Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Optimization of Cutting Parameters for Milling Enset Fiber Reinforced Epoxy Composite

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science (MSc.) in Mechanical Engineering (Manufacturing Engineering)

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I hereby declare that this thesis entitled: **Optimization of Cutting Parameters for Milling Enset Fiber Reinforced Epoxy Composite**, is my original work and that it has not been submitted partially or in full for a degree in any university/ institution, which complies with the regulations of the university and meets the accepted standards concerning originality and quality.

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Abstract

Machining of composite materials is accompanied by fiber pullouts, fiber breakages, delamination of laminates, matrix burnings, which degrades quality and performance of the product. These challenges able to be reduced with controlled or optimized machining parameters. This study investigates the optimization of cutting parameters for end milling of enset fiber reinforced epoxy composite materials. Spindle speed, feed rate and depth of cuts were considered as an input parameter, and surface roughness and material removal were considered as quality responses.

Specimens were fabricated from 30% weight fraction of enset fiber and epoxy resins with 1.5% of MEKP hardeners by using hand layup processing techniques. The fibers were extracted from Endiber Woreda, Gurage Zone, South Region, Ethiopia. The compressive, flexural and impact strength tests were performed based on ASTM standards. The test results demonstrate that, enset fiber reinforced epoxy composites have the average compressive, flexural and impact strengths of 23.2 MPa, 89.36 MPa and 114.59 KJ/m^2 respectively.

The milling operations have been performed on CNC milling machines at different cutting parameter levels by using 10 mm diameter HSS end mill cutters. The experimental runs were designed based on Taguchi L_9 (3^3) orthogonal arrays. The influence of cutting parameters is determined by the analysis of variance (ANOVA) and optimization is performed by coupling grey relational analysis with principal component analysis.

The results of ANOVA revealed that depth of cut has greater contributions (49.47%) followed by spindle speed (43.50 %) and feed rate (4.39 %) respectively on the gray relational grades (GRG). The optimum values of surface roughness and material removal rate simultaneously were obtained at lower spindle speed (1000) rpm, higher feed rate (300) mm/min and medium depth of cut (1.5) mm.

Keywords: *Enset fiber, Epoxy resin, Cutting parameter, Surface roughness, Material Removal Rate, GRA, ANOVA*

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List of Abbreviations

ANOVA	Analysis of Variance
ASTM	American Standard Testing Methods
CNC	Computer Numerical Control
DoE	Design of Experiment
Fd	Delamination factor
FFRP	Flax Fiber Reinforced Polymer
gcc	Gram per Centimeter Cube
GRA	Gray Relational Analysis
Gp	General Purpose
HSS	High Speed Steel
JFRP	Jute Fiber Reinforced Polymer
MEKP	Methyl Ethyl Keton Peroxide
MPa	Mega Pascal
MRR	Material Removal Rate
NFRP	Natural Fiber Reinforced Polymer
OA	Orthogonal Array
PCA	Principal Component Analaysis
S/N	Signal-to-Noise Ratios
SFRP	Synthetic Fiber Reinforced Polymer
RSM	Response Surface Methodolgy
UTM	Universal Testing Machine

Nomenclature

NaOH	Sodium Hydroxide
OH	Hydroxide
M_f	mass fractions of fibers
m_f	mass of fibers
m_c	mass of composites
Mm	mass fractions of matrix
m_m	mass of the matrix
V_f	volume fraction of fibers
v_f	volume of fibers
v_c	volume of composites
V_m	volume fraction of matrix
v_m	volume of matrix
ρ_c	Density of the composite material
x_i^0(k)	Original sequence
x_i^*(k)	Preprocess sequence
Δ_{0i} (k)	Deviation sequence
ξ_i (k)	Gray Relational Coefficient
ψ	Distinguishing coefficient
ω_k	Weighted values of the k^{th} responses
$\gamma_m(k)$	Gray Relational Grade

Chapter One

Introduction

1.1 Background of the Study

Natural fibers have advantageous properties than synthetic fibers in terms of sustainability, economical aspects, and ecological aspects [1][2]. And also it has high strength to weight ratio, lack of toxicity [3][4]. Due to these advantages, the usability of natural fibers as a reinforcement increases for manufacturing fiber reinforced polymer composite. Kenaf, sisal, banana, jute, flax, hemp, and coconut fibers are the most common plant fibers that used in various application areas like aerospace's, marines, automotive, constructions, furniture's, sporting goods etc. [5][6].

Natural fiber reinforced polymer (NFRP) composites are fabricated in primary manufacturing processes with a near net shape of the final product [7]. However, secondary manufacturing processes such as milling operations needed to make slots and holes for facilitating the joining processes of final parts. Further, it is necessary to trim unwanted parts and to make complex features and dimensional tolerances [8][9]. However, machining of NFRP composites are challenging tasks due to an isotropic and heterogeneous properties of fibers. The machining process causes delamination's, deboning of reinforcement phases and matrix phases, fiber push-outs, thermal degradations, matrix cracking, micro-hole formations in the matrix etc. [10].

In machining of NFRP composites, material removal rate and surface roughness are the important aspects for deciding production rates, mechanical performances and quality of products. Material removal rate indicates the machining times of work pieces [11]. Surface roughness depicts the formations of thermal degradations, deboning of reinforcement phases and matrix phases, fiber pullouts, matrix cracking etc., [3] [12].

The main goals of the manufacturing industries are manufacturing a product with low cost and better quality in less working time. However, achieving higher production rate with better surface quality during milling operations are the main challenging tasks due to contradictory objectives of productivity and quality [13]. Productivity increases as the machining time decreases, while the quality of the product may decrease. Quality of products improved as the machining time increases, while, production rate decreases [13-15]. Therefore, it is essential to optimize quality and productivity simultaneously to overcome the conflict objectives of productivity and quality [15].

In previous works, researchers investigate the machining behaviors of NFRP composites to optimize roughness of the surface and material removal rate. However, in most of the cases, optimization was considered based on single objective function of Taguchi methods [16][17]. Since, Taguchi methods could not optimize multi objective quality responses [18]. Two or more objective functions of responses can able be optimize by coupling Taguchi method with grey relational analysis (GRA) techniques [19]. Optimization of multi objective functions by Taguchi based GRA was proposed by Deng in 1982 [20]. In multi objective function optimization process, GRA assumes each responses has equal weights [21] . However, in real case each response may not have equal weight contributions. The principal component analysis was developed by Pearson in 1901 and used to determine the weights of each response by simplifying the correlated functions to uncorrelated functions [22].

This study starts with characterizations of mechanical properties of enset fiber reinforced epoxy composites and make a hypothesis that enset fiber reinforced epoxy composites can able to be an alternative material for various applications like wall panels. Mainly this study concerns on the optimization of cutting parameters for milling enset fiber reinforced epoxy composites. The milling operation conducted at different levels of spindle speed, feed rate and depth of cut. Optimization process has been performed by Taguchi based grey relational analysis coupling with principal component analysis. Finally, confirmation tests were conducted based on obtained optimal machining parameter levels to validate the results.

1.2 Problem Statement

In Ethiopia, the usage of enset fibers is limited only for traditional applications like to make ropes, sacks, bags, mates, etc. It has negligible contribution in agro-economic sector. Limited studies conducted on the characterization of mechanical properties and machining behaviors of enset fiber reinforced composites. In order to expand the usability of enset fiber reinforced composite materials, mechanical properties and machining behaviors needs investigations.

Machining of natural fiber reinforced composites are challenging tasks due to an isotropic and heterogeneous structures of composites. The quality of machined surface significantly influenced by machining parameters (cutting parameters, cutting tools, cutting conditions). Inappropriate machining parameters cause's delamination of laminates, micro cracks, fiber breaks, fiber pullouts, fiber matrix de-bonding and matrix burning [3] [5]. Rough surfaces wears out more rapidly, has lower overall performance and has higher coefficient of frictions than smooth surfaces and initiates crack propagations, creeps, fatigues and corrosions [23].

Furthermore, obtaining better machined surface quality and higher production rates simultaneously are the challenging tasks in milling process due to multi-objective functions of surface roughness and material removal rates [15][18].

Therefore, this study characterizes the compressive, flexural and impact strengths of enset fiber reinforced composites and make a hypothesis that enset fiber can able to use in industrial applications. Further, the study analyzes and optimizes the effects of cutting parameter in milling enset fiber reinforced composites to improve the machined surface quality and increase production rates simultaneously.

1.3 Objectives of the Study

1.3.1 General Objectives

The general objective of this thesis is optimizing cutting parameters (spindle speed, feed rate and depth of cut) for end milling of enset fiber reinforced epoxy composites.

1.3.2 Specific Objectives

- Fabricate 30% weight fractions of randomly oriented chopped enset fiber reinforced epoxy composites and characterize the compression, flexural and impact strengths.
- Analyze effects of machining parameters (spindle speed, feed rate, and depth of cut) on the quality responses (surface roughness and material removal rate).
- Determine the influence of spindle speed, feed rate and depth of cut on the surface roughness and material removal rate.
- Identify optimum levels of spindle speed, feed rate and depth of cut to obtain better surface finish and maximum material removal rate simultaneously.

1.4 Scope of the Study

The scope of this study includes fabricating 30% weight fractions of randomly oriented chopped enset fiber reinforced epoxy composite materials by using hand layup fabrication techniques, characterizations of mechanical properties (compression strengths, flexural strengths, impact strengths) of fabricated composites, performing end milling operations at three levels of spindle speed (1000, 1500, 2000) rpm, feed rate (100, 200, 300) mm/min and depth of cut (1, 1.5, 2) mm based on L_9 OA, analyzing effects of spindle speed, feed rate and depth of cut on the surface roughness and material removal rate and optimize levels of input parameter by using Taguchi based gray relational analysis (GRA) with principal component analysis (PCA) methods. Finally specify the optimum levels of spindle speed, feed rate and depth of cut and conducting confirmation tests.

1.5 Research Questions

1. Is Taguchi based gray relational analysis (GRA) optimization method can improve the quality of machined surface and material removal rates simultaneously?
2. Which input parameters (spindle speed, feed rate, depth of cut) has significant effect on the surface roughness and material removal rate in end milling enset fiber reinforced epoxy composites?
3. At what levels of machining parameters, surface roughness and material removal rate simultaneously optimum?

1.6 Significance of the Study

It helps to identify optimum levels of spindle speed, feed rate and depth of cut to obtain better machined surface quality and maximum production rate simultaneously for end milling of enset fiber reinforced epoxy composites.

1.7 Limitation of the Study

The study cannot address the effects of pre machining parameters such as fiber orientations, fiber geometries, and weight fractions, tool parameters (tool material type, geometry, diameter) and machining conditions (dry, air cooled, oil cooled). The study does not consider the effects of cutting parameters on cutting forces and torque.

1.8 Organization of the Thesis

This thesis documented basically on the optimization of cutting parameters for milling enset fiber reinforced epoxy composites. The thesis organized by five chapters and the content of each chapter's presents as follows.

Chapter One: Backgrounds of the study, problem statement, general and specific objectives of the study, scopes of the study, research questions, significances of the study and limitations of the study stated in this chapter.

Chapter Two: Covers the review of relevant research papers regarding composite materials with its classifications, natural fiber composite materials, natural fibers with their chemical, mechanical properties, application of NFRP composites, machining of NFRP composites, challenges in machining.

Chapter Three: Materials required for sample preparation, fabrication procedures of specimens, experimental setup for characterizations and milling operations are presented in this chapter.

Chapter Four: This chapter includes the results and discussions of characterizations of mechanical properties of the specimen materials with comparisons of literature works. And also, it covers the optimization procedures of milling parameters, analysis of machining parameters, analysis of variances and confirmation tests.

Chapter Five: Presents the conclusions of thesis work, recommendation and future works.

Chapter Two

Literature Review

2.1 Composite Material

Composite material is a new categories of engineering material that consists of at least two constituent materials. The constituent materials combined at a macroscopic level and are insoluble in each other and there is a distinct interphase separating them. The main constituent materials are matrix phase and reinforcement phase [3].

Based on matrix types, composite materials can be classified in to three group's namely metal matrix composites (MMC), polymer matrix composites (PMC) and ceramic matrix composites (CMC). In MMC, the matrix constituents are metallic materials like aluminum, titanium, which have potentials for structural materials at high temperature. In CMC, the matrix constituents are ceramic materials like silicon carbides (SiC), aluminum oxides (Al_2O_3), which have damage tolerant mechanical properties. In PMC, the matrix constituents are polymeric material i.e., either thermoplastic material or thermosetting material. Figure 2.1 below shows classifications of composite materials based on their matrix types [1][8].

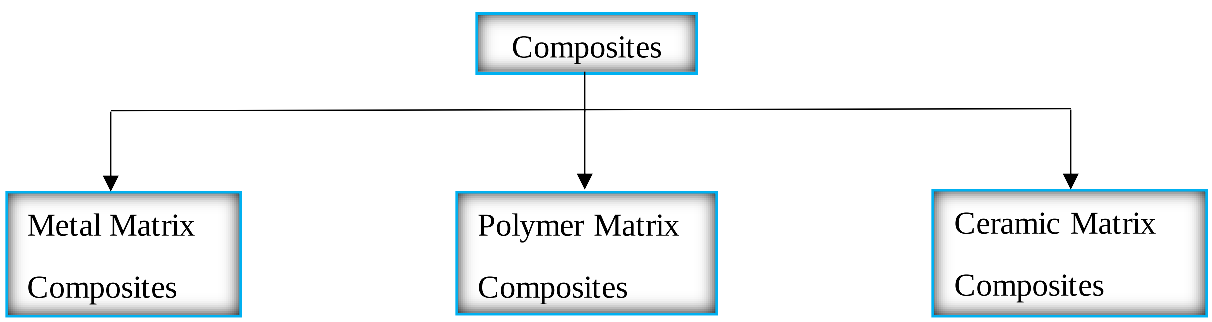


Figure 2.1: Classification of composite materials based on matrix types [8]

And also, composite materials can be categorized based on their reinforcement material geometries, shapes, sizes etc. as shown in Figure 2.2 below.

The reinforcement phase can be present in the form of fibers, particulates, whiskers or laminates.

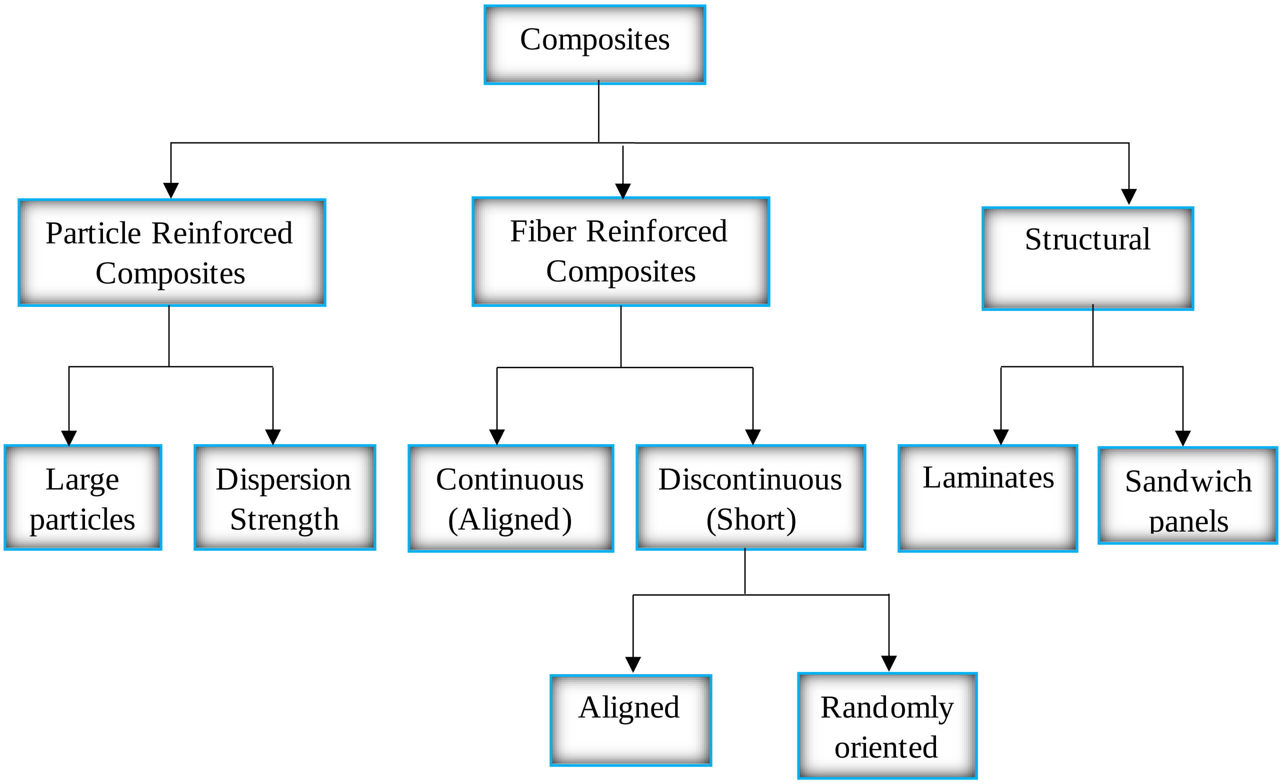


Figure 2.2: Classifications of composite materials based on reinforcement phase [2]

2.2 Selection of Constituents of Composite Materials

2.2.1 Matrix Material Selection

Matrix material is a material i.e., either metal, ceramic or polymers that has the roles of [24]:

- Binds reinforcing materials together
- Within the composite structure, it transfers loads and stresses.
- Support the overall structure of the composite
- Protects the composite from external agents such as chemicals, and other contaminants.
- Protects fibers from wear and tear caused by handling.

The properties of matrix materials determines the ability of composite resistance to most of the degradation tasks such as delamination, crack propagation, water absorption, impact damage, thermal creep, and chemical attack that eventually lead to failure of the structure [25].

Matrix materials should have the desired properties of reduced moisture absorption, low shrinkage, low coefficient of thermal expansion, good flow characteristics to penetrates the fiber bundles completely and eliminates voids during the compacting/curing process, reasonable strength, modulus and elongation (elongation should be greater than fiber), elasticity to transfer load to reinforcements, excellent chemical resistance, easily process able into the final composite shape, dimensional stability [26].

Matrix materials may be either a polymer, metal, or ceramic. Polymer matrix materials are commonly used in commercial and high performance applications, while ceramic and metal matrices are usually applied in high-temperature environments, such as motor engine, turbine [27]

Selection of matrix materials in composite depends on the following factors [6]:

- End applications of materials
- Compatible mechanical strengths with the reinforcement materials
- Service conditions such as temperature, humidity, exposure to chemical atmosphere, abrasion by dust particles, etc.
- Easiness to use in the selected fabrication methods
- Life expectancy
- Resultant composite cost effectiveness

2.2.2 Reinforcement Material Selection

Reinforcement material is material that provides strengths, rigidity, corrosion resistances, and heat resistances in the composites. Reinforcement materials has the roles of [28]:

- To carry the load in the composite
- To provide stiffness, strength, thermal stability, and other structural properties in the composites
- To provide electrical conductivity or insulation, depending on the type of fiber used

The performance of the composite depends on many factors such as structure, mechanical properties, physical, and thermal properties of reinforcement materials. The salient mechanical properties of the composites such as young's modulus, tensile strength, and stiffness are practically determined by the mechanical characteristics of the fibers.

Therefore, relevant selection criteria for the choice of suitable reinforcing materials in composites are [2]:

- Compatibility with matrix material, thermal stability, density, melting temperature etc.
- Elongation at failure,
- Sizing and surface treatments for matrix and fibers adhesion and wetting,
- Dynamic behavior,
- Price and processing costs, and
- Availability, lead time, and stable supply source.

2.3 Natural Fiber

The necessity of materials that has positive impacts on the ecological aspects in addition to economical and sustainability issues increases from day to day. Economical, ecological and sustainability aspects of materials are the major issues for selecting material types. Natural fibers are a renewable resource as they have been generated by either naturally or human activities for sustainable development. And also, natural fibers have ecological advantages due to zero emissions of carbon dioxides into the environments. During processing, natural fibers mainly generate organic wastes that can be used to generate electricity and produce environmentally friendly materials for housing [29]. Generally, low cost, sustainability, flexibility during processing, less health tasks, less wear and tear during machining are the main advantages of natural fibers over synthetic fibers [30].

Depends on their purposes of extractions and usability, natural fibers are classified as primary natural fibers and secondary natural fibers. Primary natural fibers extracted and used as only for fiber purpose, while secondary natural fibers are extracted for food purpose and fibers are a by-product. Flax, jute, sisal, hemp, kenaf fibers are listed in the primary natural fiber classifications. Enset, coconut, palm, pineapple, rice husk fibers are listed in the secondary natural fiber type [31].

Table 2.1 shows the taxonomy of fibers supported by their types and origins. Natural fibers basically sourced from plants, animals and minerals. Plant fibers are composed of cellulose, hemicellulose and lignin, which can be extracted from either bast, leaf, seed, fruit, wood, stalk or grass/reed [30]. While animal sourced natural fibers comprised proteins. Due to their short growth period, renewability and wider availability, plant fibers are the most commonly accepted fibers in the industry and the most analyzed by the research community. Protein-based animal fibers are often categorized into two categories namely, α-keratin fibers like hair, wool, and feathers and fibroin fibers like silk and cobweb [30].

Table 2.1: Classification of natural fibers [9] [8]

Fiber type	Origin	Source	Example
Natural	Plant	Bast	Flax, Hemp, Jute, Banana, Kenaf, Ramie
		Fruit	Coconut, Coir, Oil, Duria
		Stalk	Wheat, Maize, Oat, Rice
		Seed	Cotton, Kapok, Milk, Rice Husk
		Leaf	Sisal, Banana, Pineapple, Palm, Abaca
		Grass/reed	Bamboo, Corn
		Wood	Hardwood, Softwood
	Animal	Silk	Worms, Tussah, Spider, Mulberry
		Wood	
		Hair/Wool	Cashmere, Goat hair, Horse hair, Lamb wool
	Mineral	Asbestos	
		Ceramic	Silica, Alumina
		Metal	Titanium, Copper, Aluminum
Synthetic	Organic	Kevlar, Polyethylene, Polyester	
	Inorganic	Carbon, Glass, Boron	

Figure 2.3. Shows the schematic structures of natural fibers. Natural fibers have intricate cell structures, consisting of different layers with a distinctive thickness and chemical compositions. The cell walls of natural fibers consist of a thin primary wall and three secondary cell walls.

The middle layers of fibers are thick and called as lumen [31]. A series of cellular micro fibrils helically wound along the middle hollow fiber axis as shown in the figure below. The age of the plant, their species, climate, harvesting time and processing procedures and techniques would significantly affect the structure of fibers as well as their physical and chemical composition. Those are the most significant factors that determining the overall properties of the fibers. Spiral oriented micro fibrils are more ductile than parallel oriented micro fibrils. Since, parallel oriented micro fibrils are more rigid and inflexible [8].

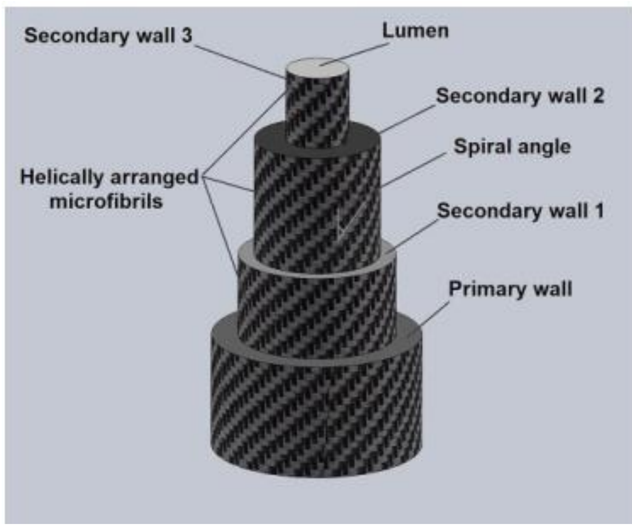


Figure 2.3: Structure of natural fibers [8]

2.3.1 Enset Fiber

Enset fiber is a plant fiber extracted from the pseudostem and leaf parts of the enset plant. It is extracted by means of two methods i.e., stripping and decortications. Stripping is the most widely used extraction methods. The stripping process has two steps. The first one is setting aside the fibers outer layer from every leaf sheath, this outer layer being termed "tuxy" and the operation "tuxying"; and second getting rid of pulpy material, as a final result freeing the fiber strands from the tuxy, the operation being termed stripping or cleansing. Both operations want to be done as soon as possible after the stalk is felled. The tuxying operation is frequently completed internal the field. The workman inserts a point of a knife between the outer and middle layers of the leaf sheath, liberating a cease of the outer layer 1 to three-inch huge. This strip or tuxy is pulled off the whole period of the sheath. When all tuxies are removed from the leaf sheath, it is miles eradicated from the stalk and allowed to remain on the sector for natural fertilizer. Usually, each different workman choices up the tuxies and comprises them to the location whereby the stripping or cleaning operation is to be achieved. Figure 2.4 shows the extraction process of enset fibers from enset plats. The extracted fibers are then sun dried and used in rural areas, to make sacks, bags, ropes, cordage, mats, sieves and tying materials for construction [32].

Figure 2.4: a)Enset plant, b) Extraction process, c) Extracted fiber [7]

These fibers are very long, often cut to 1-2 m during extraction but can be extended to 6m or more depending upon the height of pseudostem, the method of extraction and the intended end use. It is also strong and flexible enough to be used for many applications [7].

The mechanical properties of a single enset fibers are determined with its physical state and chemical composition of the cell walls such as crystallite content, shape, orientation, size, thickness of cell walls, and finally defects like lumen [31]. Natural fibers suffer from natural variability in structural properties as can be seen in the value ranges presented in Table 2.2. This variability of properties is caused by several factors, some are induced by seed density, fiber maturity, fiber age, soil quality, fiber extraction technique, fiber source and location on the plant, harvest timing, climate and some are related to the procedures of testing and characterization [2].

