operation like drilling for composites material. The addition of synthetic fiber into natural fiber improve the property of composites regardless of fiber type,and content and According to (Adda et al., 2021; Malik, Ahmad, Yunus, et al., 2022) inclusion of the artificial fiber to the natural fiber during fabrication result in minimized fiber pullout ,matrix cracking and deboning which yield improved mechanical property and reduced delamination of the drilled sample .In his study alumina is added to increase interfacial bonds at interphase. In view of that, the input parameter for the drilling operations in this study was determined on basis of the literature review. The following table shows lists of parameters with their corresponding levels.

Table 3.5 Process parameters and theirs level

S.NO	Parameters	Levels			
1.	Spindle speed(Rpm)	500	750	1250	
2.	Feed rate (mm/rev)	0.03	0.06	0.12	
3.	Drill diameter (mm)	3	6	12	

3.8.3 Drilling setup

HSS (High speed-steel) drill bit

HSS bits are heat-resistant due to their rapid-speed orientation which make them suitable for machine drilling. For the study M2 HSS general-purpose drill bit of $3mm$,$6mm$ and $12mm$ diameter was used.

Figure 12 HSS drill bit with different diameter

Table 3.6 HSS property table (Cardarelli & Cardarelli, 2018)

Property	Value
Density (g/cm³)	7.7
Hardness (HRC)	60-67
Tensile Strength (MPa)	1860-2480
Yield Strength (MPa)	1700-2300
Young's Modulus (GPa)	210
Thermal Conductivity (W/m·K)	11.5-24
Coefficient of Thermal Expansion	11-12 × 10^-6 /°C

CNC machine: is a machine which performs different operation like graving, milling and drilling. It follows a set instructions or code that specifies the coordinates of the machine tools. It has the ability to create precise and complex shape that is difficult to make by hand. The experiment was conducted using a high precision computer numerical control (CNC) Vertical Milling Machine (CNC) of (Model: XHS7145, No. KH1509141) has been used to carry out the drilling experiments. A CNC machine is found in Shager city steel manufacturing and flexible engineering S.C. To minimize the Vibrations that reduce drilling accuracy by causing deviations from the intended path or hole diameter variations the location of the drillled hole was set aat far apart with dimension of $60mm$.

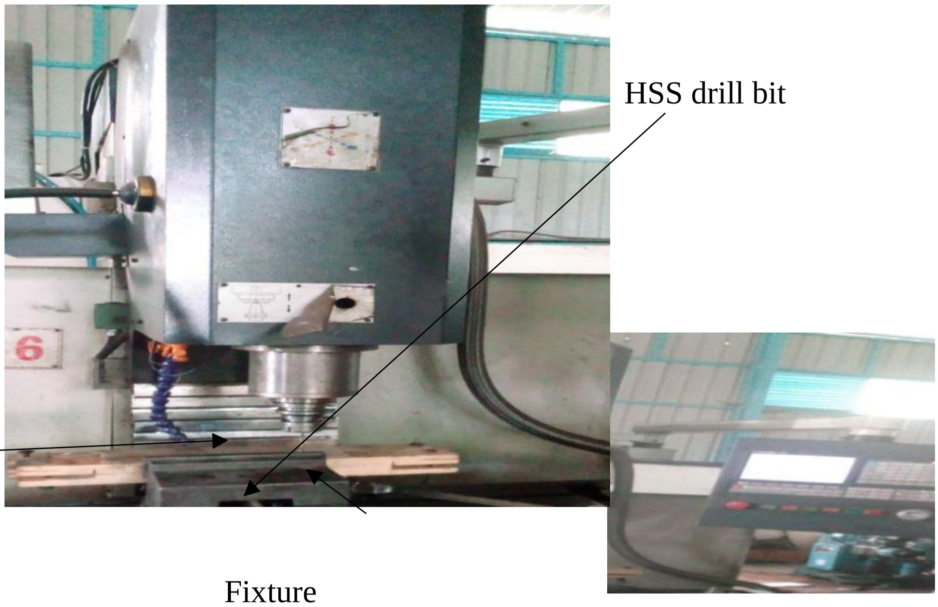


Figure 3.13 Drilling machine setup

According to design principle of product creating part and joining them is necessary .From other joining method fastening through hole form suitable and simple product. As composites materials are prone to delamination which is result of separation of the layers of the composites due to applied force it's required to select input parameter in suitable approach.

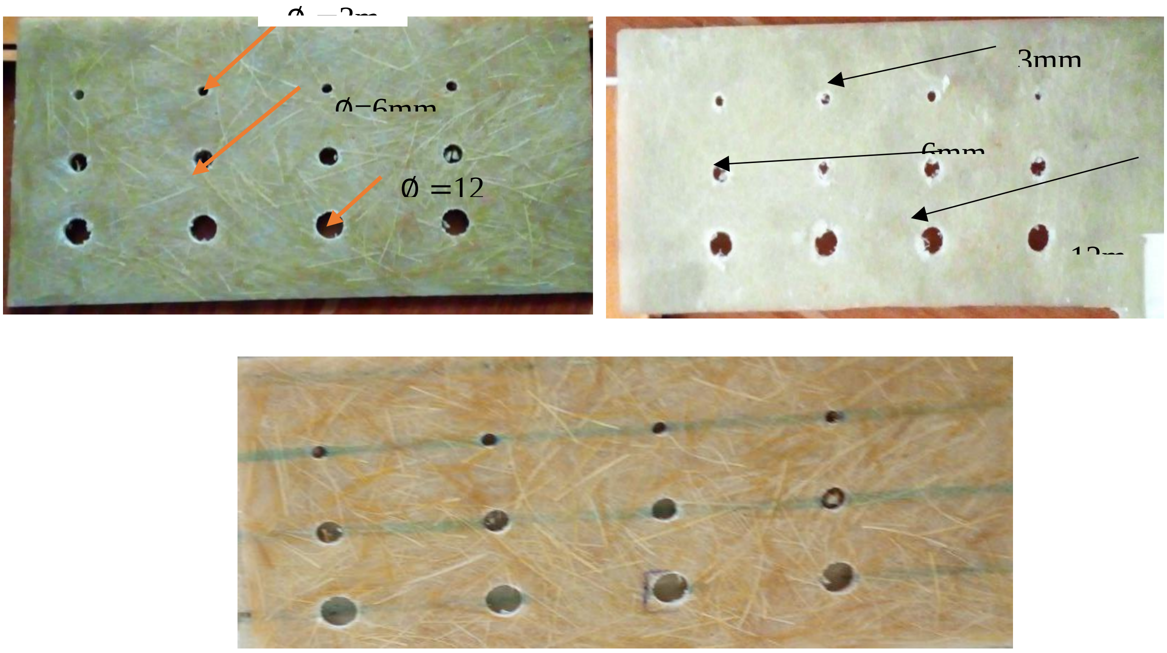


Figure 3.14 Drilled composite

3.9 Measurement of the Output Parameters

The drilled composite samples were checked for parameters for which the quality of the product was determined. The parameters reflect the quality of drilled composites are hole surface roughness, hole roundness, and delamination.

3.9.1 Surface roughness

Surface roughness is a measure of the irregularities and defects on the surface of drilled hole. It affects the functionality and performance of drilled hole and the fastened joint. It is the average of the absolute vertical deviations of the surface from the mean line and it is the simple and widely used parameter for measuring of surface of roughness in terms of values (R_a) and calculated as follow.

$$R_a = \frac{1}{L}\int_0^L \{y(x)\}\, d(x) \qquad (3.\ 17)$$

(Kalpakjian & Schmid, 2022)

Where: R_a is arithmetic mean which described in μm, L is length of surface profile and $y(x)$ is the vertical deviation of the surface profile from the main line at any point X.

The measurement of the surface roughness of the drilled composites was done using a Zeta 3D optical profilometer with associated arithmetic mean roughness at Addis Abebe and Technology University, Ethiopia via the help of a Zeta 3D optical profilometer tester (Zeta-20) model of Keyence VR-5000. Recommended magnification for improved precision was $10 \times$ lens magnification (Shahabaz et al., 2020).It was required for drilled composites to section into half for the simplicity of the measurement. The sectioning was required for scanning the hole wall surface without vagueness.

a)

b) Surface roughness tested sample

Figure 3.13 a) sectioned part of samples b) surface roughness tested machine

3.9.2 Holeroundness

Hole roundness is the measure of the deviation of distorted hole from perfect circle. Factors like feed rate, spindle speed and material property are necessary for minimized distortion of hole. Circularity has influence on assembly and alignment in turn which influence the performance and quality of parts (Yenigun & Kilickap, 2021).Hole roundness is measured in terms of (circularity) roundness error. The image of the drilled hole was taken and analyzed with the help of ImageJ. The formula used to calculate circularity is taking the difference of the minimum circumscribing and maximum inscribing circle diameter of the hole.

$$Roundness\ (circularity) = \frac{D_{max-}D_{min}}{2} \tag{3. 18}$$

(Huda, 2020)

Where: D_{max} is the maximum hole diameter and D_{min} is the minimum hole diameter

3.9.3 Delamination

Delamination is the damage that occurs in species of composites due to sudden impact, moisture and fatigue which cause them to lose their ability to withstand stress and strain. It reduce strength, durability and stiffness of the composite materials which determine the life of the jointed part. In this study the delamination of drilled hole was measured by taking image of sample with camera and ImageJ image editing software with $10 \times$ magnification with 0.1 resolution .Mathematically delamination is enumerated as delamination factor in which drilling induced –damage of the composites was indicated (Jones et al., 2017). Delamination is exist at both side of drilled hole. The propagation of delamination and the size of the damage are influenced by the drilling thrust force developed during the process as result of the input parameter. Some researchers have also used a ratio of the damaged area to the hole area (Patel et al., 2018) .During delamination test the composite material was positioned and an image was taken. That image is taken in an equal pixel which was used to measure the damage (maximum width). After the measurement of the maximum width of damage (Dmax) suffered by the material, the damage normally assigned by the delamination factor (F_d) was determined.

$$D_f = \frac{D_{max}}{D} \tag{3. 19}$$

(Öchsner, 2023)

Where: F_d is delamination,D_{max} is damaged zone diameter and D is the nominal diameter of the hole

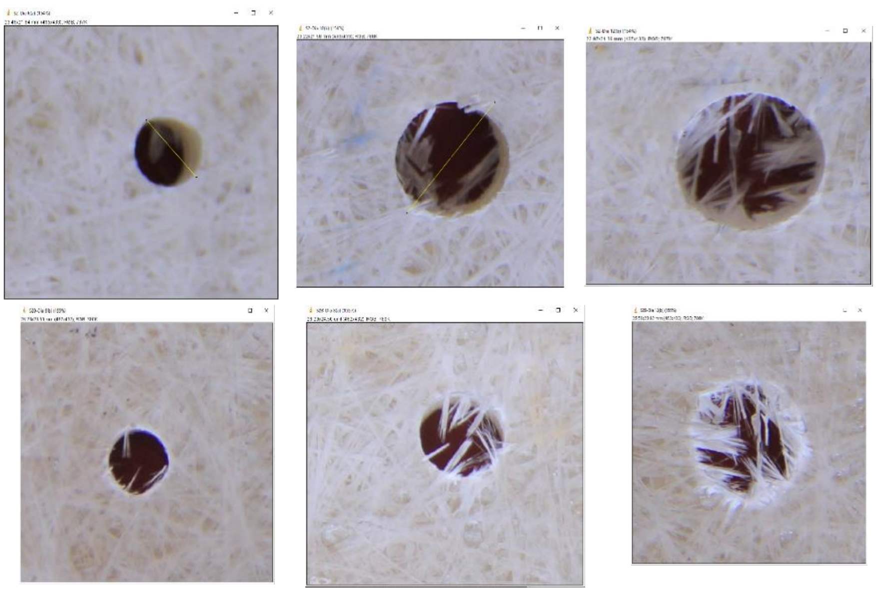


Figure 3.16 Delamination at diffrent parameter level

3.10 Analysis and optimization of the material behavior

3.10.1 Design of Experiment

Design of experiments (DoE) technique is a powerful tool, which permits us to carry out modeling and analysis of the influence of the process variables on the response variables.

The response variable is an unknown function of the process variables, which are known as design factors or independent variables. In a drilling operation, there are many factors that cab be considered as the machining parameters. From those factor most of literature has taken spindle speed, feed rate and drill diameter as input parameter by many researchers in this study research study these parameters were selected as design factors. From response surface design Box-Behnken design, three level for each factor and purpose built to fit a quadratic model with two center was selected for the model.

3.10.2 Analysis of variance (ANOVA)

ANOVA is a standard statistical technique that is used to analyze experimental data. It was used to determine which parameters have a significant influence on the quality attribute. It also used to determine the influence of all control parameters using idea of percentage contribution. The Percent contribution measure associated influence of each control parameter on the performance characteristic of results in the analysis of variance. This analysis used a significance level of 5%, corresponding to a 95% level of confidence. Based on its statistical findings, it is determined that the existence or absence of significant variation in the output. The significance value in the ANOVA is the **P** value. The P value is the probability of obtaining F value, accepting the null hypothesis. Subsequently compering P value with significance level which is $\alpha(0.05)$ then decided ANOVA as significant when p is less than 0.5 and as insignificant for above 0.5 value. The percentage contribution of each model term in relation to the sum of the squares was measured. The relative relevance of each model term is typically shown by the % contribution, which is a rough but useful guide. The percentage contribution of every significant parameter was determined by variance analysis.

Each term used in ANOVA table was degined here.

Block: the block indicates the proportion of answer variance that can be discribed to blocks.

Model: The overall model test for significance is displayed in the model row.

Terms: The model is tested separately after being divided into individual terms.

Residual: The residual row displays the amount of response variation that remains uncounted for.

Cor Total: The variation around the observations' mean is displayed in this row.

Sum of Squares: The total of the squared discrepancies between the sources of that row's varation and the general average.

Degrees of Freedom (df):

The quantity of estimated parameters needed to calculate the sum of squares from the source.

F Value: A test used to compare the residual mean square to the mean square of the source.

Probability > F: (P-value) Chance of witnessing the reported F-value in the event that the null hypothesis—that is, no factor effects—is correct. Low probability values demand that the null hypothesis be disproved. The probability is equivalent to the F-distribution's integral under its curve.

3.10.3 Optimization using genetic algorithm in MATLAB

Genetic Algorithm

Genetic algorithms (GAs) are a type of evolutionary algorithm inspired by the process of natural selection. They are used to solve optimization and search problems by mimicking the biological processes of evolution, such as selection, crossover, and mutation. Here are some reasons why genetic algorithms are used: GAs are inherently parallel, work with a population of solutions rather than a single solution which leveraged to improve computational efficiency.

Finding the cutting speeds, feed rates, and drill diameter that would minimize surface roughness, delamination and circularity roughness (Ra) was the main objective of this optimization.The optimization technique involved genetic algoritm method in the matlab.The regression model developed by expert 13 software design was used to characterize the output responses. The process of implementing a genetic algorithm for optimization began with the creation of regression models for each of the output responses in a MATLAB workspace. Additionally, important variables such as the quantity of variables, the upper and lower bounds of the input process parameters (feed rate, cutting speed, and depth of cut), and all other required inputs were entered. The optimization was then initiated by choosing the population type, which is used to specify the type of input to the fitness function. The initial random population composed of a viable population that complies with all linear requirements and limitation.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The steps followed in chapter three resulted in experimental result. This section provides the output value of the tested parameter for both first and secondary operation. In the first operation the experimental test like mechanical characterization such as tensile strength, impact strength, flexural strength, hardness and physical characterization (water absorption) results for fabricated bamboo-sisal-alumina polyster composite were stated and investigated. Then the sample with best property was selected and drilled using CNC machine to visualize the effect of input parameters on drilled specimen. The result was analyzed for output parameters (surface roughness, circularity, morphology and delamination).

4.2 Experimental Results and Analysis

4.2.1 Mechanical characterization

4.2.1.1 Impact strength analysis

From experimental work the impact strength value of six different sample was the following. Impact strength tell us information about the energy absorbed by the material. The type of the material either it is brittle or ductile was identified by the fracture tip of the species. Poor interfacial bonding of bamboo-sisal polymer reinforced composite resulted in to low impact strength. To overcome the compatibility of fiber and matrix surface treatment and inclusion of ceramic particles was intended in this work. According to the revealed result bamboo-sisal polyster composites without addition of alumina had 4.85J impact strength value. The maximum energy absorbed among the samples were 10.5J for sample 4.For sample 5 and 6 where the Wt. %. Of alumina was relatively high to other samples the amount of energy absorbed were reduced. As the result stated in (Mousavi et al., 2022) increased amount of alumina in natural fiber polymer reinforced composites resulted in decreased amount of impact strength of composites due to created stress concentrations and crack initiation sites in the composites.

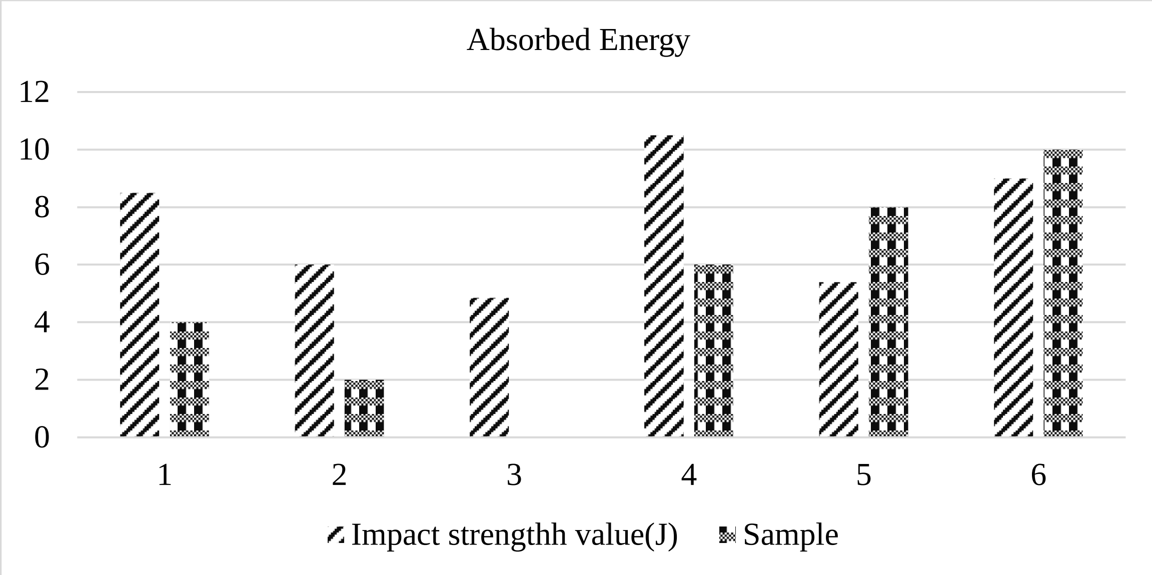


Figure 4.1 Figure Impact strength of samples

Examining the energy absorbed for drilling part provides crucial insights into materials ablity to withstand the drilling process. Sample 1 and 4 exhibit the highest energy absorption indicating drilling performance and resistance to damage, while sample 3 absorbs the lowest energy, showing potential susceptibility to drilled induced damage.

4.2.1.2 Hardness Analysis

Results obtained from the experimental work of hardness test of the hybrid bamboo-sisal polyster composites synthesized through hand lay-up method was listed in the following table. According to the given results the maximum and the minimum hardness value was 38.59HV and 48.2 HV respectively. For the samples the hardness value was increased based on the concentration of alumina. In sample 2 the hardness value of pure bamboo-sisal reinforced polyster composite was improved by 5.6% with the inclusion of alumina in relative to sample 3. As indicated in (Arputhabalan et al., 2021) the addition of alumina to natural fiber reinforced composite resulted in enhanced hardness value. According to the finding obtained from (Sahoo et al., 2022) the performance of the natural fiber reinforced composite is depend on the hardness value due to the fact that increasing hardness value can improve mechanical properties. However, excessive hardness resulted in cracking. With various considered factors which affect the fiber dispersion, fiber matrix interaction and fiber-matrix stress transfer in NFRcs the optimal hardness value has vital role for intended performance.

Table 4.1 Hardness value of hybrid bamboo-sisal reinforced polyster composite

	Hardness value(HV)			
Sample code	Trial 1	Trial 2	Trial 3	Average
S1	39.58	37.51	38.7	38.59333
S2	39.4	40.2	40.9	40.16667
S3	43.2	39	41.67	41.29
S4	41.9	38.6	39.4	39.96667
S5	48.8	47.2	48.6	48.2
S6	44.9	43.2	41.7	43.26667

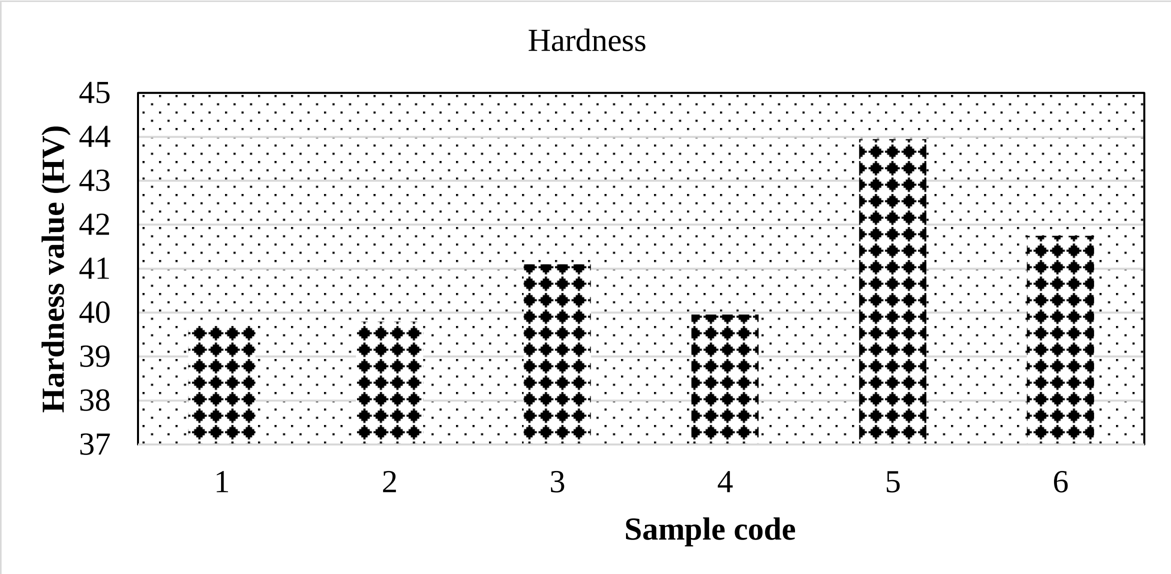


Figure 4.2 Hardness value

As showed above the hardness values exhibit variablity across the six samples and within each sample across the three trials. This indicates that the manufacturing factors influence hardness measurements. Among the samples S1,S2,S4 and S6 the hardness values display relatively consistent values.In Sample S3 and S5 there is greater variablity between trials hardness value.Depending on the average hardness values sample5 demonstrates the highest average hardness among all samples,suggesting a formulation with superior resistance to intendation due to the role of alumina concentration.The variation in hardness across samples is attributed to diffrences in the distribution and interaction of alumina within the composite matrix,affecting its overall hardness(Kadhim et al., 2022).The hardness value is directly related to mechanical behaivour in turn with performance off material.

4.2.1.3 Flexural strength analysis

A flexural strength was conducted to determine the material's ability to resist bending under applied load. With help of three-point bending test, the maximum load was applied at the middle of freely supported beam specimen and the average value of the tasted were listed below for all fabricated six samples. The volume of fibers and the addition of alumina powder had effect on the amount of the flexural strength. Starting from sample 1 to 6 as some variation on weight percentage was there, and the magnitude of flexural strength was also changed. According to (Bhat & Saxena, 2023) results showed that the introduction of alumina enhances the flexural strength of bamboo-fiber reinforced polymer composites by increasing the stiffness and toughness of both fibers and matrix. The higher flexural strength value of the samples, the more resistant to they are to bending which improves the durability and reliability of composite under load.

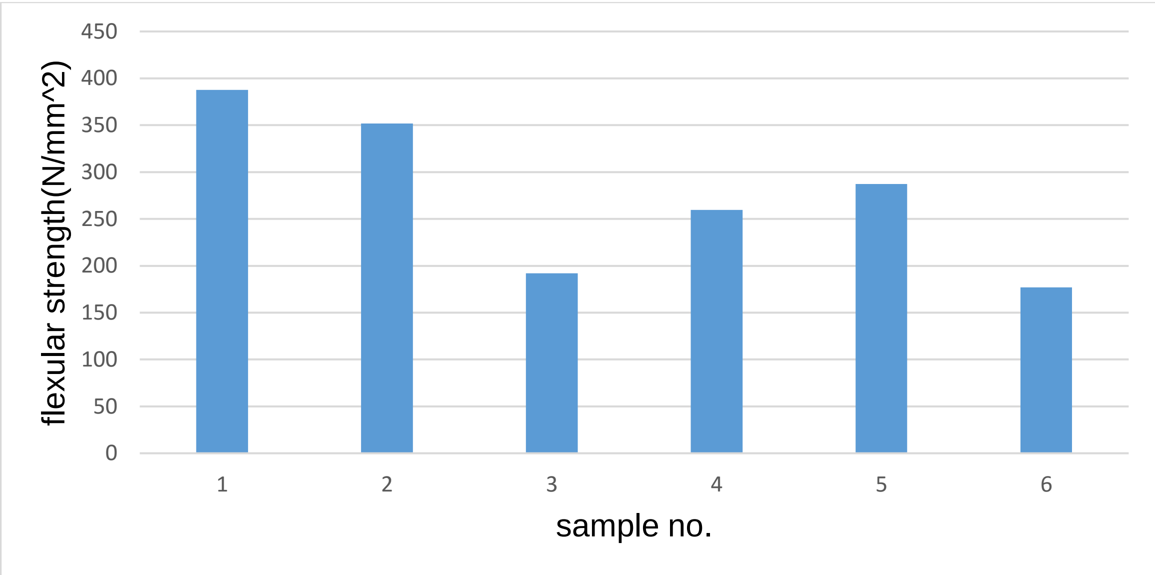


Figure 4.3 Flexural strength of samples

The result revealed a range of flexural strengths across six composite samples with varying compositions of bamboot fiber, sisal fiber, aluminum oxide, and polyester resin. Sample S1 has the highest flexural strength at 387.557 N/mm^2, indicating a strong reinforcement effect. Sample S3 has a lower flexural strength, indicating the importance of Al2O3 in enhancing mechanical properties. The presence of aluminum oxide generally enhances flexural strength, while the distribution and ratio of basalt and sisal fibers also affect the composite's performance.

4.2.1.4 Water absorption analysis

Water absorption properties of hybrid BSFRPC samples with and without inclusion of synthetic fiber alumina were determined by immersing the specimen for different hours in a water at room temperature. The purpose of this test was to determine the amount of water absorbed under certain conditions. The weights of the specimens were measured using a digital mass balance after they were immersed in water. The results were found in the table below.