Physical, chemical and mechanical properties of Ethiopian enset fibers are investigated. The findings of the study revealed that enset fibers can be used for industrial applications including window panels, door panels, partition boards, furniture’s, etc. [7].

Table 2.2: Physical, chemical and mechanical properties of natural fiber [8][33]

Fiber Type	Density g/cm^3	Cellulose (%)	Hemi cellulose (%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation (%)
Bamboo	0.6 – 1.1	26 – 43	20.5 – 30	140 – 800	11 – 32	2.5 – 3.7
Banana	1.35	57.6 – 62.5	19 – 29.1	180 – 914	12	1.5 – 9
Coir	1.15 - 1.46	32 – 46	0.15-0.3	95 – 230	2.8 – 6	15 – 51.5
Cotton	1.5-1.6	82 – 96	2 – 6.3	287 – 800	5.5 – 12.6	3 – 10
Flax	1.4 – 1.5	71 – 75.2	8.6 – 20.6	343 – 2000	27.6 – 103	1.2 – 3.3
Hemp	1.4 – 1.5	68 – 81	2 – 22.4	270 – 900	23.5 – 90	1 – 3.5
Jute	1.3-1.5	61 – 71	14 – 20	320 – 800	8 – 78	1 – 1.8
Kenaf	1.4	53.5 – 72	20.3 – 21	223 – 930	14.5 – 53	1.5 – 2.7
Pineapple	1.5	80.5	17.5	413 – 1625	1.5	1 – 3
Ramie	1.0 – 1.55	68.6 – 76.2	13 – 16	400 – 1000	24.5 – 128	1.2 – 4
Sisal	1.33 – 1.5	47.6 – 78	10 – 17	363 – 700	9 – 38	2 – 7
Enset	**1.4**	**64. 46 – 67.89**	**22.47**	**67 – 923**	**12 – 69**	**3.2**

Abdela et al. [33] characterized the tensile and flexural properties of a single Enset fiber by using optimal experiment design and digital image correlation techniques. Fibers were extracted manually from Kokosa woreda, West Arsi zone, Oromia region, Ethiopia. The results of their experiments revealed that Enset fibers has a density of 1.4 g/cm^3, tensile strength of 67 MPa – 923 MPa, mean tensile strength of 647MPa, Elastic modulus of 12GPa – 69 GPa, mean elastic modulus of 46 MPa and flexural strength at maximum load of 121.6 MPa – 215.0 MPa.

Teli et al. [32] studied the chemical, physical and thermal properties of Ensete Ventricosum plant fibers. The fibers were obtained from gumer woreda, gurage zone, southern region, Ethiopia. The results revealed that enset fibers consists of 64.46 ± 0.23% cellulose, 22.47 ± 0.27% hemicellulose, 6.88 ± 0.55% lignin, 5.66 ± 0.02% ash and 0.54 ± 0.03% solvent extractiveness. The fiber also has 352 MPa average tensile strength, 3.2 % elongation at break, 64.9% crystallity index and 12.2% moisture content with high thermal stability. The findings of the study showed that enset fiber has a comparable mechanical property like that of mostly applicable natural fibers such as sisal, flax, hemp, and jute.

2.4 Natural Fiber Reinforced Composites

2.4.1 Enset Fiber Reinforced Composite

Lemi et al. [34] studied the mechanical properties of enset fiber reinforced general purpose epoxy resin composite by fabricating sample plates using hand layup fabrication process. The volume fraction of the fibers was 20%, 30%, 40% and 60% and treated with 2% of sodium hydroxide (NaOH). The results of the experiment showed that enset fiber reinforced composites at 30% weight fractions of fiber has greater tensile strength (42 MPa) and impact strength (3.2 J). He concluded the fabricated enset fiber reinforced composites has light weight and good mechanical properties and it can able to applicable in building and construction industries, storage devices and furniture's.

Fitsum et al. [35] investigated impact strengths and water absorption properties of raw and alkali treated enset fiber reinforced polyester resin composites. The samples were fabricated by using hand layup followed by a compression technique at 10%, 20% and 30% weight fractions of chopped (10mm length) enset fiber. The fibers were treated with 5% NaOH alkaline solution. The experiments showed that 30% weight fractions of treated enset fiber composites have greater impact strength (66.25 KJ/m^2) than other weight fraction contents. They concluded that enset fiber reinforced composites can replace synthetic fibers like glass fibers in manufacturing automotive interior parts like door panels, window panels, seat backs, dash board.

2.5 Fabrication Methods of Natural Fiber Reinforced Composite Materials

The selection of a suitable manufacturing process to form the structure is of paramount importance in the development of the final composite engineering properties into the desired shape with minimum defects [36]. The preliminary assessment to choose the most appropriate manufacturing process involves considering several main criteria including the shape, size, and desired properties of the composites, in addition to the manufacturing cost, production speed, and the properties of raw materials [9] .

2.5.1 Hand Layup Fabrication Method

The hand layup fabrication method is the oldest and most common fiber reinforced polymer composite manufacturing methods [37]. Hand layup processing techniques basically involves manual placement of fabric layers, or plies in the mold and succeeding application of resin matrix to form a laminate stack. After placing of fibers in the mold and pouring of resins on the surface of fibers, the resins uniformly distributed with the help of rollers, brushes, or press machines. And also, rolling or squeezing wet composites are used to remove entrapped air, and consolidate the composite layers to ensure better interaction between the reinforcement and the matrix and to obtain the desired thickness [31]. There are four steps in hand layup manufacturing methods. These are mold preparation, gel coating, layup, and curing sequentially. Versatility, low tooling cost and suitability for long fibers are the advantages of hand layup methods, while it is labor-intensive where the laminate quality, resin mixing, and laminate resin contents are highly depending on the operator skills, as in this method not much fiber loading is possible [36]. It is applicable for manufacturing aircraft components, automotive parts, boat hulls, dash boards and discs… etc.

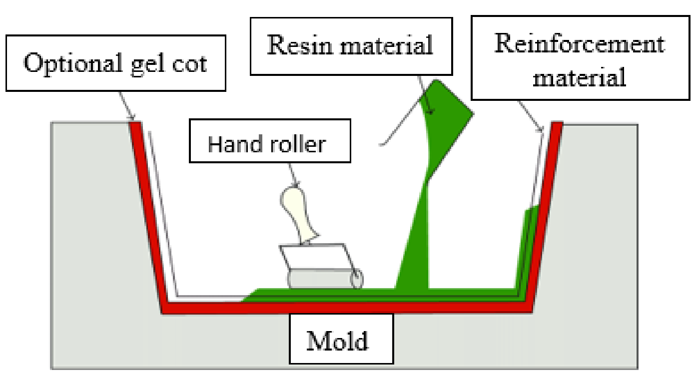


Figure 2.5: Hand layup process setup [8]

2.6 Applications of Natural Fiber Reinforced Composite

The usability of natural fibers as a reinforcement increases from day to day for in numerous application areas. Various types of natural fibers such as sisal, flax, jute, hemp, kenaf, oil palm reinforced composite materials have received great importance for various application areas such as automobiles, structural components, furniture's, building materials etc., [38]. Table 2.3 presents the applications of different natural fibers for various application areas in the past years.

Table 2.3: Applications of natural fibers [7] [38][39]

Fiber type	**Applications**
Wood	Window frame, panels, door shutters, decking, railing systems, and fencing
Flax	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding, and laptop cases
Rice husk	Building materials such as building panels, bricks, window frame, panels, decking, railing systems, and fencing
Oil palm	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking, and other building materials
Hemp	Construction products, textiles, cordage, geotextiles, paper & packaging, furniture, electrical, manufacture bank notes, and manufacture of pipes
Jute	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geotextiles, and chip boards.
Ramie	Use in products as industrial sewing thread, packing materials, fishing nets, and filter cloths. It is also made into fabrics for household furnishings
Coir	Building panels, flush door shutters, storage tank, packing material, helmets
Cotton	Furniture industry, textile and yarn, goods, and cordage
Kenaf	Packing material, mobile cases, bags, insulations, clothing-grade cloth, soilless potting mixes, animal bedding, and material that absorbs oil and liquids
Sisal	In construction industries such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp
Bagasse	Window frame, panels, decking, railing systems, and fencing

2.7 Machining of Natural Fiber Reinforced Composite Materials

Composites are fabricated using various fabrication methods (hand layup process, compression molding, resin transfer molding, extrusion process) to a near-net shape of final product. However, they still need some secondary operations since they cannot be welded together or glued without difficulty to achieve the specific final shape and required tolerance. Thus, the machining process is the common solution to facilitate joining of composite components to other parts in complex assemblies [3].

There are several traditional and unconventional strategies for machining composite materials as shown in Figure 2.6.

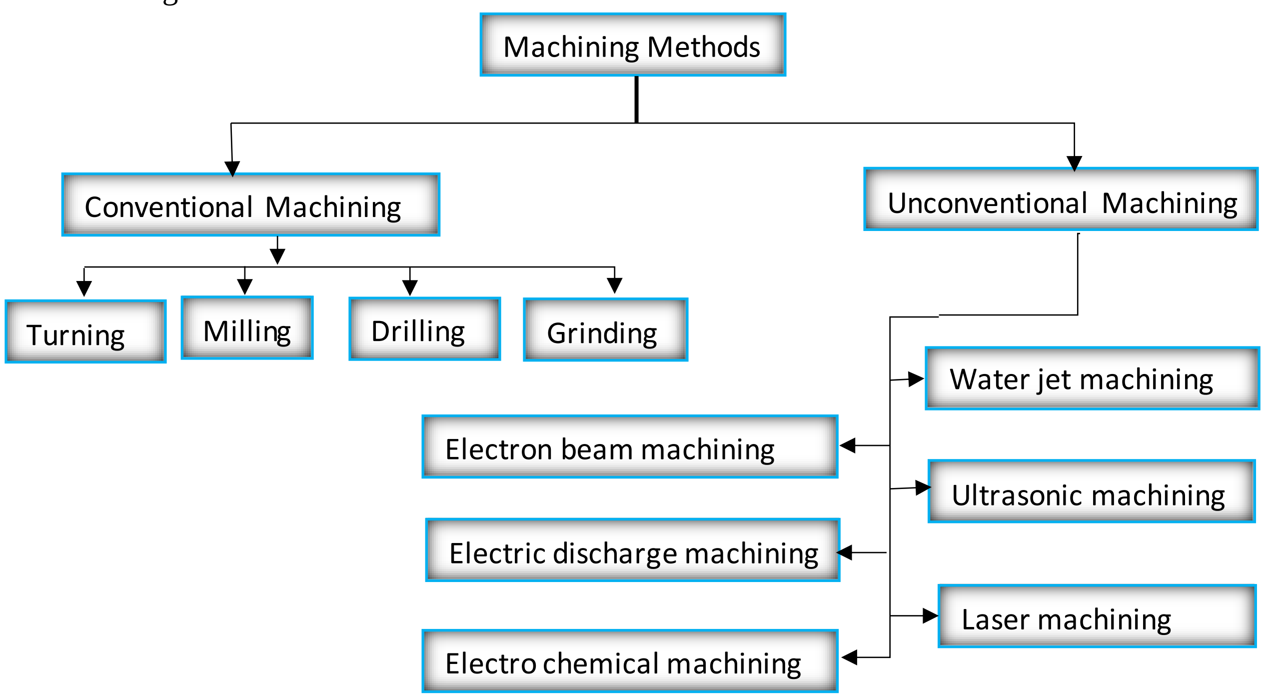


Figure 2.6: Machining of composite materials [3]

2.7.1 Milling of Natural Fiber Reinforced Composite (NFRC)

Based on the type of milling cutters and their purpose, there are various types of milling operations such as plain milling, face milling, side milling, profile milling, gear milling, end milling etc.

End milling operation is one of the most necessary operation next to drilling in machining NFRP composites. End milling operation is the process of creating slots, geometrical features, keys or grooves on flat surface work-piece materials which may be vertical, horizontal or at angle in the table surface.

2.7.1.1 Effects of End Milling Parameters on Quality Responses

Vinayagamoorthy et al. [9] conducted end milling operations on woven jute fiber reinforced isophtalic polyester by using vertical milling machine with 7mm diameter, 4-flueted high speed steel end mill cutters. Experiments were designed based on Taguchi L_9 (3^3) orthogonal arrays. The objective of the study was to analyze the effects of spindle speed, feed rate and depth of cut on the thrust force and torque by changing the values of input parameters. Experimental results were analyzed by using Taguchi method and responses were predict by using fuzzy logic. The findings of the study revealed that speed and depth of cut were the most influencing factors on thrust force whereas speed, feed, and depth of cut are the predominant parameters influencing torque. In thrust force, high speed, high feed and medium depth of cut were the optimum machining conditions, whereas high speed, low feed and low depth of cut were the optimum condition for torque.

Babu et al. [5] evaluated the effects of spindle speed and feed rate on the surface roughness and delamination factors of GFRP, JFRP, HFRP and BFRP by conducting milling operations on CNC milling center with carbide end mill cutters. The objective of the study was determining the desired optimum cutting parameters for minimized appearances of surface roughness and delamination factor and establishing the correlation between cutting speed and feed rate with surface roughness and delamination factor. They were designed their experiments with Taguchi L9 (2^4) orthogonal arrays. The findings of the study revealed that feed rate and cutting speed has significant contribution on the delamination factor (F_d) and surface roughness (R_a) of milled fiber reinforced composites. Lower delamination and better surfaces finishes reached at higher cutting speed levels and lower feed rate levels.

Sankar et al. [18] optimized the levels of spindle speed, feed rate, depth of cut and fiber orientation angles on milling jute fiber reinforced polyester composite by using Taguchi based Grey Relational Analysis coupled with principle component analysis for obtaining optimum values of cutting force, surface roughness and material removal rates. The objectives of the study were investigating the milling process on jute fiber composite material for optimum machining parameters. Milling operation were carried out on column and knee type milling machines at different levels of spindle speed, feed rate, depth of cut and fiber angle. They were designed their experimental runs using Taguchi Design of Experiments (DoE) statistical technique. The findings of the study showed that the most influencing factors was in the order of depth of cut, fiber angle, cutting speed and feed rate. The optimal combination of speed, feed rate, depth of cut and fiber orientation angles obtained from the set with 500 rpm, 25 mm/ min, 2 mm and 30^0 respectively.

Harun et al. [16] studied the effects of milling parameters on the surface roughness in milling kenaf fiber reinforced plastic composite using Taguchi Method. The objectives of the study were optimizing the ranges of cutting parameter (cutting speed, feed rate and depth of cut) levels in order to improve the surface quality by minimizing surface roughness's. Their experiments were designed based on Taguchi L_9 (2^8) orthogonal arrays and milling operations were conducted on CNC milling machine by using 4 flute HSS end mill having 10mm diameter. The findings of the study revealed that feed rate and cutting speed were the most effective factors affecting the surface roughness during the milling of kenaf fiber-reinforced composites. The optimum parameters for the minimum surface roughness were the cutting speed at 1000 rpm, feed rate at 200mm/min and the depth of cut 1.0 mm.

Zurayyen et al. [40] investigated the effects of machining parameters namely spindle speed and feed rate on the delamination factors of banana fiber reinforced polyester composites. The experiment was conducted on HAAS CNC milling machine with 6 mm diameter of HSS flat end mill at three levels of cutting speed (16, 24, 32) m/min, feed rate (0.1, 0.2, 0.3) mm/rev and 2 mm constant depth of cut. The objective of the study was investigating the influences of machining parameters on the banana fibers under delamination. The findings of the study revealed increasing feed rate increases delamination factors, while sudden increase in spindle speed decreases delamination factors.

Sivakiran et al. [17] conducted facing operations at five levels of cutting speed, feed rate and depth of cut by using carbide cutting tools on conventional machines. The sample specimens were randomly oriented chopped banana fiber reinforced hybrid polymer composites. The objectives of the study were investigating the influences of cutting speed, feed rate and depth of cut on the surface roughness and material removal rates by designing experiments based on response surface methodology. ANOVA techniques was employed to find the levels of influences of cutting speed, feed rate and depth of cuts on surface roughness and material removal rate. The results of experiments showed that cutting speed, feed rate and depth has positive effects on the material removal rate. While feed rate and depth of cuts has negative influences on surface roughness. They concluded that feed rate has maximum influence on material removal rate and surface roughness followed by speed and depth of cut.

Celik et al. [41] experimentally studied effects of milling parameters on jute fiber reinforced polymer composites by preparing a sample with different orientation angles ($0^0/90^0$, $\pm45^0$, $30^0/-60^0$) by using vacuum infusion method fabrication techniques. The objective of the study was examining the effects of milling parameters (cutting speed feed rate and number of cutting tool flutes) on the output responses (cutting forces, delamination factor and surface roughness). They conducted milling operations on Brother Speedio S500X1 model vertical machining at different levels of cutting speed and feed rate and constant depth of cut by using 8mm diameter TiAIN coated cemented carbide end mills with two, three, four flutes. The result of their experiment showed that increasing the number of the flutes of the cutting tools reduced the cutting force, delamination factor and surface roughness. As cutting speed increases, surface roughness decreases, while delamination factor increases. As feed rate increases, both surface roughness and delamination factor increase.

Celik et al. [42] examined the effects of process variables (spindle speed, feed rate and cutting tool material type) on the processes responses (cutting force, delamination factor, surface roughness and vibration amplitude) in milling JFRP and FFRP by conducting milling operations on CNC milling machines with 4mm HSS, Tin coated HSS and wolfram carbide end mill cutters. The results showed that when spindle speed increases from 2500 rpm to 7500 rpm, vibration amplitude and delamination factor increased, while cutting force and surface roughness decreased with increasing spindle speed. When feed rates increase from 0.01 mm/rev to 0.02 mm/rev, all of responses (cutting force, vibration amplitude, delamination factor and surface roughness) increased. Wolfram carbide material types were the most appropriate for cutting force, delamination factor and surface roughness. However, in vibration amplitude, the lowest values were HSS material types. Delamination factors and surface roughness in FFRP composites were higher than those of JFRP composites. Cutting forces of FFRP composites were lower than those of JFRP composites.

Rajendran et al. [43] investigated the machinability characteristics and multi response optimization of jute fiber reinforced epoxy composites in end milling operations using gray relational analysis (GRA) method. The purposes of the study were optimizing performance responses namely surface roughness (Ra), tool wear rate and material removal rate (MRR) by conducting milling operations at different levels of cutting parameters namely spindle speed, feed rate and depth of cut. Their experiments were designed based on Taguchi L_{27} (3^3) orthogonal arrays. GRA were employed decreasing surface roughness and tool wear rates with maximum material removal rates. The results of their experiments showed that optimum surface roughness's, tool wear rate and material removal rates were obtained at a set of 6000 rpm spindle speed, 0.25 mm/min feed rate and 0.5 mm depth of cuts.

Mustafa et al. [44] examined the parametric effects of spindle speed, feed rate and number of end mill fluent on the output responses of delamination factor and surface roughness by performing milling operations on woven flax fiber reinforced composite materials. The experimental runs designed based on Taguchi L_{18} orthogonal arrays. Milling operations were conducted at three different levels of spindle speed, feed rate and number of end mill fluent on three axis CNC milling machine, by Tongtai EZ-5A model with FANUC controller with high-speed steel end mill cutters and experimental data were analyzed by signal to noise ratio. The findings of the study revealed that spindle speed and feed rate had equal effects on delamination factor and surface roughness, whereas the number of end mill flute had a marginal influence on the aforementioned machining outputs.

Table 2.4 summarizes the pre-machining parameters (matrix and fiber type) and in-machining parameters such like cutting parameter (speed, feed rate and depth of cut) and tool parameters (tool diameter, tool material types and tool geometry) that the researchers used in investigating the milling characteristics of NFRP composite materials.

Table 2.4: Summery of literatures

Materials used		Tool	Parameters			Responses	Optimization method	Reference
Matrix	Reinforcement	Material	Speed	Feed rate	DoC			
RIMH 135 Epoxy	Jute	8mm dia TiAlN-coated CC EM	628, 1256, 1914	0.04, 0.08, 0.12	2	Fc F_d Ra	Taguchi Method	[42]
Polyester	Banana	6mm dia, HSS	850, 1275, 1700	0.1, 0.2, 0.3	2	F_d	Taguchi Method	[45]
Epoxy	Jute, Flax	4mm, HSS, TiN coated HSS	2500, 5000, 7500	0.01, 0.015, 0.02	2	Fc, Va, Ra, Fd	Taguchi Method	[41]
Polyester	Hemp, Jute, Banana, Glass	5mm dia CC end mill	1020, 1530, 2040	0.1, 0.2, 0.3	2	F_d Ra	Taguchi + ANOVA	[5]
Un-saturated polyester	Kenaf	10mm dia, 4-flueted HSS end mill	500, 1000	200, 1200 mm/min	1, 2	Ra	Taguchi + ANOVA	[16]
Polyester	Banana	Carbide cutting tool	100, 300, 500,	0.05, 0.1, 0.15, 0.2, 0.25	0.4, 0.8, 1.2,	Ra, M_{RR}	RSM + ANOVA	[17]

			700, 900		1.6, 2			
Isopthalic polyester	Jute	7mm dia, 4-fluted HSS EM	210, 660, 1750	0.04, 0.08, 0.15	1, 1.5, 2	Ft, T	Taguchi + fuzzy logic	[10]
Polyester	Jute	-	125, 180, 250, 355, 500	16, 25, 40 mm/rev	2, 4, 5, 6, 8	Fc, Ra, M_{RR}	Taguchi + GRA with PCA	[46]

The findings from the literature showed that spindle speed, feed rate, and depth of cut were the most significant machining parameters that had significant effects on quality responses during the milling of NFRP composites. The optimum quality responses were obtained at various levels of spindle speed, feed rate, and depth of cuts by different researchers. The optimum levels of spindle speeds, feed rate, and depth of cut were obtained in the ranges between 1000 rpm to 2000 rpm, 100 mm/min to 300 mm/min, 1mm to 2 mm respectively.

2.7.2 Challenges in Milling of NFRP Composites

Generally, the machining process is performed to produce the required shapes within the prescribed dimensional tolerances and achieve optimum quality surfaces. The quality of machined surfaces depends on both the pre-machining parameters and in-machining parameters [31]. Pre-machining parameters includes matrix types, fiber types, and fabrication method types. In-machining parameters includes cutting parameters (speed, feed rate, depth of cut), tool parameters (tool material type, tool diameter, tool geometry) and cutting conditions (dry, wet, cooled) [47].

Inappropriate selection of the pre-machining parameters and in-machining parameters causes several challenges in the times of milling NFRP composites. Challenges or defects that induced in the surfaces caused by pre-machining parameters includes matrix imperfection, poor and rich resin area, voids, burrs etc. The defects can be overcome or minimizes by selecting the best fitted matrix and fiber type with suitable fabrication techniques [32].

In addition to pre-machining parameters, uncontrollable in-machining parameters causes several challenges that greatly affects the quality of machined surfaces. The most common challenges that affect the quality of machined surfaces are delamination, fiber pull outs, fiber push outs, [5].

2.7.2.1 Delamination

In machining of NFRP composites, delamination is one of the most critical defects, described as the loss of adhesion between the layers. It is mainly an inter-ply failure phenomenon induced by an exterior force, such as milling, which results in separation of different layers of reinforcement or plies as show in figure 2.7 [48]. It has been found as a major concern during machining of laminated composites, which leads to separation of the layers of reinforcements or plies [49]. It is caused by matrix cracking, bending cracks, and shear cracks, and can affect the compression strength of composite laminate, and it will slowly cause the composite to experience failure through buckling [50].

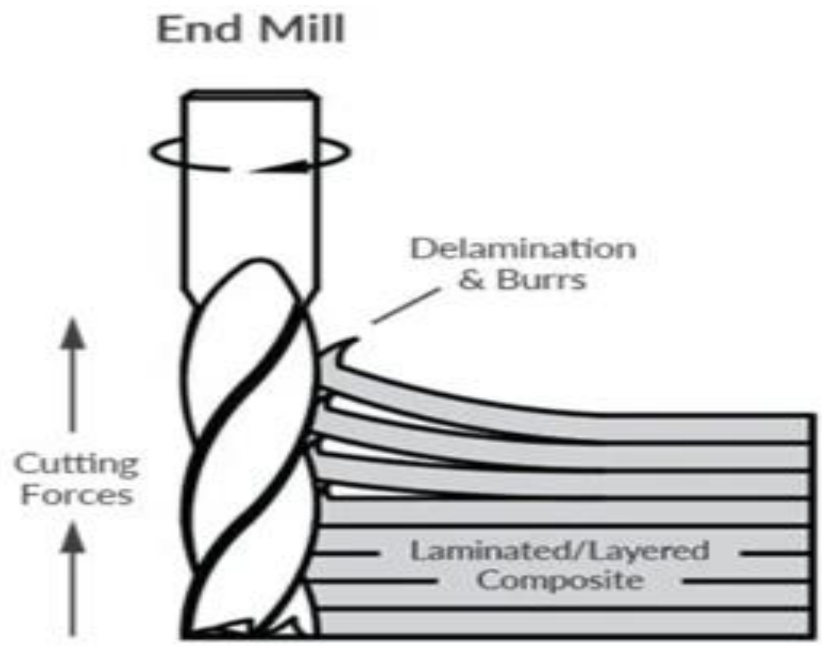


Figure 2.7: Delamination of laminated composites during machining [48]

2.7.2.2 Surface roughness

The performance of the machined parts along with the cost of production is notably affected by the produced surface roughness [51]. In machining of NFRP composites, surface roughness is a very important quality responses, as the mechanisms of creep, wear, fatigue, and corrosion depend on it and it also demonstrates the level of irregularity on circumferential walls of the machined surfaces [52]. Thus, surface finish quality can be considered as an importnt issue in the field of engineering machining, which can noticeably affect the functioning of composite parts as well as cutting parameters and machine selection during the planning process [31].Surface roughness indicates the degrees of fiber pullouts, cracks, voids etc as shown in Figure 2.8.