Table 4.2 Water absorption test results of BSFRPC

	Immersion period in Hr.			
Sample code	24	48	96	Average %
S1	0.23	0.348	0.422	0.333
S2	0.179	0.273	0.216	0.223
S3	0.474	0.542	0.553	0.523
S4	0.572	0.631	0.702	0.635
S5	0.56	0.593	0.603	0.585
S6	0.613	0.663	0.75	0.675

Table showed that water absorption test results which provide moisture absorption characteristics of the hybrid bamboo-sisal alumina reinforced polymer composites(BSFRPC) over diffrent immersion periods.As immersion period increases ,so does the water absorpttion for all samples.sample 4 exhibits the highest water absorption across all immersion period,with values of 0.572,0.631,and 0.702 at 24,48,and 96 hours respectively,resulting in an average absorption of 0.635%.This suggest that sample 4 has relatively higher moisture absorption capacity compared to other samples (Abd Halip et al., 2019),indicating potential susceptibility to moisture –related degradation or dimensional changes over time.On the other hand,sample 2 demonstrates the lower ater absorption characteristics,with values of 0.179,0.273 and 0.216 at 24,48,96 hours respectively, resulting in an average absortion of 0.223%.The result indicates that the sample is less prone to absorpting moisture compared to other samples ,indicating better moisture resistance and potentially improved durability in humid environments.

4.3 Selection of Sample for Drilling Operation

Grey Relational Analysis Method was used to select best sample among fabricated Bamboo-sisal-alumina samples. This method is used to solve interrelation between various response.with the help of a grey relational grade relation among the responses were analyzed.In this study Impact strength,hardness,water absorption and flexular strength are used as response to be analysed.The experimental results are converted to signal-Noise ratio.During the analyze the three sorts of S/N ratio are used:the smaller the better,the larger the better and the nominal the better (Kuo, 2017).The S/N ratio for this study falls under the smaller the better(water absorption) and larger the better (Impact,tensile strength and hardness value).This is done to select the samples for the secondary operation which is drilling.The S/N ratio is calculated using equation (3.14) and (3.15) .The steps described in the chapter 3 were utilized to obtain desired out put.

STEP1: Transformation of data into S/N ratio

Data obtained from the results were converted to S/N ratios

Table 4.3 Transformation of data into S/N ratio

	Experimental results					
Sample code	**Hardness(HV)**	**Impact (J)**	**Water absorption**	**Hardness**	**Impact**	**Water absorption**
S1	38.59333	8.5	0.333	16.357	31.73	4.32
S2	40.16667	6	0.223	18.8367	22.57	4.85
S3	41.29	4.5	0.523	12.87	12.15	12.76
S4	39.96667	10.5	0.635	14.4932	22.77	10.96
S5	48.2	5.39	0.585	17.4912	42.38	27.86
S6	43.26667	10	0.675	13.8699	13.38	10.23

STEP2 : Normalization of S/N ratios This transformation is done on single input to uniformly distribute and scale the data into the an acceptable range using equation (3.14) for smaller the better and equation(3.15) for larger the better.

Table 4.4 Normalization of S/N ratios

Normalized value of responses				
s.no.	sample code	Hardness	Impact	Water absorption
	s1	0.347	0.576	0
	s2	1	0.388	0.053
	s3	0	0	0.396
	s4	0.012	0.5771	0.33
	s5	0.535	1	1
	s6	0.09	0.24	0.305

Step3 : Determination of deviation sequences and grey relational coefficient.using equation (3.18) with the identification coefficient assumed as 0.5 (Arun Ramnath et al., 2018)

Table 4.5 Deviation sequence of normalized data

Sample code	**Hardness deviation**	**Impact deviation**	**Water absorption deviation**
S1	0.65	.424	0
S2	0	.612	0.053
S3	1	1	0.396
S4	0.988	0.4229	0.33
S5	0.465	0	1
56	0.91	0.76	0.305

Step4 : compute grey relational coefficient grade for grading the samples based on the grey rational grade.Equation (3.18) is used for computing the value of grey relational grade.

Table 4.6 Compute grey relational coefficient grade

	Grey relational coefficient			Grey relational	Rank
sample code	Hardness	Impact	Water absorption	grade	
s1	0.434	0.243	0.018	1	1
s2	0.814	0.413	0.145	0.78	5
s3	0.303	0.47	0.234	0.505	6
s4	0.508	0.334	0.242	0.701	2
s5	0.61	0.272	0.355	0.596	4
s6	0.528	0.351	0.22	0.686	3

Based on the grey relational grade, from highest to lowest four samples s1,s4, and s6, were selected for the secondary operation(drilling) .

4.3.1 Investigation of drilling characteristics

Analyzing the output parameters of drilling in Bamboo-sisal-alumina composites involved investigation of drilling characteristic output like delamination both at entry and exit ,surface roughness and morphological analysis based on the given input parameter.DOE analysis was used to analyze the effect of each process parameter on drilling parameter on drilling parameter.

4.3.1.1 Analysis of surface Roughness

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces (Ra) usually wear more quickly and have a higher friction coefficient than smooth surfaces. In many drilling applications, particularly those requiring precision or smooth finishes, efforts are made to minimize surface roughness. as the surface quality determines the precision of the drilled component. Roughness in fiber-reinforced composite laminates occurred due to the improper fracture of fibers, which tends to expose sharp fiber ends on the inner surface of the drilled hole. Variation in the surface roughness leads to the material failing under fatigue and fastener load, which cause misalignment, high friction, and heat generation at the drilled hole wall surfaces (Margabandu & Subramaniam, 2020).

The performance of mechanical components often described in terms of the surface roughness of the given of the material. In this work the surface roughness on the drilled part of the sample was expressed as Ra(average surface roughness).Ra was determined as the effect of input parameter (feed rate, spindle speed and drill diameter) at three level .figure 4() showed surface roughness variation for spindle speed, feed rate and drill diameter.The non-homogeneous property of the composite cause the surface irregular due to the cutting mechanism involved .The cracking of matrix developed in the drill face during tool penetration. The high drill force caused the fibers to pullout protrude from, and became deboned from the matrix. At the exit point the fibers were broken and fragmented. Since the irregularities and scattering in the surface value there are different failure that occur as response to iinput parameter as reported by (Shanmugam et al., 2021) .

4.3.1.2 Surface roughness statiscal analysis

Fit summary :

The Fit Summary program aids in regression calculation by fitting polynomial models to a selected response. It calculates effects, produces statistics, and compares models. The program suggests Quadratic models, while cubic models are aliased.The linear model is significant compared to the mean, but selected quadratic model as the highest order polynomial.this model explains significantly more of the variation in the response (p-value small), insignificant lack of fit (p-value > 0.10) and reasonable agreement between Adjusted R-squared and Predicted R-squared (within 0.2 of each other).

Table 4.7 Fit summary for surface roughness (R2)

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.0288	0.0943	0.4527	0.1456	
2FI	0.4276	0.0915	0.4611	-0.3263	
Quadratic	**0.0020**	**0.3385**	**0.9689**	**0.8552**	**Suggested**
Cubic	0.3385		0.9910		**Aliased**

Table 4.8 Sequential Model Sum of Squares surface roughness

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	
Mean vs Total	285.79	1	285.79			
Linear vs Mean	0.1671	3	0.0557	4.58	0.0288	
2FI vs Linear	0.0378	3	0.0126	1.05	0.4276	
Quadratic vs 2FI	**0.0810**	**3**	**0.0270**	**39.10**	**0.0020**	**Suggested**
Cubic vs Quadratic	0.0026	3	0.0009	4.27	0.3385	Aliased
Residual	0.0002	1	0.0002			
Total	286.08	14	20.43			

Table 4.9 Model Summary Statistics of (R2)

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.1102	0.5790	0.4527	0.1456	0.2466	
2FI	0.1094	0.7098	0.4611	-0.3263	0.3828	
Quadratic	**0.0263**	**0.9904**	**0.9689**	**0.8552**	**0.0418**	**Suggested**
Cubic	0.0141	0.9993	0.9910		*	Aliased

4.3.1.3. Analysis Of Surface Roughness

The ANOVA is where the descriptive statistics and statistical tests are presented. In general, look for low p-values to identify important terms in the model. From the Analysis of Variance for surface roughness in Table 4-10 it is observed that The **Model F-value** of 46.00 implies the model is significant. There is only a 0.33% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. From the Table(4.11) the diffrence batween predicted R-Squared and Adjusted R-Square is less than 0.2,then the model is fitting the data and it was reliably used to interpolate .And adequate Precision in Table were greater than 4 was 24.4758 then it was found that the model had a signal that was strong enough to be optimized. The calculation of the percentage of contribution in this ANOVA involved dividing the sum of squares for each individual source by the sum of squares for the Cor Total.

Table 4.10 ANOVA for Quadratic model of surface roughness

Source	Percent contribution	Sum of Squares	df	Mean Square	F-value	p-value	
Model		0.2858	9	0.0318	46.00	0.0011	Significant
A-speed	33.53	0.0968	1	0.0968	140.26	0.0003	
B-feed rate	8.56	0.0247	1	0.0247	35.72	0.0039	
C-drill diameter	4.57	0.0456	1	0.0456	66.05	0.0012	
AB	8.4.5	0.0132	1	0.0132	19.12	0.0119	
AC	8.32	0.0240	1	0.0240	34.80	0.0041	
BC	0.17	0.0005	1	0.0005	0.7662	0.4308	
A^2	14.48	0.0418	1	0.0418	60.47	0.0015	
B^2	2.42	0.0070	1	0.0070	10.14	0.0334	
C^2	9.63	0.0278	1	0.0278	40.32	0.0032	
Residual	.97	0.0028	4	0.0007			
Lack of Fit		0.0026	3	0.9609	4.27	0.94385	not significant
Pure Error	100.00	0.0002	1	0.0002			
Cor Total		0.2886	13				

Table 4.11 Fit Statistics of surface roughness

Std. Dev.	0.0263	$\mathbf{R^2}$	0.9904
Mean	4.52	**Adjusted $\mathbf{R^2}$**	0.9689
C.V. %	0.5816	**Predicted $\mathbf{R^2}$**	0.8552
		Adeq Precision	24.4758

Regression model for Surface Roughness

The statistical link between surface roughness and drilling parameters was ascertained using this model. This model was used to determine the change in drilling parameters linked to the change in surface roughness.

$$R2 = 4.043 + 0.000293\ A{:}speed + 1.234\ B{:}feed\ rate + 0.01678\ C{:}drill\ diameter \quad (4.1)$$

4.3.1.4 Parametric influence on the Surface Roughness

The graph of Normal Probability plot versus internally studentized residual on figure 4.5 a showed that the residuals follow a normal distribution, thus follow straight line.

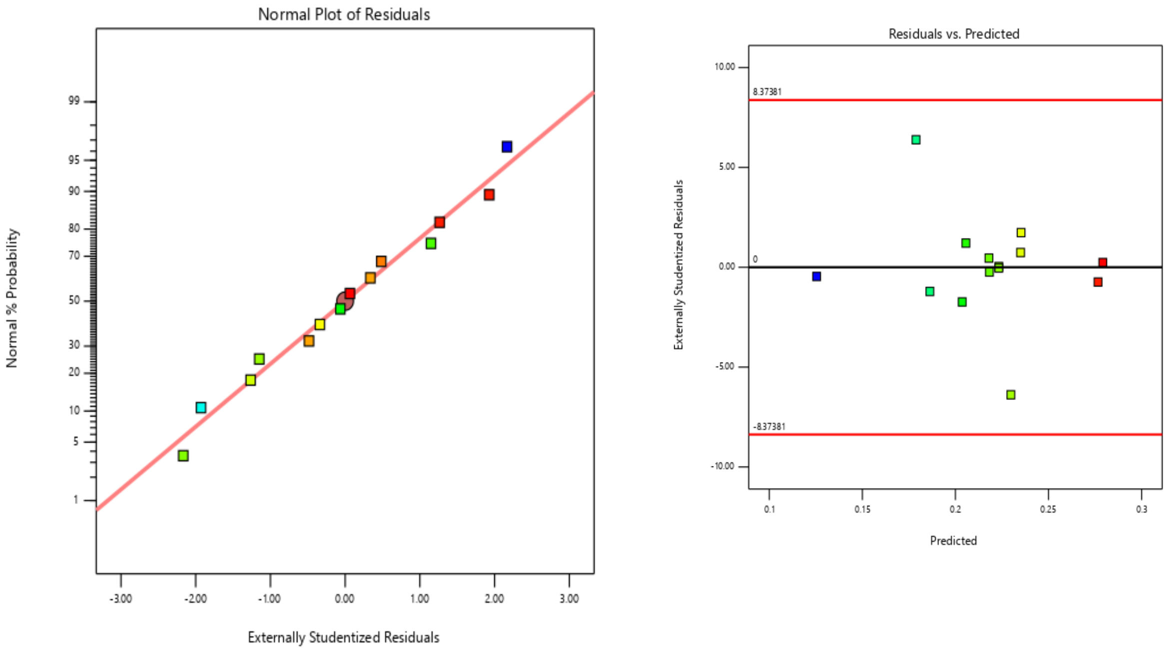


Figure 4.4 Normal plot versus residuals of surface roughness

A) Effect of feed rate on the Surface Roughness

The feed rate (B) has the significant effect on surface roughness, with both strong linear and quadratic terms indicating that higher feed rates substantially increase roughness. At first indicated that as the feed rate increases, the surface roughness initially decreases slightly from 0.03 mm/rev to 0.075 mm/rev, then increases as the feed rate goes up to 0.12 mm/rev. This trend suggests that there is an optimal feed rate (around 0.075 mm/rev) where the surface roughness is minimized. Beyond this point, increasing the feed rate leads to a higher surface roughness.it was observed from study and from ANOVA feed rate is significant factor affecting surface roughness as its P-value indicated 0.0039 with percent contribution of as similar observation stated here

Reported in (Goutham et al., 2023**)** a higher feed rate can lead to increased surface roughness because the tool cuts deeper per revolution, leading to larger chip removal and potentially rougher surface. Figure shows the interaction effect of feed rate and spindle speed on surface roughness. Suggested that the surface roughness increases at a slightly lower rate when both speed and feed rate are increased together, compared to the sum of their individual effects.

B) Effect of spindle speed on the surface roughness

spindle speed had both linear and quadratic effects on surface roughness. The linear effect of speed Spindle speed had a positive linear effect on surface roughness, showed that higher spindle speeds tend to increase surface roughness,as seen in while the quadratic effect indicating a very slight reduction in the rate of increase in surface roughness at higher spindle speeds (Rajamurugan et al., 2022) these findings suggested that spindle speed was a factor in determining surface roughness .The highest value of surface roughness, 4.684 µm, corresponds to a spindle speed of 875 RPM with a feed rate of 0.12 mm/rev. Conversely, the lowest value of surface roughness, 4.16 µm, corresponds to a spindle speed of 500 RPM with a feed rate of 0.075 mm/rev. The interaction effect of spindle speed and drill diameter on surface roughness was expressed in very small negative coefficient, indicating a minimal effect on surface roughness.

C) Effect of drill diameter on the surface roughness

The ANOVA table results and the regression equation revealed a significant impact of drill diameter on surface roughness (Ra), with changes in diameter significantly affecting the model's overall significance, the drill diameter (C) affects the surface roughness as indicated by the F-value of 66.05 and a p-value of 0.0012. These values show that changes in drill diameter substantially impact the surface roughness, contributing to the model’s overall significance. The positive coefficient (0.13031) for drill diameter (C) was sign that shows, increasing the drill diameter tends to increase surface roughness. Figure (4.6) shows the interaction (drill diameter and speed effect on surface roughness. The study revealed that the combination of speed and drill diameter significantly impacts surface roughness, with the initial reduction being a significant effect. The interaction between speed (A) and drill diameter (C) (AC) shows a significant effect, with an F-value of 34.80 and a p-value of 0.0041.

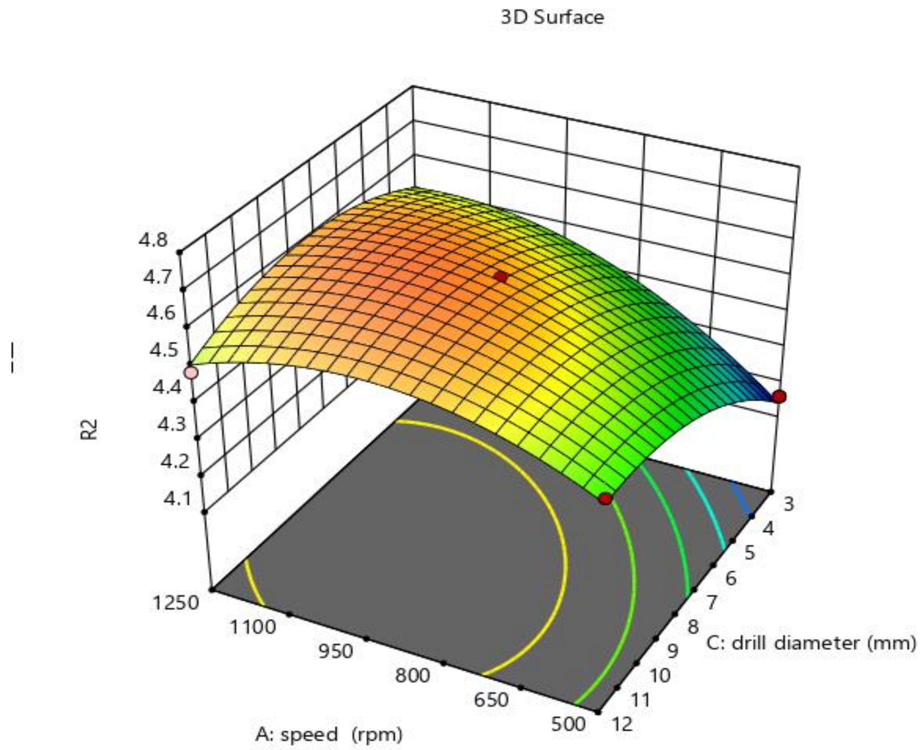


Figure 4.5 Interaction effect of AC

4.3.1.2 Delamination

Delamination was observed at both entry and exit sides of fiber-reinforced composites specimens during drilling. From the experimental results delamination at the exit side of the hole was more severe than that of entry side delamination, as this occured for statistical analysis the exit delamination was considerd.

Delamination statistical analysis

Fit summary :

The fit summary evaluates the model's adequacy and performance, using statistical measures and diagnostics to assess the model's ability to accurately describe the relationship between factors and response variables. The quadratic model was selected because it significantly improves the fit over simpler models.
As explained in the table (4.12-4.16) quadratic model was suggested and cubic was aliased i.e.,it is the highest order model that explains significantly more of the variation in response (p-valu small) ,reasonable agreement between Adjusted R-squared and predicted R-squared withion 0.2 of each other.

Table 4.12 Fit summary Delamination (1)

Source	**Sequential p-value**	**Lack of Fit p-value**	**Adjusted R^2**	**Predicted R^2**	
Linear	0.0043		0.6322	0.3857	
2FI	0.2029		0.7170	0.1709	
Quadratic	**0.0001**		**0.9958**	**0.9794**	**Suggested**
Cubic			1.0000		**Aliased**

Table 4. 13: Sequential Model Sum of Squares of Delamination

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Mean vs Total	19.96	1	19.96			
Linear vs Mean	0.1949	3	0.0650	8.45	0.0043	
2FI vs Linear	0.0355	3	0.0118	2.00	0.2029	
Quadratic vs 2FI	**0.0411**	**3**	**0.0137**	**156.12**	**0.0001**	**Suggested**
Cubic vs Quadratic	0.0004	3	0.0001			Aliased
Residual	0.0000	1	0.0000			
Total	20.23	14	1.44			

Table 4.14 Model Summary Statistics delamination

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.0877	0.7171	0.6322	0.3857	0.1670	
2FI	0.0769	0.8476	0.7170	0.1709	0.2254	
Quadratic	**0.0094**	**0.9987**	**0.9958**	**0.9794**	**0.0056**	**Suggested**
Cubic	0.0000	1.0000	1.0000		*	Aliased

4.3.1.3 Analysis of Variance

ANOVA is a robust statistical tool used in research to analyze the significance of factors and their interactions. In the provided analysis, the significance of each factor is determined by p-values, where p-values less than 0.0500 indicate that the model terms are significant. In this case, the significant model terms include A (spindle speed), B (feed rate), AB (interaction between spindle speed and feed rate), AC (interaction between spindle speed and drill diameter), BC (interaction between feed rate and drill diameter), A^2 (quadratic effect of spindle speed), B^2 (quadratic effect of feed rate), and C^2 (quadratic effect of drill diameter). These significant terms highlight the critical factors and their interactions that influence the response variable, delamination .

The difference between the Predicted R-Squared and Adjusted R-Squared values is less than 0.2, indicating that the model fits the data well and can be reliably used for interpolation. This small difference demonstrates that the model's predictive capability is consistent with its explanatory power. Additionally, the Adequate Precision value, which measures the signal-to-noise ratio, is 167.3320, significantly greater than the threshold value of 4. confirmed that the model had a strong enough signal to be used for optimization and to navigate the design space effectively. The percentage contribution of each factor in the ANOVA was calculated by dividing the sum of squares of each individual source by the sum of squares of the total (Cor Total), providing insight into the relative impact of each factor on the delamination.

Table 4.15 ANOVA for Quadratic model of Delamination

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	Percent contribution %	
Model	0.2715	9	0.0302	343.96	< 0.0001	99.89	significant
A-speed	0.0091	1	0.0091	103.92	0.0005	3.35	
B-feed rate	0.1391	1	0.1391	1586.64	< 0.0001	51.17	
C-drill diameter	0.0467	1	0.0467	532.18	< 0.0001	17.18	
AB	0.0324	1	0.0324	369.49	< 0.0001	11.92	
AC	0.0006	1	0.0006	7.13	0.0558	0.22	
BC	0.0025	1	0.0025	27.94	0.0061	0.92	
A^2	0.0004	1	0.0004	4.24	0.1087	0.15	
B^2	0.0155	1	0.0155	176.40	0.0002	5.70	

C^2	0.0170	1	0.0170	194.34	0.0002	6.26	
Residual	0.0004	4	0.0001				
Lack of Fit	0.0004	3	0.981				Not significant
Pure Error	0.0000	1	0.0000				
Cor Total	0.2718	13				100.00	

Table 4.16 Fit Statistics

Std. Dev.	0.0094	**R^2**	0.9987
Mean	1.19	**Adjusted R^2**	0.9958
C.V. %	0.7843	**Predicted R^2**	0.9794
		Adeq Precision	57.5393

Regression model for delamination

The regression technique was utilized to analyze the statistical relationship between drilling input parameter parameters and delamination and to predict the response at specific levels of each factor.

R3=1.1890-0.0019A: speed-0.184B:Feed rate+0.00199C:drill diameter (4. 22)

4.3.1.4 Parametric effect on the delamination

The parametric impact on delamination during the drilling process include: drilling speed, feed rate, drill diameter and the interaction effect between the parameters.Figure (4.7) provided Normal Plot of Residuals to assess the normality of the residuals from ANOVA and a regression analysis. The data points on the plot largely follow a straight line, but was a bit of deviation from the line at the extreme ends which suggests that the residuals are approximately normally distributed.

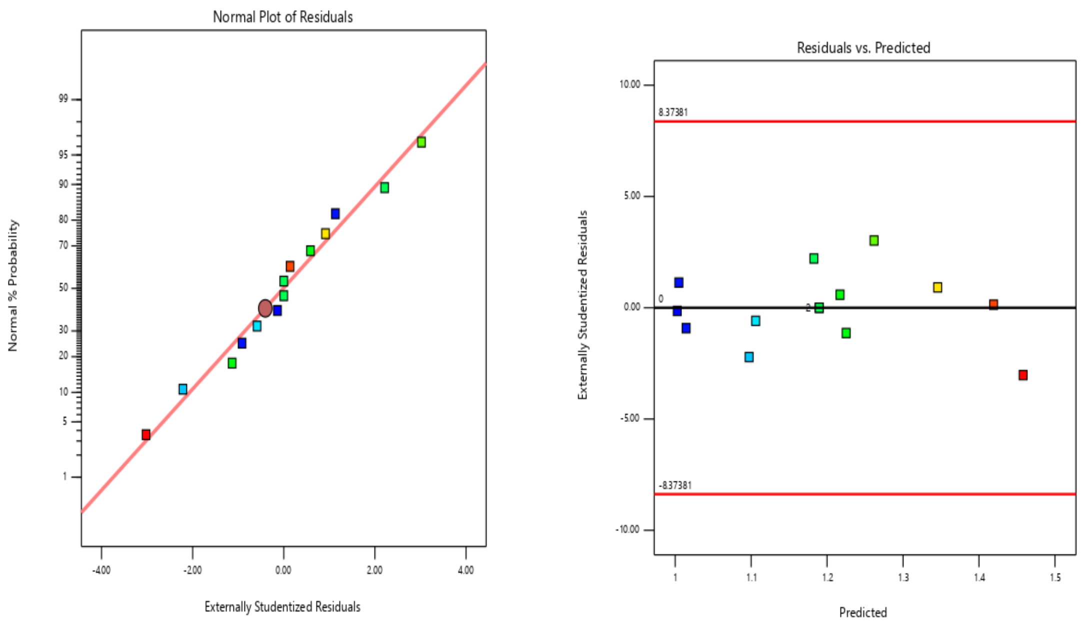


Figure 4.6 Normal plot versus residuals of Delamination

The analysis of variance (ANOVA) results provied the effect of factors including drill speed,feed rate,and drill diameter,on delamination in drilling operations.Among the factors analyzed,the feed rate(B) and drill diameter (C) show the most substantial impact on delamination,contributing 51.17% and 17.18 % to the total variance respectively.Drill speed(A) contributed a smaller (3.35%) contribution.

A)Effect of spindle speed on the delamination

The impact of speed on the delamination was lower compared to the other two factors,but it was significant model in the model.The F-value for drill speed was is 109.32 with tP-value of 0.0005,confirmed its statistical significance.The model suggested that drill speed(A) had a direct relationship with the delamination as reported by (Babu et al., 2022; Mahesh & Kandasamy, 2023). Increasing drill speed resulted in increased value in delamination . The interaction between feed rate(AB) contributed 11.92% to the model. The combined effect of the (BC) was minimum compared to the other factor.