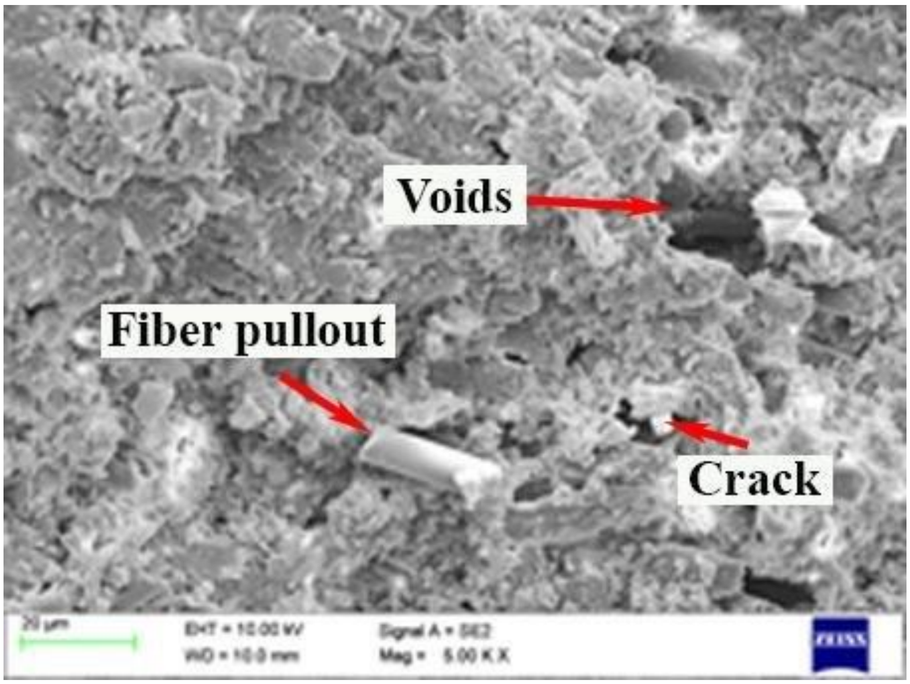


Figure 2.8: SEM image of machined surfaces [50]

2.8 Literature Gaps

Significant studies investigated in the machining behaviors of NFRP composites. Some of them are presented in the above sections. However, the literatures have some gaps:

- The findings of studies suggest that enset fibers has sufficient potentials to applicable as reinforcement for various applications. However, limited studies conducted on the machining behaviors of enset fiber reinforced composites.
- During investigations of machining behaviors, researchers mostly concerned on surface roughness, delamination factor and cutting force only. Material removal rate is not taken into account, even though it has an impact on the quality of machined surfaces.
- In most studies, researcher's only analyses effects of cutting parameters on single performance responses. The effects of machining parameters on two or more quality responses not adequately analyzed.
- Optimization of multi objective responses in machining natural fiber reinforced composites not optimized simultaneously in most studies. However, in real case, optimizing a single response may yield positively in some responses but it may affect adversely in other responses.
- Mostly the researchers assume the weights of quality responses contributing equal loads. However, it may not contribute equally in real cases.

Chapter Three

Materials, Conditions and Methods

3.1 Methodology

As shown the flow chart of the experimental procedure in Figure 3.1. The study started by surveying literatures that, focused on the investigation of machining behaviors of NFRP composites. Constituent material types, weight fractions, fabrication methods selected based on literatures. After that, the fibers were prepared in the form of chopped fibers and the specimen were fabricated by using hand layup processing techniques. Fabricated specimens were characterized in order to determine the compressive strength, flexural strength, and impact strength. Cutting parameters such as spindle speed, feed rate and depth of cut were considered as input parameters. Quality responses such as surface roughness and material removal rate were considered as an output response. The milling operations were conducted based on the L9 (3^3) orthogonal arrays. The results are analyzed by coupling gray relational analysis (GRA) with principal component analysis (PCA) methods. The influence of each machining parameters on the response was determined by an analysis of variance (ANOVA). Finally, confirmation tests were conducted based on the optimum levels of machining parameters in order to verify the results.

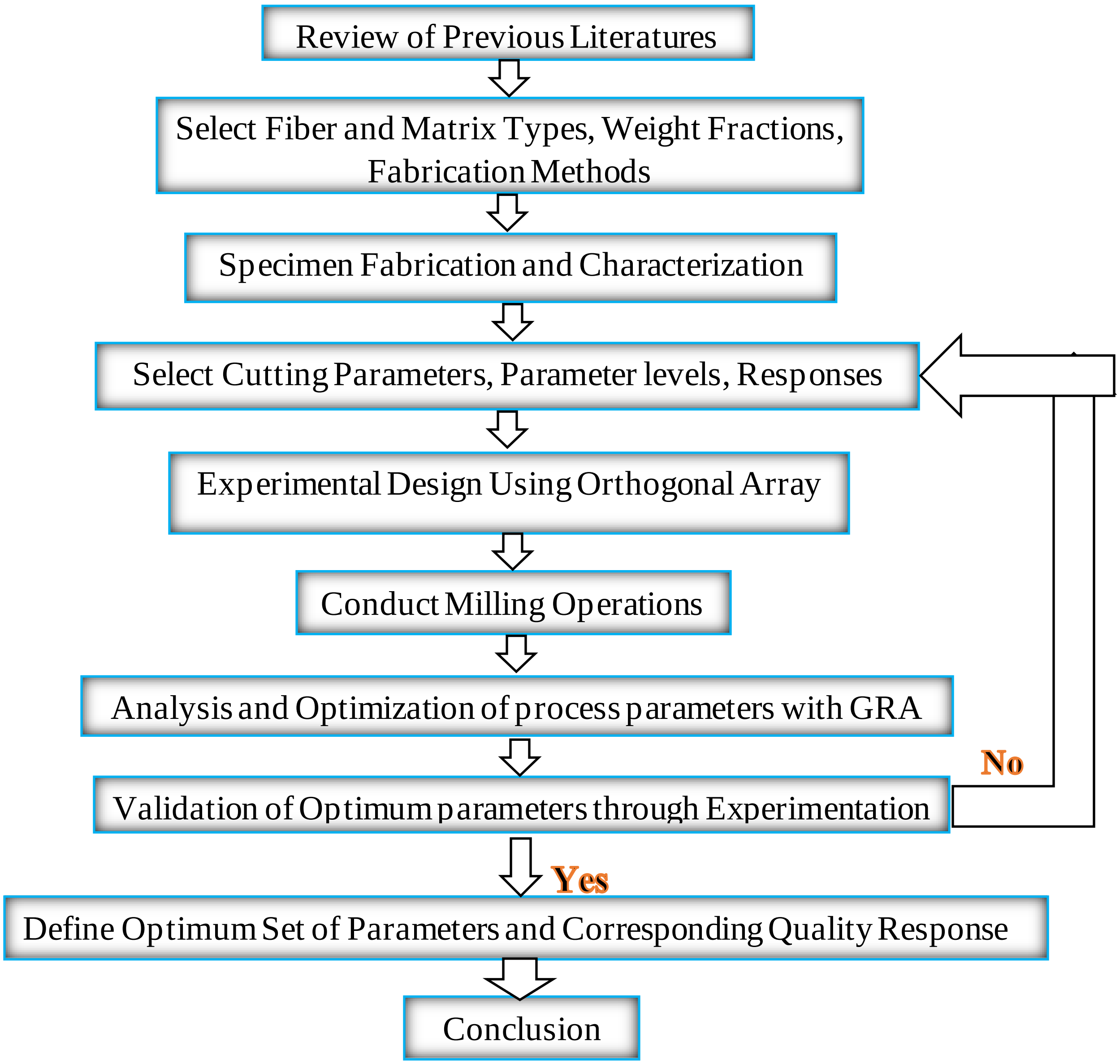


Figure 3.1: Methodology

3.2 Materials

In this thesis, the specimens were fabricated by combining two constituent materials i.e matrix materials and reinforcement materials. Methyl ethyl ketone peroxide (MEKP) and sodium hydroxide (NaOH) were used to cure the resin and treat the fiber respectively.

3.2.1 Matrix Materials

The resin used for this study was epoxy resin with brand name of general-purpose epoxy resin, purchased from world fiber glass and water proofing engineering company located in Addis Ababa, Ethiopia.

It is mostly used thermoset plastic in polymer matrix composites due to its superior mechanical properties like excellent adhesion, good possibility utilizing addition-type reactions, low cure shrinkage and low cost, availability, suitable for hand lay-up at a convenient atmospheric condition [53].

General purpose epoxy resins are suitable for [41]

- Construction of small, medium-sized boats and other applications.
- General-purpose industries, artificial rock, dustbin, road signage.
- FRP furniture and panels.
- Adequate wetting and impregnation of reinforcement needed.

Table 3.1: Mechanical and physical properties of resin

Properties	**Values**
Specific gravity	1.2 g/cc
Tensile strength	50 MPa
Tensile modulus	3000 MPa
Elongation	2.5 %
Flexural strength	80 MPa
Flexural modulus	3000 MPa
Volume shrinkage	7%
Viscosity	575– 675 cps

3.2.2 Hardeners

Hardeners are used as a catalyst to cure the resins with a short period of times, which causes a chemical reaction without changing its own composition. It initiates the solidifications processes of the epoxy resin and monomer ingredient from liquid to a solid state [42]. The curing agent applied in this work for the liquid epoxy resin was hardener with brand name of methyl ethyl ketone peroxide (MEKP) hardener purchased from world fiber glass and water proofing engineering company located in Addis Ababa, Ethiopia.

3.2.3 Mold Realizing Agent

Honey Wax is a unique, high gloss paste used as a mould release agent during the time of composite fabrication process. Honey Wax makes a durable wax surface that remains intact for multiple pulls and consumes processing times due to its exceptional ease of application and buffing. Honey wax used to provide reproducibility, glossiness, and a hard releasing film which simplifies the fabrication processes. The residual film is more durable and resistant to abrasion and easier to apply than other processed waxes [42].

Figure 3.2: Honey wax mold realizing agent

3.2.4 Reinforcement Materials

For this thesis work false banana (enset) fiber used as a reinforcement, extracted from endibr woreda, gurage zone, south region, Ethiopia.

Figure 3.3: Enset fiber

Figure 3.4: Pellet form of NaOH

Table 3.2: Properties of Ethiopian enset fiber [32]

Properties	**Values**
Density	1.4 gcc
Tensile strength	67 – 923 MPa
Young's modulus	12 – 69 MPa
Elongation	3.2%
Moisture content	10 – 15%

3.2.5 Sodium Hydroxide (NaOH)

Sodium hydroxide (NaOH) is a caustic reagent, made-up of solid white crystals that absorbs water from the air. It is used to fabricate soaps, rayon, paper, products that explode, dyes, and petroleum products. It can also be used in tasks such as processing cotton fabric, metal cleaning and processing, oxide coating, electroplating, and electrolytic extraction [43]. NaOH accessible in the form of pellets, flakes, granules. As shown in figure 3.4, in this work, pellet form NaOH was used for treating the surfaces of enset fibers.

3.3 Sample Preparation Methods

3.3.1 Weight Fractions of Enset Fiber

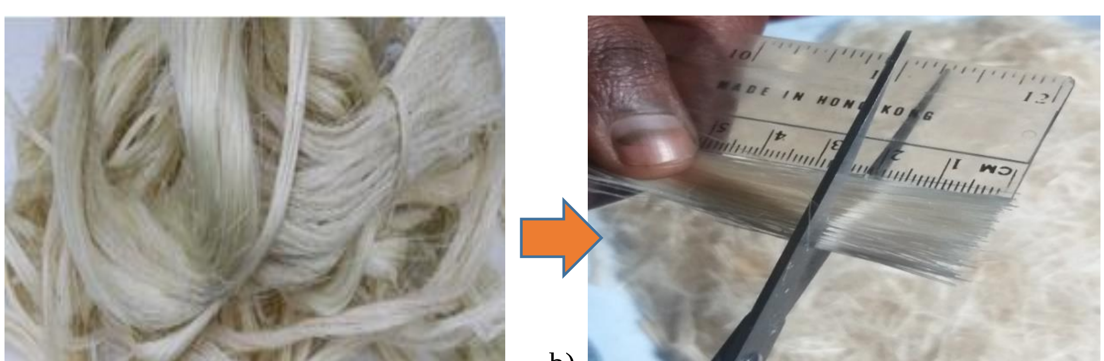
One of the factors that determines the overall performances of the composite materials are the volume or weight fractions of fibers. The roles of the fibers are enhancing the strengths of the composites. As the fiber content increases, the load carrying capacity of the composites also increases. However, the wettability of fibers in the matrix decreases. Due to pure wettability fibers, the load carrying capability of the composites decreases. Therefore, selecting optimum weight fractions of fiber are the primary tasks before manufacturing composites. Adequate researches have been done for identifying optimum weight fractions of fibers. Lemi D. [34] and Fitsum et al. [35] studied the mechanical properties of enset fiber reinforced polymer composites at 10, 20, 30, 40 and 60 weight percent fractions of enset fibers and concluded that 30% weight fractions of enset fiber reinforced composites has greater mechanical properties than other weight percent's of fibers.

Based on these results, in this research, specimens were fabricated from 30% weight fractions of enset fiber and 70% weight fractions of resins.

3.3.2 Preparation of Enset Fiber

Fiber length are one of the main factors that has significant effects on the mechanical properties i.e., tensile strength, flexural strength, compression strength and impact strengths of NFRP composite materials. Venkateshwaran et al. [17] studied tensile strengths, flexural strengths and impacts strengths of banana fiber reinforced epoxy composites by fabricating specimens with 5mm, 10mm, 15mm and 20mm fiber lengths. The results of experiments showed that maximum tensile strength, flexural strength and impact strengths obtained at 5mm, 15mm and 20mm fiber lengths respectively. Khanam et al. [54] studied fiber length effects on the tensile, flexural and compressive strengths of coir/silk fiber reinforced hybrid composites. Their samples were prepared from coir/silk fibers with 10mm, 20mm and 30mm fiber lengths by using hand layup fabrication techniques. The results of experiments showed that coir/silk hybrid fiber reinforced hybrid composites have highest tensile, flexural and compression strengths at 20mm fiber lengths. Bisaria et al. [55] investigated mechanical properties of randomly oriented short jute fiber reinforced epoxy composite specimens by fabricating 30 wt. % of jute fiber in the various lengths of 5, 10, 15 and 20 mm using Hand lay-up method. The results showed that tensile and flexural properties were found maximum for the composite with 15 mm fiber length whereas the impact properties were found maximum for the composite specimen with 20 mm length of fiber.

Depending upon these researcher experimental results, extracted fibers were prepared with 20mm length by using scissor. Figure 3.5 shows preparations of chopped enset fibers with 20mm length.



a) b)

Figure 3.5: Preparation of enset fiber a) Long fiber b) Enset fibers cutout with 20mm length

3.3.3 Alkali Treatment of Enset Fiber

Besides their advantages, natural fibers have its weakness. The first one is inadequate interfacial surface adhesion between the matrix phase and reinforcement phase. These challenges caused by the hydrophilic nature of natural fibers and hydrophobic nature of matrix materials [31]. The second weakness of NFRP composite is high sensitivity nature of moisture absorption properties which means low resistance to moistures. Poor interfacial surface adhesion and high moisture absorption properties of natural fibers has significant impacts on the overall properties of NFRP composite materials [32]. Mechanical properties of NFRP composites depend on the degrees bonding strengths between the fiber and matrix. Poor coupling between the fiber phase and matrix phase causes ineffective stress distribution within composites which leads insufficient mechanical strengths [31].

In order to overcome these challenges, fiber surfaces could be modified either by means of physical methods (thermo treatment, calendaring, stretching, and electric discharge) or by chemicals (alkaline treatment, silane treatment, acetylation, and benzoylation) [33].

Alkali treatment requires less time to prepare and much lower price compared to other chemical treatment. Most of the research studies have found and reported that surface treatment of natural fibers by alkaline treatment method has proved effective in increasing adhesion between the fiber surface and the matrix, thereby enhancing the overall performance of the NFRP composites [6][38]. Alkaline treatment increases the roughness of the surfaces of natural fibers by cleaning a certain amount of oils, wax, lignin and hemicellulose that covers the external surfaces of fibers. Higher surface roughness improves the mechanical interlocking between the fiber and matrix [56].

One of the important parameters for alkali treatment that affects the mechanical interlocking of fiber and matrix is percent of alkaline concentration and soaking time. The cellulose component the fibers will be damaged by excessive concentration and soaking time during alkali treatment of natural fiber, hence mechanical properties lowers [57]. Ibnu et al. [33] examined effects of sodium hydroxide (NaOH) concentration treatments on the tensile strength, flexural strength and elasticity modulus of banana fiber reinforced polyester composites. The fibers were soaked in 0%, 5%, 10% and 15% of NaOH for one hour at room temperature. The results showed that banana fiber reinforced composites have highest tensile strength, elasticity modulus, flexural strength and flexural modulus when fibers treated with 5% NaOH concentration.

Khan et al. [58] studied effects of NaOH treatment on the mechanical properties of banana fiber reinforced epoxy composites by immersed fibers with 0%, 2.5%, 4.5% and 6.5% NaOH solutions for four hours at room temperature. The result of experiments revealed that specimens made from 4.5% NaOH solution treated banana fibers has greater tensile and comprehensive strengths.

Jayabal et al. [59] studied effects of soaking time on the mechanical properties of kenaf reinforced epoxy composites by immersed specimens within 6% concentration of NaOH solutions for 0, 12, 24 and 48 hours. Results revealed that composites have highest mechanical strengths when fiber soaked NaOH solution for 24 hours.

Based on the reviews, in this study, enset fibers was soaked in 5% of sodium hydroxide (NaOH) solution for 24 hours and then washed by using water to clean residues or traces of NaOH. Finally, the fibers were dried-up in sunlight for at least 48 hours. Figure 3.6 shows the procedures of fiber treatments. Firstly, the chopped fiber soaked in 5% of NaOH treated waters for 24 hours as shown figure 3.6a. Secondly, treated fibers washed by water until the residues cleans as shown figure 3.6b. Lastly, the fibers were dried by sunlight's for at least 48 hours for reducing water absorbability properties as shown figure 3.6c.

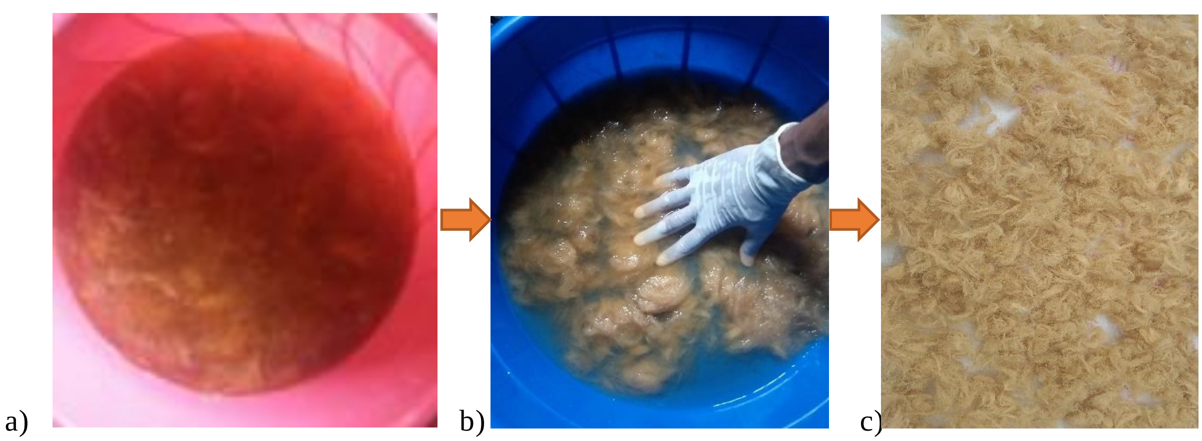


Figure 3.6: Treatment of enset fibers **a**) Enset fibers soaked in 5% NaOH for 24 hours **b**) Washing of enset fibers **c**) Drying of enset fibers

3.3.4 Volume Fraction of Fiber and Matrix in the Composite

Volume fraction of fiber is the ratio of volume of the fiber to volume of the composite. Mathematically calculated as follows

$$V_f = \frac{v_f}{v_c} \tag{3.1}$$

Where; V_f = volume fraction of fiber, v_f = volume of fiber and v_c = volume of composites

Volume fraction of matrix

Volume fraction of matrix is the ratio of volume of the matrix to volume of the composite. Mathematically calculated as follows:

$$V_m = \frac{v_m}{v_c} \tag{3.2}$$

Where; V_m = volume fraction of matrix, v_m = volume of matrix and v_c = volume of composites

$$V_m + V_f = 1 \tag{3.3}$$

$$v_c = v_m + v_f \tag{3.4}$$

3.3.5 Mass Fraction of Fiber and Matrix in the Composite

Mass fraction of fibers

Mass fractions of fibers are calculated as the ratio of mass of fibers to mass of composites

$$M_f = \frac{m_f}{m_c} \tag{3.5}$$

Where; M_f = mass fractions of fiber, m_f = mass of fiber and m_c = mass of composite

Mass fraction of matrix

Mass fractions of matrix's are calculated as the ratio of mass of fibers to mass of composites

$$M_m = \frac{m_m}{m_c} \tag{3.6}$$

Where; M_m = mass fractions of matrix, m_m = mass of the matrix and m_c = mass of the composite

$$M_f + M_m \tag{3.7}$$

$$m_c = m_f + m_m \quad (3.8)$$

3.3.6 Density of the Composite

Density of the composite material is defined as the ratio of mass of the composite material to their volume of the composite material [37]. Mathematically it can be expressed as equation (3.9)

$$\rho_c = \frac{m_c}{v_c} \quad (3.9)$$

Where, ρ_c = density of the composite material, m_c = mass of the composite material

v_c = volume of the composite material

Since, $v_c = v_f + v_m$ and $v = \frac{m}{\rho}$

Where, ρ = density, m = mass and v = volume

Therefore,

$$\frac{m_c}{\rho_c} = \frac{m_f}{\rho_f} + \frac{m_m}{\rho_m} \quad (3.10)$$

Multiply both sides of equation 3.10 by the ratio of $\frac{1}{m_c}$ in order to find density of the composite.

$$\frac{m_c}{\rho_c} * \frac{1}{m_c} = \frac{m_f}{\rho_f} * \frac{1}{m_c} + \frac{m_m}{\rho_m} * \frac{1}{m_c}$$

$$\frac{1}{\rho c} = \frac{1}{\rho_f} * \frac{m_f}{m_c} + \frac{1}{\rho_m} * \frac{m_m}{m_c}$$

Since, $\frac{m_f}{m_c} = Mf$, $\frac{m_m}{m_c} = Mm$

$$\frac{1}{\rho_c} = \frac{Mf}{\rho_f} + \frac{Mm}{\rho_m} \quad (3.11)$$

M_f = 30% = 0.3 Mm = 70% = 0.7 ρ_f = 1.4 gcc ρ_m = 1.2 gcc

$$\frac{1}{\rho_c} = \frac{0.3}{1.4} + \frac{0.7}{1.2}$$

$$\rho_c = 1.24 \text{ g/cm}^3$$

3.3.7 Calculation of the Weight of Fiber and Matrix for Milling Specimen Preparation

The specimen dimension was proposed by considering number of slots created by end mill cutters, diameter of end mill cutters and gaps between slots.

In this thesis, 9 milling operations will conducted on one sample, diameter of end mill cutter is 10mm and the gap between two slots is 20mm. Dimensions of the specimens are 290 mm width, 100mm length and 10 mm thickness.

Volume of the specimen is calculated by multiplying the length, width and thickness of the specimen.

$$\text{Volume of the composite specimen } (v_c) = \text{length*width*thickness}$$

$$= 29\text{cm}*10\text{cm}*1\text{cm}$$

$$= 290\ \text{cm}^3$$

$$\text{Mass of the composite } (m_c) = \text{volume of the composite } (v_c) * \text{density of the composite } (\rho_c)$$

$$m_c = 290\ \text{cm3} * 1.24\ \text{g/cm3}$$

$$= 359.6\ \text{g}$$

In this study, mass fraction of the enset fiber was 30%, while mass fraction of the epoxy resin was 70% of the overall composition. Therefore, mass of the fiber and mass of the matrix calculated as follows:

$$m_f = M_f*m_c$$

$$= 0.3 * 359.6\ \text{g}$$

$$= 107.88\ \text{g}$$

$$m_m = M_m * m_c$$

$$= 0.7 * 359.6\ \text{g}$$

$$= 251.72\ \text{g}$$

3.3.8 Calculation of the Weight of the Fiber and Matrix for Compression Strength

Volume of the composite (v_c) = 140 mm * 60 mm * 4mm

= 14cm*6cm*0.4cm

= 33.6 cm^3

Mass of the composite (m_c) = volume of the composite (v_c) * density of the composite (ρ_c)

m_c = 33.6 cm^3 * 1.24 g/cm^3

≈ 45

Mass of the fiber = mass fraction of the fiber * mass of the composite

= 0.3 * 45

m_f = 13.5 g

Mass of the matrix = mass fraction of the matrix * mass of the composite

= 0.7 * 45

m_m = 31.5 g

3.3.9 Calculation of the Mass of the Fiber and Matrix for Flexural Strength

Volume of the composite (v_c) = 140 mm * 60 mm * 3.2 mm

= 14 cm * 6 cm* 0.32 cm

≈ 29 cm^3

Mass of the composite (m_c) = volume of the composite (v_c) * density of the composite (ρ_c)

m_c = 29 cm^3 * 1.24 g/cm^3

m_c = 35.96 g

Mass of the fiber = mass fraction of the fiber * mass of the composite

= 0.3 * 35.55 g

m_f = 10.788 g

Mass of the matrix = mass fraction of the matrix * mass of the composite

= 0.7 * 35.55 g

m_m = 25.17 g

3.3.10 Calculation of the Weight of the Fiber and Matrix for Impact Strength

Volume of the composite (v_c) = 140 mm * 60 mm * 3 mm

= 14 cm*6 cm*0.3 cm

≈ 28 cm^3

Mass of the composite (m_c) = volume of the composite (v_c) * density of the composite (ρ_c)

m_c = 28cm^3 * 1.24 g/cm^3

= 34.72 g

Mass of the fiber = mass fraction of the fiber * mass of the composite

= 0.3 * 34.72g

m_f = 10.42g

mass of the matrix = mass fraction of the matrix * mass of the composite

= 0.7 * 34.72 g

m_m = 24.3 g

3.3.11 Mold Preparation

Mold is a material that used to give the required shape of the specimen. It is prepared from 4mm thickness mild steels by means of bending and welding operations. It has two parts, sectioned rectangular container and lid plates. The sectioned rectangular containers used as a frame to form the shapes of the required specimens. Lid plates placed on the top surface after the fiber and epoxy was applied in the container to facilitate the compression processes.