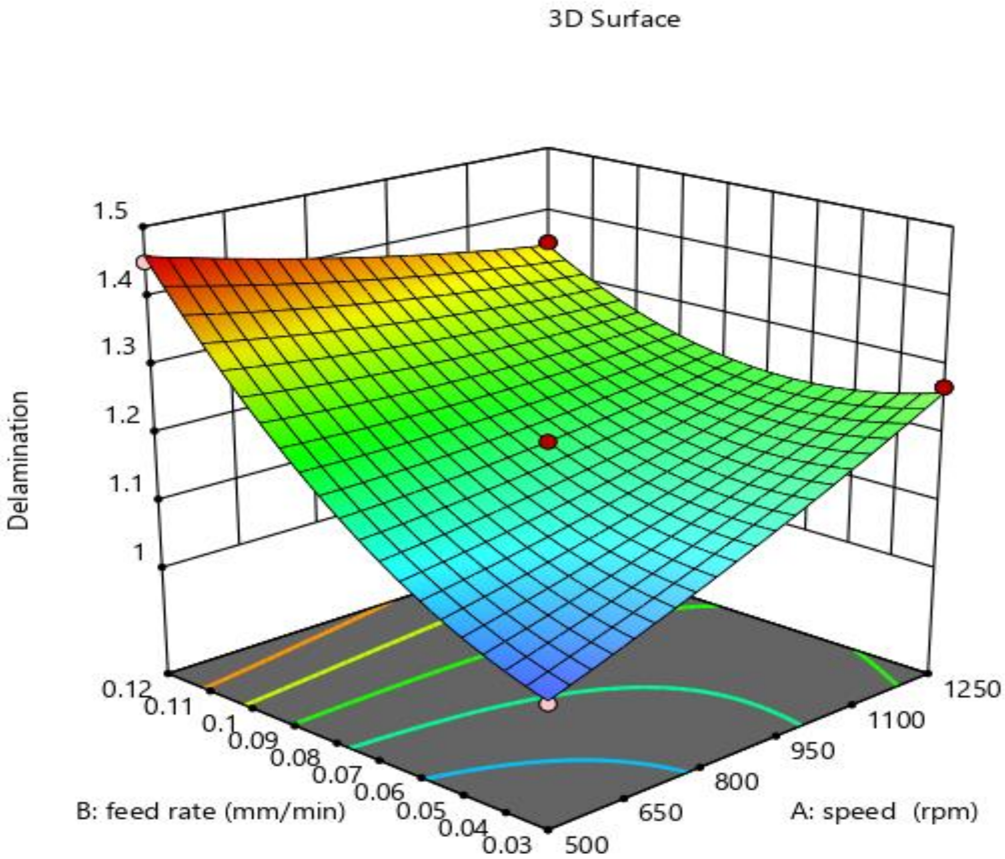


Figure 4.7 Interaction effect of AB on delamination

B) Effect of feed rate on the delamination

The feed rate is a critical factor influencing delamination in drilling operations,with composite materials. According to ANOVA results the feed rate(B) was the most significant contributor to the accounting for 51.17% of the total variation delamination. The F-value 1586.64 with P- value statistical significance of the factor.The model indicate that the direct relationship was existed between the feed rate and delamination. Higher feed rate resulted in higher delamination and lower feed rate resulted in lower feed rate. As demonstrated in (Azmi et al., 2024; George et al., 2024) higher feed rates increase thrust forces,leading to more delamination of the drilled hole due to elevatedx meechanical stresses during drilling.Interaction effect between drill speed and feed rate(AB) was show significance with percentage contribution of 11.92 to the model with a F-valu 369.49 and P- value<0.0001.The combined effect on delamination show more influence than their individual effects.

C) Effect of drill diameter on delamination

Based on the ANOVA result the effect of drill diameter on delamination was significant with the percentage contribution of 17.18%. (Goutham et al., 2023)Larger drill diameters tend to increase delamination due to higher separation forces at cutting edge,leading to damage at hole.it has shown in the regression equation nonlinear relation was exist.

4.3.1.5 circularity

Fit summary provides a comprehensive overview of the reponse analysis like circularity analysis, and facilitating a clear understanding of how well the object conforms to a circular shape.circularity is a technique for calculating an object's proximity to a perfect circle. The **Model F-value** of 1831.83 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.**P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Table 4.13 Fit summary circularity

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.0182	0.0038	0.5031	0.1758	
2FI	0.7004	0.0034	0.4133	-0.6950	
Quadratic	**< 0.0001**	**0.0827**	**0.9992**	**0.9961**	**Suggested**
Cubic	0.0827		1.0000		**Aliased**

Table 4.14 Sequential Model Sum of Squares of circularity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Mean vs Total	0.6517	1	0.6517			
Linear vs Mean	0.0121	3	0.0040	5.39	0.0182	
2FI vs Linear	0.0013	3	0.0004	0.4897	0.7004	
Quadratic vs 2FI	**0.0062**	**3**	**0.0021**	**1735.24**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	4.713E-06	3	1.571E-06	78.54	0.0827	Aliased
Residual	2.000E-08	1	2.000E-08			
Total	0.6712	14	0.0479			

Table 4.15 Model Summary Statistics of circularity

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.0273	0.6178	0.5031	0.1758	0.0161	
2FI	0.0297	0.6841	0.4133	-0.6950	0.0331	
Quadratic	**0.0011**	**0.9998**	**0.9992**	**0.9961**	**0.0001**	**Suggested**
Cubic	0.0001	1.0000	1.0000		*	Aliased

Table 4.16 ANOVA for Quadratic model delamination

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0195	9	0.0022	1831.83	< 0.0001	significant
A-speed	0.0036	1	0.0036	3064.14	< 0.0001	
B-feed rate	0.0083	1	0.0083	7032.65	< 0.0001	
C-drill diameter	0.0001	1	0.0001	90.70	0.0007	
AB	0.0005	1	0.0005	412.81	< 0.0001	
AC	0.0002	1	0.0002	181.40	0.0002	
BC	0.0006	1	0.0006	499.09	< 0.0001	
A^2	0.0018	1	0.0018	1501.63	< 0.0001	
B^2	0.0009	1	0.0009	753.19	< 0.0001	
C^2	0.0023	1	0.0023	1977.21	< 0.0001	
Residual	4.732E-06	4	1.183E-06			
Lack of Fit	4.712E-06	3	1.571E-06	78.54	0.933	not significant
Pure Error	2.000E-08	1	2.000E-08			
Cor Total	0.0195	13				

Table 4.17 Fit Statistics circularity

Std. Dev.	0.0011	**R²**	0.9998
Mean	0.2157	**Adjusted R²**	0.9992
C.V. %	0.5042	**Predicted R²**	0.9961
		Adeq Precision	177.5832

Regression for circularity

Circularity=0.1062+0.000052A: speed+0.713B:feed rate+0.00081c:drill diameter (4. 23)

4.3.1.6 Parametric impact on the circularity of drilled hole.

The graph of normal plot residuals suggest whether the model used for circularity analysis was appropriate or not.As shown in the figure most of the data points lie close to the red line ,which represents the expected values if the residuals were normally distributed. Theplot suggested that the residuals were approximately normally distributed.

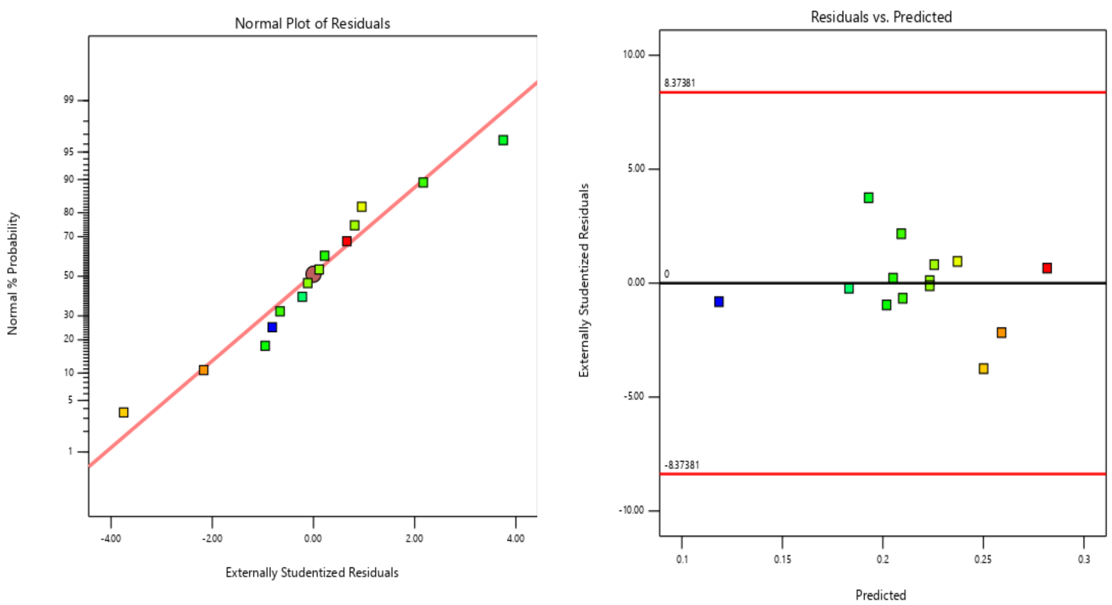


Figure 4.8:Normal plot

A)Effect of speed on the circularity

Based on the ANOVA results for the quadratic model assessing the effect of spindle speed (A), on circularity, spindle speed has a highly significant impact on circularity, as indicated by its p-value of < 0.0001. The sum of squares for spindle speed is 0.0036, and the corresponding F-value is 3064.14, which signifies a substantial contribution to the model. The regression equation shows that spindle speed (A) has a positive linear coefficient of 0.000366544 and a negative quadratic coefficient of -1.67556e-07, indicating that increasing spindle speed initially increases circularity, but after a certain point, further increases in speed slightly reduce circularity due to the quadratic term's influence which go inhand as stated in (Helmi Abdul Kudus et al., 2021; Malik, Ahmad, & Gunister, 2022; Saraswati et al., 2019) . The interaction effects of spindle speed (A) with feed rate(F) and drill diameter (C) and circularity were significant as shown in the ANOVA table. The below figure(4.10) shows the 3D surface projecton of the contour plot graph for interaction effects of spindle speed ,feed rate and drill diameter on the circularity of drilled hole.

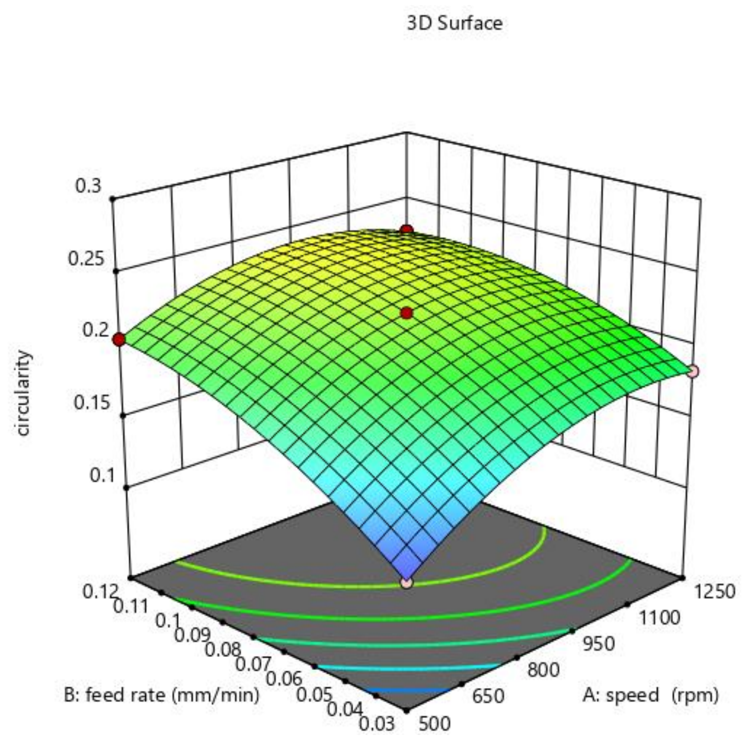


Figure 4.9 The effect of spindle speed, feed rate, and drill diameter on the circularity

Effect of spindle speed feed rate and drill diameter on the circularity

The AB interaction term had a sum of squares of 0.0005 and F-value of 412.81 with a P –value <0.0001 ,indicating a strong intraction between spindle speed and feed rate and and also based on the regression equation coefficient (-0.000654815),the interaction had negative impact on the circularity.Indicated combined increase in both factor tends to decrease the circularity. Similarly the ,AC interaction term with sum of squares 0.0002 and F-value of 181.4 ,and P-value of 0.0002 signifies a significant interaction between spindle speed and and drill diameter.The regression coefficient showed that as spindle speed and drill diameter increase resulted in circularity.

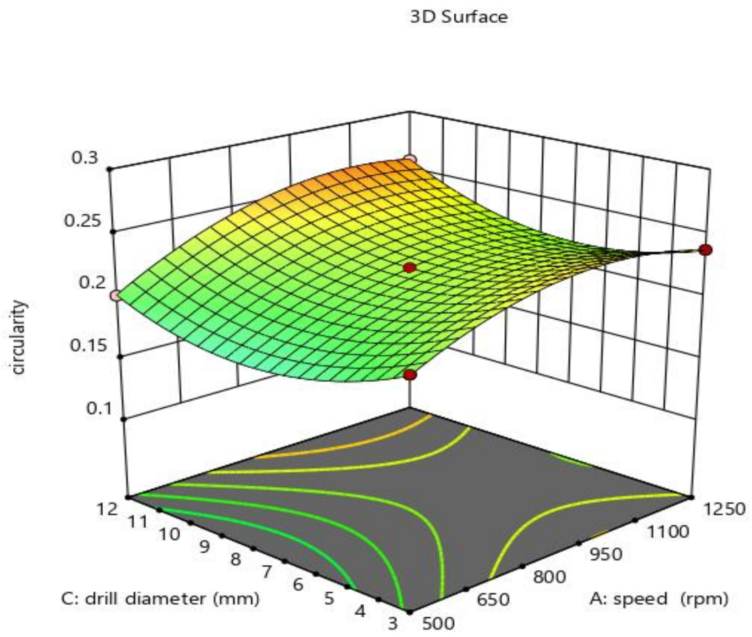


Figure 4.10 Interaction effect AC on circularity

A) Effect of Feed rate on the circularity

The effect of feed rate (B) on circularity was highly significant, as demonstrated by the ANOVA results. The feed rate has a sum of squares of 0.0083, which is the highest among the individual factors, and an F-value of 7032.65 with a p-value < 0.0001. The feed rate is a major determinant of circularity. The regression coefficient for feed rate is 2.07574, indicating that an increase in feed rate results in a substantial increase in circularity (Nassar et al., 2017). The BC interaction term suggested that combination of higher feed rates and larger drill diameters can synergistically enhance circularity

B) Effect of drill diameter on the circularity

The effect of drill diameter (C) on circularity, as indicated by the ANOVA results, is significant but less impactful compared to feed rate and spindle speed. The sum of squares for drill diameter is 0.0001, with an F-value of 90.70 and a p-value of 0.0007. Indicated that while drill diameter does influence circularity, its impact is not as pronounced as the other two factors. The linear coefficient for drill diameter in the regression equation is -0.027512, suggesting that an increase in drill diameter results in a decrease in circularity. Thus negative relationship indicates that larger drill diameters tend to produce less circular holes or features. The BC interaction term had coefficient of 0.06, suggested a more substantial synergistic effect between feed rate and drill diameter on circularity. Indicated that while larger drill diameters alone tend to reduce circularity, their adverse effects can be mitigated by appropriate feed rates and spindle speeds.