The sizes of the mold were designed based on the sizes of the specimen.

Figure 3.7: Mould

3.3.12 Hand Layup Techniques

Polymer matrix composite materials could be fabricated with either open mold or closed mold processing techniques or other methods. Open mold processing techniques include hand layup, spray layup, autoclaves while closed mold processing techniques include compression molding, injection molding, transfer molding. Hand layup, spray layup, filament winding, pultrusion, resin transfer molding, autoclave molding, and compression molding fabrication methods suited for thermosetting polymer materials like epoxy [60] [61].

In this thesis, hand lay-up processing techniques selected to fabricate chopped enset fiber reinforced epoxy composite specimens due to their low tooling costs and simplicity. The procedures of hand lay-up were as follows.

Step 1: Smear the polyethylene plastic by mold realizing agent's in-order to prevent sticking of the resins as shown in the figure 3.8 below.

Plastics was used at the top and bottom of the mold plate to get a good surface finish of the product.

Figure 3.8: Applying wax on polyethylene plastics

Step 2: Measure the required amounts of chopped enset fiber and resins based on their calculations by using electronic mass balances as shown in figure 3.9a and 3.9b respectively. After measuring of resins, the required amouts of hardners was added as shown in figure 3.9c and steered continously at least for one minutes to spread the hardner adquently as shown in figure 3.9 d.

a) Fiber measurement

b) Matrix measurement

c) Hardner measurment

d) stirring of matrix and hardener

Figure 3.9: Measuring of constituent materials

Step 3: Clean the mold and placed wax smeared polyethylene plasics in the mold as shown in figure 3.10a. Then after, poured the resin as shown figure 3.10b and spread the resins on the overall surfaces of the mold by means of brushes as showon figure 3.10c. After that, placed the fiber on the polymer surfaces as shown in figure 3.10d. After placing of fibers on the polymer, again spread the resins by means of brushs on the fibers as shown in figure 3.10f. This process repeats until the required amounts of fibers and resins finished. Finaly, the lid plate was placed on the top sides of the mold as shown in figure 3.10h.

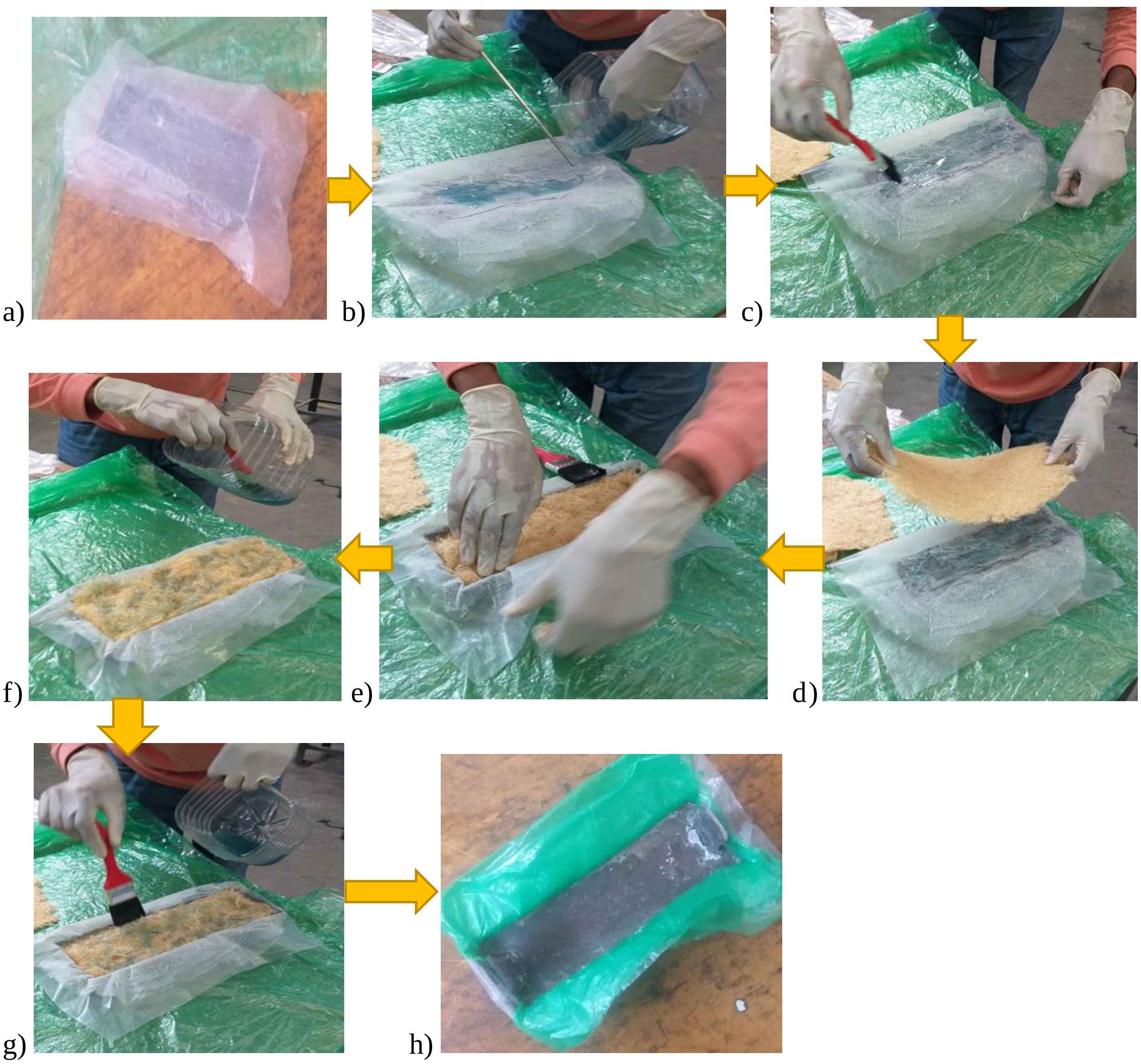


Figure 3.10: Hand lay-up manufacturing procedures

Step 4: After placing the upper plates, 5 MPa pressures was applied by means of hydraulic press machines as shown figure 3.11 below to remove the trapped airs and excess resins. And also pressing processes improves the wettability of the fibers.

Figure 3.11: Pressing of the specimens

Step 5: Finally, lefting for 24 hours for curing of the specimen. It is recommended by the resin manufacturers. After curing, the specimens taken apart from the molds.

3.4 Specimens Preparation for Testing

In this thesis, sample plates were cut out from specimens by using band saw machines as shown in figure 3.12 below. Dimensions of test pieces was prepared based on American Society of Testing Methods (ASTM) for each testing types (compression strength, flexural strength and impact strength).

Figure 3.12: Circular band saw

The ASTM standard types with values of length, width and thickness of test pieces are:

Compression test specimen: Specimens for compression test was prepared based on ASTM D3410. It has dimensions of 80mm length, 10mm width and 4mm thickness [62].

Flexural test specimen: Specimens for flexural test was prepared based on ASTM D790. It has dimensions of 127mm length, 12.7mm width and 3.2mm thickness [63].

Impact test specimen: Specimens for impact test was prepared based on ASTM D256, ISO 180. It has dimensions of 65mm length, 10 mm width and 3mm thickness [61].

3.5 Characterization Procedures and Conditions

The mechanical property (compression, flexural and impact) of the test's pieces were characterized at Bishoftu Defense Engineering College, Ethiopia. Gunt Hamburg WP 310 Hydraulic material testing machine having maximum 50KN capacity was used for compression and flexural testing. The impact testing was conducted using Charpy impact tester.

3.5.1 Characterization of Compression Strength

Compression tests used to evaluate material properties when subjected to uniaxial compression load at a relatively low and uniform loading rate. Compressive strength, compressive young's modulus, compressive strain, deformation beyond yield point, and compressive yield stress of materials evaluated by means of compressive tests [50].

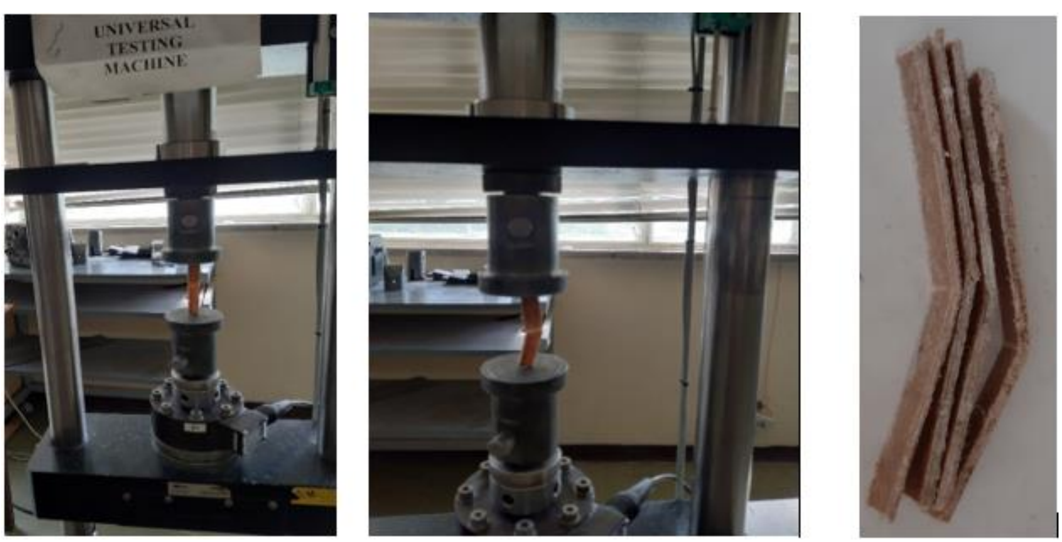


Figure 3.13: Compression testing process

In this thesis, the compressive strengths of enset fiber reinforced epoxy composites were measured by applying a compressive load using UTM machines. The specimen was placed properly in the testing machine as shown in figure 3.13a. After that a compressive load was applied on the specimen until it fractures as shown in figure 3.13b, 3.14c.

3.5.2 Characterization of Flexural Strength

Flexural tests used to determine the capability of a material to resist bending forces that applied perpendicularly to its longitudinal axis. Flexural properties of materials are one of the major parameters to examine the suitability of composite materials for structural applications.

In this thesis, the flexural properties of enset fiber reinforced epoxy composites were measured by applying forces at the center of the specimen.

As shown in figure 3.8a, the specimen is held by two cylindrical support noses while a third cylindrical loading nose applies a force to the center of the specimen, causing it to bend.

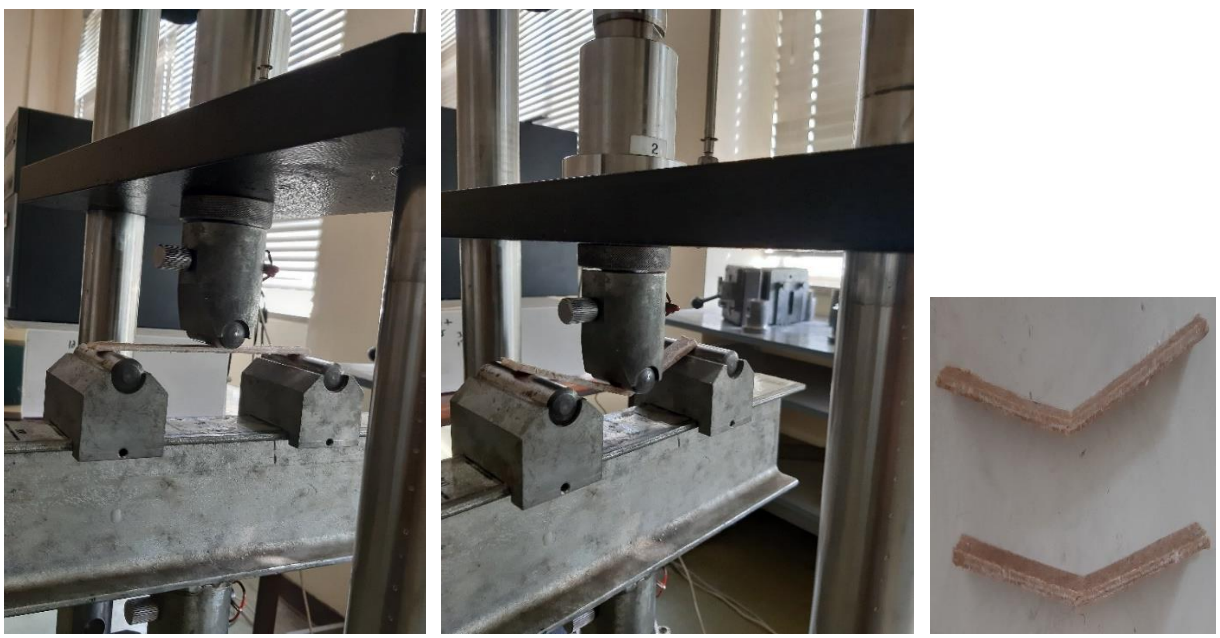


Figure 3.14: Flexural test procedures

3.5.3 Characterization of Impact Strength

Impact test is used for determining the impact strength, toughness and notch sensitivity of materials. The specimen was clamped into the bed of the tester and it is hit by a pendulum which was dropped from an angle of 45 degree to impact the specimen and fracture it.

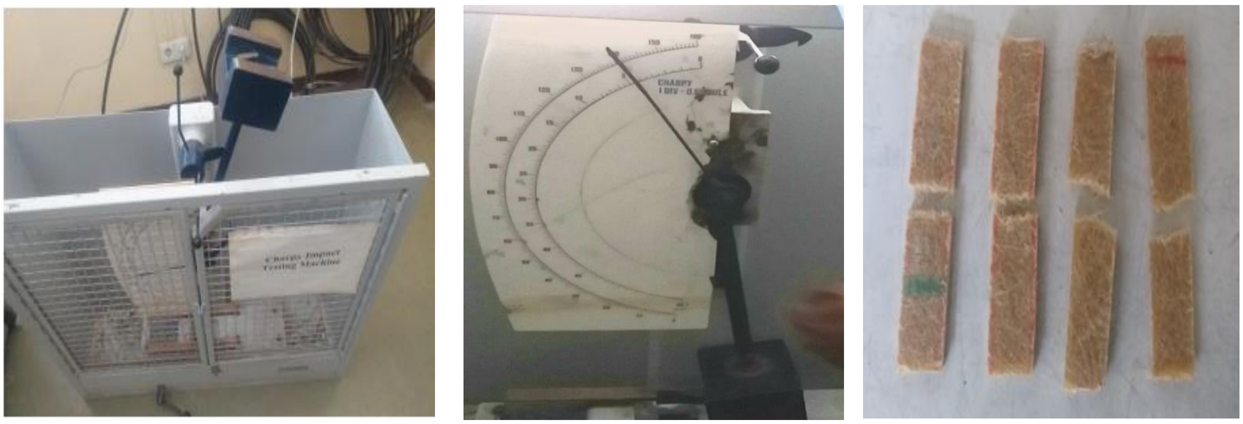


Figure 3.15: Impact test procedures

3.6 Design of Experiments for Milling Operation

In this thesis, Taguchi methods was employed to design experimental runs for milling of enset fiber reinforced epoxy composites. Taguchi methods was developed by Dr. Genichi Taguchi, who is a Japanese engineer [64]. Taguchi methods are a power tool for improving the production rate and product qualities with minimum production cost and processing times in machining operations. Taguchi method uses a special design of orthogonal arrays (OA) to study the entire parameter space with only a minimum number of experimental runs. OA provide a set of well balanced (minimum) experiments with optimum settings of control parameters [65].

Generally, a process to be optimized has several control factors which has direct impact on the target or desired value of the quality responses. The optimization then involves determining the best control factor or input parameter levels in order to achieve the targeted output response values.

Figure 3.16 shows the designations models of Taguchi methods [66].

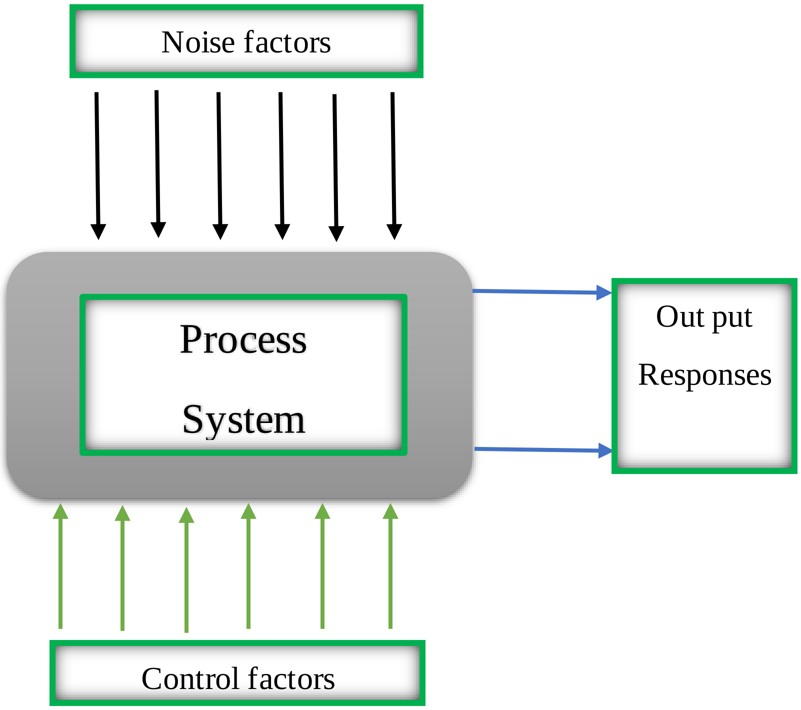


Figure 3.16: Model of the design of experiment

Advantages of design of experiments [67]

- Minimize number of experimental runs
- Identify optimum values of parameters
- Assessment of experimental error can be made
- Qualitative estimation of parameters can be made
- Inference regarding the effect of parameters on the characteristics of the process can be made

3.6.1 Approaches to the Milling Operation Design

In accordance with the steps that are involved in Taguchi's Method, a series of experiments are to be conducted. In this thesis, end milling operation on enset fiber reinforced epoxy composite using a CNC milling machine has been carried out. The procedures are as follows [68] .

Step 1: Identification of main functions and its side effects

The main functions of this study are end milling operation on enset fiber reinforced epoxy composite using a CNC milling machine. The side effects of the main functions are variations in surface roughness and material removal rates.

Step 2: Identify the control factors, noise factors, testing condition and quality characteristics

In machining process, cutting parameters, tool parameters, machining conditions have influences on the quality characteristics. Cutting parameter has most significant control parameters in milling of NFRP composite [49][28]. Hence, spindle speed, feed rate and depth of cuts considered as input parameters in this study. Control factors that have significant influences on the quality responses in machining of NFRP composite and noise factors are listed in Table 3.3. noise factors are uncontrollable factors during the machining times, and cannot determine their effects on the responses.

Table 3.3: Factors that affects quality responses

Control factors	Spindle Speed	Feed rate	Depth of cut	
Noise factors	Temperature	Operator skill	Vibration	Raw material type

Cutting forces, torque, delamination, surface roughness, material removal rates are some the quality characteristics, which considered in machining process. Delamination, material removal rate and surface roughness are the most required output responses in machining NFRP composites. Delamination is mostly occurred in laminated fiber reinforced composites [69]. In this study, specimens were fabricated from chopped fibers, hence surface roughness and material removal rates considered as quality responses delamination is not considered. The testing conditions and output responses to be observed in this study are listed in table 3.4 below.

Table 3.4: Testing conditions and quality characteristics

Quality characteristics	Surface roughness, material removal rate
Specimen material	Enset fiber reinforced epoxy composite
Cutting tool material	High speed steel (HSS)
Operating machine	CNC milling machine
Cutting tool diameter	10 mm
Cutting tool geometry	Two flute twist end mills

Step 3: Identify the objective function to be optimized

In the Taguchi method, the term signal represents the mean or desired value for the quality responses and term noise represents the undesirable value (standard deviation) for the responses [70]. According to the nature of the problem, the Taguchi approach divides optimization problems in to three types, using a log function of desired output as objective functions for optimization [71]. These are:

1. Smaller-the-Better,
2. Larger-the-Better and
3. Nominal-the-Best.

Signal-to-Noise ratios (S/N) are log functions of desired output responses, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

In this study, surface roughness and material removal rates are the output responses to be optimized. Surface roughness and material removal rates has conflict objectives in machining of materials. The objectives of surface roughness are decreasing the values of roughness’s as much as possible to improve the quality of machined products, while the objectives of material removal rates are increasing as much as possible to raise the production rates by minimizing processing times.

Therefore, the appropriate Taguchi signal to noise (S/N) ratios for surface roughness are Smaller-the-Better. Mathematically, it is expressed as shown equation 3.11.

$$\text{S/N Ratio} = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} yi^{2}\right) \qquad (3.12)$$

For material removal rate, Higher-the-Better Taguchi signal to noise ratios are appropriate one and mathematically expressed as equation 3.12.

$$\text{S/N Ratio} = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{yi^{2}}\right) \qquad (3.13)$$

Where, yi indicates results of responses at i^{th} experiments

n indicates number of output responses

Step 4: Identify the levels of machining parameters

The cutting parameters with their respective levels tabulated in Table 3.5. The spindle speed, feed rate, depth of cut was set at 1000–2000 rpm, at 100–300 mm/min, 1–2 mm respectively, which is analogues to some of the previous values found in the literatures.

Table 3.5: Cutting parameters and their values

Input parameters	**Level 1**	**Level 2**	**Level 3**
Spindle speed (rpm)	1000	1500	2000
Feed rate (mm/min)	100	200	300
Depth of cut (mm)	1	1.5	2

Step 5: Select a suitable Orthogonal Array and construct the Matrix

The selection of suitable Orthogonal array (OA) is an important task in Taguchi method. Orthogonal arrays are a special standard experimental design that requires minimum number of experimental runs to find the main factor effects on output responses. The minimum number of experimental trails required in orthogonal array is given by [13] [64]:

$$N_{min} = 1 + F\,(L-1) \qquad (3.14)$$

Where, N_{min} is the number of experiments to be conduct, F is the number of control factors, L is the number of levels,

In this study, number of control factors (F) was equal to three namely spindle speed, feed rate and depth of cut and each control factors have three levels, L= 3.

Therefore, $N_{min} = 1 + 3\,(3-1) = 7$

The standard of OA types is tabulated in table 3.6 below. L9 orthogonal array types are appropriate for three factors, three level parameters.

Table 3.6: Standards of design of experiments [64]

Levels ^{factors}	Number of experimental runs	Orthogonal array types
2^3	4	L_4
2^7	8	L_8
2^5		
2^3		
3^4	**9**	$\mathbf{L_9}$
$\mathbf{3^3}$		
4^5	16	L_{16}
2^{15}		
2^1 x 3^7	18	L_{18}
2^2 x 3^6		
3^7		
2^1 x 3^6		
2^1 x 3^4		
2^1 x 3^3		
3^3	27	L_{27}

Therefore, L9 (3^3) was selected in this study to construct the matrix. The most suitable orthogonal array for experimentation is L9 array as shown in Table 3.7.

Table 3.7: L9 orthogonal array [56]

Number of experiments	**Control Factors**		
	1	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Step 6: Conduct the matrix experiment

Based on the above OA, experiments were conducted on CNC milling machines with 10mm diameter high speed steel (HSS) end mill cutter as shown in Figure 3.17. CNC programs were developed to run the milling operations based on control factors with their respective levels.

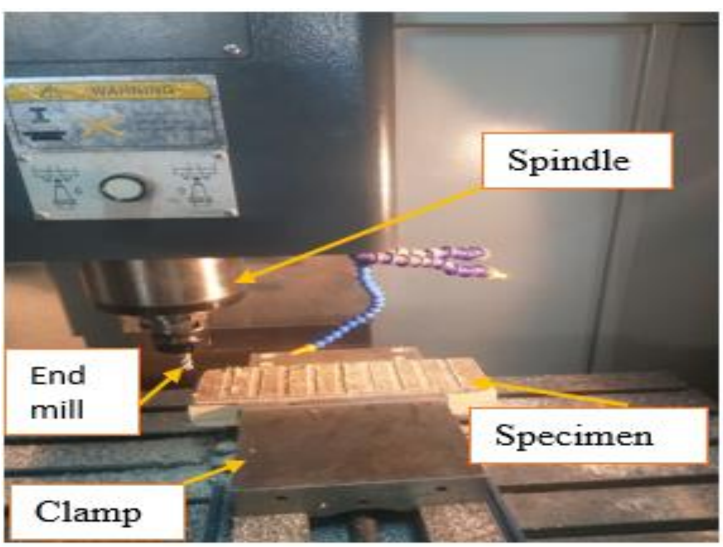


Figure 3.17: Milling operation setup

The basic steps for conducting milling operations are:

Step 1: preparing the rectangular specimens of size 300mm x 90mm x 10mm for performing CNC end milling operation

Step 2: adjusting the reference points of x, y, z axis and checking the machine systems that ready for performing milling operations

Step 3: creating the CNC part program for tool paths with specific commands using various levels of spindle speed, feed rate and depth of cut and then performing end milling operation.

Table 3.6: Experimental layouts of L9 (3^3) orthogonal array

Experiment Number	$L_9(3^3)$ Orthogonal Array		
	Input parameters		
	Spindle speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
1	1000	100	1
2	1000	200	1.5
3	1000	300	2
4	1500	100	1.5
5	1500	200	2
6	1500	300	1
7	2000	100	2
8	2000	200	1
9	2000	300	1.5

3.6.2 Measurement of Quality Responses

3.6.2.1 Surface Roughness Measurement

After the conducting milling operations, roughness of the surface was measured by means of 3D optical surface profiler (Zeta 20 model) with 10X magnification lenses as shown in Figure 3.18a. The measuring process repeats four times for each experimental run at different samples and the average values of four measurements was selected as the measured results. Out of all the surface roughness condition measuring criteria, average surface roughness (Ra) is often used to characterize the roughness of the machined surfaces [11].

Surface roughness Ra is the arithmetic deviation from the mean line of the roughness as shown in Figure 3.19.

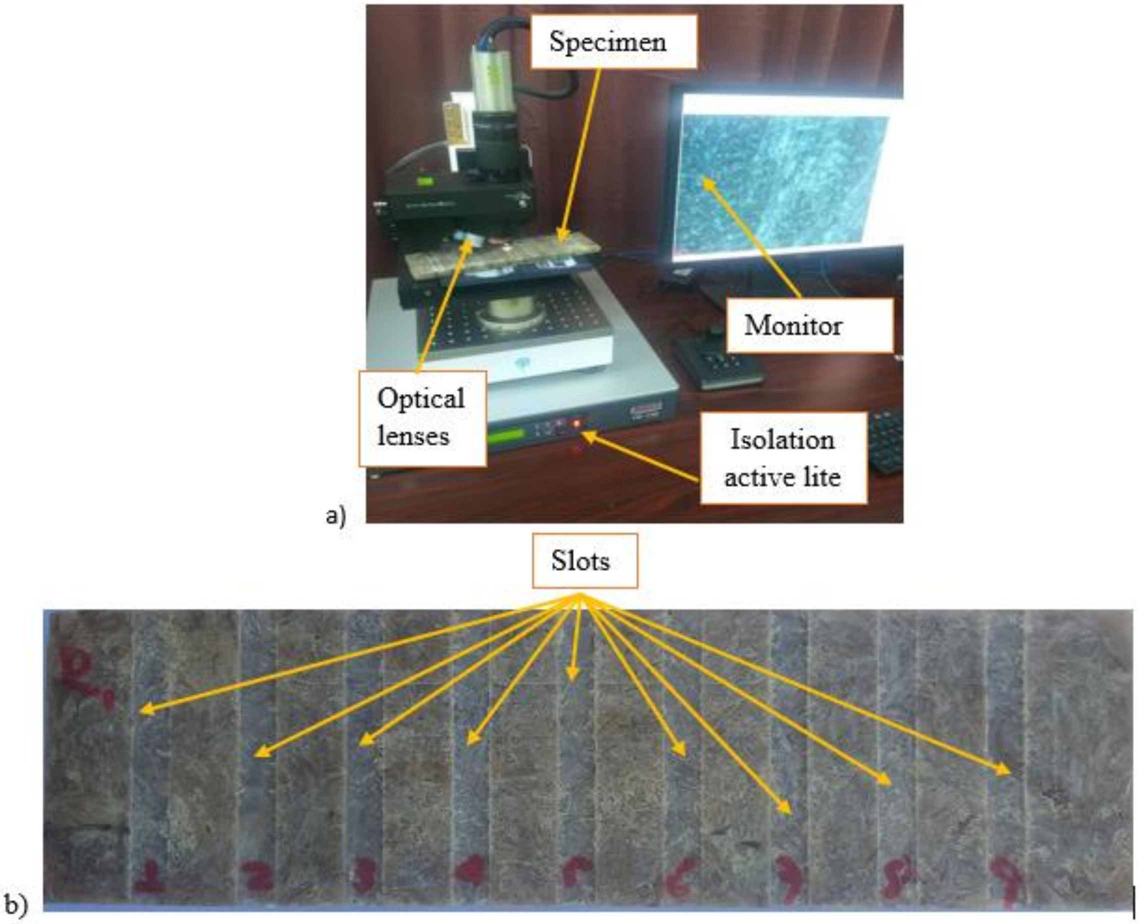


Figure 3.18: Surface roughness measurement

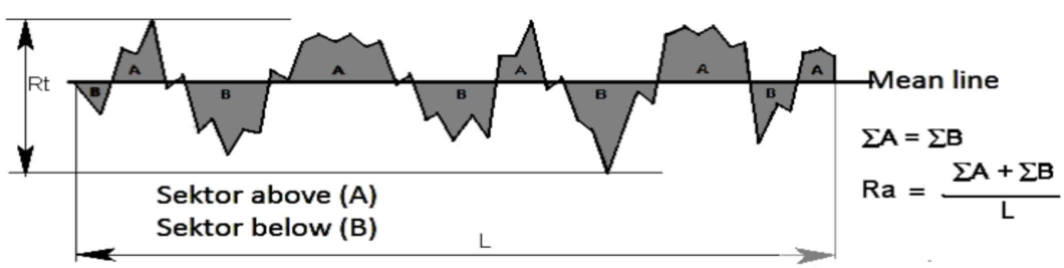


Figure 3.19: Schematic of parameter definition used to compute the mean arithmetic deviation (Ra) [10]

3.6.2.2 Material Removal Rate Measurement

The removal rate of materials during machining was calculated by means of equation 15. [15]

Material Removal Rate (MRR) = Dc*F*d (3.15)

Where Dc = diameter of cutter or cut width (mm), F = feed rate (mm/min), d = depth of cut

Chapter Four

Results and Discussions

4.1 Results

4.1.1 Mechanical Property Results

In this study, compression strength, flexural strength and impact strength tests were conducted. Each test was replicate four times for validation of the results.

4.1.1.1 Compression Strength Test Result

The stress vs elongation curve results under compression loading are presented in the Appendix section of this thesis.

Table 4.1: Compression strength test results

Compression strength test results (MPa)				
Sample 1	Sample 2	Sample 3	Sample 4	Average
22.81	18	25	27	23.2

4.1.1.2 Flexural Strength Test Results

The flexural strength test was conducted on three-point bending test. Results of four sample tests were taken. To obtain the flexural strength the machine used the following formula.

Section modulus (Wb) $Wb = \frac{B*H^2}{6}$ (4.1)

Maximum bending Moment (M_{bmax}) $M_{bmax} = \frac{F_{max}*L}{4}$ (4.2)

From this,

Flexural Strength (δ_{bmax}) $\delta bmax = M_{bmax} = \frac{M_{bmax}}{Wb}$ (4.3)

Where, B = Width of specimen H = Thickness of specimen

F_{max} = Maximum applied force L = Span length

The graphs of each trial of flexural strengths presented in the appendix sections.

Table 4.2: Flexural strength test results

Flexural strength test results (MPa)				
Sample 1	Sample 2	Sample 3	Sample 4	Average
87.89	96.68	84.96	87.89	89.36

4.1.1.3 Impact Strength Test Result

Impact strengths was calculated by using equation 4.4 below [25].

$$IS = \frac{E}{w.t} \tag{4.4}$$

Where, E is absorbed energy in joules in breaking the specimen, *w* is width of the specimen and *t* is thickness of the specimen

Table 4.3: Impact strength result

	Sample 1	Sample 2	Sample 3	Sample 4	Average
Impact energy (J)	2.5	3	2.5	3	2.75
Impact strength (kJ/m^2)	104.17	125	104.17	125	114.59

4.1.2 Comparison of Mechanical Properties with Literatures

In this study, enset fiber reinforced composites are proposed for wall panels, partition boards. The main requirements of materials that used for these applications are compression strength, flexural strength and impact strength. Therefore, characterizing these mechanical properties are necessary to make a hypothesis that enset fiber reinforced composite can able to be applicable for various application areas like wall panel and partition boards.

The mechanical property results of enset fiber reinforced epoxy composite materials are compared with current wall panel and partition board material and mostly used natural fiber reinforced composite materials as shown in Table 4.4. The test results revealed that, Ethiopian enset fiber reinforced epoxy composite materials have adequate potentials that able to be applicable for various application areas like wall panels and partition boards for the future.

Table 4.4: Comparison with previous works of mechanical properties

Matrix	Fiber	Fiber orientation	Fiber/Matrix Ratio	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Strength (KJ/m^2)	Reference
GP Epoxy	**Enset**	**Random**	**30/70**	**23.2**	**89.36**	**114.59**	**Current**
Gp Epoxy	Enset	Random	,,	-	-	106.7	[34]
Polyester	Enset	,,	30/70	-	-	66.25	[35]
Epoxy (LY 556)	Banana	,,	,,	-	56	187	[72]
,,	Sisal	,,	,,	-	61	206.69	
Epoxy	Sisal	Uni directional	40/60	-	72	101.92	[73]
Epoxy	Jute	,,	,,	-	89	76.92	
Epoxy	Banana	,,	,,	-	75	88.46	

4.2 Milling Operation Results

The experimental results of surface roughness and material removal rates for each experimental runs are tabulated in table 4.5.

Table 4.5: L9 OA for results of quality responses

Exp No	Spindle speed	Feed rate	Depth of cut	Surface roughness (μm)					Material removal rate
				Sample 1	Sample 2	Sample 3	Sample 4	Average	
1	1000	100	1	7.017	6.553	6.638	7.615	6.955	1000
2	1000	200	1.5	5.473	4.26	4.301	3.998	4.508	3000
3	1000	300	2	8.415	8.377	9.690	9.140	8.905	6000
4	1500	100	1.5	5.966	5.708	6.415	4.074	5.540	1500
5	1500	200	2	9.377	8.492	8.142	7.966	8.494	4000
6	1500	300	1	10.66	10.46	10.98	10.61	10.677	3000
7	2000	100	2	7.647	7.975	7.835	7.154	7.652	2000
8	2000	200	1	10.77	11.74	11.49	11.07	11.267	2000
9	2000	300	1.5	8.811	8.616	9.690	8.515	8.908	4500

4.3 Analysis Approach

4.3.1 Grey Relational Analysis

GRA has been used for optimizing multiple response characteristics in machining NFRP composite. It is a very useful tool for converting multi-objective problems into a single objective [54] [74]. In this study, the objectives chosen were minimizing the roughness of the surface for improving the quality of the milled surfaces, and maximizing material removal rate for increasing the production rate. To convert two response optimization problem with different objectives in to a single response problem, there are some procedures [75]. The first one is normalizing the experimental data from the range of zero to one. The second one is estimating grey relational coefficients based on normalized experimental data.

The third one is obtaining overall grey relational grades by averaging the grey relational coefficients corresponding to each selected response.

Figure 4.1: Objectives of grey relational analysis

Step 1: Data Preprocessing (Grey Relational Generation)

Data preprocessing or data normalization is the first procedure in grey relational analysis techniques. In a preprocessing data sequence, the actual data requires normalization in order to get a comparable sequence [22]. Hence data preprocessing converts the actual sequence to a comparable sequence. The actual data were normalized between a range of zero to one. Depending on the necessity of the objective functions in the normalization of data, there are three categories of data normalizations. These categories are "the-larger-the-better" when the objective need to obtain maximum value, "the-smaller-the-better" when the objective need to obtain minimum value, and "the-nominal-the-better" when any specific value is desired [76].

For surface roughness, the objective is minimizing the functions, hence the normalization is defined as "lower-the-better", and computed as equation (4.5).

$$x_i^*(\text{Ra}) = \frac{\max x_i^0(\text{Ra}) - x_i^0(\text{Ra})}{\max\left(x_i^0(\text{Ra})\right) - \min\ (x_i^0(\text{Ra}))} \tag{4.5}$$

Where, $x_i^*(\text{Ra})$ = reference sequence after pre-processing for the i^{th} experiment

$x_i^0(\text{Ra})$ = original sequence of i^{th} experiment

$\max\left(x_i^0(\text{Ra})\right)$= largest value of original sequence $x_i^0(\text{Ra})$

$\max\left(x_i^0(\text{Ra})\right)$= smallest value of original sequence $x_i^0(\text{Ra})$

For material removal rate, the objective is maximizing the functions, hence the normalization is defined as "larger-the-better", are computed as equation (4.6).

$$x_i^*(\text{MRR}) = \frac{x_i^0(\text{MRR}) - \min\ (x_i^0(\text{MRR}))}{\max\left(x_i^0(\text{MRR})\right) - \min\ (x_i^0(\text{MRR})} \tag{4.6}$$

Where, $x_i^*(\text{MRR})$ = reference sequence after pre-processing for the i^{th} experiment of MRR

$x_i^0(\text{MRR})$ = original sequence of MRR of i^{th} experiment

$\max\left(x_i^0(\text{MRR})\right)$= largest value of $x_i^0(\text{MRR})$

$\min\ (x_i^0(\text{MRR})$= smallest value of $x_i^0(\text{MRR})$

Experiment 1, $x_1^*(\text{Ra}) = \frac{11.267 - 6.955}{11.267 - 4.508} = 0.638$

$$x_1^*(\text{MRR}) = \frac{1000 - 1000}{6000 - 1000} = 0$$

The remaining experimental runs was calculated as based on this and the results tabulated in Table 4.6 below.

Table 4.6: Pre-processing reference sequence

Ex. No.	**Reference sequences, $x_i^*(k)$**	
	$x_i^*(Ra)$	**$x_i^*(MRR)$**
1	0.638	0
2	1	0.4
3	0.349	1
4	0.847	0.1
5	0.410	0.6
6	0.087	0.4
7	0.535	0.2
8	0	0.2
9	0.349	0.7

Step 2: Deviation Sequence of pre- processed data

Deviation sequence (Δ_{0i} (k)) is the absolute values of the difference of reference sequence $x_i^*(k)$ and the comparability sequence $x_0(k)$ used to calculate grey relational coefficients. It is computed mathematically as equation (4.7) [45].

$$\Delta_{0i}(k) = |x_0(k) - x_i^*(k)| \quad (4.7)$$

Experiment 1,

Δ_{01} (Ra) = $|1 - x_i(Ra)|$

= |1 – 0.654 |

= 0.346

Δ_{01} (MRR) = $|1 - x_i(MRR)|$

= |1 - 0 |

= 1

The remaining experimental runs was calculated as based on this and the results tabulated in Table 4.7 below.

Table 4.7: Deviation sequence

Ex. No.	Deviation sequence Δ_{0i} (k) = $|x_0(k) - x_i^*(k)|$	
	Δ_{0i} (Ra)	Δ_{0i} (MRR)
1	0.362	1
2	0	0.6
3	0.651	0
4	0.153	0.9
5	0.590	0.4
6	0.913	0.6
7	0.465	0.8
8	1	0.8
9	0.651	0.3

Step 3: Grey Relational Coefficient (GRC)

When the data is preprocessed, the normalized data are used to determine Grey relational coefficient values. Grey relational coefficient defines a relation between the standard and normalized experimental values.

Mathematically, it is calculated as equation (4.8) [46].

$$\xi_i(k) = \frac{\Delta min + \psi \Delta max}{\Delta 0i(k) + \psi \Delta max} \quad (4.8)$$

Where, ξ_i (k) = GRC of individual response variables, Δmin = minimum deviation of each response variable, Δmax = maximum deviation of each response variable, ψ = distinguishing or identification coefficient, defined in the range [0, 1], generally set at 0.5 to allocate equal weights to every parameter [47].

Minimum deviation (Δmin) = 0, Maximum deviation is (Δmax)= 1

Experiment 1,

$$\xi_1(Ra) = \frac{\Delta min + \psi \Delta max}{\Delta 01(k) + \psi \Delta max}$$

$$= \frac{0 + 0.5*1}{0.362 + 0.5*1}$$

= 0.580

$$\xi_1(MRR) = \frac{\Delta min + \psi \Delta max}{\Delta 01(MRR) + \psi \Delta max}$$

$$= \frac{0 + 0.5*1}{1+0.5*1} = 0.333$$

The remaining experimental runs was calculated as based on this and the results tabulated in Table 4.8 below.

Table 4.8: Grey relational coefficient

Ex. No.	**ξ_i (k)**	
	ξ_i (Ra)	**ξ_i (MRR)**
1	0.580	0.333
2	1	0.455
3	0.434	1
4	0.766	0.357
5	0.459	0.556
6	0.354	0.455
7	0.518	0.385
8	0.333	0.385
9	0.434	0.625

To computing the grey relational grade (GRG), the weights of each quality responses should be determined. The weights of surface roughness and material removal rates could be determined by means of principal component analysis.

4.3.2 Principal Component Analysis

The principal component analysis (PCA) is a path to recognize patterns in the correlated data and expressing the data in such a way so as to highlight their similarities and differences [75]. The main advantage of PCA is that once the patterns in data have been identified, the data can be compressed, i.e., by reducing the number of dimensions, without much loss of information. In multivariate studies, the information of observations overlaps due to many variables and their internal correlation to some extent. PCA can simplify this issue by dimension reduction to find uncorrelated competitive factors that reflect original information as much as possible to represent all of the original variables [22].

The producers involved to find PCA are [77]:

1. Forming new matrix
2. Finding of correlation coefficient array
3. Calculating the eigenvalues and eigenvectors of principal components

Step 1: Forming new matrix

The first steps in order to find out the principal components are forming a new matrix by combining the sequences of gray relational coefficient values. The general form of the GRC settled in the form of matrix is as shown in equation (45) [78].

$$\xi_i = \begin{bmatrix} \xi 1\ (1) & \xi 1\ (2) & --- & \xi 1\ (n) \\ \xi 2\ (1) & \xi 2\ (2) & --- & \xi 2\ (n) \\ --- & --- & --- & --- \\ \xi m\ (1) & \xi m\ (2) & --- & \xi m\ (n) \end{bmatrix} \quad (4.5)$$

i = 1, 2, ---, m   k = 1, 2, ---, n

Where, ξ_i is the gray relational coefficients of each response variable, m is total number of experimental runs and, n is number of output responses.

Step 2: Correlation coefficient array

The correlation coefficient array is determined as follows [76]:

$$R_{kl=} \left(\frac{Cov(\xi i(k), \xi i(l))}{\sigma_{\xi i}(k) x \sigma_{\xi i}(l)} \right) \quad (4.7)$$

k = 1, 2, ---, n; l = 1, 2, ---, n

Where, $Cov(\xi i(k), \xi i(l))$ is the covariance of $\xi i(k), \xi i(l)$ sequences, $\sigma_{\xi i}(k) x \sigma_{\xi i}(l)$is the standard deviations of $\xi i(k), \xi i(l)$ sequences respectively [m].

$$Cov(\xi i(k), \xi i(l)) = \ Cov \begin{bmatrix} \xi i(k), \xi i(k) & \xi i(k), \xi i(l) \\ \xi i(l), \xi i(k) & \xi i(l), \xi i(l) \end{bmatrix} \quad (4.8)$$

$$= Cov \begin{bmatrix} \xi i(Ra), \xi i(Ra) & \xi i(Ra), \xi i(MRR) \\ \xi i(MRR), \xi i(Ra) & \xi i(MRR), \xi i(MRR) \end{bmatrix} \quad (4.9)$$

Step 3: Calculating the eigenvalues and eigenvectors

The eigenvalues and eigenvectors are calculated from the correlation coefficient array as follows [18]:

$$[R - \lambda_k I_m] V_{ik} = 0 \tag{4.9}$$

Where, λ_k is the eigenvalues of the correlation coefficients, $V_{ik} = [a_{k1} a_{k2} ---- a_{kn}]^T$ is the eigenvectors corresponding to the eigenvalue, $\sum_{k=1}^{n} \lambda_k = n$, **k = 1, 2, …, n**

Table 4.9: Eigen values and explained variation for principal components

Principal component	Eigen value	Explained variation (%)
1st	1.267	63.35%
2nd	0.733	36.65%

Eigen values that have greater explained variation corresponds to the first principal component [46].

Table 4.10: Eigen vectors for principal components

Response variable	Eigenvector		Contribution
	1st principal component	2nd principal component	
Surface Roughness	- 0.707	- 0.707	0.5
Material Removal Rate	0.707	- 0.707	0.5

The eigenvalues of the 1st principal component contribute 63.35% as shown in Table 4.9. The percent of contributions of 1st principal components greater than the percent of contributions of 2nd principal components. Hence, the squares of the corresponding eigenvectors of 1st principal component are selected as the weighting values of the related output responses [46]. As shown the eigenvector values of principal components in Table 4.10, surface roughness and material removal rate have equal values in the GRA. Thus, surface roughness and material removal rate have an equivalent effect on the gray relational grade (GRG).

4.3.3 Computing Gray Relational Grade (GRG)

Grey relational grade (GRG) is computed to evaluate the influences of each parameter level on the output responses and to determine the optimal parameter level setting [54]. Gray relational grade is the weighted average of gray relational coefficients of multi-objectives responses [22]. Mathematically, it is expressed as equation (4.5).

$$\gamma_m(k) = \sum_{k=1}^{n} \omega_k \, \xi_i(k) \qquad (4.5)$$

Where, ω_k is the weighted values of the k^{th} responses in the entire.

$$\sum_{k=1}^{n} \omega_k = 1$$

The weights of each output responses acquired by the principal components in the above section. Surface roughness and material removal rate have equal weights (0.5). Therefore $\omega_k = 0.5$.

$$\gamma_1 = (0.5 * 0.580) + (0.5 * 0.333)$$

$$= 0.457$$

The GRG for each level of the processing parameters is summarized and shown in Table 4.11.

Table 4.11: Calculated weighted GRG and its order for nine comparability sequences

Exp. no	**weighted grey relational grade ($\gamma(k)$)**	**Order**
1	0.457	6
2	0.727	1
3	0.717	2
4	0.562	3
5	0.508	4
6	0.405	8
7	0.451	7
8	0.359	9
9	0.530	5

The larger the grey relational grade shows the better the multiple performance characteristics [18]. Experimental run 2 have better output response results followed by experimental run 3. Based on their orders of GRG as shown in Table 4.11, surface roughness and material removal rate have optimum values at 1000 rpm spindle speed, 200 mm/min feed rate and 1.5 mm depth of cut. However, the relative importance among the processing parameters for multiple performance characteristics still needs to be known, so that the optimal combinations of the processing parameter levels can be determined.

4.4 Machining Parameter Optimization Processes

4.4.1 Finding the Optimal Levels of Machining Parameters

The average GRG is computed to evaluate the influence of each cutting parameter levels on the responses and to determine the optimal parameter level setting [13]. The average GRG for each cutting parameters (spindle speed, feed rate, depth of cut) at each level is tabulated in Table 4.12:

Table 4.12: Response table for means of grey relational grade

Parameters	Gray relational grade			Delta	Rank
	Level 1	Level 2	Level 3		
Spindle speed	**0.634***	0.492	0.447	0.187	2
Feed rate	0.490	0.531	**0.551***	0.061	3
Depth of cut	0.407	**0.606***	0.559	0.199	1
Total mean of the grey relational grade (γ_m) = 0.522					
***** Indicates optimum levels					

Delta value indicates the difference between the maximum and minimum average grade values of each level of the cutting parameters. The value of delta helps to determine the effects of each cutting parameters on responses. The greater delta value holds the significant influences over the response results [54]. As shown the results of delta values in Table 4.12, spindle speed has significant effects on the GRG followed by depth of cut and feed rates respectively.

The highest value of the average Grey relational grade (0.634) found at the minimum levels of spindle speed. For feed rate, the highest value is 0.551 and found at the highest feed rate level.

While, the highest average value of Grey relational grade (0.606) for depth of cut obtained at medium depth of cut. Therefore, the optimum cutting parameter level setting is 1000rpm spindle speed, 300 mm/min feed rate and 1.5 mm depth of cut.

4.4.2 Effects of Cutting Parameters on Performance Characteristics

4.4.2.1 Effect of Cutting Parameters on Surface Roughness

As shown the main effect plots for S/N ratios in Figure 4.2, roughness of the surface increases with increase in spindle speed. This is due to increasing of friction between cutting tool and work pieces as spindle speed increases. Formation of higher friction initiates the formation of temperatures at the machining zone which causes burnings of constituent materials, hence increase surface roughness. [79]. Feed rates has negative impacts on the surface quality. As feed rate increases, roughness also increases because of the formations of more built up edges due to tool resistance offered by work pieces on tool causes deteriorated surface, hence degrades machined surfaces [41]. Surface roughness decreases up to certain value of depth of cut, after that it increases. The optimal cutting parameter levels for optimum surface roughness is 1000 rpm spindle speed, 100 mm/min feed rate and 1.5 mm depth of cut.