4.4 Optimization of Parameters

For drilling operations to be more effective and high-quality over a range of Fitness function must be solved by employing a genetic algorithm in order to solve this optimization problem utilizing the GA gamultiobj function tool, which corresponds to Solver.Fitness function is the multi objective vector) function to be optimized. In this work, regression model developed by Design Expert software and ANOVA model has been employed as mathematical model which establishes the relation between input and output were converted to general equatThe developed mathematical model was converted into a MATLAB R2018a function. This function was input to the gamultiobj Toolbox of MATLAB R2018a as the objective function. Upper and lower bounds were specified as per the levels of the machining parameters and the number of variables was set at 3. The objective function values are obtained for minimizing of surface roughness,delamintion and circularity. Double vector population type was used to specify the type of input to the fitness function, 1000 population size was taken as number of individuals in each generation.

4.4.1 Optimization of surface roughness

Minimizing surface roughness is, therefore, essential for enhancing product quality and reducing manufacturing costs. In this study, the results of our optimization efforts to minimize surface roughness using MATLAB, a powerful computational tool widely used for engineering and scientific applications through Genetic Algorithm was presented in the following figure.The optimmum result was obtained at third generation.

- The optimal value at spindle speed(rpm) ,feed rate(mm/rev) and of drill diameter (mm)were found to be 1250rpm,0.075mm/rev and 3mm whic was 4.277.

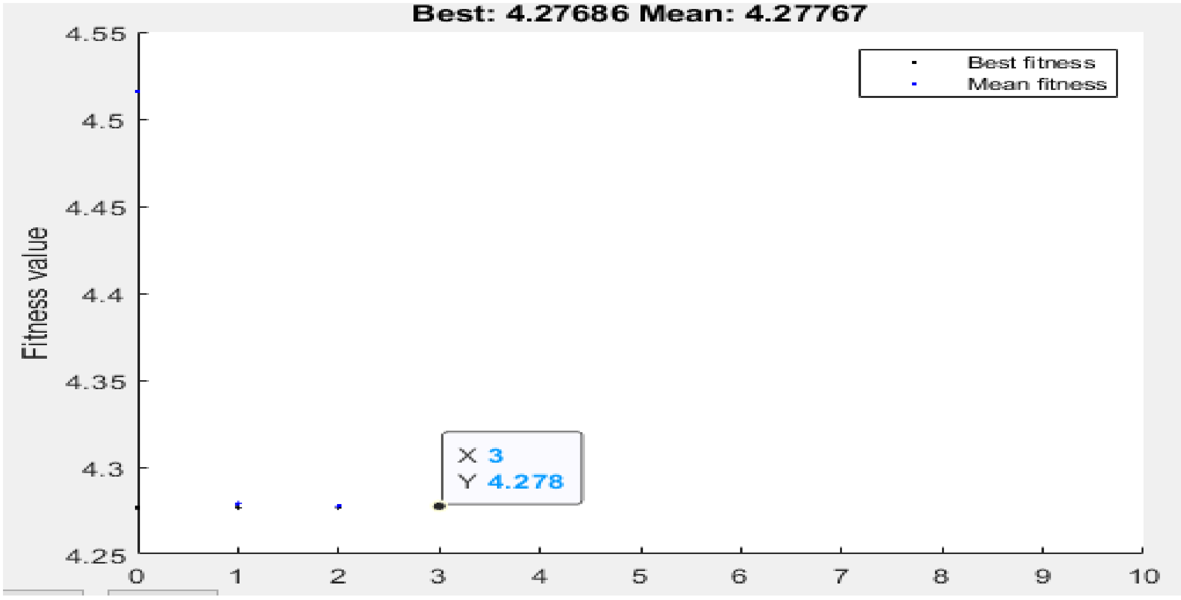


Figure 4.11 Number of vairable versus fitness value

4.4.2 Optimization of Delamination

After 50 generations, the genetic algorithm converged to the best answer. When comparing the modified parameters to the original setup, the delamination factor was optimized.The optimum value was found at third generation at higher feed rate smaller feed rate and drill diameter.Figure shows the optimum value of delamination.The optimized value was-

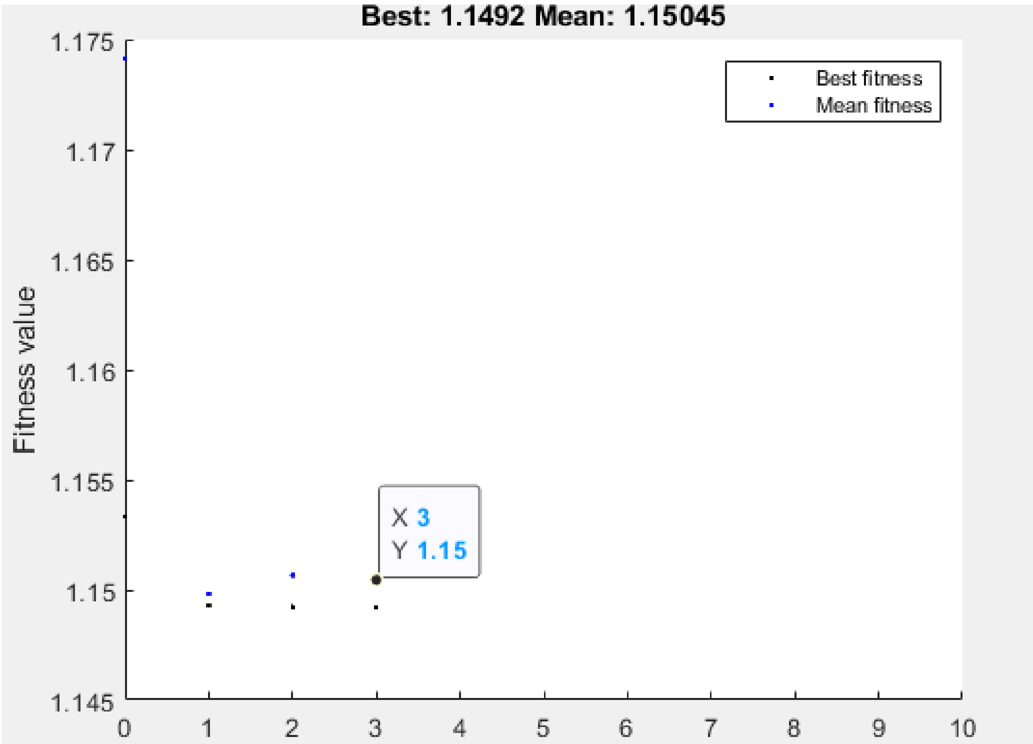


Figure 4.12 Fitteness value Versus Generation of delamination

4.4.3 Optimization of circularity

In manufacturing operations, circularity is an essential quality parameter, especially when producing round and cylindrical products. Minimizing variations from perfect circularity is crucial since they can have an impact on component fit, performance, and appearance. In this study, the circularity was we optimized using a genetic algorithm (GA) that was implemented in MATLAB with the goal of achieving the most accurate and consistent roundness in produced parts.The optimized result was found at spindle speed, feed rate and rill diameter of 500rpm, 0.075mm/rev and 3mm at third generation.

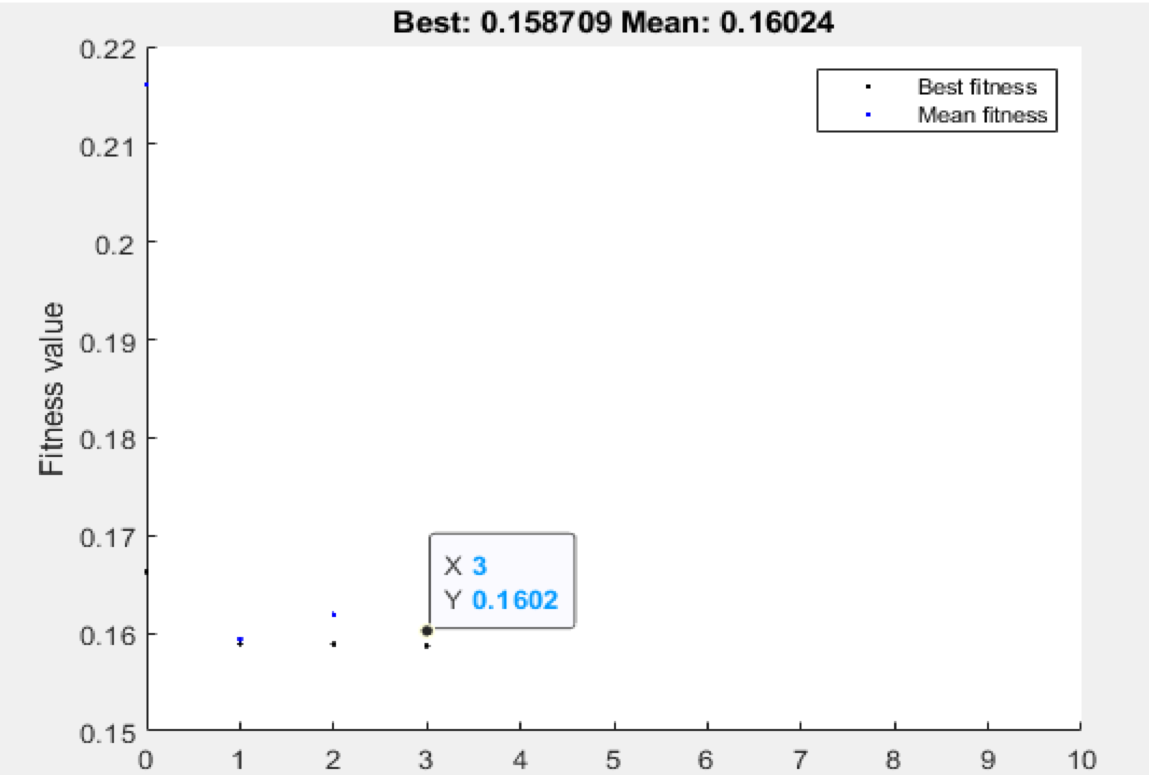


Figure 4.13 Fitness value versus Generation

4.5 Morphology Analysis

The surface mrphology of the composites was examined through 3D optical profilometer analysis. Morphology is used to check the bonding and filler materials distribution in the matrix. Figure (4.15).Shows the micrographs of the drilled surfaces,observed in the drilled bamboo/sisal-alumina reinforced polyster composites.The texture of the drilled samples shows the image of smooth texture of sample1 with selected parameter of 1250rpm,0.03mmrev/min and 3mm drill diameter,It was attributed to the reduction in drill diameter and feed rate and increased in spindle speed resulted in good surface texture.

The drilling of composites with an shows defects such as fiber fractures, fiber pull-out, delamination, groove, voids, deformation, porosity, cavities, and debonding of fibers from the matrix, as illustrated in Figure 4.14 rough surface texture that occurred with the high-speed steel tools. The surfaces of the hole drilled with an HSS drill have large fiber pullouts and high surface roughness because of the generation of a higher thrust force (Margabandu & Subramaniam, 2020).