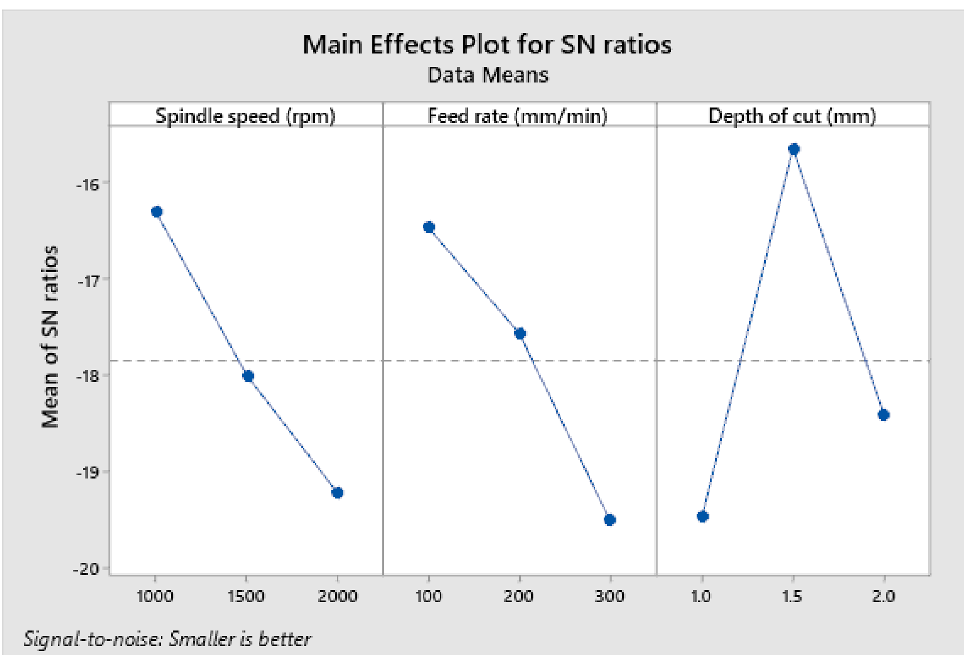
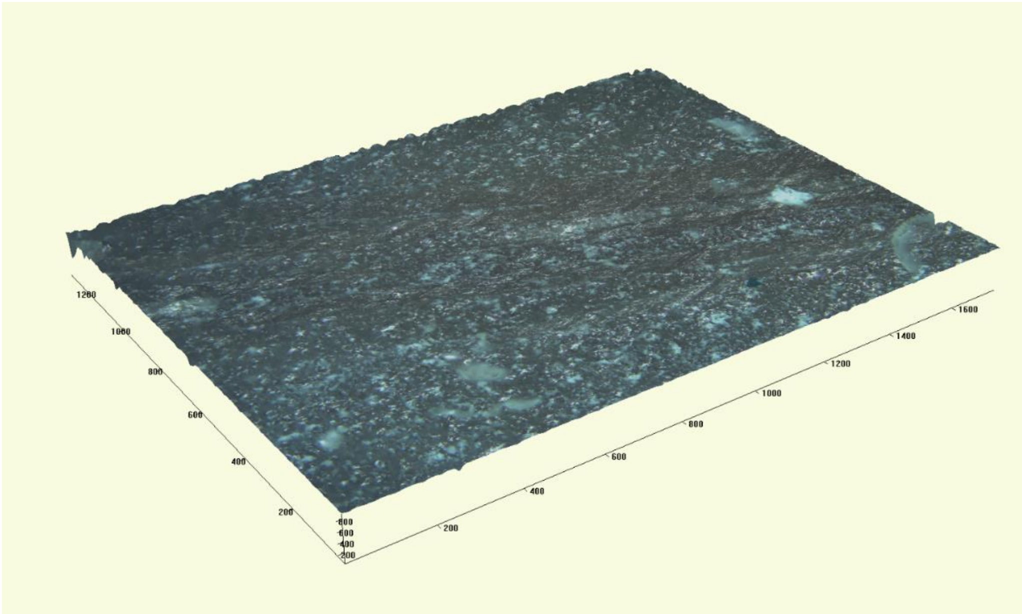
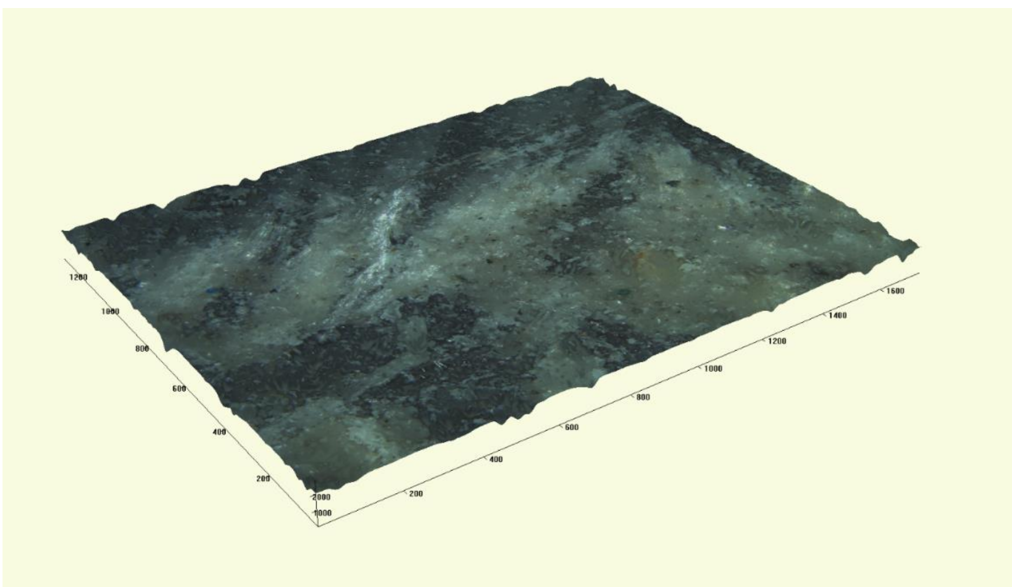


Figure 4.2: Effects of cutting parameters on surface roughness



a. 1000 rpm spindle speed, 200 mm/min feed rate, 1.5 mm depth of cut



b. At 3000 rpm spindle speed, 200 mm/min feed rate, 1 mm depth of cut

Figure 4.3: Micro structures of machined surfaces

4.4.2.2 Effect of Cutting Parameters on Material Removal Rate

Figure 4.3 reveals the main effect plots for signal to noise (S/N) ratios of material removal rates at various levels of spindle speed, feed rate and depth of cut. Spindle speed has no effects on the material removal rate. While, feed rate and depth of cut has direct relations with material removal rates. As feed rate and depth of cut increases, material removal rate also increases, and vice versa.

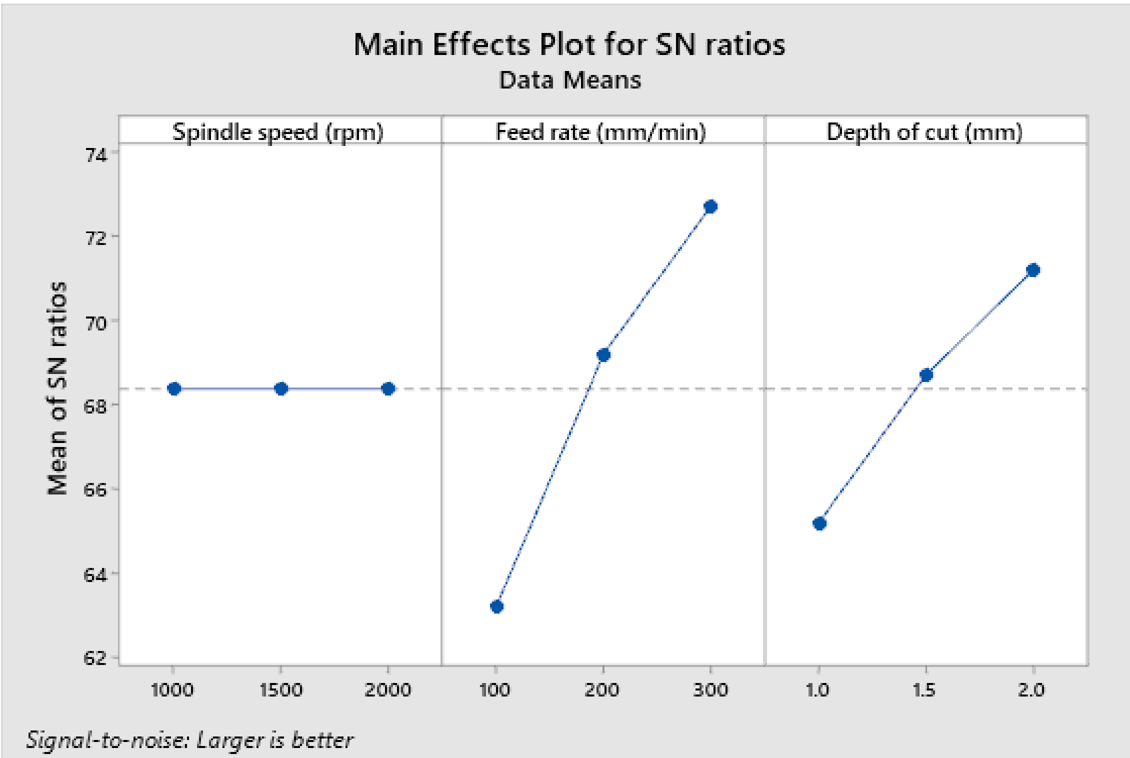


Figure 4.4: Effects of cutting parameters on material removal rate

4.4.2.3 Effect of Cutting Parameters on GRG

Figure 8 depicts the main effect plots for S/N ratios of GRGs. To achieve maximum efficiency with better roughness, the optimum parameter setting is low spindle speed, high feed rate and medium depth of cut. This result is also consistent with optimum parameter setting of GRGs presented in Table 4.12.

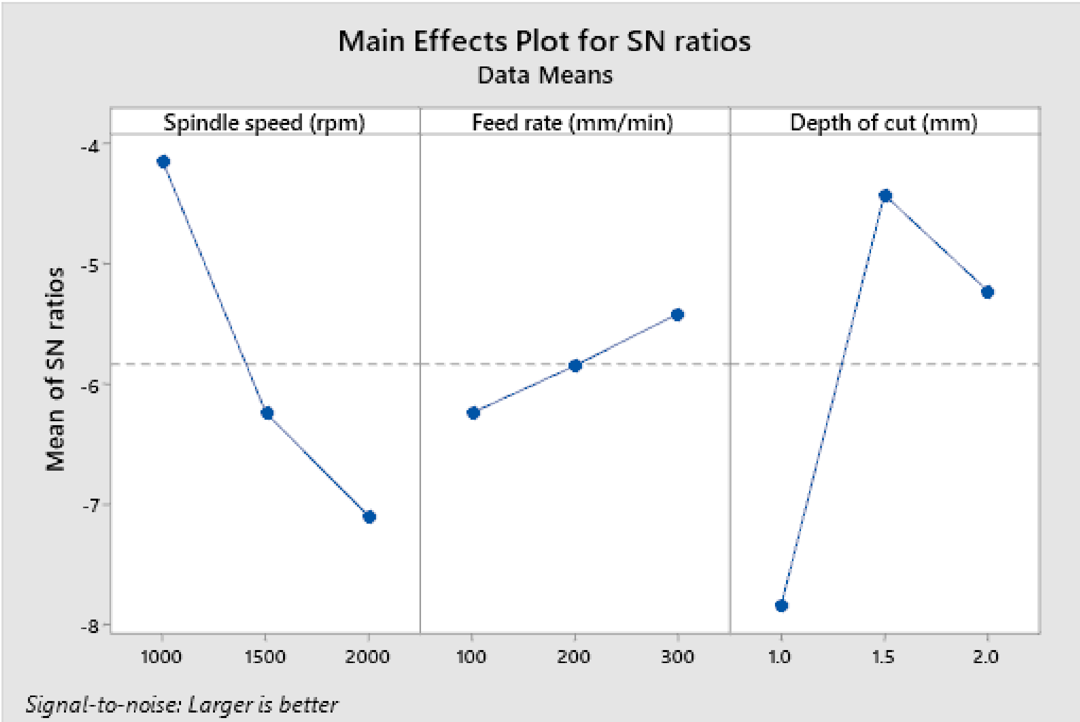


Figure 4.5: Effect of cutting parameters on GRG

4.4.3 Interactions Plots for Responses

Interaction plots are used to understand the interaction effects of input parameters on the responses. The line space in the interactions illustrates the significance of the parameter interactions. Hence wider line space indicates significant effects of interactions on the responses, while narrow line spaces indicates less significances of parameter interactions [15]. And also non parallel line interactions indicates the magnitudes of significance levels [80].

The more non parallel lines indicate the more significance of interactions.

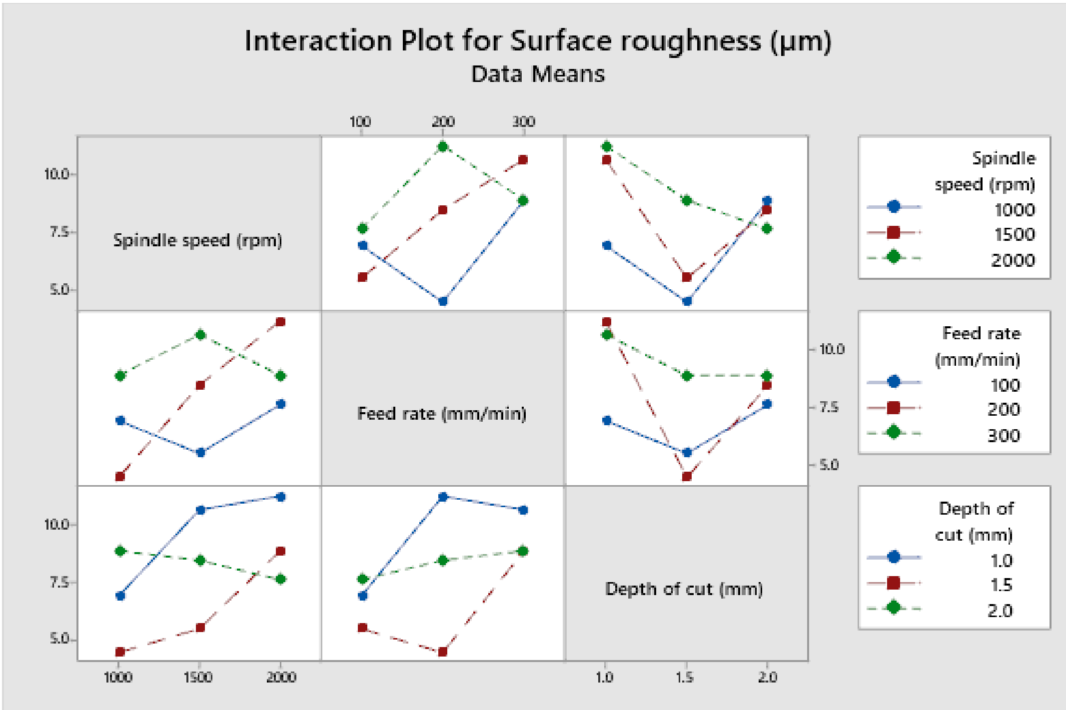


Figure 4.6: interaction plot for surface roughness

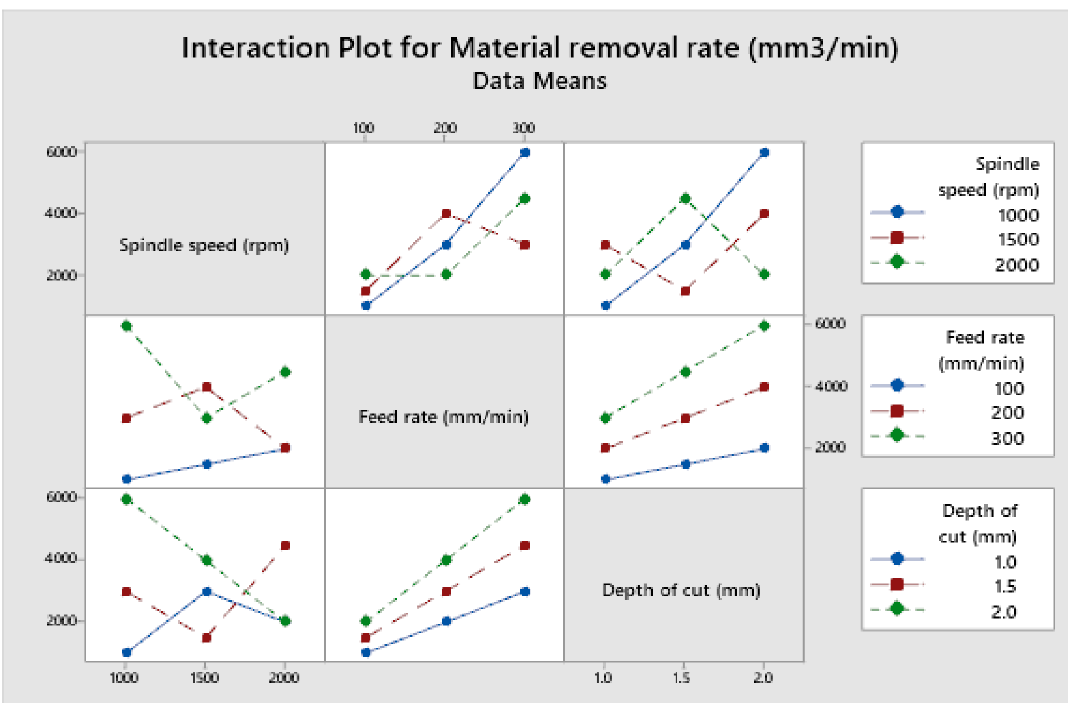


Figure 4.7: interaction effect for material removal rate

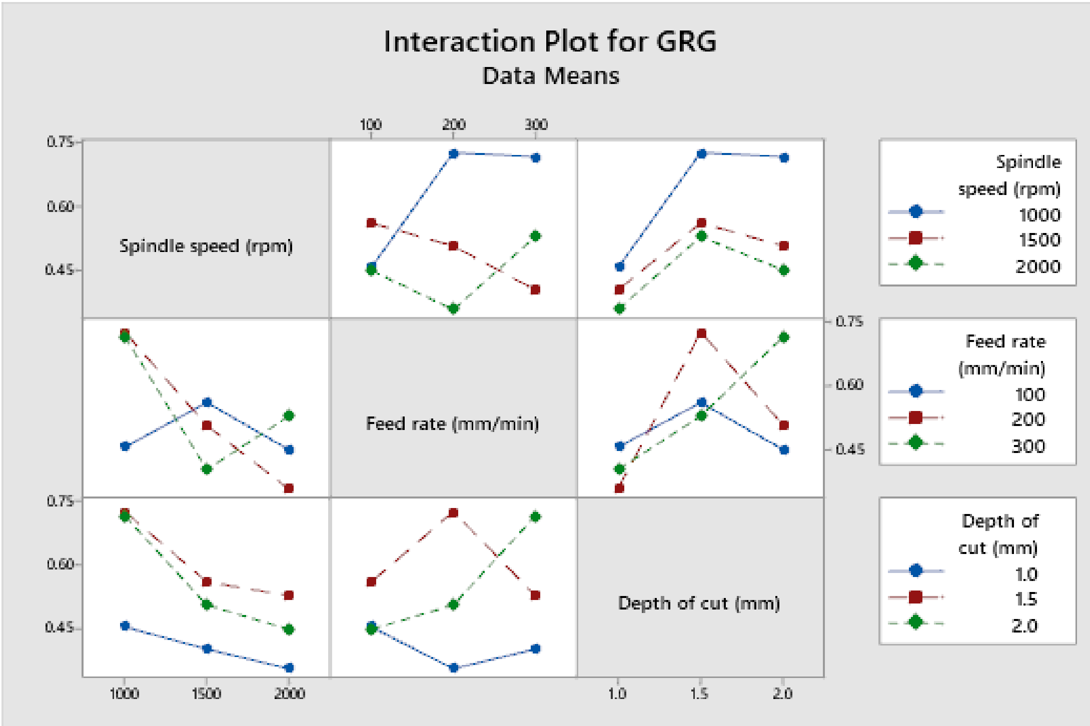


Figure 4.8: Interaction effect for grey relational grade

4.4.4 Analysis of Variance

An analysis of variance (ANOVA) was carried out in Minitab 19 to determine the most influential cutting parameters in milling enset fiber reinforced epoxy composites. The confidence levels of the ANOVA were 95%. The sources with P-value that less than 0.05 are considered to have a statistically significant contribution to the performance measures [16] and also if F > 4, the input parameter has a significant impact on the response characteristics [15]. The sum of squares (SS) column of the table shows the relative contribution of each factor to the total variance of the factor. Degree of Freedom (DOF) shows the indication of the amount of the information contained in a data set. The residual error or percentage error is the error that may occur during the measurement of the responses and relates to the uncontrollable or uncertain factors. It shows the feasibility and sufficiency of an experiment. If the percentage of errors less than 15%, the experiment is acceptable, while percentage of errors greater than 15%, the experiment is unacceptable [46].

4.4.4.1 ANOVA for Surface Roughness

The analysis of variance for surface roughness, carried out to investigate the influences of spindle speed, feed rate and depth of cut on surface roughness in milling enset fiber reinforced epoxy composites. The result shows that depth of cut has greater influence than other cutting parameters. Depth of cut contributes (42.86%) followed by feed rate (29.68%) and spindle speed (23.93%). As shown in the table 4.13, the percentage of error for contributions is 3.53%, which is less than 15%. It shows that the outcome is acceptable.

Table 4.13: ANOVA for Ra

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Spindle speed	2	9.356	23.93%	9.356	4.6782	6.78	0.128
Feed rate	2	11.601	29.68%	11.601	5.8007	8.41	0.106
Depth of cut	2	16.758	42.86%	16.758	8.3789	12.15	0.076
Error	2	1.379	3.53%	1.379	0.6896		
Total	8	39.095	100.00%				

4.4.4.2 ANOVA for Material Removal Rate

The analysis of variance for material removal rate, carried out to investigate the influences of cutting parameters on material removal rate in milling enset fiber reinforced epoxy composites. Feed rate contribute significantly (65.85%) followed by depth of cut (29.27%) and spindle speed (2.44%) respectively. The P-value of feed rate is less than 0.05, hence it contributes significantly. Spindle speed has lowest contributions on the material removal rates.

Table 4.14: ANOVA for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Spindle speed	2	500000	2.44%	500000	250000	1.00	0.500
Feed rate	2	13500000	65.85%	13500000	6750000	27.00	0.036
Depth of cut	2	6000000	29.27%	6000000	3000000	12.00	0.077
Error	2	500000	2.44%	500000	250000		
Total	8	20500000	100.00%				

4.4.4.3 ANOVA for GRG

Depth of cut has greater significant effects on the GRGs followed by spindle speed and feed rate. Depth of cut, spindle speed and feed rate contribute 49.47%, 43.50% and 4.39% respectively. The percentage of error is 2.64%, it shows the proposed model is highly acceptable.

Table 4.15: ANOVA for GRG

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Spindle speed (rpm)	2	0.057158	43.50%	0.057158	0.028579	16.48	0.057
Feed rate (mm/min)	2	0.005763	4.39%	0.005763	0.002881	1.66	0.376
Depth of cut (mm)	2	0.065009	49.47%	0.065009	0.032504	18.74	0.051
Error	2	0.003469	2.64%	0.003469	0.001734		
Total	8	0.131398	100.00%				

4.5 Confirmation Test

Confirmation test is conducted at the optimum levels of cutting parameters that recommended in the investigations to verify the results of output responses. The optimum levels of cutting parameters were 1000rpm of spindle speed, 300mm/min of feed rate and 1.5mm of depth of cuts and the same is considered for the confirmation test. The results of confirmation tests are tabulated in Table 4.16.

Table 4.16: Confirmation test result

	Sample 1	Sample 2	Sample 3	Sample 4	Average
Surface roughness	3.231	3.308	2.702	3.998	3.310
Material removal rate	4500				

Surface roughness and material removal rate results at the best parameter settings out of nine experiments in comparison with confirmation test results are presented in Table 4.17. The comparison of results showed that surface roughness is improved from 4.508 to 3.310 μm and the material removal rate (MRR) is greatly increased from 3000 to 4500 mm^3/min. This improvement revealed that Taguchi method coupled GRA effectively improves the surface roughness and material removal rate simultaneously for end milling of enset fiber reinforced composite.

Table 4.17: Results of Ra and MRR at best experimental run and optimal parameter settings

	Best experimental run	Optimum cutting parameter
Parameter level	A1B2C2	A1B3C2
Ra (µm)	4.508	3.310
MRR (mm^3/min)	3000	4500

Chapter Five

Conclusion, Recommendation and Future Work

5.1 Conclusion

The study presents characterization of mechanical properties enset fiber reinforced epoxy composite. The results suggest that, enset fiber reinforced epoxy composite has adequate potentials to be applicable for an alternative material for different application areas like wall panels, furniture's. It has comparable mechanical properties with most commonly applicable natural fiber reinforced composites.

Further, the effect of cutting parameters on the surface roughness and the material removal rate analyzed to identify optimum parameter settings. The cutting parameters optimized using Taguchi based GRA coupled with PCA to improve the machined surfaces and increase production rates simultaneously. It has been established that Taguchi based GRA is an effective optimization method for milling enset fiber reinforced epoxy composite. The overall results are summarized as follows:

- 30% weight fractions of enset fiber reinforced epoxy composites have:
  - Compressive strength of 23.2 MPa
  - Flexural strength of 89.36 MPa
  - Impact strength of 114.59 KJ/m^2
- The results of effects of cutting parameters on responses showed that
  - For surface roughness, the best result obtained at parameter settings of 1000rpm spindle speed, 100mm/min feed rate and 1.5mm depth of cut.
  - For material removal rate, the best result obtained at parameter settings of 300mm/min and 2mm depth of cut. Spindle speed has no effect on MRR.
  - The higher grey relational grade is obtained at 1000 rpm spindle speed, 300mm/min feed rate and 1.5mm depth of cut parameter settings.

- Contributions of each input parameters on responses was analyzed using ANOVA.
  - Depth of cut (42.86%) is the most significant factor in affecting surface roughness followed by feed rate (29.68%) and spindle speed (23.93%) respectively.
  - Feed rate (65.85%) is the most significant factor in affecting material removal rates followed by depth of cut (29.27%) and spindle speed (2.44%) respectively.
  - For grey relational grade, depth of cut (49.47%) has more influences followed by spindle speed (43.5%) and feed rate (4.39%) respectively.
- The optimal combinations of cutting parameter levels to obtain optimum values of surface roughness and material removal rate simultaneously was:
  - Spindle speed: Level 1: 1000 rpm
  - Feed rate: Level 3: 300 mm/min
  - Depth of cut: Level 2: 1.5 mm
- Confirmation test results proved that the determined optimum combinations of cutting parameters satisfies the real requirements of end milling operations of enset fiber reinforced composites.

5.2 Recommendation

- Enset fiber reinforced epoxy composite materials can able to applicable for an alternative material for different applications areas like wall panel and furniture.
- Conducting milling operations at lower spindle speed and feed rate with medium depth of cuts recommended to obtain better machined surface quality.
- Conducting milling operations at higher feed rate and depth of cut recommended to increase the production rates.
- Conducting milling operations at lower spindle speed, higher feed rate and medium depth of cuts recommended to achieve better machined surface quality and higher material removal rates simultaneously.

5.3 Future Work

There are lots of machining parameters that have significant influences in machining of enset fiber reinforced epoxy composites such as orientation of fibers, fabrication techniques, tool parameters (tool diameter, tool geometry, tool material, number of flutes) and cutting conditions (dry, air coolant, oil coolant). Some of suggested future works which could not addressed in this works are listed below.

- Further analysis and optimization cutting parameter levels in machining enset fiber reinforced epoxy composites by fabricating specimens other than hand layup processing techniques and randomly oriented fibers.
- Analyze the effects of cutting tool diameters, geometers, and number of flutes and optimize their levels.
- Analyze effects of cutting conditions (dry, air coolant, oil coolant) and optimize it.
- Analyze and optimize machining parameter effects on the responses of cutting forces, delamination, torque, cutting temperatures etc.