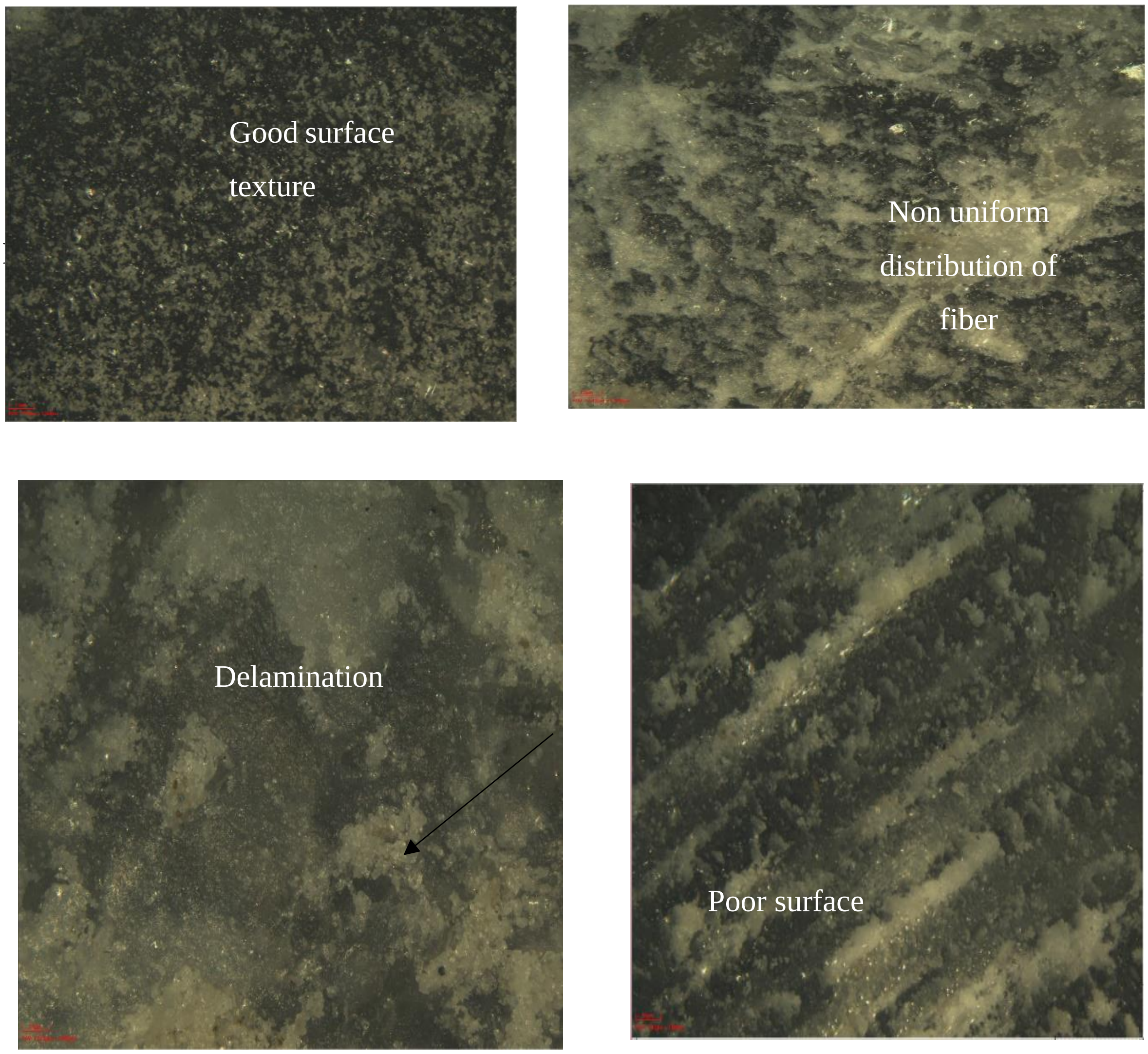


Figure 4.14 Morphology of drilled surface

CONCLUSIONS AND RECOMMENDATION

SUMMARY OF FINDINGS AND CONCLUSIONS

In this study, both bamboo and sisal fibers were extracted manually from sisal plants and bamboo plant and the alumina fiber was from the local market. Alkaline treatment was carried out for sisal and bamboo fiber at 5% NaOH the time given for bamboo fiber was more than that of sisal to remove cellulose, lignin, and other fats and finally washed using distilled water. Next to that the sisal/bamboo fibers reinforced polyester hybridized composite material was fabricated and characterized the mechanical properties specifically tensile, flexural, impact, and hardness strength by using laboratory tests phsical test water absorption test held. Machining trials by drilling holes on bamboo/sisal-alumina hybrid polyester were developed, and the effect of cutting parameters (feed, speed, sequence, and drill diameter) and the drilling-induced damages, mainly exit delamination, circularity(roundness) error, and surface roughness, of fiber-reinforced composite samples were carried out experimentally using design expert and grey relational analysis method. From the experimental results, the following conclusions were made:

- ✓ According to the literature, the behavior of natural fiber composites was inferior to that of synthetic fiber composites. However, mechanical behavior natural fiber was enhanced with hybridization, as confirmed by this work. The mechanical properties of the composite depend on the inclusion of alumina and the best behavior was observed for the bamboo/sisal with higher weight percentage of.
- ✓ From the hybrid bamboo/alumina and sisal/alumina the first had higher mechanical properties showing enhanced property..
- ✓ It was observed that during flexural testing the fracture was quite located with no damage in regions far from the fractures. This behavior indicates good adhesion between the layers of natural and synthetic fibers, despite the discrepancy in their properties.Among the samples tested for flexular strength the combination when only the natural fiber combined was lower as compared with natural with synthetic one.
- ✓ As grey relational analysis did for the selection of samples for the machining operation The hybrid composites with better drilling properties can withstand the maximum flexular strength of 387.4 MPa, hardness of 48.2 MPa, impact strength of 9.333 $J/mm^{2,}$ and Hardness of 10.5 MPa.

- ✓ The contribution made by cutting speed, feed rate, and drill diameter, was high towars minimizing the delamination, circularity and surface roughness output.
- ✓ An HSS twist drill with a smaller drill diameter was suggested for drilling the hybrid fiber-reinforced polymer composites as it produces lower delamination factors and roundness error with low surface roughness compared to non-hybrid composites like sample 3 but needs frequently changing to gate good surface finish.
- ✓ The minimum delamination factor and surface roughness of the composite sample for the optimum drilling are observed at spindle speeds of 1250 rpm, feed rate of 0.075 mm/rev, 3mm drill diameter, and with sample number one concluded that the optimum drilling condition, hole quality, and surface finish occur at higher speeds, and lower feed rates, with the HSS twist drill bit of diameter of 6mm,
- ✓ The minimum circularity (roundness) error of the composite sample for the optimum drilling was observed at spindle speeds of 750 rpm, feed rate of 0.03 mm/rev, 6mm drill diameter, and composite with an outer layer with sisal fiber. Which was occur at the lowest speeds, and lower feed rates, with the HSS twist drill bit of diameter of 6mm, and sample 4
- ✓ From hybrid design expert and grey relational analysis, we obtain that Cutting speed, feed rate, drill diameter, and character of material are influencing factors for minimizing the delamination factor, circularity, and surface roughness.
- ✓ The image analysis using ImageJ, and the 3D optical profilometer, image of the drilled hole revealed that Fiber pullouts, uncut fiber, fiber deformation, fiber and matrix uncut, matrix cracking and deterioration, internal delamination are the dominant factors of the hole during machinability was which affect the drilling of composite materials. Further, it was visible that the quality of the holes made with a small drill bit diameter in hybrid composites was much superior to the hole made with a big HSS drill bit diameter in all the samples.
- ✓ From the experimental investigation and characterization result, henceforth, can generalize that the hybrid Bamboo/sisal hybrid fiber reinforced polyester matrix composite material has significantly good

mechanical strength and machinability along with the inherent importance of being cost-effectiveness, and environmentally friendly, low specific to weight ratio and so on for various application by setting parameter in the selective way.

Recommendations

Based on the result and conclusions found from this study, the following recommendations were made

- ✓ It will be better to use natural fiber reinforcement composite since we can get intermediate mechanical properties and have relatively good machinability properties also minimum cost relative to pure synthetic composites.
- ✓ This study was limited to one factor recommended further study to relate the property of composites to their machinablity.
- ✓ Recommended that if possible standardize the properties of natural fiber according to their species and location.

Future work

- ✓ The study can be further extended to different fabrication techniques and study its parametric effect on mechanical, physical Property.
- ✓ Extend the finding to validation of advanced numerical models of composites drilling be conducting using experimental data and simulation, along with an in-depth understanding of the macro/meso level mechanisms that correlate to cutting parameters and lead to damage during the process.

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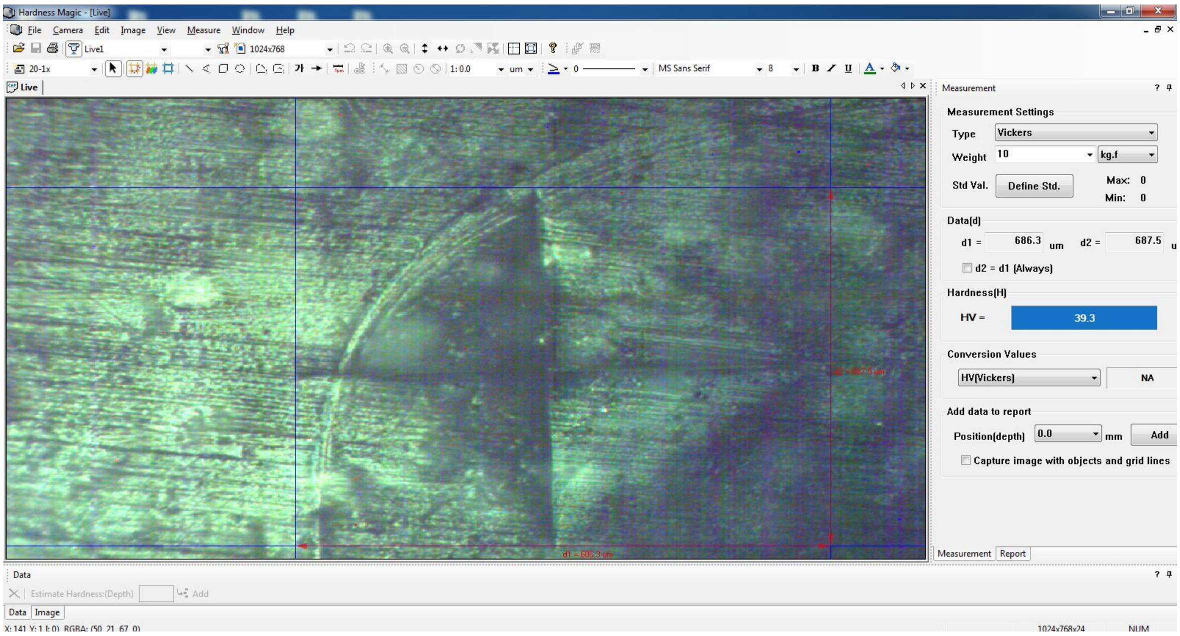
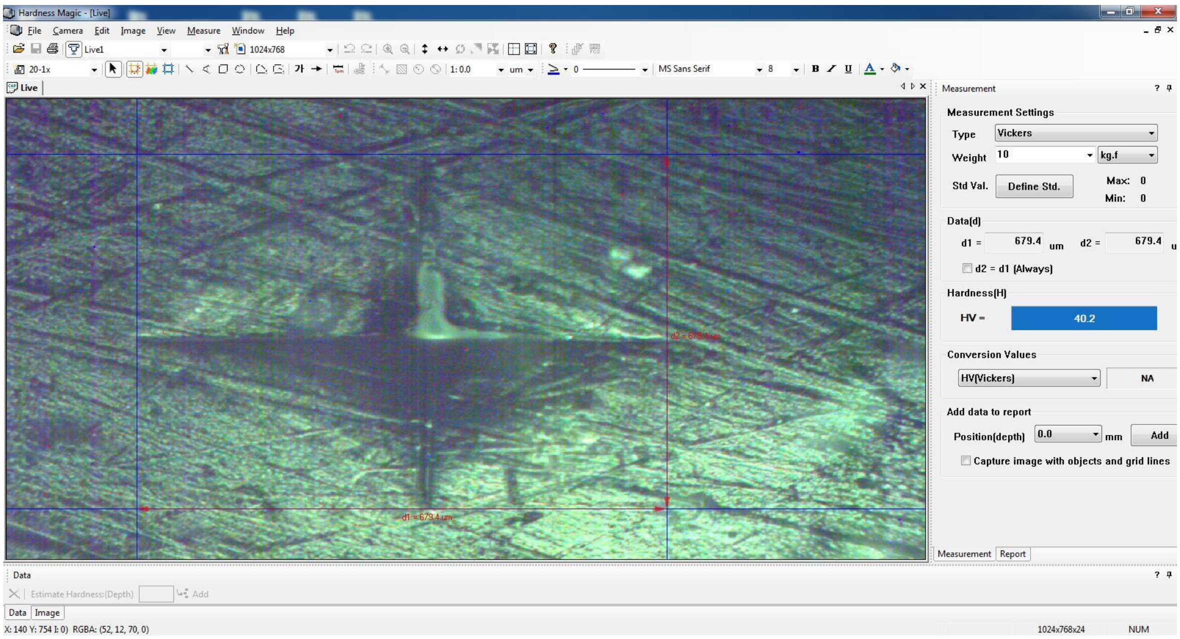
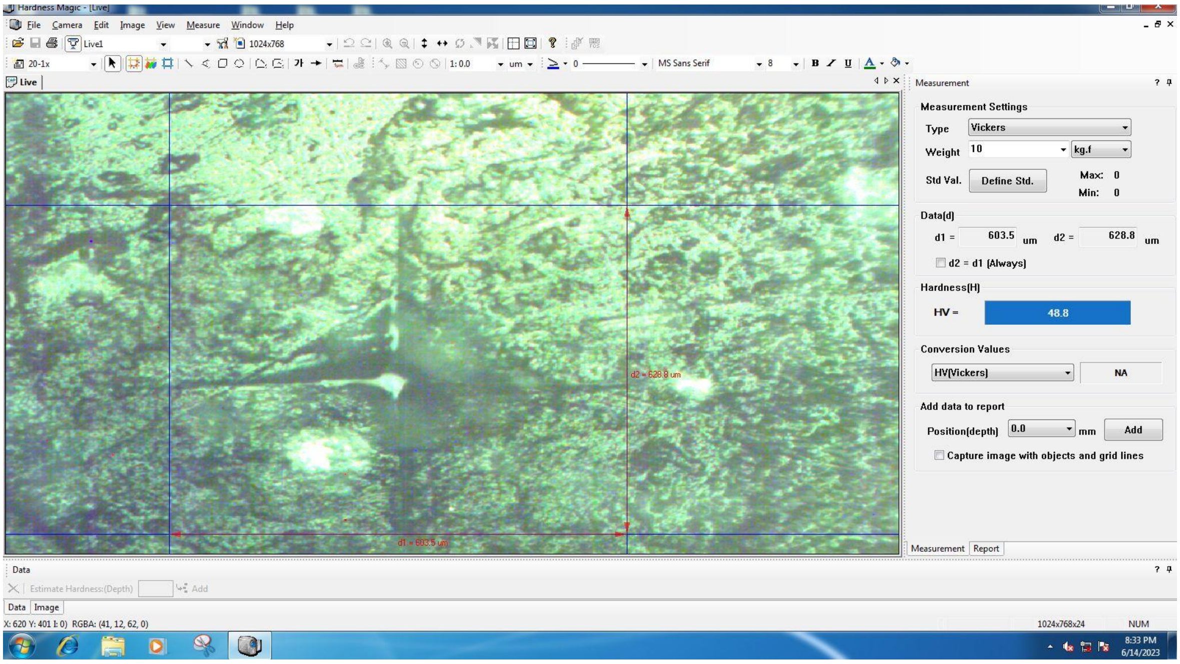
APPENDIX –I Mechanical property of tested samples