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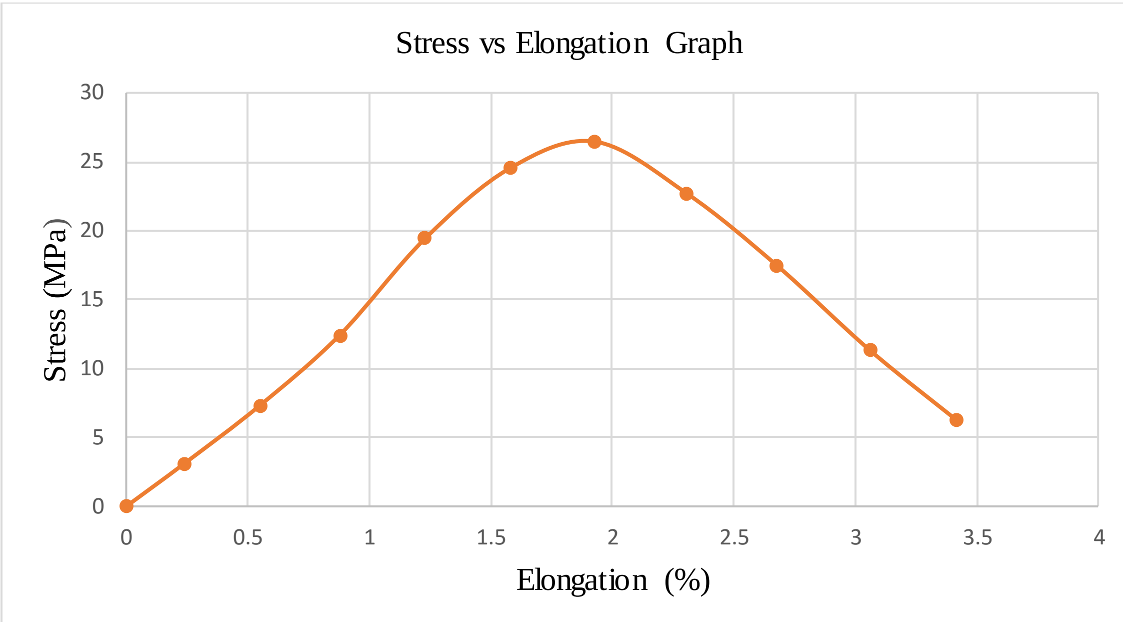
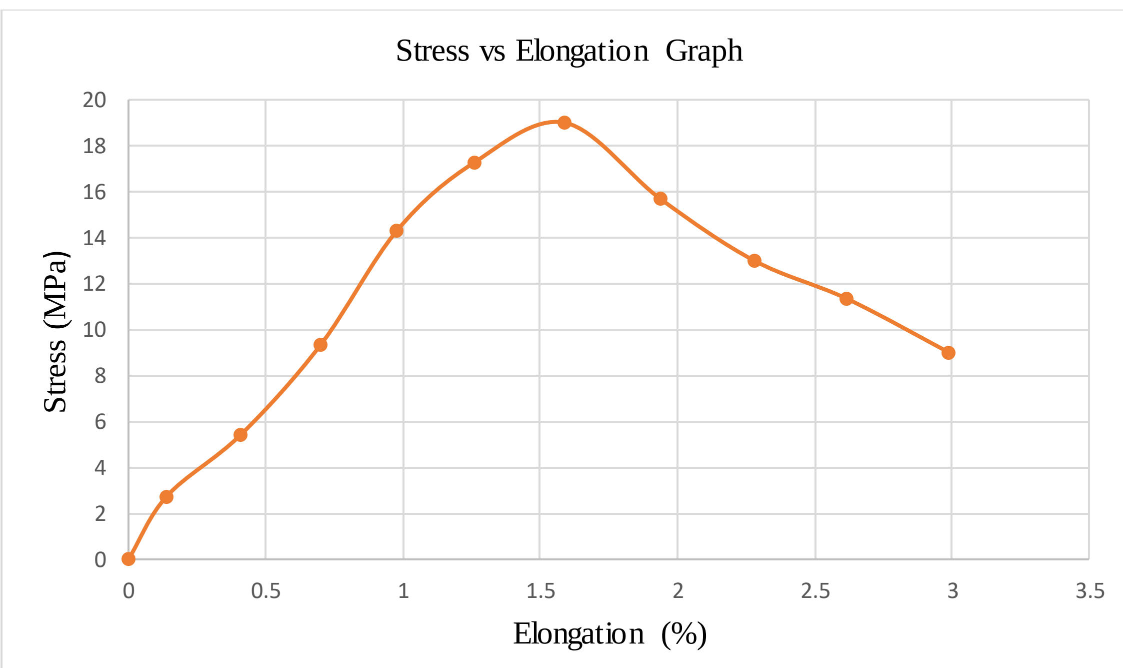
Appendix A

Compression Strength Test Result

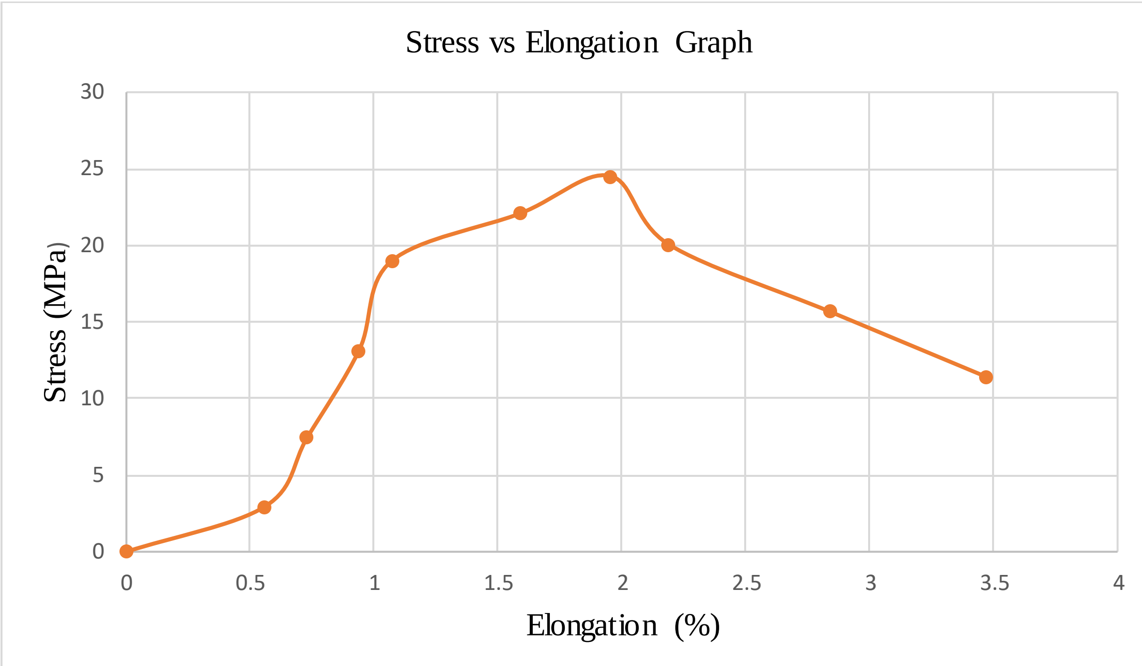
Sample 1



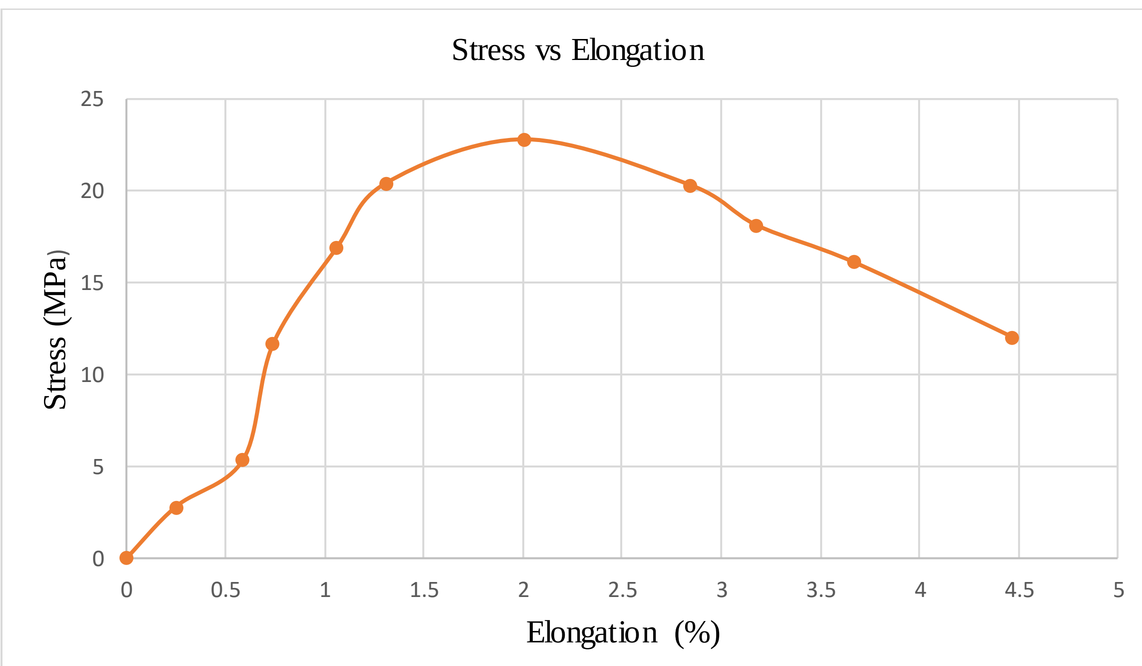
Sample 2



Sample 3

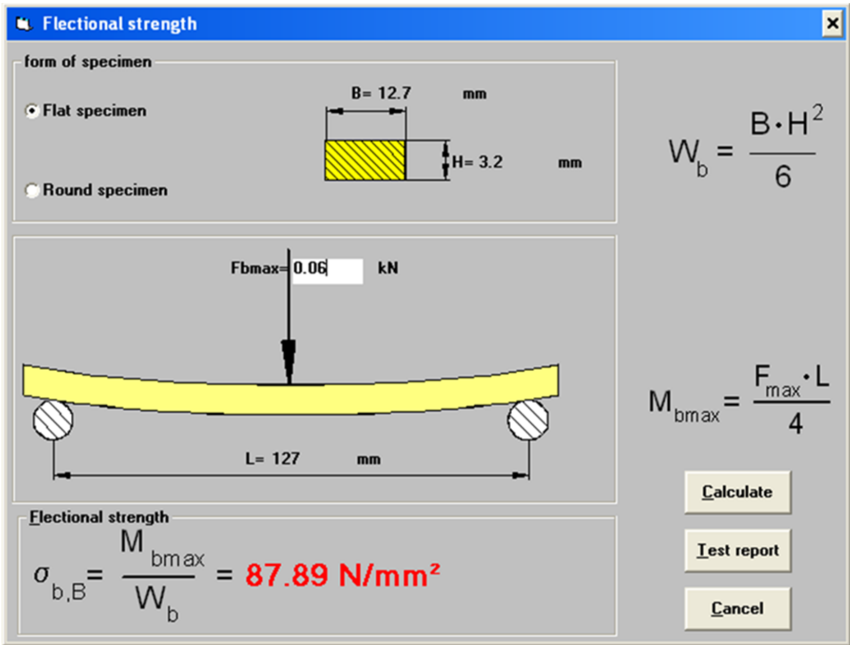


Sample 4

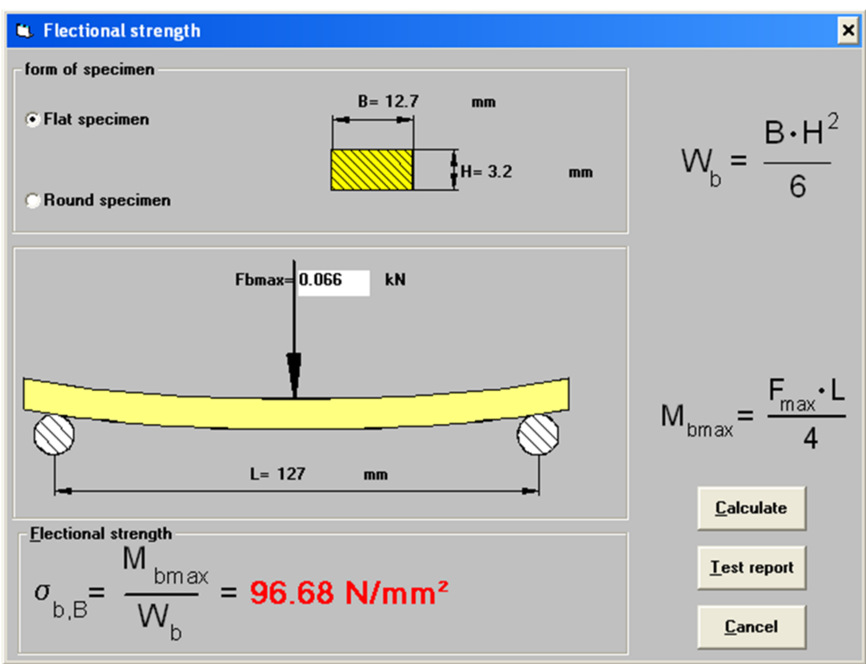


Flextural Strength Test Results

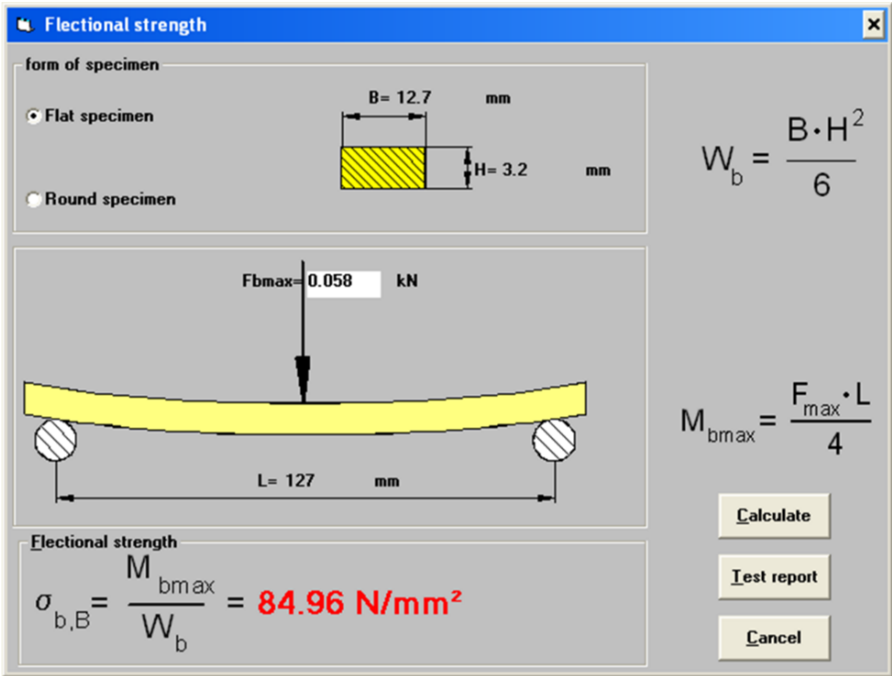
Sample 1



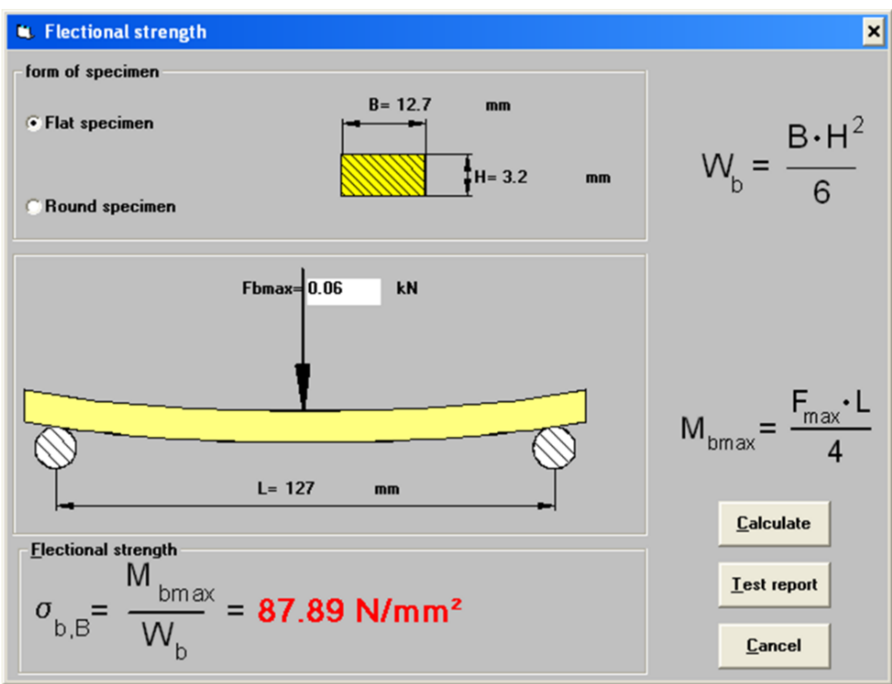
Sample 2



Sample 3



Sample 4



Appendix B

CNC part programs

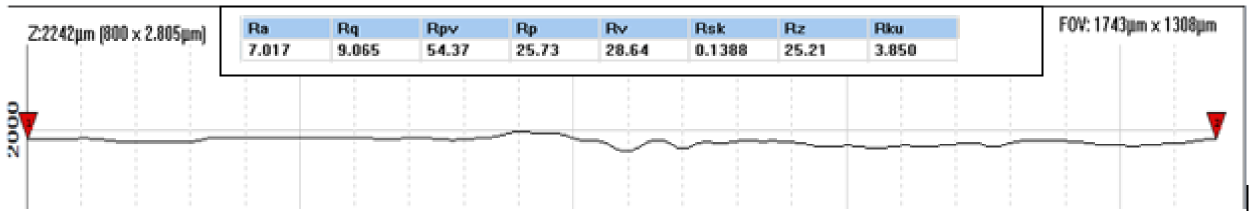
```
O1314;
G90 G54 G17 G21;
G00 X25.0 Y0.0;
G40 G80;
M06 T01;
M03 S1000;
Z30;
G01 Z-1 F100;
X25 Y90.0;
G00 Z30;
X50 Y90;
G01 Z-1.5 F200;
X50 Y0;
G00 Z30
X75 Y0;
G01 Z-2 F300;
X75 Y90;
G00 Z30;
X100 Y90;
M03 S1500;
G01 Z-1.5 F100;
X100 Y0;
G00 Z30;
X125 Y0;
G01 Z -2 F200;
X125 Y90;
G00 Z30;
X150 Y90;
G01 Z-1 F300;
X150 Y0;
G00 Z30;
X 175 Y0;
M03 S2000;
G01 Z-2 F100;
X175 Y90;
G00 Z30;
X200 Y90;
G01 Z-1 F200;
X200 Y0;
G00 Z30;
X225 Y0;
G01 Z-1.5 F300;
X225 Y90;
G00 Z30;
X0 Y0;
M05;
M30;
```

Appendix C

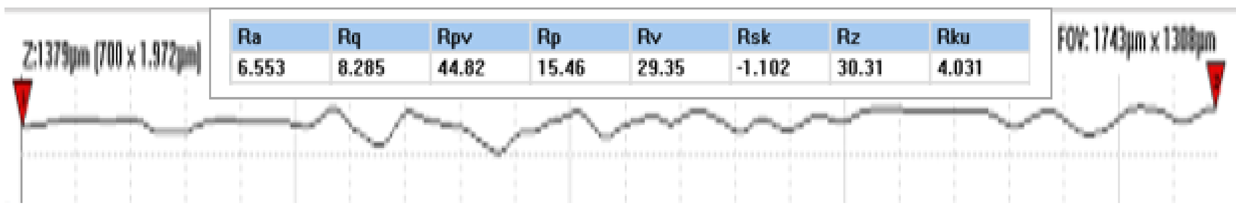
Surface Roughness Result

Experiment 1

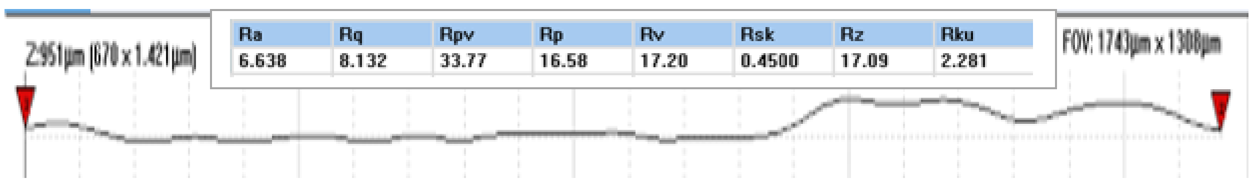
Sample 1:



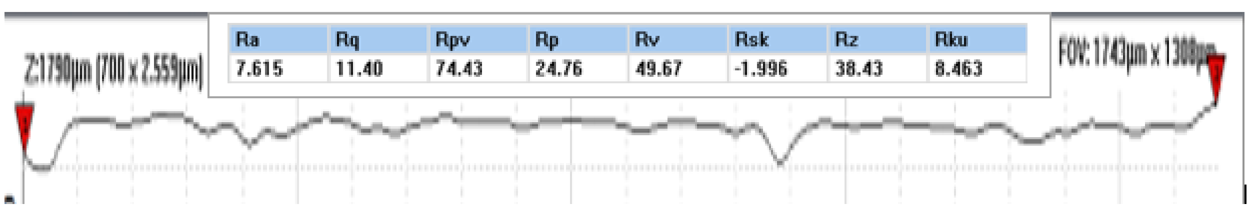
Sample 2:



Sample 3:

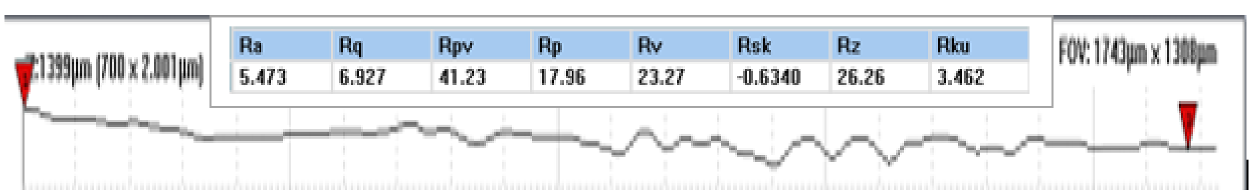


Sample 4:

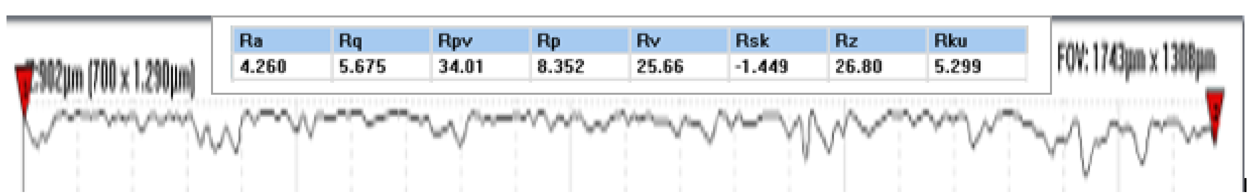


Experiment 2:

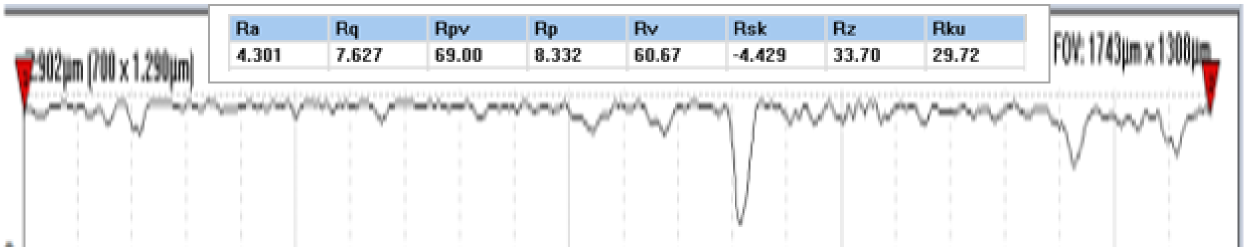
Sample 1:



Sample 2:

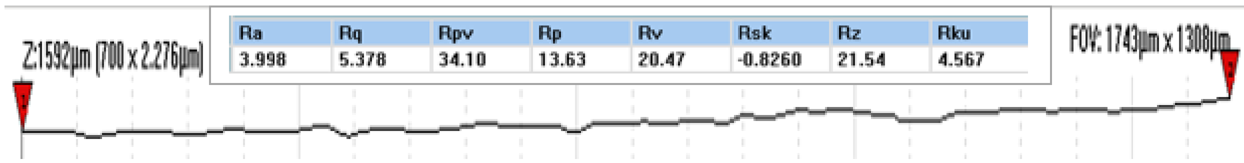


Sample 3:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
4.301	7.627	69.00	8.332	60.67	-4.429	33.70	29.72

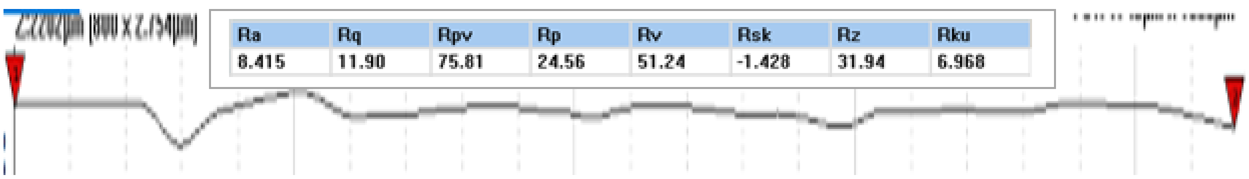
Sample 4:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
3.998	5.378	34.10	13.63	20.47	-0.8260	21.54	4.567