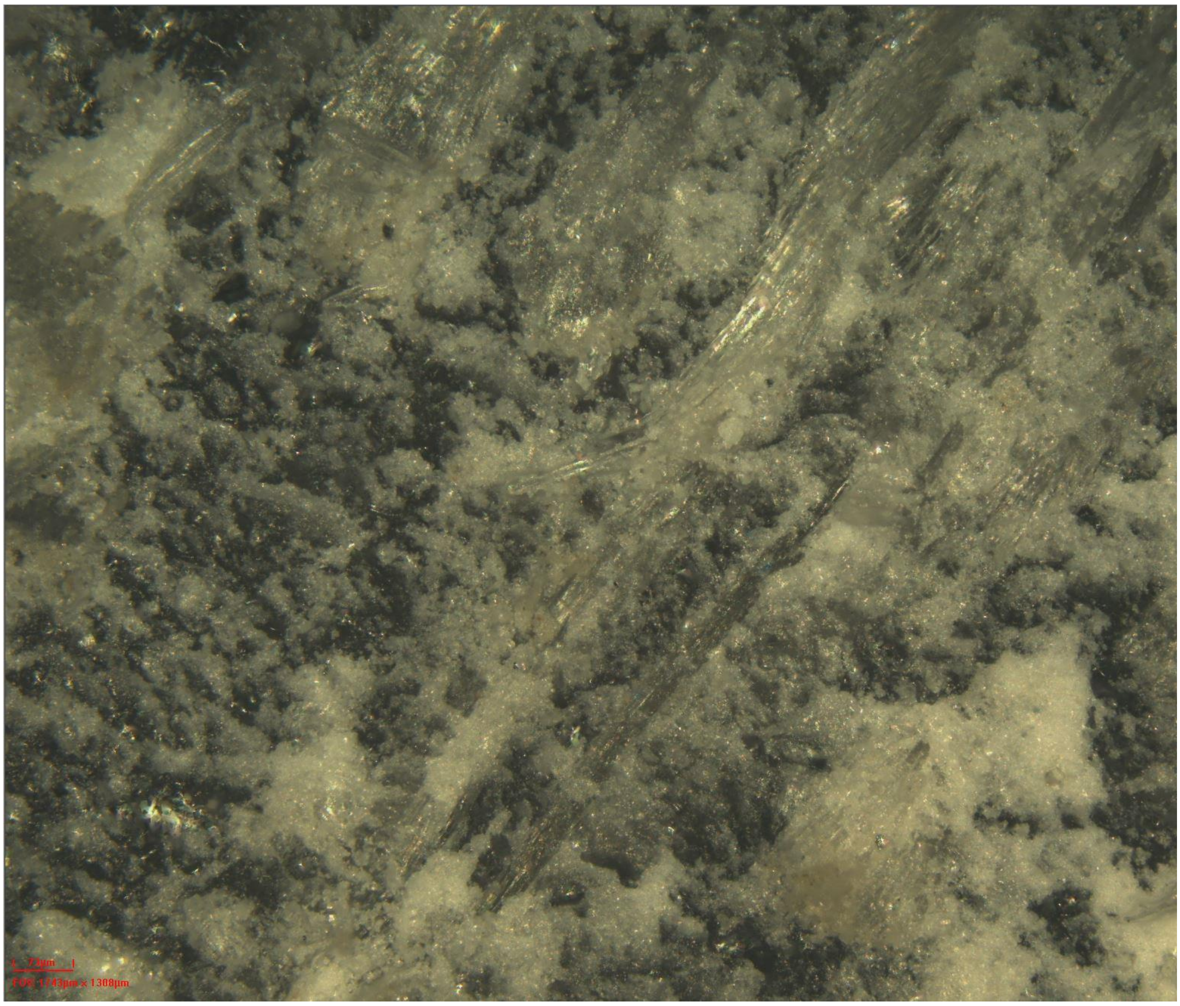


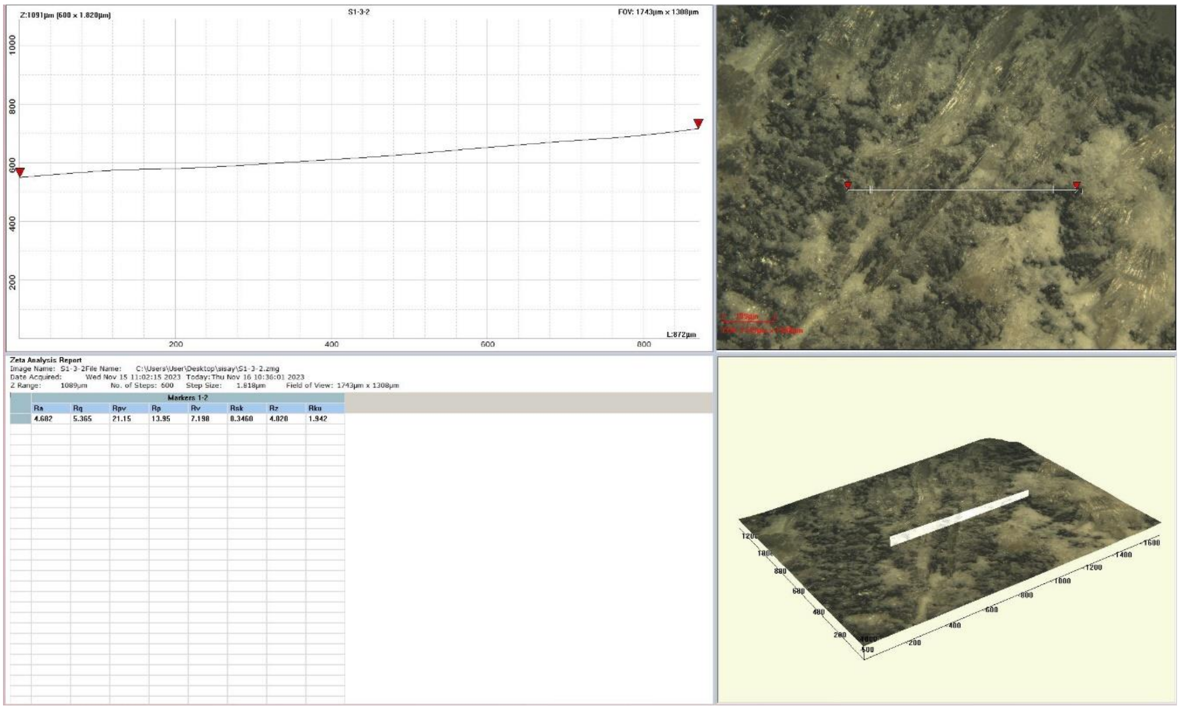
Appendix-II Surface Roughness Response Using Zeta-20, 3D Optical Surface Roughness Measuring Instrument

Zeta Analysis Report							
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
3.49	4.398	19.84	11.8	8.036	0.6253	10.36	2.97
2.985	3.965	20.36	8.012	12.34	-0.5798	10.38	3.593
3.352	4.355	27.58	17.58	9.993	0.4913	12.44	4.462
4.341	5.922	46.17	10.11	36.05	-1.371	18.15	6.526
3.85	4.781	29.95	14.26	15.68	-0.7837	14.35	3.361
3.224	4.214	19.6	11.81	7.79	0.7438	12.75	3.302
4.468	5.772	31.88	12.21	19.66	-0.7133	17.02	3.609
5	6.446	30.76	8.47	22.29	-1.091	10.64	4.298
3.449	4.232	19.35	10.06	9.298	-0.0582	11.99	2.451

4.494	6.218	35.24	24.19	11.05	1.114	18.93	5.432
5.073	6.932	37.21	20.2	17.01	0.1043	11.14	3.871
5.037	8.171	49.52	23.85	25.68	-0.696	22.15	4.109
3.573	4.893	26.77	13.96	12.8	0.043	11.73	4.012
3.702	4.503	22.26	10.42	11.84	0.1559	9.737	2.665
4.125	5.025	21.4	9.669	11.73	-0.1691	16.93	2.441
5.531	10.72	49.26	11.42	37.84	-1.445	29.04	4.57

APPENDIX-III MORPHOLOGY ANALYSIS





APPENDEX-IV Design experiment output

		Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3	Response 4
Std	Run	A:speed	B:feed rate	C:drill diameter	R1	R2	R3	circularity
		Rpm	mm/min	mm				
1	1	500	0.03	7.5	0.1246	4.3	1.193	0.118
8	2	1250	0.075	12	0.2753	4.49	1.191	0.2582
9	3	875	0.03	3	0.2178	4.42	1.2199	0.2095
3	4	500	0.12	7.5	0.2075	4.53	1.28	0.2052
11	5	875	0.03	12	0.182	4.6	1.1795	0.1939
14	6	875	0.075	7.5	0.2232	4.62	1.1897	0.2232

13	7	875	0.075	7.5	0.2234	4.6	1.1958	0.2234
2	8	1250	0.03	7.5	0.1844	4.67	1.193	0.183
12	9	875	0.12	12	0.2796	4.684	1.136	0.2821
4	10	1250	0.12	7.5	0.21884	4.6702	1.16	0.226
10	11	875	0.12	3	0.2266	4.55	1.143	0.2491
7	12	500	0.075	12	0.2013	4.46	1.138	0.2013
6	13	1250	0.075	3	0.2376	4.5	1.1099	0.2376
5	14	500	0.075	3	0.2363	4.16	1.1	0.21

APPENDEX-V MATLAB code and result

```
clear all
clc
close all

%% Define Objective Function and Constraints
R2 = @(x) - (-4.043 - 0.01678.*x(3) - 1.234.*x(2) -
0.000293.* x(1)); % minimize objective function

g1 = @(x) x(1) - 1250; % constraint 4
g2 = @(x) x(2) - 0.12; % constraint 2
g3 = @(x) x(3) - 12; % constrain

%% Define Genetic Algorithm Parameters
nvars = 3; % number of decision variables
lb = [500, 0.03, 3]; % lower bounds of decision variables
ub = [1250, 0.12, 12]; % upper bounds of decision
variables
options = optimoptions('ga', 'Display', 'iter',
'PopulationSize', 1000, ...
```

```
    'MaxGenerations',   10,   'FunctionTolerance',   1e-6,
'PlotFcn', @gaplotbestf);

%% Run Genetic Algorithm
[x, fval] = ga(R2, nvars, [], [], [], [], lb, ub, ...
    @(x) deal([g1(x), g2(x), g3(x)], []), options);

%% Display Results
disp('Optimization Results:')
disp(['R2 in (μm): ', num2str(-fval)])
disp(['OPTIMUM VALUE OF N, f, D: ', num2str(x)])
```

Name	Value
fval	4.2769
g1	@(x)x(1)-1250
g2	@(x)x(2)-0.12
g3	@(x)x(3)-12
lb	[500,0.0300,3]
nvars	3
options	1x1 GaOptions
R2	@(x)-(-4.043-0.01678....
ub	[1250,0.1200,12]
x	[500,0.0300,3]

```
clear all
clc
close all

%% Define Objective Function and Constraints
R3 = @(x) - (-1.1890 - 0.00199.*x (3) + 0.184.*x (2) +
0.000019.* x (1)); % minimize objective function

g1 = @(x) x (1) - 1250; % constraint 4
g2 = @(x) x (2) - 0.12; % constraint 2
g3 = @(x) x (3) - 12; % constrain

%% Define Genetic Algorithm Parameters
nvars = 3; % number of decision variables
```

```
lb = [500, 0.03, 3]; % lower bounds of decision variables
ub = [1250, 0.12, 12]; % upper bounds of decision variables
options = optimoptions('ga', 'Display', 'iter', 'PopulationSize', 1000, ...
    'MaxGenerations', 10, 'FunctionTolerance', 1e-6, 'PlotFcn', @gaplotbestf);

%% Run Genetic Algorithm
[x, fval] = ga(R3, nvars, [], [], [], [], lb, ub, ...
    @(x) deal([g1(x), g2(x), g3(x)], []), options);

%% Display Results
disp('Optimization Results:')
disp(['R3 (): ', num2str(-fval)])
disp(['OPTIMUM VALUE OF N, f, D: ', num2str(x)])
```

Name	Value
fval	1.1491
g1	@(x)x(1)-1250
g2	@(x)x(2)-0.12
g3	@(x)x(3)-12
lb	[500,0.0300,3]
nvars	3
options	*1x1 GaOptions*
R3	@(x)-(-1.1890-0.0019...
ub	[1250,0.1200,12]
x	[1.2500e+03,0.1200,3]