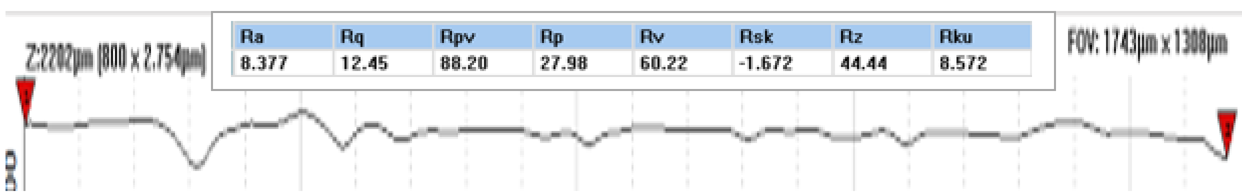
Experiment 3:

Sample 1:



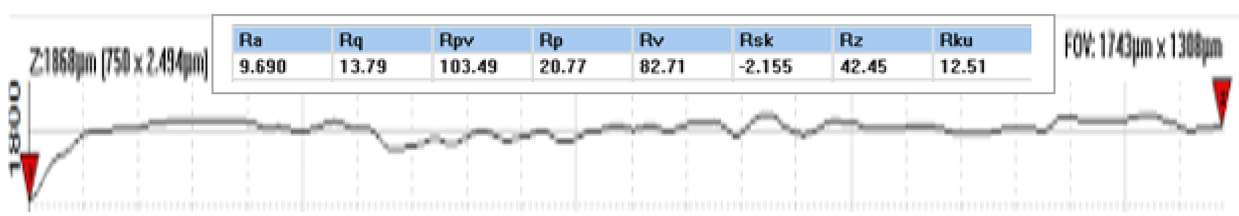
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.415	11.90	75.81	24.56	51.24	-1.428	31.94	6.968

Sample 2:



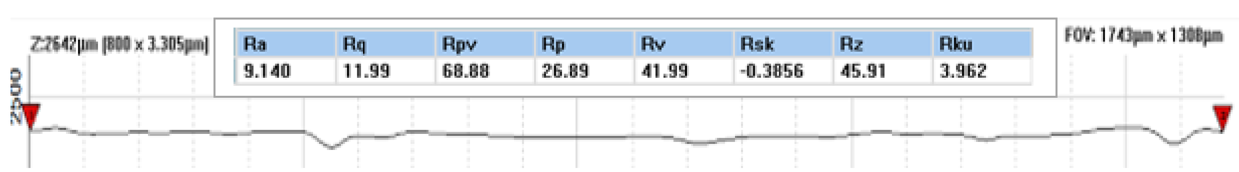
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.377	12.45	88.20	27.98	60.22	-1.672	44.44	8.572

Sample 3:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
9.690	13.79	103.49	20.77	82.71	-2.155	42.45	12.51

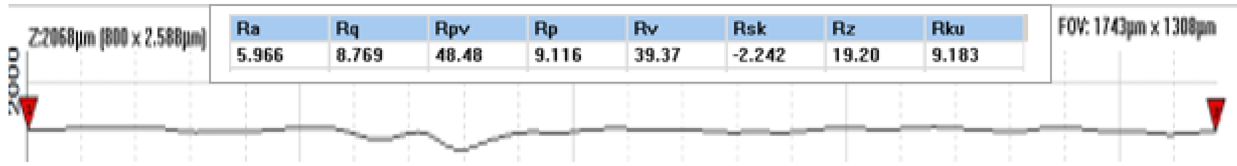
Sample 4:



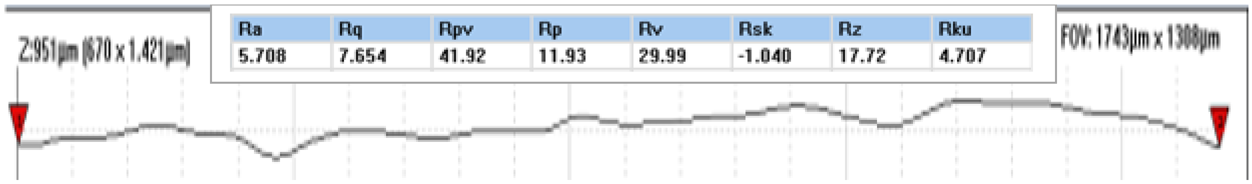
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
9.140	11.99	68.88	26.89	41.99	-0.3856	45.91	3.962

Experiment 4:

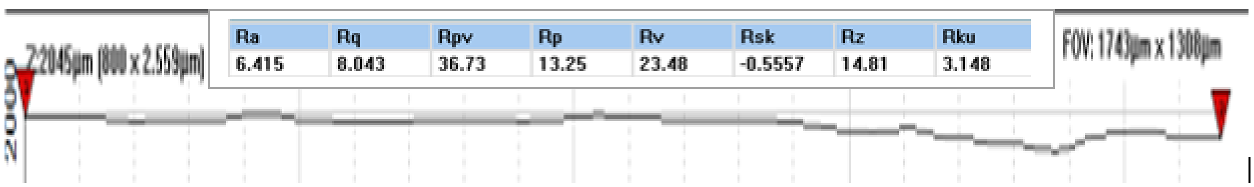
Sample 1:



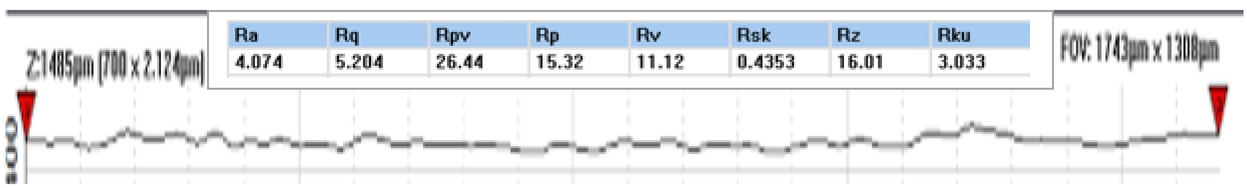
Sample 2:



Sample 3:

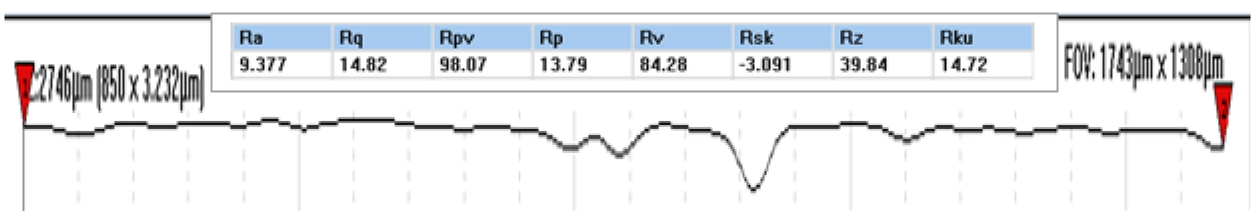


Sample 4:

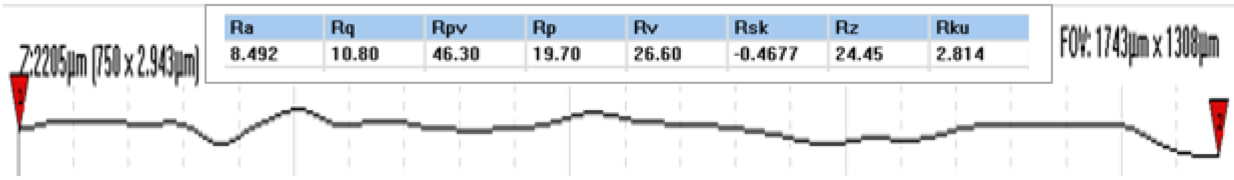


Experiment 5:

Sample 1:

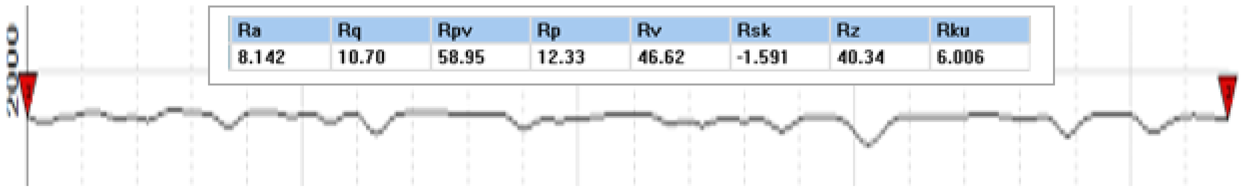


Sample 2:



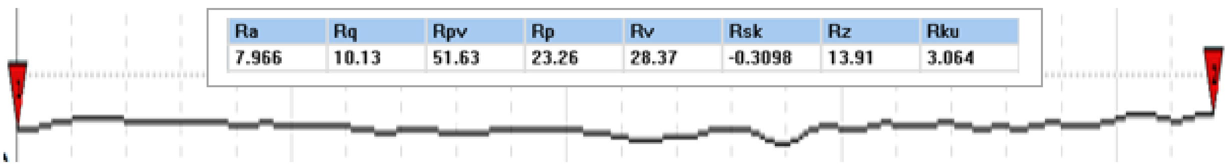
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.492	10.80	46.30	19.70	26.60	-0.4677	24.45	2.814

Sample 3:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.142	10.70	58.95	12.33	46.62	-1.591	40.34	6.006

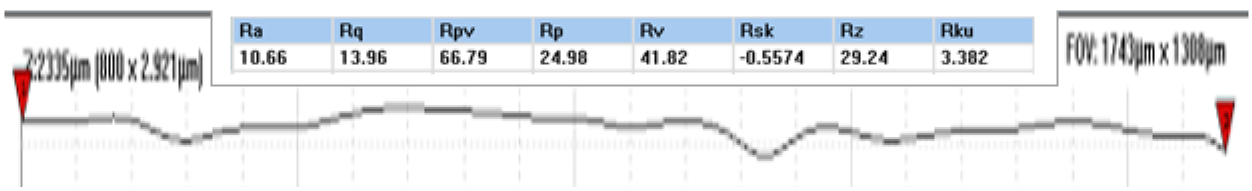
Sample 4:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
7.966	10.13	51.63	23.26	28.37	-0.3098	13.91	3.064

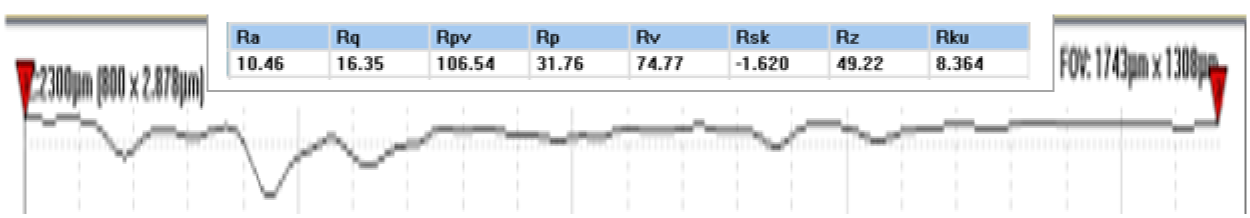
Experiment 6:

Sample 1:



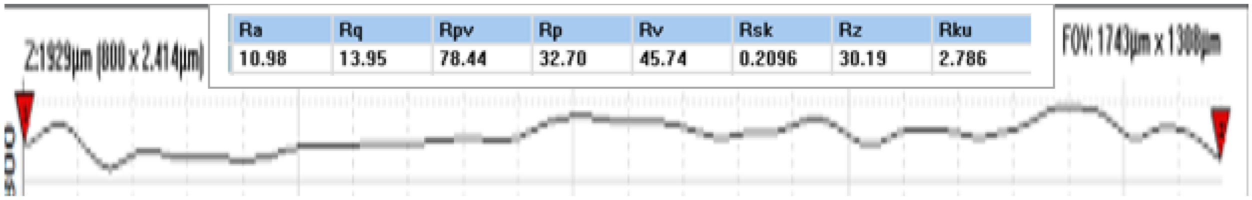
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
10.66	13.96	66.79	24.98	41.82	-0.5574	29.24	3.382

Sample 2:

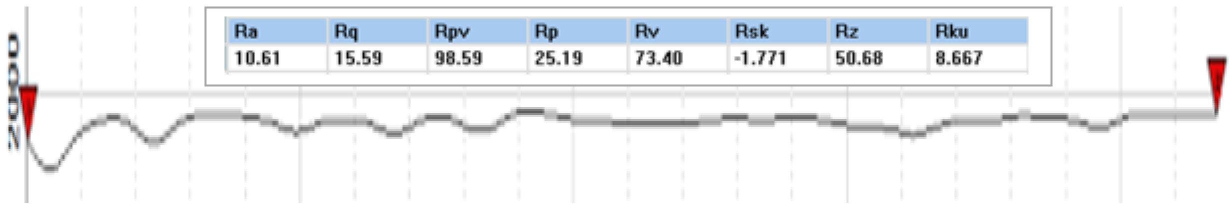


Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
10.46	16.35	106.54	31.76	74.77	-1.620	49.22	8.364

Sample 3:

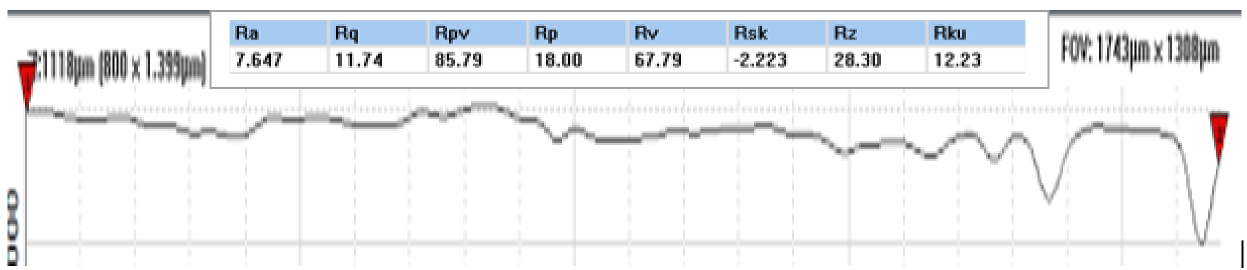


Sample 4:

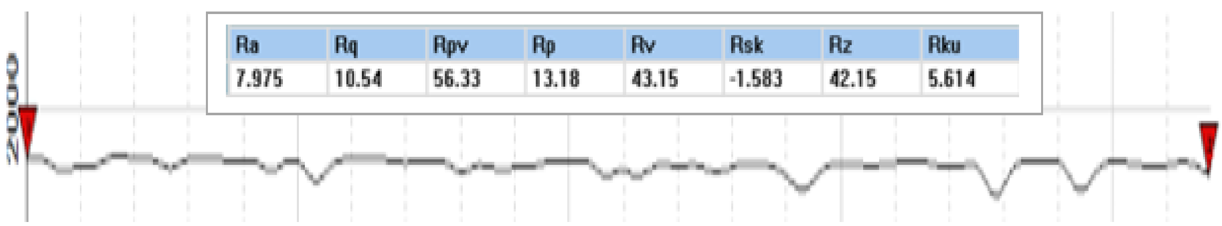


Experiment 7:

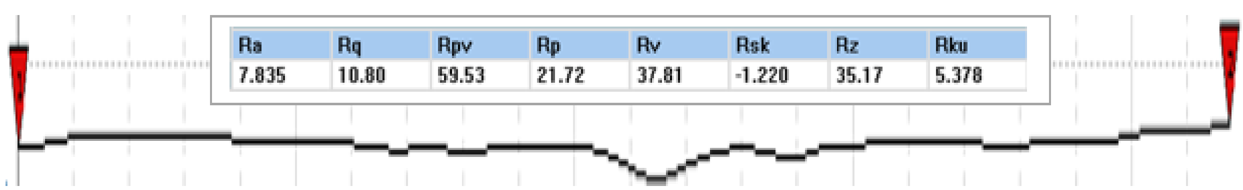
Sample 1:



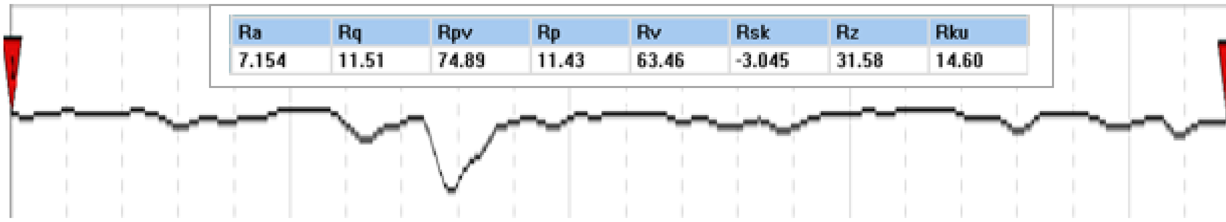
Sample 2:



Sample 3:

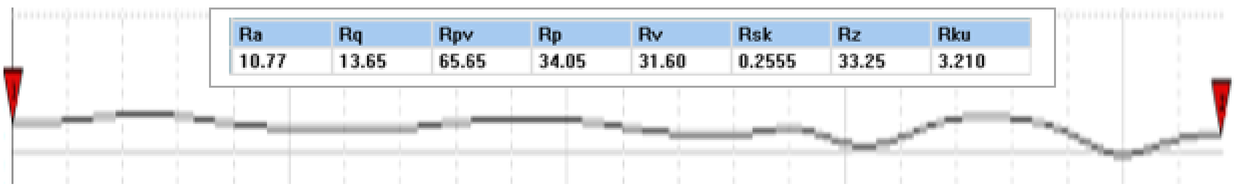


Sample 4:

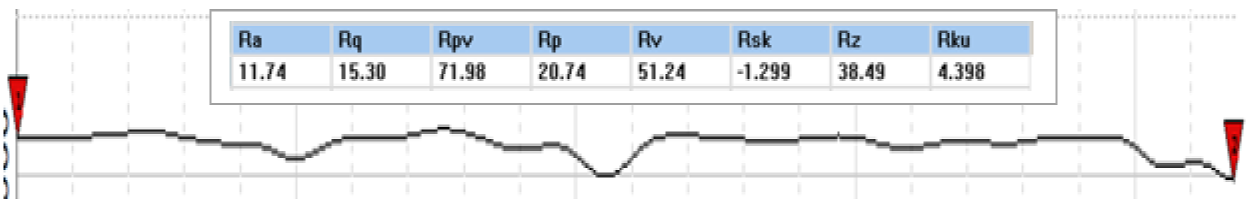


Experiment 8:

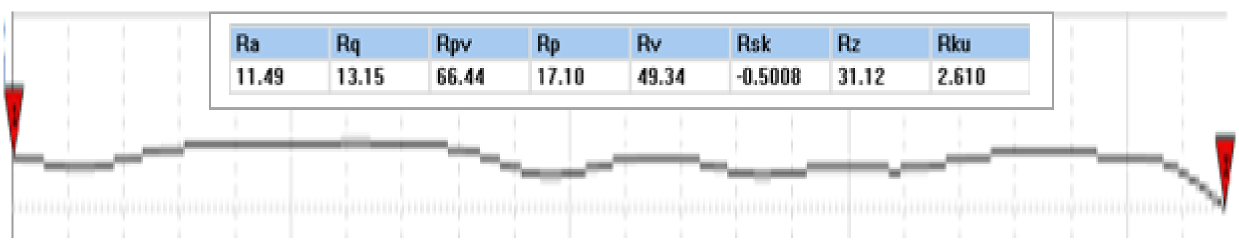
Sample 1:



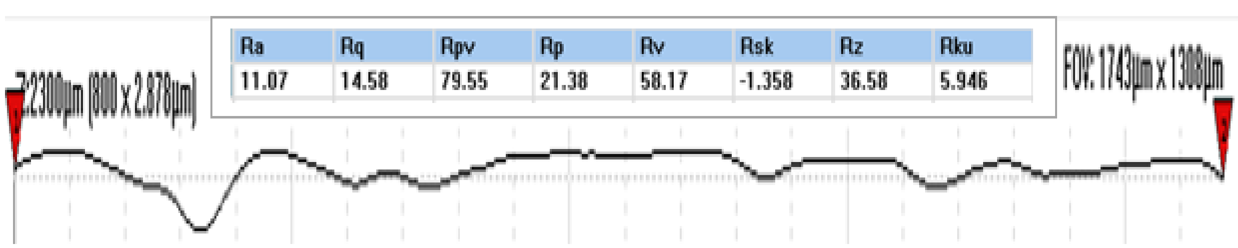
Sample 2:



Sample 3:

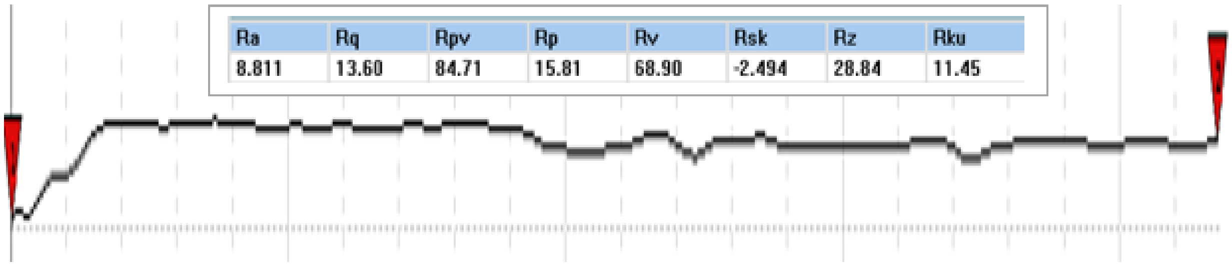


Sample 4:



Experiment 9:

Sample 1:

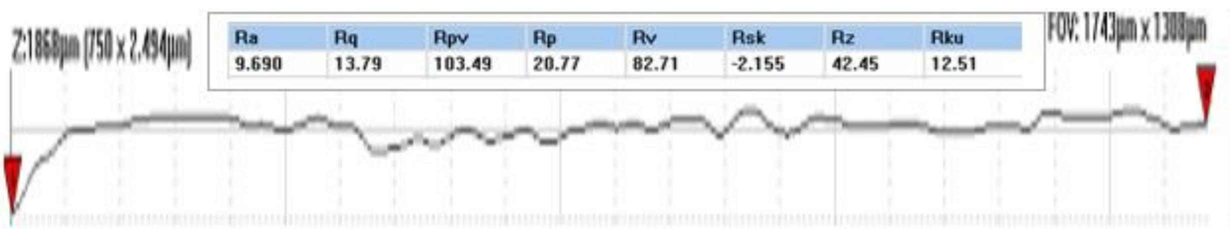


Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.811	13.60	84.71	15.81	68.90	-2.494	28.84	11.45

Sample 2:

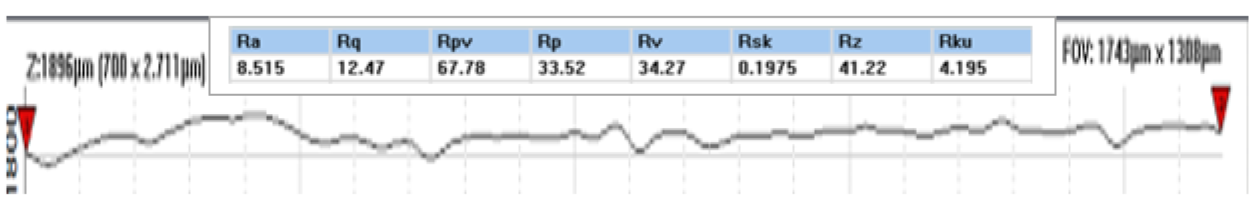
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.616	14.21	114.56	33.87	80.69	-2.541	47.40	13.32

Sample 3:



Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
9.690	13.79	103.49	20.77	82.71	-2.155	42.45	12.51

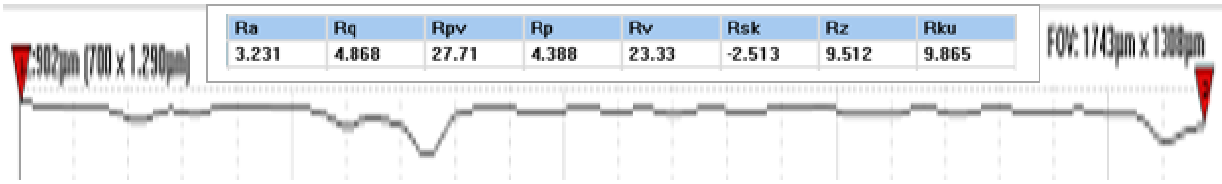
Sample 4:



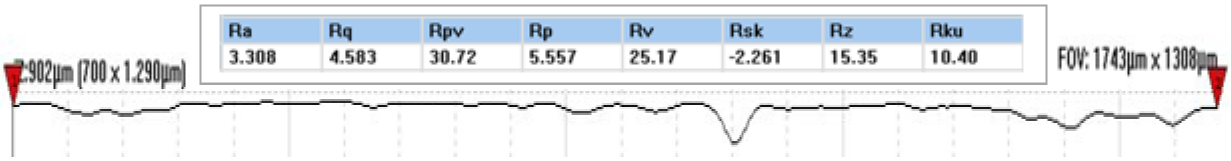
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
8.515	12.47	67.78	33.52	34.27	0.1975	41.22	4.195

Confirmation Test Result

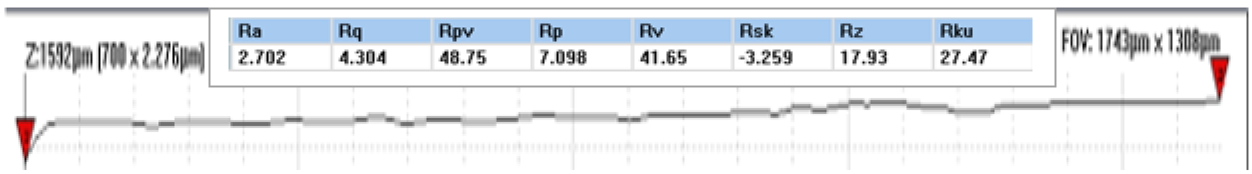
Sample 1:



Sample 2:



Sample 3:



Sample 4: