Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

Fabrication and Investigation of the effect of Machining Parameters on the Performance of Machining Al-TiB_2 Composites

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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Addis Ababa, Ethiopia

January, 2023

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Submitted in accordance with the requirements for the degree of

MASTER OF SCIENCE (M.Sc.) in MECHANICAL ENGINEERING (MANUFACTURING ENGINEERING)

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Declaration

I hereby declare that this thesis research: **"Fabrication and Investigation of the effect of Machining Parameters on the Performance of Machining Al-TiB_2 Composites"** is my own work and this work has not been submitted elsewhere for the award of any other degree or diploma. It is being submitted for the degree of Master of Science in Manufacturing Engineering, and all sources of material used for this thesis have been duly acknowledged.

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This thesis research has been submitted for examination with our approval as a thesis advisors.

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Acknowledgment

First and foremost, I want to express my gratitude to the Almighty GOD for allowing me to begin and complete my thesis work in this difficult situation.

I want to express my deepest gratitude to my thesis advisor, Mr. Henok Zewdu, for genuine guidance, valuable support, and checkups during this thesis work. I want to thank the mechanical and industrial engineering staff of AAiT for their excellent hospitality and invaluable support during this entire journey of my study.

I want to thank the Federal TVET Institute in general and Mr. Gezae Mebratu, the Manufacturing Engineering department head, and all the machine shop crew.

I want to express my special thanks to my mother Zewde Lemma, my father Kassahun Tefera, my wife Tesfanesh Berihun, my son Atnatiwos Nobel , my brothers, and my sisters as they are always by my side in all needs.

Finally, I'd like to express my gratitude to my family and best friends who were supporting and encouraged me during this entire study period.

Abstract

Aluminum-based metal matrix composite materials are mostly used to design automobile parts and aircraft structures due to their lightweight and high strength. In this study, the stir casting method was used for the fabrication because it is the most effective method for manufacturing metal matrix composites due to its more effective and fairly uniform distribution. Machining of metal matrix composites was difficult in the turning process. This study investigates optimum cutting parameters for turning Al 6061- 10% TiB_2 *composite materials.*

The mechanical properties of Al-10% TiB_2 *composite were analyzed using the following tests: tensile test, hardness, and impact test. Al 6061- 10%* TiB_2 *has a mechanical property i.e. tensile test the maximum result from the specimens was 242MPa but the average was (208MPa), hardness test by Rockwell hardness test the average result was (74.9HRH), and finally the Impact result was (311.67KJ/*m^2*).*

The study considered the cutting parameters which are the cutting speed, depth of cut, and feed rate as input, surface roughness and material removal rate are the responses by using coated carbide tool on a CNC lathe machine. The effect of cutting parameters on Surface roughness and material removal rate were studied and analyzed. Experiments were conducted based on the Taguchi design of Experiments with orthogonal array L9, and the optimization of the results works with Analysis of Variance (ANOVA).

The optimum responses of MRR and surface roughness were obtained at high cutting speed 1500rpm, high depth of cut 1.5mm, and medium feed rate 100mm/min.

Key words: Aluminum 6061, Titanium boride, Stir casting, Microstructure, Surface roughness, Material removal Rate and ANOVA

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List of Abbreviations

Al-MMC:	Aluminum-Metal Matrix Composite
AMC:	Aluminum matrix composite
MMC:	Metal matrix composite
PM:	powder metallurgy
TiB_2:	Titanium boride
MRR:	Material removal rate
SF:	Surface finish
FSP:	Friction stir process
EDM:	Electrical discharge machining
DOE:	Design of Experiment
CNC:	Computer numerical control
ANOVA:	Analysis of Variance
SEM:	Scanning Electron Microscopy
PDC:	Polycrystalline Diamond

CHAPTER ONE

1. Introduction

1.1 Background of the Study

A "composite" is when two or more different materials are combined together to create a one superior and unique material. This is an extremely broad definition that holds true for all composites; however, more recently the term "composite" describe reinforced plastics [1]. In the past few decades, the world wide need for research on aluminum matrix composites (AMCs) has increased due to the composite's high strength-to-weight ratio, low cost, and high wear resistance [2]. Aluminum matrix composites are widely used and manufactured in many industries. Aluminum alloys are preferred materials in several engineering applications due to their low density [3].

Metal matrix composite (MMC) is the mixture of metal (matrix) and hard ceramic material (reinforcement). Aluminum metal matrix is characterized into lightweight materials that can be used as an alternative to monolithic aluminum alloys. It has good properties of hardness, corrosion resistance, high specific strength, wear resistance, lighter, less expensive, and durability [4]. Aluminum matrix composites are intended to substitute monolithic materials including aluminum alloys, ferrous alloys, titanium alloys, and polymer-based composites in several applications.

The matrix (base) material used in this research is Al 6061, it is a hardened aluminum alloy, containing Magnesium and Silicon as its major alloying elements. This alloy is currently the second most utilized aluminum alloy in the US today, it has good mechanical properties. Al6061 alloy has the highest strength and ductility of aluminum alloys with excellent machinability and good bearing and wears properties [5], [6]. To provide strength and wear resistance a large number filler particles of ceramic materials such as SiC, ZrN, TiN, TiB_2, Al_2O_3, and SiO_3 have used reinforcements for the manufacturing of composites [5]. For this research the reinforcement was Titanium di boride (TiB_2). Due to their remarkable properties, titanium alloys are used in the aerospace, automotive, chemical, and biomedical industries. Titanium di boride is one of the potential materials for high-temperature structural applications and also for controlling rod components in high-temperature nuclear reactors [7].

Titanium boride is combined with aluminum in order to strengthen and improve its properties. These materials are exposed to sliding movements in certain Automotive applications like cylinder liners, inlet and exhaust valves, pistons, control rods, brake drums, and transmission shafts resulting in wear which is the most prevailing problem in industries [8], [9]. The addition of high- strength, excellent wear protection, excellent corrosion resistance, and high-modulus refractory particles to a ductile metal matrix produces a metal matrix composite whose mechanical properties are intermediate between the matrix alloy and ceramic reinforcement. Therefore, they are more competitive on the MMCs market and find wider application in industries.

Primary processes for manufacturing metal matrix composites in industries are categorized into two main groups, these are solid state processes and liquid state processes. From liquid state process of fabrications of the aluminum metal matrix composites stir casting process is a good and versatile method [5]. In this process, the discontinuous reinforcement particle is distributed in the molten metal which is continuously stirred and immediately poured into a cool sand mold and allowed to solidify.

Machining of composite material is performed with conventional and non-conventional machining processes. In the present research work, the casted composite material is machined by a non-conventional machining process with a CNC lathe machine to inspect different mechanical properties of the composite, surface finish, and material removal rate by varied cutting parameters. Machining metal matrix composite materials are difficult as compared to monolithic materials like steel, aluminum, etc. Turning, milling and drilling are the three most common conventional machining processes used in industry [10]. In the turning process, heat is generated and it must be removed from the machining zone [4], [11].

Turning is one of the primary important metal cutting processes utilized widely in finishing operations. Surface finish and Metal removal rate are the output responses in the manufacturing sectors. According to the literature cutting parameters including cutting speed, depth of cut and feed rate, etc. influence the surface finish and material removal rate.

On this research turning operation by a CNC lathe machine total nine experiments were conducted by taking cutting speed, depth of cut and feed rate as process parameters.

1.2 Problem Statement

Aluminum alloys have relatively low costs from other materials. Due to this reason demand for machining of aluminum composite has been growing significantly. In the fabrication of Al- TiB_2 there are so many factors that affect the quality of the product. From these factors, porosity and lack of uniform dispersal of the reinforcements are the cores [12]. By using the stir casting method the porosity was minimized, better impact strength and uniform distribution of the reinforcements were obtained which result better product quality.

Productivity in machining means manufacturing a good quality product at a lower cost in a lesser time. There are several factors that impact surface roughness in real life, e.g., cutting conditions, type of inserts and material used. The important measure of quality in machining is surface roughness which is mainly affected by cutting parameters including cutting speed, feed rate, and depth of cut [13]. In metal matrix composite machining determining optimum parameters at which the best surface finish is obtained a greatly improves the productivity of the machining process as achieving good surface finish is the major problem during machining. The material removal rate is one of the measures of productivity during machining and it also depends on cutting parameters.

In machining of aluminum 6061 with Titanium di boride reinforced composites the one problem is understanding the properties of the composite and this composite in machining time needs very high cutting speeds to get the best results [14]. In addition, the cutter tool cutting edges must be hard and very sharp in working time. This kind of equipment can represent a substantial investment to the machine shop on a limited budget.

Finally, studying the Machining of Al-TiB_2 and optimizing cutting parameters for good surface finish and optimum material removal rate to increase the productivity of the machining process by using Taguchi Design to finish by ANOVA.

1.3 Objective of the study

1.3.1 General Objective

The main objective of the research was to fabricate Al6061 - TiB_2 composites with the stir casting method, test the mechanical properties, and evaluate the effect of cutting parameters on machining performance, including surface finish and material removal rate.

1.3.2 Specific Objectives

The specific objectives of this study:

- ✓ Fabrication of Al6061- TiB_2 composite by stir casting method
- ✓ Evaluate mechanical properties (tensile test, hardness test and impact strength)
- ✓ Evaluate effect of turning parameters on machining performance (MRR and SF)
- ✓ Optimize turning parameters for better performance (MRR, SF)
- ✓ Conduct the optimum results.

1.4 Scope of the Study

The scope of this thesis involves the fabrication of Al6061- 10 % TiB_2 composite by using a stir casting process. The mechanical properties of the composites were evaluated using the tensile test, hardness test, and impact test, and the composite specimens were machined by varying the cutting parameters.

Finally, the Taguchi method orthogonal array L9 used cutting parameters (cutting speed, feed rate, and depth of cut) in a lathe machine with a coated carbide cutting tool to get optimum surface finish and material removal rate results. This thesis provides information on machining parameters, such as surface finish and MRR.

1.5 Significance of Study

Composite materials have a significant role in today's technological developments. Because of their excellent wear resistant properties, aluminum alloy-based metal matrix composites are widely used for sliding wear applications. The use of reinforcements to enhance mechanical properties such as hardness has been adopted by many researchers.

Any manufacturing industry is directly related to the quality of the product to be manufactured and the total cost of machining. Turning is one of the most widely used machining processes due to its wide application in metal matrix composites. Surface roughness is an important measure of product quality.

Machining parameters have a significant effect on the machining performance and the end product. The study has shown that improving the machining process can increase the profit margin by increasing the quality of the final product. This study was highly significant for the metal matrix composite manufacturing industries, particularly for automotive and aerospace applications.

The other significance of the study is for researchers who want to further explore about the machining of Al- 10% TiB_2 composite.

1.6 Research Questions

1. How to fabricate Titanium di boride reinforced composite using Al6061 matrix with stir casting method?
2. Which turning parameters affect or influences the surface quality of the product and how?
3. What are the optimum machining conditions to achieve better Machining performance?

1.7 Limitation

The first challenge, there was no titanium boride material in country Ethiopia for fabrication. Both of working materials could not be found locally, so the matrix and reinforced materials was imported from China. Due to covid 19 in china, Importers can't import items like battery, powder and liquid from Alibaba.com market at that time. Finally, Ethiopian Trade and industry Minister write a letter to the customs and revenue minister to out the material from Cargo. It takes a lot of time to get the letter stating that the material would not cause any harm if imported and would use for thesis work.

The second challenge shortage of materials to prepare mold and for machining the some machines ware not present in Addis Ababa University. The mold is prepared in Ethiopian Technical University and there is lack of experimental test machines.

1.8 Structure of the thesis

The thesis comprises of five chapters.

Chapter 1: The chapter in a background of study contains in fabrication of Al-TiB_2 and machining of the composite with a lathe machine. Including the mechanical properties of the composite and parameters on the performance of machining Al-TiB_2 composites. In this chapter the problem of statement, objectives of the study, the scope of the thesis, the significance of the study, and limitations in working time were discussed.

Chapter 2: In this chapter, all relevant research papers were reviewed regarding on metal matrix composite, aluminum matrix composites, fabrication, and mechanical Properties of Titanium Boride. The topic covers the application of the composite, the selection of the cutting material for the specimen, and the gaps in the literature are widely and deeply reviewed.

Chapter 3: In this chapter to brief the materials as matrix and reinforcement additional to check the microstructure of the reinforcement. This cover the fabrication and procedures to fabricate the composite.

Additionally in this chapter, the cutting tool material, turning process, and Taguchi Design method for surface roughness and material removal rate were discussed here.

Chapter 4: This chapter includes the experiment results investigated the mechanical properties of tensile, hardness, and impact test of Al-TiB_2 composite. Signal to Noise ratio of both surface roughness and material removal rate are discussed. Finally by using ANOVA Grey relational grade and better machining rank are also investigated in this chapter.

Chapter 5: The final chapter was presents the final conclusion results of the overall thesis, and recommendation for future research works.

CHAPTER TWO

2. Literature Review

2.1 Introduction

Composite materials are the material created by combining two or above constituent materials with distinctly dissimilar physical or chemical properties. The new material with characteristics is different from the first individual components. The final structure preserves the uniqueness and distinction of the various parts. There are a variety of reasons why new materials can be favored, some of which include the fact that the materials are stronger, tougher, lighter, or less expensive than conventional materials [15].

The industries today need hard and good wear resistance materials with light weight are in good demands, especially in aircraft, submarine, and automotive industry due to good toughness characteristics, excellent corrosion resistance, good acceptance of applied coatings, relatively high strength, good workability, good finishing characteristics, and good weld ability with due to wide availability.

Metal matrix composites have shown potential for enhanced wear resistance over unreinforced alloys. These composites have many advantages over monolithic metals, including higher specific modules, higher specific strength, specific stiffness, better wear resistance, good impact, and excellent corrosive resistance [3].

Metal matrix composites are the new age materials that are being preferred by the automotive and aerospace industries for their enhanced properties. Metal Matrix composites are attractive in physical and mechanical properties. These materials exhibit a higher strength-to-weight ratio, hardness, stiffness, wear resistance, etc. as compared to conventional metals and alloys [16]. Metal matrix composites shows better mechanical properties and can be made near net shape dimensions.

Metal matrix composites are strongly influenced by microstructural parameters of the reinforcement such as shape, size, orientation, distribution, and volume fraction [6]. Aluminum alloy matrices with ceramic particles are mainly due to the low density, low coefficient of thermal expansion, and high strength of the reinforcements and also due to their wide availability.

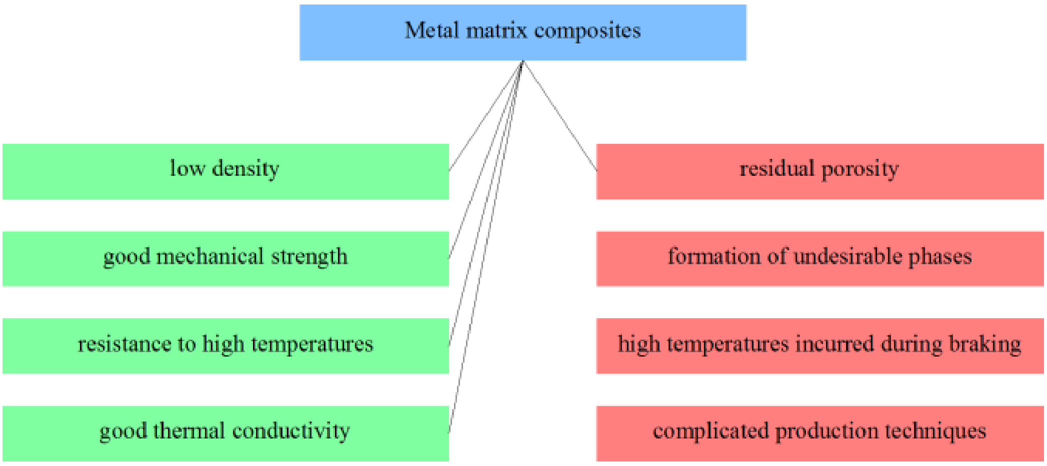


Figure 2. 1 Selected MMC properties from the point of view of applicability in friction materials [17]

For metal matrix composites, powder metallurgy (PM) is costly but is suitable for small components. The stir casting technique is frequently used for the commercial manufacture of Al-MMC. Industrial maturity and the low potential cost of the melting process are reasons is a cost-effective process. The Stir casting process also known as the vortex technique which is widely used for manufacturing MMC [4].

The matrix in this study is Al6061- TiB_2 composite which investigates the mechanical properties of the composite material tested such as tensile test, hardness test, and Impact test.

2.2 Selection of components of composite materials

Materials selection is an important step in the engineering design process. Material selection of composite materials, compared to homogenous materials like metals and plastics is quite difficult to perform due to the isotropic nature of the materials [18].

The below major attributes are considered in a material selection system:

- ✓ The material selection system should facilitate new product development activity
- ✓ To reduce manufacturing costs and increase product quality
- ✓ To increase the manufacturing threshold, and
- ✓ To decrease manufacturing time.

2.2.1 Matrix Material Selection

The matrix is monolithic material in which usually the reinforcement is embedded and must be uniformly distributed throughout the matrix. Materials such as Aluminum, Magnesium and Titanium can be used as matrix materials. After study of various researchers Aluminum is most likely metal matrix materials it has low melting temperature and good strength with different reinforcement particles [19].

As compared with other aluminum alloys in aluminum MMCs, like Al 6061, Al 2124, Al 7039, Al6351 and Al 2124 all are matrix materials. But from all Al 6061 alloy was selected as the base line material as it possesses good formability, corrosion resistance [14], light in weight, good thermal and electricity conductor, highest strength and ductility of the aluminum alloys with excellent machinability and good bearing and wear resistance properties. Aluminum 6061 is a metal alloy with low density and high thermal conductivity and low wear resistance [5]. To improve this drawback Al 6061 is reinforced with ceramic materials to increase hardness, wear resistance and young's modulus.

2.2.2 Reinforcement material Selection

Titanium Di-Boride is a hard ceramic material with more resistance to corrosion, excellent thermal conductivity, and more hardness [20]. Titanium di-boride has high electrical conductivity they can be easily machined [5].

Suresh et al. [21], analyzed the tribological and mechanical behavior of Al 6061-TiB_2 metal matrix composites. On this, the reinforcing ceramic particle is titanium di boride because it exhibits low specific gravity, good thermal conductivity, and superior wear resistance.

Mohanavel et al. [22] reviewed the mechanical properties of TiB_2 particles reinforced with Aluminum alloy matrix composites in many manufacturing processes. On this TiB_2 was the candidate filler material as compared to other filler contents because the TiB_2 particle is a strengthening agent for aluminum metal matrix composites.

2.3 Fabrication of Al-TiB_2 Composite

The fabrication of metal matrix composites can be achieved by the accumulation of the reinforcement phase in the matrix. In engineering materials, the MMCs can be manufactured by a unique technology such as casting as it is inexpensive and proposes many other options for materials and processing conditions. Different fabrication techniques are used for the preparation of Aluminum MMCs, such as stir casting, powder metallurgy, squeeze casting, in-situ process, deposition technique, and electroplating [23].

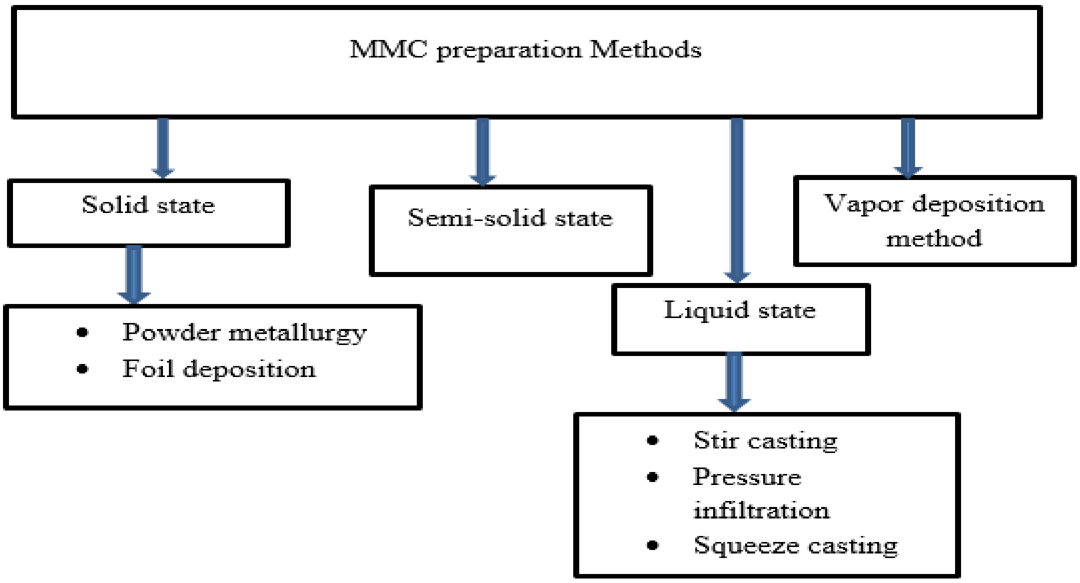


Figure 2. 2 Classification of MMC based on MMC preparation methods [24].

Surresh et al. [25] studied the mechanical behavior and wear prediction of Al-TiB_2 composites with various percentages of reinforced TiB_2 particles. In this study for fabrication high energy stir casting method was used. The conclusions drawn are hardness values increase with the addition of TiB_2 reinforcement with the Al 6061 matrix, and the ultimate strength and tensile results of Al 6061 increase with the increase in the amount of TiB_2.

Christy et al. [26] investigated the microstructure and mechanical properties of Al 6061/ TiB_2 with twelve percent of the fabrication techniques used for this composite by using an in-situ process. Involving the salt metal reaction between titanium and boron-containing salts in the presence of molton aluminum 6061 alloy. He concluded the procedure of in-situ reaction was successfully produced in the composite and the composite exhibited higher values of hardness and tensile test than the base alloy.

Johny James et al. [9] showed a comparative study of the composite Al6061 alloy reinforced with ten percent of SiC and TiB_2. The two specimens was fabricated by using stir casting techniques the morphology were studied by optical microscope to analyze particle distributions in the aluminum metal phase. The mechanical property tensile strength of TiB_2 composite is 30% higher and wear resistance behavior is also higher than SiC composite.

In liquid phase processing techniques the molten metal in a liquid state is cast into varies molds of desired shapes [27]. The main and widely used process under this category is stir casting.

Stir casting is the economical, effortless, and most commercially adopted technique. In this process, the cemented particles introduce by the mean of mechanical stirring into molton metal. Reinforcement is added forcefully into the molton stage of aluminum and obtaining homogeneity during solidification the fabricated composite depends on stirring speed, stirring blade angle, stirring time, pouring temperature, solidification rate, and reinforcement percentage [28]. In this research for fabrication stir casting is advantages because by its simplicity, flexibility and applicability in large volume production.

Titanium boride (TiB_2) is a ceramic material and has sufficient electrical conductivity (10^5S/Cm) [20]. Porosity is the major problem in casting. In order to avoid porosity, preheating the mold is a good solution because it helps in removing the entrapped gases [29].

2.4 Properties of Al-TiB_2 Composite

Aluminum metal matrix composites have a low weight, are well hard, and have strong corrosion resistance. The machinability of metal matrix composites is not the same as other metal materials because of the abrasive reinforcement element [23].

Table 2. 1 Properties of ceramic reinforcements [5]

	Density gm/cm^3	**Melting point ^{o}c**	**Elastic Modules (GPa)**	**Hardness (HB500)**
Properties of TiB_2	4.52	2970	461.4	3250

Suresh and Shenbaga [30] investigated on microstructure and wear behavior of TiB_2 on Al6061 metal matrix composites by various weight of reinforcement. The mechanical characteristics of Al 6061-TiB_2 reveal that there is an increase in the hardness property of the aluminum with the increase of reinforcement of TiB_2. The results show that the reinforcement improves the wear resistance character of aluminum and increases the strength of aluminum.

Suresh et al [21] studied the mechanical behavior of Al 6061-TiB_2 using stir casting of the composites it was noticed that the hardness of the composite at twelve percent is 77.93 HV values and increase the amount of TiB_2 there was an improvement in tensile strength, modules and wear resistance characteristics.

Aluminum metal matrix composite reinforced with TiB_2 the cast composite samples carefully machined. The outcome of machining component like feed, cutting speed and depth of cut on surface roughness explored through turning operation. Surface roughness decrease with reduce the feed and lift the cutting speed and depth of cut. Machining of MMCs great surface quality because due to plasticity of ceramic reinforcement, non-uniformity and high abrasive nature [31].

The industries today need hard and tough materials along with light in weight characteristics as they are in good demands, especially in automobile sectors. The results which indicate that better properties like tensile strength, flexural strength, and hardness and impact strength can be obtained up to the addition of 6% of TiB_2 reinforcements in Al alloy [20].

2.5 Application of Al-TiB_2 Composite

Aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for varies high performing components that are being used for varieties of applications; owing to their lower weight and excellent thermal conductivity properties.

Due to its low density and excellent strength to weight ratio, aluminum and its alloys offer a wide range of possible applications [32]. Although there is great potential for aluminum MMCs in many applications, their utilization is now constrained by their poor machinability [33].

From thermal analysis Al 6061 is a suitable material for a brake disc, high speed machinery, high-speed rotating shafts and automotive engine parts in terms of mechanical and thermal properties [34].

2.6 Selection of cutting tools

During the machining of MMCs, many reinforcement materials are found to be harder as compared to most commonly used carbide and high-speed (HSS) tools [35]. Al-TiB_2 composites are considered difficult-to-cut materials due to the hard ceramic reinforcement, which causes severe machinability by increasing cutting tool wear, cutting force, etc [23].

Tool selection is an important criterion in machining the metal matrix composites. High-speed steels (HSS), straight grade (K) of cemented carbide, and diamond-based tools are the main tools which used for machining aluminum alloys [36].

B. Umroh et al. [37] experimentally reported the optimal cutting conditions when high speed turning of Al6061 Alloy by using a carbide cutting tool to determine surface roughness, flank wear, and tool life. The final results show that the carbide tool is successful and he recommends to supporting or to increase productivity carbide cutting tool was important in metal cutting industries.

2.7 Surface roughness and material removal rate

A lot of research work has been performed to reduce the surface roughness of the machined component in the machining of aluminum alloys. Surface roughness is an important factor in evaluating machining quality as it has a significant effect on mechanical properties, such as wear resistance and fatigue strength of the machined product. Cutting parameters such as cutting speed, feed rate and depth of cut greatly influence the surface roughness of machined product. Surface roughness measurement is the primary machinability index that influences the functional capability of the machined component. The functional parameters such as corrosion and fatigue resistance are enhanced by minimized roughness value [4].

Metal matrix composites machining and conventional alloys machining was significant different in many aspects of machining. Machining mainly depends on the matrix, reinforcement material and its volume fraction [38]. The following section discusses some relevant research works.

James. S [39] studied on the machining and mechanical properties of Al6061 with ten percent of TiB_2 investigated surface roughness during turning operations. The effect of machining parameters are cutting speed feed rate, depth of cut, and weight of Titanium di boride. The

Experiments for turning operation conducting according to the Taguchi method orthogonal array L_{27}. The parameters cutting speed (60, 90 & 120m/min), feed rate (0.1, 0.2 & 0.3 m/rev), depth of cut (0.5, 0.75, 0.1mm) and percentage of reinforcement (0, 2.5 & 5%). Finally, the conclusion shows that cutting speed and feed rate is a highly significant factor in surface roughness.

Ranganath M S et al [40] investigated and optimized the Al 6061 alloy for the roughness of the surface produced during turning operation. The process parameters are cutting speed (1600, 1900, and 2200 rpm), feed rate (0.12, 0.18, and 0.24), and depth of cut (0.25, 0.5, and 0.75) in CNC turning of Al 6061 in dry condition. By using Taguchi's design and analysis of the variance method feed and cutting speed are the most influential parameters on surface roughness. An increase in cutting speed decreases the surface roughness up to a certain extent, the surface finish gets poorer as the feed increases.

Joardar [31] adopted Response Surface Methodology (RSM) to optimize the process parameters in turning casting aluminum metal matrix composite reinforced by Titanium di boride. Turning is carried out on a CNC lathe machine in dry condition with a PDC cutting tool. The influence of attributes are cutting speed (30, 60 & 90m/min), feed (0.1, 0.2 & 0.3mm/rev), and Depth of cut (0.5, 1 & 1.5mm) on surface roughness were examined with the established of Numerical model through ANOVA analysis. The analysis shows that reduction of feed rate results in improved surface finish. In addition, cutting speed and feed is the most imperative element in impacting the response.

Abdallah [36] performed a turning experiment with aluminum alloy 6061 material to optimize cutting parameters for low surface roughness and material removal rate value using the Taguchi method. The design factors for Al6061 alloy cutting speed (150, 250 & 350rpm), feed rate (0.12, 0.16 &0.20) and Depth of cut (04, 0.6 & 0.8). The percentage contributions of the effect of cutting speed was 45%, feed rate 36%, and depth of cut 19%. The minimum value of surface roughness error was 4.4 %. It was found that feed rate greatly affects surface roughness followed by cutting speed and depth of cut respectively.

The present study concerning the machining Al6061-TiB2 composites, subsequent analysis of input process parameters like cutting speed, feed rate and depth of cut on the output responses like surface roughness and material removal rate, followed by optimization of cutting parameters was reported. Table 2.2 summarizes the researchers used in the turning optimizations of the composite material.

Table 2. 2 Summary of the Literature

Reference No.	**Material**	**Tool Material**	**Parameter of Study**	**Analysis Method**	**Response**	**Result Obtained**
Krishnamurthy and Venkatesh (2013) [14]	Al6063-TiB_2	Carbide cutting tool	Cutting speed, depth of cut and feed rate	Taguchi method	Surface finish and Material removal rate	Optimal conditions for surface finish and MRR investigates by High cutting speed and low feed rate and depth of cut.
Sahithi et al. (2019) [38]	Al6061, Al6063 and Al 6082	Coated carbide inserts	Cutting speed, depth of cut and feed rate	Taguchi method	Surface finish	The cutting performance of Al6061 better compared to Al6063 and Al6082
S. Sureshet al. (2014) [25]	Al 606l-TiB_2		Weight % of TiB_2, load and Sliding distance	ANOVA	Specific wear test	Wear resistance of Al 6061 alloy increased by addition of Titanium di boride.
Abdallah Ali et al (2014) [36]	Aluminum alloy 6061	Uncoated carbide insert	Cutting speed, feed rate and depth of cut	Taguchi method, ANOVA	Surface finish and material removal rate	Cutting speed was the most influential parameter on (Ra) followed by depth of and feed rate . The effect of cutting speed was more significant on surface roughness than MRR.
Narayana B. et al [41]	Al 7050	Carbide tool	Cutting speed, feed rate and depth of cut	Taguchi Method	Surface roughness and material removal rate	Analyzed that MRR in turning highly influenced by depth of cut and it found that if speed increases the MMR would increase.

H. Joardar [31]	Al alloy (LM6) and TiB_2	Polycrystalline diamond (PCD) cutting tool	Cutting speed, feed rate and depth of cut	ANOVA and RSM	Surface finish	Optimum combination was get at higher cutting speed and lower depth of cut and feed rate.
M. Varma [42]	AA2024/SiC	Silicon Carbide	Cutting speed, feed rate and depth of cut	Multi objective optimization	Surface finish and material removal rate	GRG increase the performance index and optimal combination of process parameters for best quality with short time.

2.8 Gaps in the Literature Review

From the above literature survey, it can be seen that many researchers have been trying to investigate the machinability of different aluminum alloys and metal matrix composites with respect to different numbers of cutting parameters and cutting tool during machining. But the machinability of aluminum 6061 reinforced with ten percent titanium boride with different cutting parameters like cutting speed, depth of cut and feed rate has not been studied enough. Therefore, it is important to study the machinability in surface finish and material removal rate of this aluminum 6061 reinforced titanium boride composite to fill the identified gap. The main intention of this thesis is to make new contribution by studying the machinability of Al-TiB_2 composites which mainly includes optimization of cutting parameters (cutting speed, feed rate and depth of cut) for minimum surface roughness and higher material removal rate and Identifying the most significant parameter that affect surface roughness and material removal rate.

CHAPTER THREE: Materials and Method

3.1 Introduction

The materials, experimental methods and machining approaches in the thesis are discussed in this chapter. The methodology to conduct the overall research is shown shortly in figure 3.1 below.

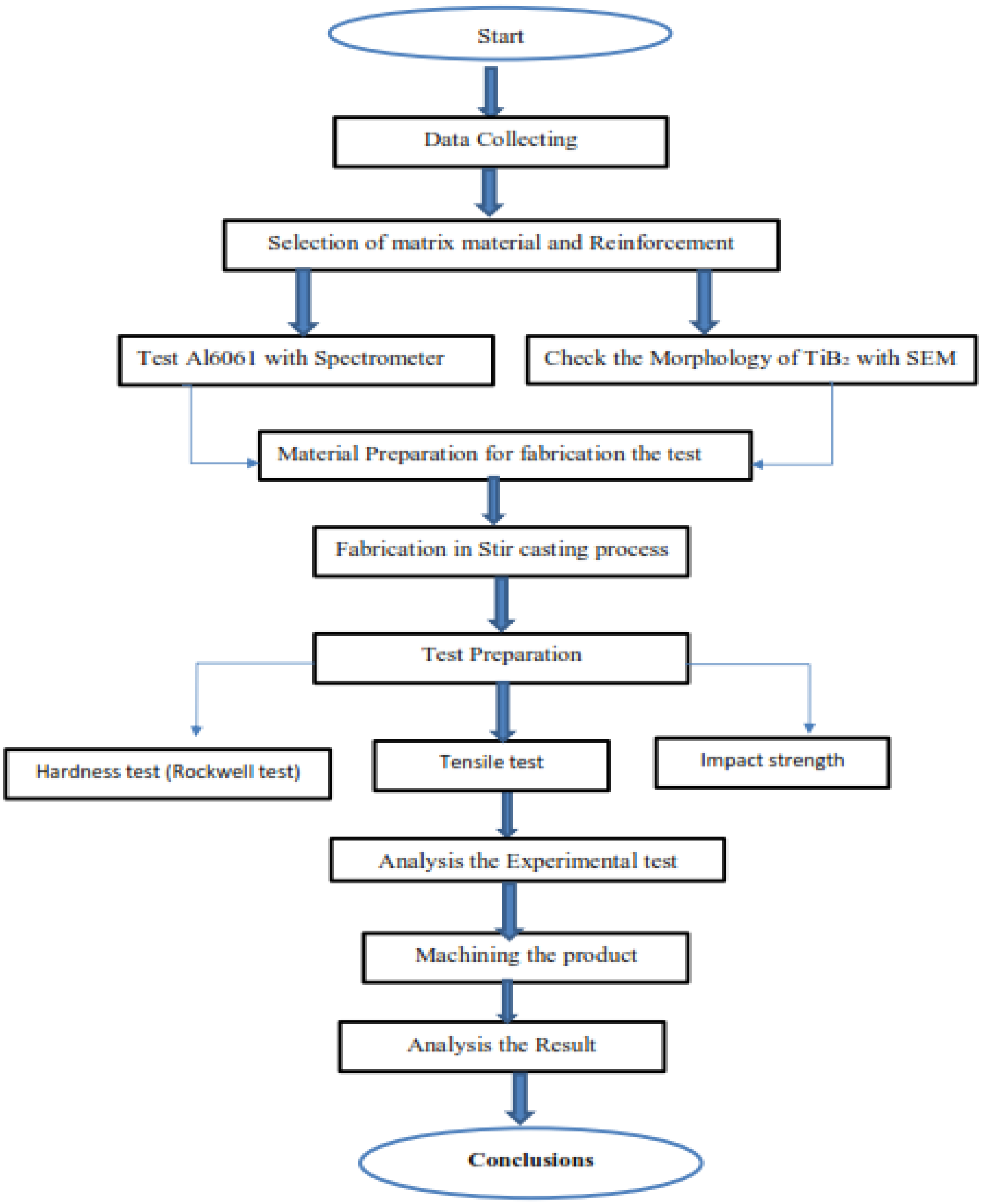


Figure 3. 1 Methodology

3.2 Materials

3.2.1 Metal Matrix: Al6061

The aluminum alloy 6000 series is the standard alloy, containing magnesium and silicon in greater amounts. From the 6XXX series on, the aluminum alloy Al6061 was widely used. But Al6061 has good mechanical properties, is easy to machine, is weldable, is well hardened, and has high strengths that 2000 and 7000 can reach.

The final applications from the composites require great hardness, wear resistance and good machinability. In this composite material, the aluminum alloy 6061 was used as the matrix phase, which is used in a variety of structural, aircraft and defense applications.

The aluminum 6061 was brought in a cast form from China, and came with FEDX to Addis Ababa, Ethiopia.

Figure 3. 2 Al6061 alloy sample

Mass spectrometers are machines used to calculating the mass – to charge ratios of charged molecules generated due to the ionization of chemical compounds. A Spectrometer measures how much a chemical substance absorbs light by measuring the intensity of light as a beam of light passes through a sample solution. This measurement can also be used to measure the amount of a known chemical substance. Composition examination of aluminum alloy 6061 a spectroscopic test was conducted at Ethiopian Technical University.

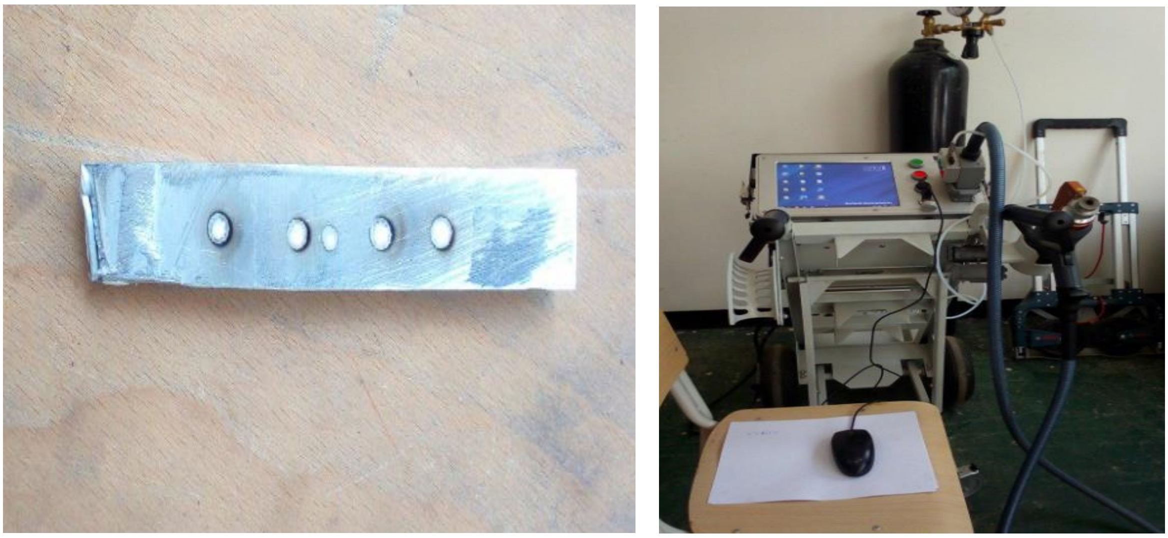


Figure 3. 3 Al 6061 alloy chemical composition test by spectrometer machine

Table 3.2 shows the chemical compositions of the Al6061. It has main constituents of Fe (0.803%) and Mg (0.385%). As an additional alloying element it contains Cu (0.269%) and Mn (0.0843%).

Table 3. 1 Chemical composition of Al6061 result (wt. %)

Element	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ni**	**Be**	**Ca**
Average	98.02	0.0134	0.803	0.269	0.0843	0.385	0.0566	0.162	0.0049	<0.0005	0.012

3.2.2 Reinforcement: Titanium Boride

Titanium Boride was used as reinforcement. It is a widely used ceramic in production of aluminum based metal matrix composite material other than aluminum oxide, boron carbide, etc. Titanium boride is a known ceramic material with high strength and durability it has a high melting point, hardness, and high wear resistance properties [5]. The specimen was fabricated by adding 10 wt. % of TiB_2 with aluminum metal matrix by using a stir casting process.

Table 3. 2 Chemical Composition of TiB_2 before heat treatment

1	TiB_2 Content Mass (%)	99.0- 99.5
2	O Content Mass (%)	$\leq 0.5 - 0.7$
3	C Content Mass (%)	$\leq 0.2 - 0.3$
	Properties and Parameters	
4	Density (g/cm3)	4.1 – 4.2
5	Electrical Resistance, μohm*cm (at 25 ^{0}C)	14.0 - 15.0
6	Thermal Conductivity, watts/ Meter Kelvin (at 25 ^{0}C)	60 – 70
7	Thermal expansion Coefficient, K^{-1}	7.2 – 8 *10^{-6}
8	Grain Size, Microns	5 – 10

This table was obtained from the factory that manufactures this composite (https://www.huaweimaterial.com).

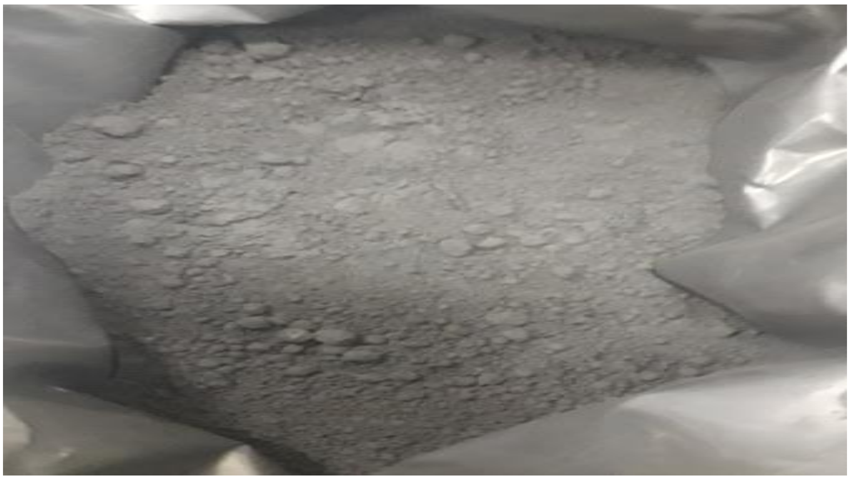
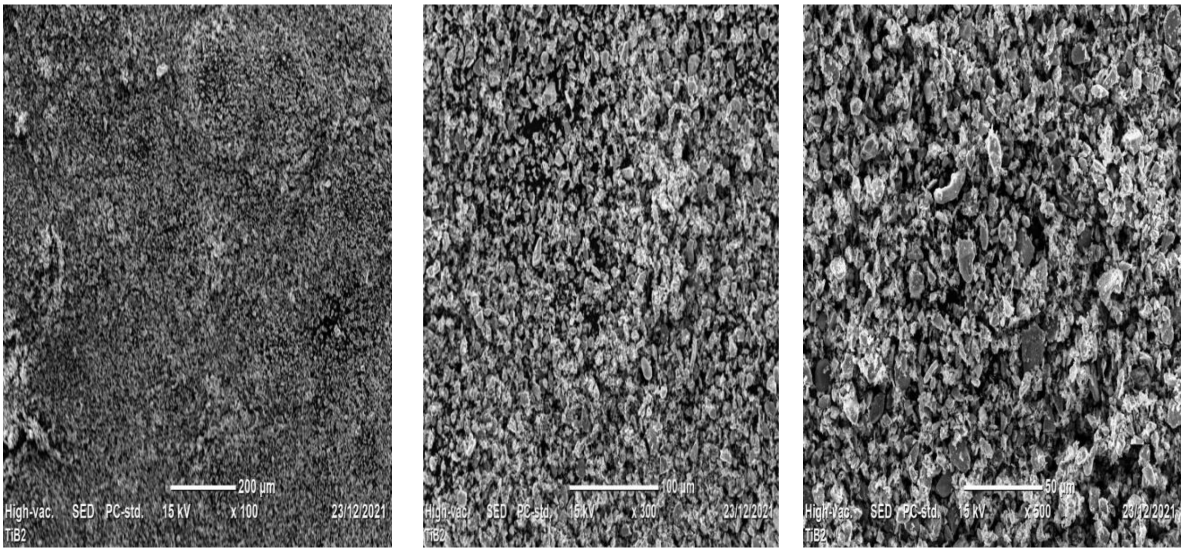
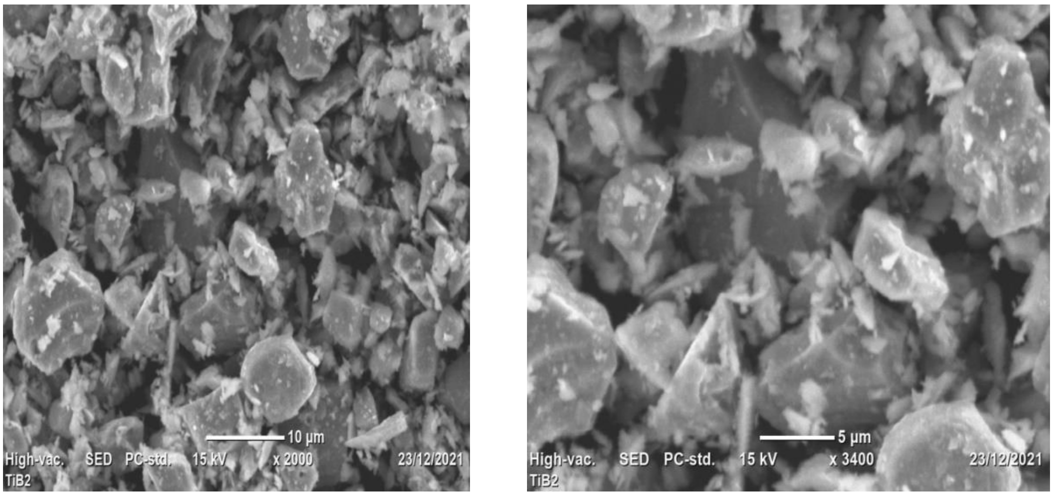


Figure 3. 4 Image of Titanium Boride composite

The essential aim of testing the morphology is to know the distribution of the reinforcing particles and predict the processing and fabrication of the composite. The operation of a scanning electron microscope (SEM) is identical to that of an optical microscope, with the specimen being imaged and composition learned using a focused electron beam as opposed to light [43]. Electron microscopes are compared with light microscopes which have much higher magnifications and an excellent resolving power than a light microscope. The below figure 3.5 shows that the magnifications size increase to see the reinforcement particles. This morphology test was done at Adama Science and Technology University. Microscopic observations of the reinforcement particle were undertaken to identify the size of the particle.



(A) (B) (C)



(D) (E)

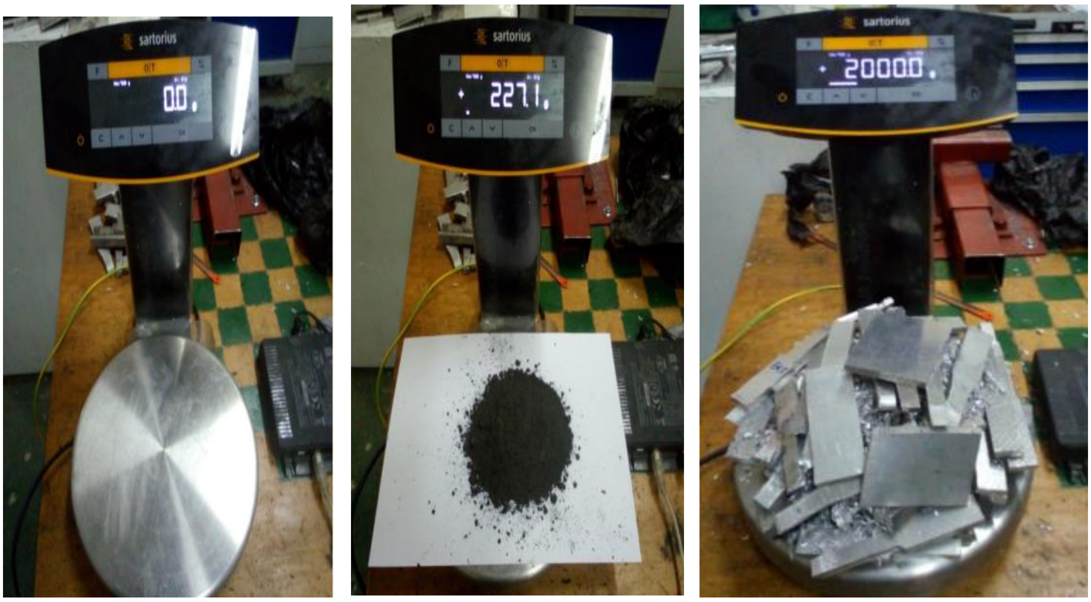
Figure 3. 5 Morphology of TiB_2 (A, B, C and D) powder using scanning electron microscope (SEM)

In the above figure 3.5, the surface morphology of the metal matrix composite is shown. The compact structure of the composite at 200X magnification was observed. As seen with the naked eye, the shape of TiB_2 powder was irregular.

3.3 Composite Preparation

Aluminum 6061 alloy has been selected as the matrix and the chemical composition was described in above table 3.1. The reinforcing material was taken TiB_2 with 10% weight. A compositional property of TiB_2 was given by the company which is stated in table 3.2. Figure 3.5 (a) indicate machine was calibrated and the machine was in Ethiopia Technical University the brand has China Sartorius (PMA7501).

The weight of Titanium boride has 10%, which has 222.2 grams and the weight of white hard paper is 4.87 grams in total if figure 3.5 (b) the weight has 227.1 grams. The weight of the matrix is more in figure 3.5 (c) Al 6061 has 2000 grams.



(a) (b) (c)

Figure 3. 6 (a) Weight measuring machine (b) 10% of TiB_2 (c) 90% of Al 6061

After collecting the required materials the next step is the fabrication of Aluminum particle reinforced composite as per ASTM standards. The techniques used during the processing of the experimental analysis were discussed in this section.

3.3.1 Preparing sand mold and patterns

Sand casting is the oldest casting technique; casting is the operation of pouring molten metal into a mould and allowing it to solidify. Sand casting is the process of melting metal and pouring it into a mold cavity created by the pattern's impression. This pattern is almost identical in size to the final sized model. Alloying serves a number of significant purposes. Increased mechanical qualities of the base metal, such as strength, hardness, impact toughness, and fatigue life, are the most typical reasons. Sand casting is the process of putting molton metal into a cavity-shaped sand mold and then allowing it to solidify.

First of all, it is necessary to blow the sand prepared by making a sieve. Next, to collect a lot amount of sand using this sieve, it is necessary to place it on the table that passes through it. The sand size that pass from sieve has from 200-250. It works to combine the sand prepared and placed on the table with the sticky molasses and water. This is because it binds the sand together. For mixing the sand and the molasses continuously mix by ten minutes by hand.

Pattern allowances play an important role in obtaining adequate patterns. The pattern size is never kept the same as that of the desired casting because the casting is subjected to various effects during cooling. Pattern allowances include allowances for shrinkage, for machining, for shaking and for distortion.

The pattern is an essential component of the sand casting process because it is the first step in creating the mold. In this experiment, the pattern was a solid pattern, which has a round rod with a diameter of 22 mm and 240 mm in length. After fabrication, the pattern dimensions were diameter 18 mm and 190 mm in length, taking pattern allowance into account. The pattern was prepared from wood according to the ASTM standards for the composite specimens. The pattern was positioned vertically parted. Vertically-Parted sand casting may be used for high-volume production runs. Which has applicable to brake discs, exhaust manifolds, and other pipes. Straight positioned the pattern vertically and packed the sand in the mold easily.

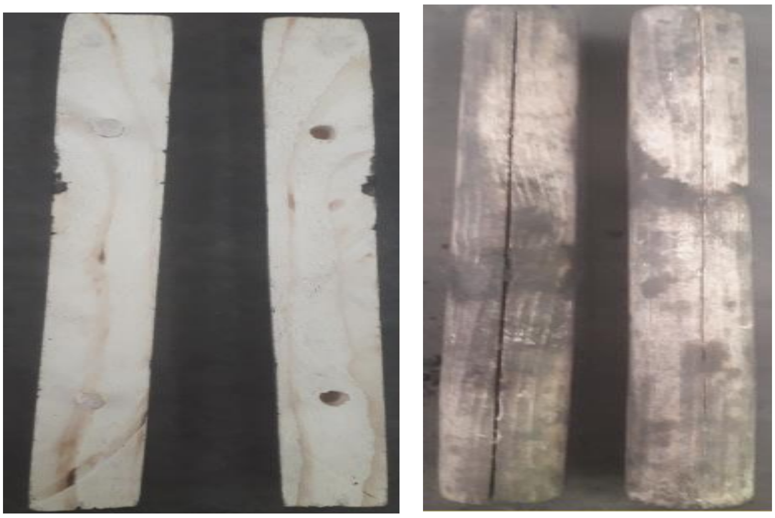


Figure 3. 7 Model of the pattern

The casting process was done in winter (December/2014 in Ethiopia) the prepared sand mold were dried for one day by atmospheric temperature before being used.

(a) Seive (b) Separate the sand with seive (c) Mixing sand and molasses

(d) Pattern (e) Arranging the pattern (f) Remove the pattern

Figure 3. 8 Mold and Casting Procedure

3.3.2 Stir casting

Aluminum metal matrix composites are fabricated using various methods like liquid state fabrication, and solid-state fabrication methods [1]. In this experiment stir casting process was selected because of the most cost-effective and simplest of other methods. The stir casting process is categorized as liquid state fabrication. The stir casting method is used for large-sized component fabrication and it is the economically available route for metal matrix composite production. Stir casting is a process in which uniformly mixed very fine powder of additives is mixed with a molton matrix metal by means of mechanical stirring [14], [44].

3.3.3 Process parameters of stir casting process

In preparing metal matrix composites by stir casting method, there are several factors that need considerable attention, including

- ✓ The difficulty of achieving a uniform distribution of the reinforcement materials
- ✓ Porosity in the cast metal matrix composites

Process parameters:

A) Stirrer design:

It is a crucial variable in the stir casting process since it helps create vortices. These are necessary for excellent surface bonding, uniform reinforcement distribution, and to prevent clustering in liquid metal.

B) Stirrer speed:

Stirring speed is a crucial factor in fostering the bond between the matrix and the reinforcement. The creation of a vortex, which is in charge of dispersing particles in liquid metal, is determined by the speed of the stirring. Literatures suggested that the speed range between 300 and 600 rpm is optimum [45]. In this thesis stirring speed is 300 rpm. Stirring speeds lower than 100 rpm and higher than 600 rpm are not generally recommended. Excessive speed (for example, above 600 rpm) usually results in adverse results such as vigorous turbulence, contaminants, gases, and oxide absorbance from the atmosphere, and therefore a poor mechanical property is expected [46]. At optimum speed, more particles with longer durations are entrapped and embedded in the metal matrix.

C) Stirring time:

As promote uniform distribution of reinforcement partials and interface bond between matrix and reinforcement, stirring time plays a vital role in stir casting method. Less stirring leads to non –uniform distribution of particles and excess stirring forms clustering of particles at some places. The stirring time between matrix and reinforcement is considered an important factor [45]. The stirring time is 5 minutes. The optimal stirring time and speed are determined by factors such as material type and composition, as well as reinforcement properties [41].

D) Preheat temperature of reinforcement:

Cast process of Al-MMC is difficult due to very low wettability of alumina particles and agglomeration phenomenon which results in non-uniform distribution and poor mechanical properties [46]. Reinforcement is heated to 500^0C for 40 minutes. It removes moisture as well as gases present in reinforcement.

By controlling the above process parameters the porosity and the uniform distribution of the reinforcement in cast metal matrix composites can be improved.

E) Melting temperature

To oxidize the surfaces of the titanium di boride particles, they were preheated at 500^0C for 40 minutes. The furnace temperature was first raised above the liquid aluminum temperature of about 750^0C to melt aluminum alloy; at this stage, the preheated titanium di boride manually added to the vortex. The furnace temperature was kept with 710 ± 10^0C during the final mixing processes. To keep the slurry in a semi-solid, it was cooled down to just the liquids.

3.3.4 Treatment of matrix and reinforcement

The formation of strong chemical bonds at the interface is favorable for the wetting of reinforcement by molten metal, which is considered as an important aspect in MMC synthesis. The lower wettability adversely affects the properties of the composite. Non-wetting of the reinforcement with the molten metal is primarily caused by the presence of oxide films on the surface of molten metal and the adsorbed contaminant on the reinforcement. Metallic coatings on the reinforcements, addition of reactive elements, such as magnesium, calcium or titanium, to the molten metal and heat treatment of particles before addition are some of the techniques to improve metal-reinforcement wettability [47].

For this research heat treatment of particles was conducted before inserting them into the molton metal matrix. Its main function is to remove gasses and impurities from the surface of the particles that help the reinforcements to transfer easily in the molton metal matrix and improve the wettability of the molton composite. Preheating of reinforcement powder causes better bonding with matrix, uniform reinforcement distribution, reduce porosity level, and enhancement of mechanical properties.

Figure 3. 9 Heat treating the reinforcement

3.3.5 Melting and Casting

From literatures Al 6061 matrix alloy melts completely at about 650^{0}C. But before placing the matrix in the furnace, the furnace is preheated at 300^{0}C for 20 minutes for the safety of the machine. Then weighted the pieces of Al 6061 were placed in the induction furnace of charging 700^{0}C. It is above the melting point of the matrix because there is a possibility of the formation of the slag at higher temperature. The weight percentages of Al6061 and ceramics for producing MMCs are 90% of Al6061 is added with 10% TiB_2.

Finally to get the desired ASTM standard size of the specimens lathe machine were used.

(a) Mixing of Al6061 TiB_2 by stirrer (b) Adding the molten MMC to mold (c) cooling the MMC

(d) (e) (f)

Figure 3. 10 Stir casting- based MMC preparation method

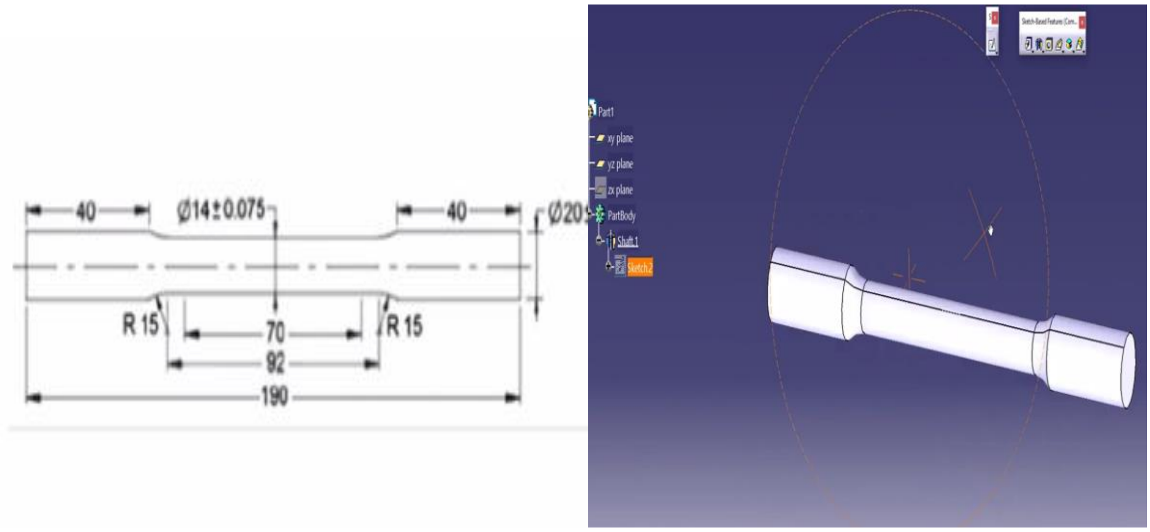
3.4 Mechanical testing of the composite specimen

The experimental specimens were fabricated from Al6061 with 10% TiB_2 composite for different tests and machined using ASTM to found the essential dimensions for the study of their properties. Universal testing machines (UTM) are fast, accurate and simple to operate.

3.4.1 Tensile testing

Tensile testing is a fundamental materials science test during which a sample is subjected to a controlled tension until failure is also known as tension testing. The results from the trial are usually used to choose a material for the associate application, for quality control, and to predict how the material can react under very different forces. The properties obtained from this test are ultimate tensile test, maximum elongation, and reduction in area. Properties like young's modulus and yield strength also are determined from this measurements [48].

Tensile test specimen preparation as ASTM E8/E8M – 16a [48]. Including machining and shrinkage allowance for aluminum metal up to +2.286mm and up to 3.937mm respectively.



A) Dimensions of tensile test specimen B) Catia design for tensile test specimen

Figure 3. 11 ASTM E8 standard

The prepared tensile test specimen has been machined in a lathe as per the ASTM E8 standard and has a round cross-section diameter of 20mm, a gauge diameter of 14mm, and a length of 190mm. The dimensions of the specimen are shown in Fig 3.11.

Figure 3. 12 Tensile Test Specimens

During the test, the specimens were placed in the grips of UTM. After griping the sample, the required data like material type, gage diameter, gage length data were added to the computer software of UTM. Then the machine started, and the load was automatically applied until the spacemen are failed. Finally, the stress- strain data are recorded during the test, and the values obtained from the software. The tensile test was done in Ethiopia Technical University. The test machine loading capacity up to 2000KN.

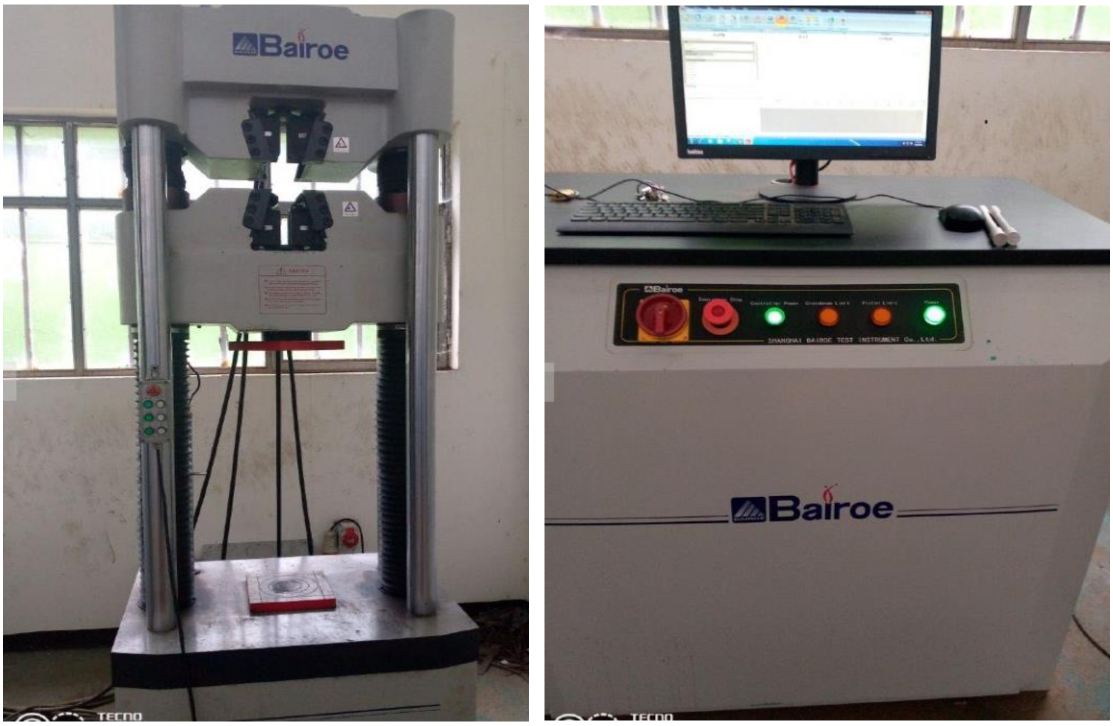


Figure 3. 13 Universal testing machine loading unit, computer and control unit

3.4.2 Hardness testing

Hardness is the capability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation, is measured. There are three most frequently used hardness testing machines: Vickers test, Brinell test, and the Rockwell test. Among these machines, in Rockwell hardness the test is fast, cheap, and relatively non-destructive, leaves only a minor indentation on the specimen.

One of the most used indentation hardness tests created for hardness testing is the Rockwell hardness test. When compared to the penetration caused by a preload, the Rockwell tester measures the depth of penetration of an indenter under a significant force (major load) (minor load). The zero position is established for minor load. The difference between depth of penetration before and after application of the major load is used to calculate the Rockwell hardness number.

There is a screen that displays the result of the test. Rockwell hardness test is also simple to operate. The values of Rockwell hardness are conveyed as a combination of a hardness number and a scale symbol that represents the indenter and the major and minor loads. The hardness number of any material is expressed by the symbol HR and the scale designation. Hardness test for 6061 aluminum alloy depends greatly on the temper of the material, but for T6 temper it is approximately 95HR.

In this research for hardness testing, polished specimens were tested using ASTM E-18 [49]. The Digital Rockwell hardness test model was Digi Rock DR3 with the specimen's diameter of 20mm and with diamond indenter with loading control of auto loading, the machine dwelling time is from one second to sixteen second for this experiment a period of 15 seconds used to examine the hardness strength of the composite samples. The test was taken at three different locations of the composite specimens and the average value was recorded as the hardness of the composite specimens. It was performed in Federal TVET Institute.

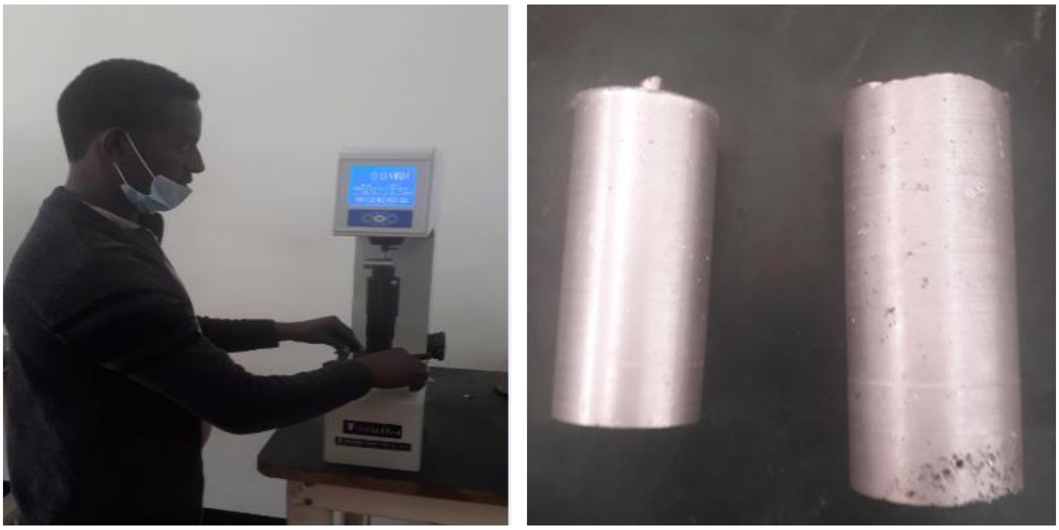


Figure 3. 14 Hardness testing machine and specimens for hardness test

3.4.3 Impact strength testing

Impact strength, which is measured in terms of energy, is a materials capacity to sustain an abruptly applied load. Frequently assessed using the Charpy impact test or the Izod impact strength test, both which assess the impact energy necessary to fracture a sample. The Charpy test sample method of impact testing does possess certain advantages; these include ease of preparation, simplicity of test method, speed, low cost per test, and low cost in test machinery [50].

Impact energies were determined according to ASTM standards E-23. By Charpy sub-size test specimens Fig 3.15 on a 300J*2J DMG impact tester pendulum type at velocity 5.24m/s at room temperature. The V-notch impact specimens having a 45^0 notch with 2.5mm depth transverse direction of plates with dimensions 55×10×10 mm. Pendulum type Charpy impact testing machine was employed to estimate the impact strength of the composite.

Three tests were performed for each condition and the results of the impacts were averaged in the units of J. This experiment was worked at Defense university Engineering collage laboratory.

(A) Impact specimens (B) Positioning the specimens in table


(C) Impact test machine (D) The specimens after fracture

Figure 3. 15 Impact test machine and the specimens after the test

The corresponding impact strength for the three different trials and its average values is given in a table. Impact strength is calculated by dividing impact energy in J by the thickness of the specimen. The test result is typically the average of three specimens. ISO impact strength is expressed in KJ/m^2. Impact strength is calculated by dividing impact energy in J by the area under the notch.

Impact strengths was calculated by using equation below [51].

$$IS = \frac{E}{w \times t}$$

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

3.5 Cutting tool material

The main concerns when machining metal matrix composites is the extremely high tool wear due to the abrasive action of the ceramic fibers or particles. Therefore, materials of very high resistance to abrasive wear are often recommended. The HSS tools are inadequate, cemented carbide tools are preferred for rough machining and PCD tools for finish machining operations. The cost of PCD tools increase the cost of production so it is necessary to carryout basic machinability, in this research work for cutting conditions using carbide tools, which can result in high productivity at low cost. The machined surface quality of composites is one of the most important concerns affecting the actual application of the composites [52].

To examine the influence of machining parameters of a surface roughness, experiments carried out by using coated carbide tool as shown in below fig 3. 16.

The tool is inserted into tool holder and the work piece is fixed in the three jaw chuck of a CNC lathe machine. For machining the cutting parameters selected are cutting speed, feed rate and depth of cut.

(a) Carbide cutting tool (b) Carbide cutting tool in CNC lathe machine (c) Tool bit

Figure 3. 16 Cutting tool

3.6 Turning process

Turning is an important machining process in which a single point cutting tool removals materials from the surface of the rotating cylindrical work piece to obtain required shape [53]. To improve productivity of the lathe machined parts is the main challenge of the metal industry. In a turning operation, it is important to select cutting parameters so that better performance can be achieved. The effect of the cutting parameters like cutting speed, depth of cut, and feed rate is reflected on surface roughness and the dimensional deviations in the material.

Turning process is widely used for machining MMCs compare to milling and drilling the reason is for turning process machine tools are inexpensive, tooling is simple and the machining operation easily analyzed, research on machining MMCs with milling is not of the same extent as that of turning [10]. Cutting tool plays a major role as far as machining is concerned, the objective of machining is to produce a product of desired shape and size with required surface quality and finish.

Computer numerical control (CNC) lathe machine was used for experimental study of Al6061-TiB_2 composite. The machine its model is CKE6150. The main technical specifications are reported in Table 3.

Table 3. 3 Main specification CNC machine tool

No.	Description	Dimension
1	Spindle center height	250 mm
2	Power	24KVA
3	Maximum workpiece length	1000mm
4	Power frequency	50 Hz
5	Voltage rating	380 V
6	Full load current	34 A
7	Spindle speed range	45 RPM – 2000 RPM
8	Overall dimension (L*W*H)	2830*1750*1620
9	Machine weight	2600nKg

Figure 3. 17 Photograph image of CNC Lathe Machine

Figure 3. 18 Machining the specimens with CNC lathe machine

In this experiment the turning operation is performed on different parameters by varying the cutting speed, depth of cut, and feed rate. The surface roughness values are measured for the corresponding parameters and the results are studied. For surface finish the value takes four time from each sample. Then from the collected data and responses are analyzed with the help of Taguchi method.

3.7 Design of Experiment

To design the experimental runs it essential to establish levels for each factor. So, in this study, the process parameters (cutting speed, feed rate and depth of cut) are taken at three different levels, as shown in Table 3.18 levels are set based on literature review. Taguchi orthogonal nine array L9 (having nine experimental runs) is designed as tabulated in Table 3.19. In the design of the experiment (DOE), the Taguchi method is mostly used in the optimization of process parameters because it can minimize experimental runs and find out significant factors in a shorter time. Taguchi also minimizes the number of trials in comparison with the other methods by using orthogonal arrays.

Taguchi approach estimates the percent contribution of each factor and predicts the response according to the optimum conditions by analyzing the experimental results and establishing the optimum conditions for a product process [41].

3.7.1 Taguchi Design

Taguchi method is a standard approach for determining the best combination of inputs to produce a product or service. Taguchi concept of robust design states that products and services should be designed so that they are inherently defect free and of high quality. Taguchi approach for creating robust design is a three step method consisting of concept design, parameter design and tolerance design.

Concept design or system design: Concept design is the first step in the Taguchi design which involves both the conceptual and functional design of the product. The conceptual design includes process technology choices and process design choices.

Parameter design: Parameter design includes the selection of control factors and the determination of optimal level for each of the factors.

Tolerance design: Tolerance design is the process of determining the tolerance around the nominal setting identified in parameter design process.

Taguchi method uses a statistical measure of performance known as signal-to-noise (S/N) ratio, which takes into consideration both the mean and the variability and offers three categories of signal to noise ratio as follows [54];

✓ Nominal is the best characteristics,

$$\frac{S}{N} = 10\log\frac{Y^2}{S^2} \qquad 3.1$$

The quality characteristics are continuous and positive (non-negative). It can take value between 0 and - ∞.

✓ Smaller in the better characteristics,

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} Yi^2] \qquad 3.2$$

It is appropriate for surface roughness, tool wear, unit cost etc.

✓ Larger is the better characteristics,

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Yi^2}] \qquad 3.3$$

It is applicable for material removal rate, fuel efficiency, etc.

Where y = observation, n = total number of observation and Yi = i^{th} response,

Y^- = Average observed data and S^2 = the variance of y.

Important machining parameters namely cutting speed, feed rate and depth of cut were considered for experimentation. The base to select parameters for depth of cut was the below table.

Table 3. 4 Work related for selection for depth of cut parameters

Name of Article	Material	Depth of cut input	Optimum depth of cut	Ref. No.
Design, analysis and optimization of brake disc made of composite material for a motor cycle	LM6- TiB2	Depth of cut (0.5,1 and 1.5)	0.5 mm	[31]
Study on machining parameters of TiB_2 reinforced aluminum 6063 composites	Al 6063- TiB_2	Depth of cut (0.25, 0.50 and 0.75)	0.75 mm	[14]
Hybrid aluminum metal matrix composite reinforced with SiC and TiB_2	SiC- TiB_2	Depth of cut (0.5, 0.75 and 1)	0.5 mm	[39]

Optimization of surface roughness in CNC turning of aluminum using ANOVA technique	Al-6061	Depth of cut (0.25, 0.5 and 0.75)	0.25 mm	[40]
Optimization of turning parameters on surface roughness based on Taguchi technique	Al 6063, Al-6061 and Al-6082	Depth of cut (0.3, 0.5 and 0.8)	0.5 mm	[38]
Optimization of CNC Turning Parameters on Aluminum Alloy 6063 using Taguchi Robust Design	Al-6063	Depth of cut (0.5, 1 and 1.5)	0.5 mm	[52]
Multi response optimization of process parameters using Grey Relational Analysis for turning of Al-6061	Al-6061	Depth of cut (1, 1.5 and 2)	1 mm	[55]
Multi-response optimization of machining parameters of turning AA6063 T6 aluminum alloy using grey relational analysis in Taguchi method	Al-6063	Depth of cut (0.1, 0.15 and 0.2)	0.15 mm	[56]
Machinability studies on turning Al-6061 alloy with 10% reinforcement of B_4C on MMC	Al-6061+10% B_4C	Depth of cut (0.5, 1 and 1.5)	0.5 mm	[57]
Performance evaluation of PCD insert 1600 grade on turning of Al-6061 reinforced with 7.5 % ZrB_2 metal matrix composite	Al-6061+7.5% ZrB_2	Depth of cut (0.5, 1 and 1.5)	1.5 mm	[58]
Effect of machining parameters on surface roughness and tool wear for 7075 Al alloy SiC composite	Al 7075 + SiC	Depth of cut (0.5, 1, 1.5and 2)	0.5 mm	[59]
Experimental analysis on surface roughness in turning hybrid metal matrix (6061Al + SiC + Gr) composites	Al-6061+ SiC+ Gr	Depth of cut (0.5, 1, and 1.5)	1 mm	[60]

Experimental investigation and Optimization Of Machining Parameters For Surface Roughness In CNC Turning By Taguchi Method	Carbon steel AISI 1045	Depth of cut (0.5, 1, and 1.5)	1.5 mm	[61]

Table 3. 5 The optimum response number in depth of cut

No.	Optimum	Number of frequency	Order
1	**0.5**	**6X**	**1**
2	0.75	1X	3
3	0.25	1X	3
4	**1**	**2X**	**2**
5	0.15	1X	3
6	**1.5**	**2X**	**2**

Cutting parameter ranges were selected by considering recommended ranges for the inserts and the work piece diameter. From the above literatures the optimum depth of cut was 0.5, 1 and 1.5mm.

Table 3. 6 Literatures for selection of optimum cutting speed

Name of Article	**Material**	**Output**	**Optimum cutting speed**	**Ref. No.**
Optimization of surface roughness in CNC turning of aluminum using ANOVA technique	Al-6061	Cutting speed (1600, 1900 and 2200)	1900 rpm	[40]
Optimization of turning parameters on surface roughness based on Taguchi technique	Al 6063, Al-6061 and Al-6082	Cutting speed (500, 1000 and 1500)	500 rpm	[38]
Optimization of cutting parameters	Al-7050	Cutting speed (500,	500 rpm	[41]

For turning aluminum alloys using Taguchi method		1000 and 2000)		
Multi objective optimization of CNC turning parameters for AA2024 / SiC MMC's using Grey Relational Analysis	AA2024 / SiC	Cutting speed (1000, 1200 and 1400)	1000 rpm	[42]
Optimization of CNC turning parameters on aluminum alloy 6063 using Taguchi Robust design	Al-6063	Cutting speed (800, 1000 and 1200)	1200 rpm	[52]
Optimization of CNC Turning Parameters on Aluminum 7015 Hybrid Metal Matrix Composite Using Taguchi Robust Design	Al-7015+ SiC (17%) + Graphite (3%)	Cutting speed (100, 125 and 150)	150 m/min	[62]
Hybrid aluminum metal matrix composite reinforced with SiC and TiB2	SiC + TiB_2	Cutting speed (60, 90 and 120)	60m/min ≈ $1000rpm$	[39]
Optimization for turning of Aluminum and Titanium di boride cast composites using response surface methodology	LM6- TiB2	Cutting speed (30, 60 and 90)	90m/min ≈ $1500rpm$	[31]
Optimization of machining parameters on temperature rise in CNC turning process of aluminium 6061 using rsm and genetic algorithm	Al-6061	Cutting speed (75, 90 and 105)	90m/min ≈ $1500rpm$	[53]
Machinability Studies on Turning Al 6061alloy with 10 % Reinforcement of B 4 C on MMC	Al-6061+10% B_4C	Cutting speed (60, 90 and 120)	90m/min ≈ $1500rpm$	[57]

Optimum results in cutting speeds

No.	Optimum	Number of frequency	Order
1	**1900 rpm**	**1X**	**3**
2	500 rpm	2X	2
3	1000 rpm	1X	2
4	**1200 rpm**	**1X**	**3**
5	150 m/min	1X	3
6	**1500 rpm**	**3X**	**1**

Cutting parameters and their level for turning are selected based on a literature review. For feed rate, it gives an average number from different related works for the parameters 50 mm/min, 100 mm/min, and 150 mm/mm, respectively.

The selected cutting parameters were shown in Table 3.7.

Table 3. 7 List of parameters and their levels

No.	**Cutting parameters**	**Parameter designations**	**Level**		
			1	**2**	**3**
1	Cutting speed (rpm)	A	500	1000	1500
2	Depth of cut (mm)	B	0.5	1	1.5
3	Feed rate (mm/min)	C	50	100	150

3.7.2 Selection of orthogonal array

The turning experiments were carried out on CNC lathe machine by using cemented carbide cutting tool inserts for machining of aluminum alloy work piece with selected cutting parameters within three levels given in the Table 3.6.

The selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments three factors each at three levels were selected. Now the Degree of Freedom (DOF) can be calculated by the formula as given below [63].

DOF = p* (L – 1) 3.4

Where, DOF = degree of freedom, p = number of factors and L = number of levels

DOF = 3* (3-1) = 6 ≈ L_9

3.5

Table 3. 8 Orthogonal arrays for the three parameter levels

Experimental No.	**Parameter**		
	(A) Cutting Speed	**(B) Depth of Cut**	**(C) Feed rate**
1	Level 1	Level 1	Level 1
2	Level 1	level 2	level 2
3	Level 1	Level 3	Level 3
4	Level 2	Level 1	Level 2
5	Level 2	level 2	level 3
6	Level 2	Level 3	Level 1
7	Level 3	Level 1	Level 3
8	Level 3	level 2	level 1
9	Level 3	Level 3	Level 2

However, the total number of experiments of the orthogonal array should be greater than or equal to the total DOF required for the experiment. Thus, the L_9 orthogonal array has been selected.

Table 3. 9 Experimental layout using an L-9 orthogonal array

No.	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	500	0.5	50
2	500	1	100
3	500	1.5	150
4	1000	0.5	100
5	1000	1	150
6	1000	1.5	50
7	1500	0.5	150
8	1500	1	50
9	1500	1.5	100

3.7.3 Analysis of Variance

Analysis of ANOVA is a statistical method used to interpret experimented data and make decisions about the parameters under study. In this study ANOVA was used to find the effect of cutting parameters (cutting speed, depth of cut and feed rate) on surface roughness of turned samples and material removal rate during turning.

Percentage contribution measures the contribution of each factor under study (cutting parameters in this case) relative to the total sum of squares. From the ANOVA table percentage contribution of each cutting parameter (cutting speed, depth of cut and feed rate) was calculated by the following formula [64].

$$P (\%) = [\frac{SSTR}{SS}] * 100 \qquad 3.6$$

Where SSTR = treatment sum of square, SST = total sum of square and P (%) = percent contribution

In this study ANOVA table was developed for both surface roughness and material removal rate by using Minitab 19 software.

3.8 Surface roughness measurement

Surface roughness is an important measure of product quality in the manufacturing industry. It depends on many parameters such as cutting parameters, machine tools, cutting tools, and work holding devices and it greatly influences the production cost and so the machine tool productivity. The surface finish is used to indicate the smoothness of a surface.

Surface roughness greatly influences the tool production cost and so the machine tool productivity. During machining cutting parameters greatly influence the surface roughness of the machined product. The final product of every machining process needs to have a low surface roughness (high surface finish). Because a good surface finish improves wear resistance, corrosion, and surface strength of the machined product.

In this study the surface roughness of all samples after turning were measured by using surface roughness tester and analyzed by using Minitab 19 software to find the optimum cutting parameter combination which results in good surface finish.

Figure 3. 19 Photograph image of surface finish tester machine model 657111

3.9 Material removal rate determination

Material removal rate (MMR) is the amount of material removed per time unit. It directly determines the productivity of the machining process as it is directly related to the amount of material removed per unit of time. In the machining process, high material removal means the removal of a large amount of material per a given time which maximizes the production rate. But a high production rate only does not mean economic machining because increasing material removal rate usually results in high surface roughness and high tool wear rate which negatively affect the overall economy of the machining process. In this study, the following formula has been used to compute the material removal rate [65].

Understanding of material removal concept in metal cutting is very important in designing process and cutting tool selection to ensure the quality of the product. Material removal rate in turning operation mean volume of material per metal that removed divided with unit time in mm^3/min. for each revolution of the work piece, a ring shaped layer of material is removed.

The aim of manufacturing this metal matrix composite material with low surface roughness and high material removal rate to produce a good quality product at a low cost. The cutting parameters such as cutting speed, feed rate, and depth of cut are very important in the turning process because they directly influence the problem.

The material removal rate is directly calculated from the experimental data. The diameter of the specimen is taken before and after the machining process using a caliper. The difference in the thickness before and after machining time divided by two gives the diameter difference of the specimens. The average diameter gets with the sum of the diameter before and after machining then divide by two. The material removal rate is expressed as the multiplication of phi, average diameter of the specimens, diameter difference, feed and cutting speed, i.e.

$$\text{MRR} = D_{av}(D - d)/2 * f * N \qquad 3.7$$

$$\text{But, Davg} = \frac{Orginal\ Diameter + final\ Diameter}{2}\ ,\ d = \frac{Orginal\ diameter - final\ Diameter}{2} \qquad 3.8$$

$$\text{Then Material removal rate MMR} = \pi \times Davg \times d \times f \times N \qquad 3.9$$

Where: Davg is Average diameter, d half of the difference two diameter, N is cutting speed and f is feed rate.

3.10 Grey relation analysis

The Grey Theory is applied in various filed including manufacturing, process, and operations [55]. Grey system theory is applied for complex problem subjected to complex data.

Steps in Grey relational analysis

1. Data pre-processing
2. Normalizing experimental data in range between zero and one.
3. Deviation sequence
4. Grey Relational Coefficient- calculated from the normalized experimental data it used to express the relationship between the actual and ideal experimental data.
5. Grey Relational Grade- averaging the weighted grey relational coefficients for each performance characteristics.
6. Find out the parameters significantly affecting the process.
7. Finally select the optimal levels of process parameters.

3.11.1 Data preprocessing and Normalizing

Grey data processing must be performed before calculating the grey correlation coefficients [66]. The data to be used in grey analysis must be preprocessed into quantitative data for normalizing raw data for another analysis. Preprocessing raw data is a process of converting an original sequence into a decimal sequence between 0.00 and 1.00 for comparison.

For surface roughness the expected data sequence was smaller-the-better, then the normalization was defined by the "larger-the-better", the equation is

$$X_i\,j\,(R_a) = \frac{Max\ \text{Yi j (Ra)} - \text{Yi j (Ra)}}{\text{Max Yi j (Ra)} - Min\ \text{(Yi j)(Ra)}} \qquad 3.10$$

Expected value of the data sequence, the normalization values for material removal rate which is "larger-the-better" performance

$$X_i\,j\,(R_a) = \frac{\text{Yi j (Ra)} - \text{min(Yi j) (Ra)}}{\text{Max Yi j (Ra)} - Min(yij)\ \text{(Ra)}} \qquad 3.11$$

Where, Yi j (Ra) Coded value of the variable, Max Yi j (Ra) upper limit of the variable and Min (Yi j)(Ra) lower limit of the variable [42].

3.11.2 Deviation Sequence

The next step is to calculate the deviation sequence of the reference sequence using this equation

$$\Delta 0i\,(K) = ||X_0^*(K) - X_i^*(K)|| \quad 3.12$$

$$\Delta \max = \frac{\max\ max}{\forall j\varepsilon i\ \forall k} ||X_0^*(K) - X_j^*(K)|| \quad 3.13$$

$$\Delta \min = \frac{\min\ \ \min}{\forall j\varepsilon i\ \ \forall k} ||X_0^*(K) - X_j^*(K)|| \quad 3.14$$

3.11.3 Grey relation Coefficient (GRC)

The correlation between the best and actual experimental results, is denoted by grey relational coefficients [56]. Which is calculated to express the relationship between the ideal and actual normalized experimental results. Thus, the grey relational coefficient can be expressed as,

$$\zeta_i\,(k) = \frac{\Delta \min + \zeta \times \Delta max}{\Delta 0i\,(k) + \zeta \times \Delta max} \quad 3.15$$

$$0 < \zeta i\,(k) \leq 1 \quad 3.16$$

Where $\Delta 0i\,(k)$the deviation sequence of the reference sequence, ζ is the distinctive coefficient and used to regulate the difference of the relational coefficient. In this work ζ = 0.05 is generally used.

3.11.4 Grey relational Grade

After obtaining the grey relational coefficient, normally the average of the grey relational coefficient is taken as the grey relational grade. The grey relational grade is defined as,

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} i\zeta i\,(k)$$

Where n is the performance characteristics. If the value of the grey relational grade has the larger value, it shows that the concerned parameter combination is very closer to optimum value.

CHAPTER Four: Results and Discussion

This chapter discussed deeply the mechanical properties of the composite specimens by comparing them with other works of literature. The experimental work was conducted to investigate the effect of main machining cutting parameters (cutting speed, feed rate, and depth of cut) on the surface roughness and material removal rate of Al-TiB_2 composite during the CNC turning process. The experiments were carried out on CNC lathe Machine by using a carbide cutting tool. The design of the experiment was used to identify the optimum cutting parameters and the most influential cutting parameters on surface roughness.

In this chapter, the outcomes of the whole experiment were discussed in detail.

4.1 Mechanical property results

4.1.1 Tensile Test

The average tensile test result was 208MPa for the three samples. It is also clear from the tensile test that an increase in the amount of reinforcement increases the yield and ultimate strength. The stress-versus-extension graph was included in the thesis Appendix.

Table 4. 1 Tensile test results

No	Ultimate tensile strength /MPa/	
1	Sample 1	185
2	Sample 2	242
3	Sample 3	195
	Average	208

4.1.2 Hardness Test

In engineering aspect, hardness is important property of material due to resistance to wear. Hardness gives the ability to the material to resist permanent deformation due to application of load. The greater the hardness of the composite, the greater resistance to the deformation. The hardness of the composite is good by comparing from other literatures. For the hardness test, two specimens were prepared; experiment five is higher hardness values from other experiments. From all the average value is taken and presented in table 4.2. The average hardness test result was 74.9 HRH. This significant improvement in the hardness of the composite as compared with the Al 6061 alloy was contributed by the presence and distribution of TiB_2 particles in the matrix. This result shows that as the reinforcement material distribution increased, the hardness also increased. The higher increase in hardness of the Al-6061 matrix alloy can be attributed to the initially soft matrix, where the reinforced particles produce a major effect.

Table 4. 2 Hardness test result of the composite

Hardness Test Result /HRH		
No	**Experiment**	**Result**
1	Experiment 1	74.5
2	Experiment 2	69.7
3	Experiment 3	90.9
4	Experiment 4	60.5
5	Experiment 5	79
Max.		**90.9**
Min.		**60.5**
Av.		**74.9**

4.1.3 Impact Test

The impact test is done in the Aluminum 6061 with 10% of Titanium di Boride composite to check the impact strength of the composite material, here Impact strengths was calculated by using equation 4.1 below [51].

$$IS = \frac{E}{w \times t} \qquad 4.1$$

Table 4. 3 Impact test results

No.	Sample Name	Absorbed Energy in (J)	Raise angle in degree	Impact Strength (KJ/m^2)
1	S1	36.5	62	365
2	S2	25	90	250
3	S3	32	78	320
	Average	31.16		311.67

4.2 Comparison mechanical properties with other literatures

Table 4. 4 Mechanical properties comparison with other literatures

No.	Matrix	Reinforcement (%)	Tensile strength	Hardness Test	Impact Test	Reference
1	Al 6061	TiB_2 (10%)	208 MPa	74.9 HRH	311.67 (KJ/m^2)	**Current**
2	Al 6061	TiB_2 (10%)	190 MPa	87 HRH	9 Impact load (Nm)	[5]
3	Al 6061	TiB_2 (12%)	210 MPa	89.66 VHN	-	[44]
4	Al 6061	TiB_2 (14%)	228 MPa	334 HV	-	[22]
5	Al 6061	TiB_2 (12%)	173.6 MPa	88.6 BHN	-	[26]
6	Al 6061	TiB_2 (12%)	137.6 MPa	72.46 BHN	-	[30]
7	Al 6061	TiB_2 (12%)	130 MPa	77.93 HV	-	[21]

Comparing the above table 4.4 mechanical properties of Al 6061- TiB_2 (10%) composite current thesis and other works of literature. The result shows better tensile strength than from other works. In the hardness test, some are measured by the Rockwell hardness test, and the current composite is normal and more desirable when compared to other reinforcements that content more than 10% of titanium di boride. The Impact test has in most articles that are not done, but as compared to other properties it as well.

4.3 Performance parameters after turning process

Turning process was done on CNC lathe machine at different combination of cutting speed, feed and depth of cut. The diameter of the work piece for experiment work was 20mm and initial pre experiment turning was done to remove any irregularities and create smooth surface for the experiment and so the diameter became 18 mm.

Experiment numbers 1, 2 and 3 were operated by similar cutting speed of 500rpm but, with different feed (50,100, and 150mm/min respectively) and depth of cut (0.5, 1 and 1.5 mm respectively)

Experiment 4, 5 and 6 were operated by cutting speed of 1000rpm but with different feed rate (100, 150 and 50 mm/min respectively) and depth of cut (0.5, 1 and 1.5 mm respectively).

The last three experiment 7, 8 and 9 operated by cutting speed of 1500rpm but with different feed rate (150, 50 and 100mm/min respectively) and depth of cut (0.5, 1 and 1.5mm respectively).

Figure 4. 1 Samples after turning operation

4.3.1 Surface finish

In this experiment, the average surface roughness values (Ra) and S/N ratios were obtained in turning of Al6061 with 10% TiB_2 composite according to the L9 orthogonal array of the Taguchi experiment design method of cutting speeds, depth of cuts and feed rates using coated carbide cutting tools as shown in table 3.7.

The S/N ratios of surface ratio were calculated according to the Taguchi's "the smaller-the-better" quality characteristics by using Minitab 19. The experimental results of surface roughness (Ra) values for each specimen and their mean values are discussed in table 4.5.

In this study, each surface roughness (Ra) value is the average of four trial readings. The mean surface roughness value of each experiment was calculated by adding trial surface roughness values and dividing by the total number of trials. Arithmetic average (Ra) is the average roughness in the area between the roughness profile and the mean line. Surface roughness is by far the most commonly used surface finish parameter. One reason is that it is fairly easy to take the absolute value of a signal and integrate the signal using analog electronics the instrument that contains no digital circuits.

For example the mean surface roughness value of the first experiment was calculated as:

$$Ra1 = \frac{1.67+1.95+2.15+1.91}{4} = 1.92$$

The below result was seen in table 4.5.

Table 4. 5 Surface roughness results for each sample test

No.	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)		Surface roughness (μm)			
					Meas. 1	**Meas. 2**	**Meas. 3**	**Meas. 4**
1	500	0.5	50	R_a	1.67	1.95	2.15	1.91
				R_z	5.63	6.63	5.47	5.05
				R_q	1.53	1.61	1.4	1.4
				R_t	6.4	7.86	8.04	6.14
2	500	1	100	R_a	0.9	0.95	0.98	0.93
				R_z	6.82	7.49	6.86	7.39
				R_q	1.76	1.77	1.70	1.95

				R_t	8.09	11.18	8.37	8.71
3	500	1.5	150	R_a	4.34	4.65	4.53	4.38
				R_z	17.56	15.98	24.43	17.04
				R_q	4.18	3.85	6.12	4.30
				R_t	28.40	23.59	4.3	25.9
4	1000	0.5	100	R_a	1.57	1.17	1.58	1.76
				R_z	11.18	12.37	11.83	12.38
				R_q	2.16	2.76	2.72	2.62
				R_t	14.89	18.87	18.41	19.67
5	1000	1	150	R_a	2.82	2.08	2.42	2.88
				R_z	7.64	10.01	9.13	8.60
				R_q	1.76	2.37	2.10	2.07
				R_t	11.14	12.33	12.31	11.36
6	1000	1.5	50	R_a	1.28	1.22	1.19	1.36
				R_z	11.62	15.39	13.65	12.57
				R_q	2.81	3.52	3.30	3.06
				R_t	15.22	18.45	18.25	20.34
7	1500	0.5	150	R_a	1.90	1.81	2.05	2.00
				R_z	10.07	10.26	11.58	11.09
				R_q	2.33	2.28	2.52	2.52
				R_t	12.32	14.73	14.07	14.41
8	1500	1	50	R_a	0.63	0.95	0.79	0.83
				R_z	4.07	3.88	4.24	3.87
				R_q	0.81	0.82	0.87	0.81
				R_t	5.35	5.35	4.69	5.19
9	1500	1.5	100	R_a	1.21	1.19	1.35	1.22
				R_z	6.24	6.28	6.38	7.34
				R_q	1.45	1.46	1.61	1.51
				R_t	9.59	8.42	9.2	9.24

Table 4.5 shows the value of average surface roughness at each experimental runs. From the table it can be seen that higher surface roughness value (4.475μm) was obtained at

experiment three and the minimum surface roughness value (0.80μm) was obtained at experiment eight. The surface roughness values of the remaining experiment lies in between these two extremes. At the below table that include the average results of the surface roughness and the values of the Signal to Noise ratio of the surface roughness from Minitab 19 software.

Design of experiment was used to analysis of average mean values of surface roughness for each factors i.e. cutting speed (A), feed rate (B) and depth of cut (C). The mean value of surface roughness for each factor which results were listed in response Table 4.6.

The design of the Taguchi techniques provides systematic, easy, and effective techniques for optimization. Depending on the feature type, there are three types of Signal to Noise ratios smaller-the-better, greater-the-better, and the nominal-the-better [67]. For surface roughness it use the smaller-the-better.

Table 4. 6 Surface roughness average result for each experiment

No.	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Average surface roughness (μm)				S/N ratio (dB)
				R_a	R_z	R_q	R_t	
1	500	0.5	50	1.92	6.56	1.5	9.11	-5.6660
2	500	1	100	0.94	11.94	2.56	17.96	0.5374
3	500	1.5	150	4.475	18.75	4.61	20.55	-13.0159
4	1000	0.5	100	1.515	7.14	1.79	9.08	-3.6083
5	1000	1	150	2.55	8.84	2.07	11.78	-8.1308
6	1000	1.5	50	1.2625	13.31	3.17	18.06	-2.0246
7	1500	0.5	150	1.94	5.69	1.48	7.11	-5.7560
8	1500	1	50	0.8	4.015	0.827	5.145	1.9382
9	1500	1.5	100	1.24	10.75	2.41	13.88	-1.8684

In the assessment of machining precision and the surface condition of a machined part, surface roughness plays an important role. For a given cutting tool, machining parameters such as cutting speed, and cutting depth have a major impact on the surface roughness. At low cutting speeds and a high depth of cut and feed rate, the surface roughness value was not good. At the same time, with a high cutting speed and low depth of cut and feed rate, the surface finish value was good.

Table 4. 7 Descriptions of roughness parameters

Roughness Parameter	Descriptions
R_a (μm)	Average roughness
R_z (μm)	Average maximum height of the profile
R_q (μm)	Root mean square roughness
R_t (μm)	Maximum height of the profile

4.3.2 Material removal rate

Material removal rate (MMR) is the amount of material removed per time unit. For this thesis MMR was calculated by equation 3.2.

Material removal rate MMR $= \pi \times \text{Davr} \times f \times d \times N$ 4.2

MRR for the first experiment can be calculated as shown below and the signal to noise ratio was calculated by the larger is the better.

MRR 1 = $\pi \times 17.75 \times 0.1 \times 0.25 \times 500$

= <u>696.68 mm^3/min</u>

Table 4. 8 Calculated material removal rate

No.	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Feed (mm/rev)	D_{avr} (mm)	MRR (mm^3/min)	S/N ratio
1	500	0.5	50	0.1	17.75	696.688	56.86076
2	500	1	100	0.2	17.5	2747.5	68.77875
3	500	1.5	150	0.3	17.25	6093.56	75.69743
4	1000	0.5	100	0.1	17.75	1393.38	62.88136
5	1000	1	150	0.15	17.5	4121.25	72.30058
6	1000	1.5	50	0.05	17.25	2031.19	66.155
7	1500	0.5	150	0.1	17.75	2090.06	66.40319

8	1500	1	50	0.033	17.5	1373.75	62.75815
9	1500	1.5	100	0.066	17.25	4062.38	72.1756

Material volume removal rate is given in Table 4.8, which was calculated by equation 4.2, where cutting speed is in rpm and feed rate is given in mm/min. The result shows that the diameter difference is multiplied by other given values. The result seen was an increase in feed and cutting speed; the removed material also increased.

4.4 Grey relation analysis

Grey Relational Analysis used to determine the optimum condition of various or multi-objective input parameters to obtain the best quality characteristics.

Table 4. 9 Surface finish (Ra) and material removal rate (MRR) results

No.	**Cutting speed (rpm)**	**Depth of cut (mm)**	**Feed rate (mm/min)**	**Surface finish R_a (μm)**	**Material removal rate (MRR) (mm^3/min)**
1	500	0.5	50	1.92	696.6875
2	500	1	100	0.94	2747.5
3	500	1.5	150	4.475	6093.5625
4	1000	0.5	100	1.515	1393.375
5	1000	1	150	2.55	4121.25
6	1000	1.5	50	1.2625	2031.1875
7	1500	0.5	150	1.94	2090.0625
8	1500	1	50	0.8	1373.75
9	1500	1.5	100	1.24	4062.375
Average Performance				**1.839**	**2734.416**

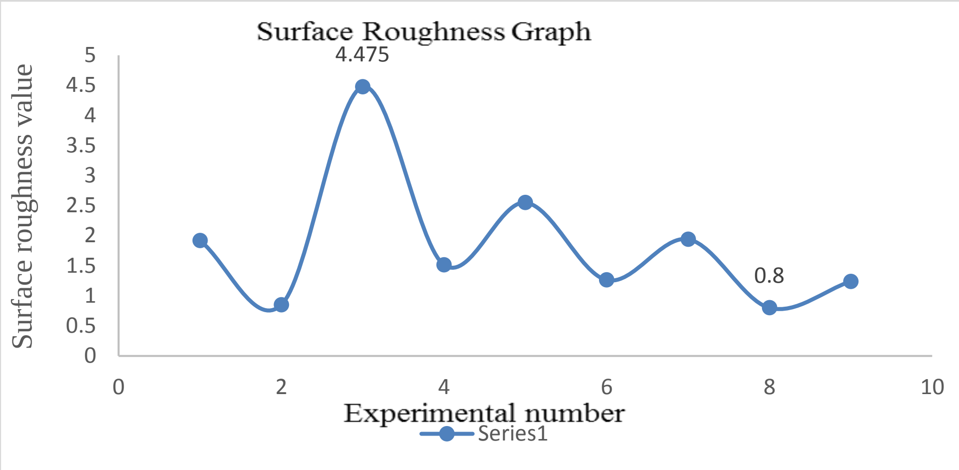


Figure 4. 2 Average Surface roughness value at different experiment

4.4.1 Data preprocessing and Normalizing

Normalization Values was answered in 4.10 table.

Table 4. 10 Normalization Results

No.	Cutting speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Surface finish R_a (μm)	(MRR) (mm^3/min)	Normalization Results	
						Surface finish R_a (μm)	MRR (mm^3/min)
1	500	0.5	50	1.92	696.6875	0.6952	0
2	500	1	100	0.94	2747.5	0.9619	0.3800
3	500	1.5	150	4.475	6093.5625	0	1
4	1000	0.5	100	1.515	1393.375	0.8054	0.1291
5	1000	1	150	2.55	4121.25	0.5238	0.6345
6	1000	1.5	50	1.2625	2031.1875	0.8741	0.2473
7	1500	0.5	150	1.94	2090.0625	0.6898	0.2582
8	1500	1	50	0.8	1373.75	1	0.1255
9	1500	1.5	100	1.24	4062.375	0.8803	0.6236

4.4.2 Deviation Sequence

The deviation sequence is the absolute value of the difference between the reference sequence and the comparability sequence used to calculate grey relational coefficients.

For Experiment 1. Normalization value of experiment was, Ra = 0.6952 and MRR= 0.

Then Exp. 1, Ra $=|1 - \text{Xi (Ra)}|$, MRR $=|1 - \text{Xi (MRR)}|$,

$= |1 - 0.6952|$ $= |1 - 0|$

= 1 = 1

Table 4. 11 Deviation Sequence table for Ra and MRR

No.	Deviation Sequence	
	Surface finish Ra (μm)	**MRR (mm3/min)**
1	0.3048	1.0000
2	0.0381	0.6200
3	1.0000	0.0000
4	0.1946	0.8709
5	0.4762	0.3655
6	0.1259	0.7527
7	0.3102	0.7418
8	0.0000	0.8745
9	0.1197	0.3764

4.4.3 Grey relation Coefficient (GRC)

The grey relational coefficient calculated using eq. (4.8) was given in table 4.12

Table 4. 12 Grey relational coefficient

No.	Grey Relational coefficient	
	Surface finish Ra (μm)	MRR (mm3/min)
1	0.6213	0.3333
2	0.9292	0.4464
3	0.3333	1.0000
4	0.7199	0.3647
5	0.5122	0.5777
6	0.7989	0.3991
7	0.6171	0.4026
8	1.0000	0.3638
9	0.8068	0.5705

4.4.4 Grey relational Grade

The larger the grey relational grade shows the better the multiple performance characteristics [68]. Experiment run two have better output response results followed by experiment three.

Table 4. 13 Grey relational Grade and its order

No.	Grey relational Grade	Order
1	0.4773	9
2	0.6878	2
3	0.6667	4
4	0.5423	7
5	0.5450	6

6	0.5990	5
7	0.5099	8
8	0.6819	3
9	0.6887	1

Based on this orders of grey relational grade as shown in the above table 4. 13, the surface finish and the material removal rate was optimum at cutting speed 1500rpm, depth of cut 1.5mm, and feed rate 100mm/min.

Table 4. 14 Response table for means of GRG

Level	**Cutting Speed**	**Depth of cut**	**Feed rate**
1	0.6106	0.5098	0.5861
2	0.5621	0.6382	**0.6396**
3	**0.6268**	**0.6515**	0.5738
Delta	0.0647	0.1416	0.0658
Rank	3	1	2

Delta values indicate the difference between the maximum and minimum average grade value of each level of the cutting parameter. The value of delta helps to determine the effects of each cutting parameters on responses. The greater delta value holds a significant influence over the response results [69]. Delta is the difference between the maximum mean and minimum mean. As shown in table 4.14 the results of delta value, Depth of cut has significant effects on the GRG followed by feed rate and cutting speed respectively. The highest delta value of average grey relational grade (0.6515) was found at a maximum level of depth of cut. For feed rate, the highest delta value was (0.6396) which has obtained at a medium level of feed rate. While the highest average value of Grey relational grade delta value (0.6268) for cutting speed was obtained at the highest level of cutting speed. Therefore, the optimum cutting parameter level is 1.5mm depth of cut, 100mm/min feed rate, and 1500rpm cutting speed.

4.5 Effect of Cutting parameters

4.5.1 Effect of cutting parameters on surface roughness

From figure 4.3 shows surface roughness increases with increase in cutting speed. Feed rate has negative impacts on the surface quality. Surface roughness increases up to certain values of depth of cut, after that it decreases.

Table 4. 15 Response table of mean for surface roughness

Level	Cutting Speed	Depth of cut	Feed rate
1	2.445	1.792	1.327
2	1.776	1.43	1.232
3	1.327	2.326	2.988
Delta	1.118	0.896	1.757
Rank	2	3	1

As shown in table 4.15 the highest results of delta value for surface roughness was (1.787) which was found with the difference between maximum and minimum level of feed rate. The lowest result was get at the medium level of feed rate the value is 1.232. For cutting speed, the result was get at (1.327) which has obtained at the maximum level. Finally, the result in depth of cut (1.43) was obtained at the medium level.

Figure 4. 3 Effect of cutting parameters on surface Roughness

Figure 4.3 shows the Taguchi result of the main effect plot for means. The minimum point in the graph for each turning parameter is the optimum condition for better surface finish. The minimum point for feed rate is at level two which is equal to 1.232, for cutting speed the minimum point is at level three which is equal to 1.327, and for depth of cut the minimum point is at level two which is equal to 1.43. This shows that the optimum turning parameters for a better surface finish are a medium feed rate, high cutting speed, and medium depth of cut. The optimal cutting parameter levels for optimum surface roughness are 100mm/min feed rate, 1500rpm cutting speed, and 1mm depth of cut.

4.5.2 Effect of Cutting parameters on Material Removal Rate

Figure 4.4 shows that the main effect plots signal to noise ratios of material removal rates at various levels of cutting parameters. Cutting speed has no effect on the material removal rate. The depth of cut and feed rate has direct relations to material removal rates. As the depth of cut increases feed rate also increases in the same way the material removal rate also increases in the same case. The optimal level of material removal rate in high level of feed rate and depth of cut. The optimal level was at cutting speed 500rpm, feed rate 1500mm/min, and depth of cut 1.5mm.

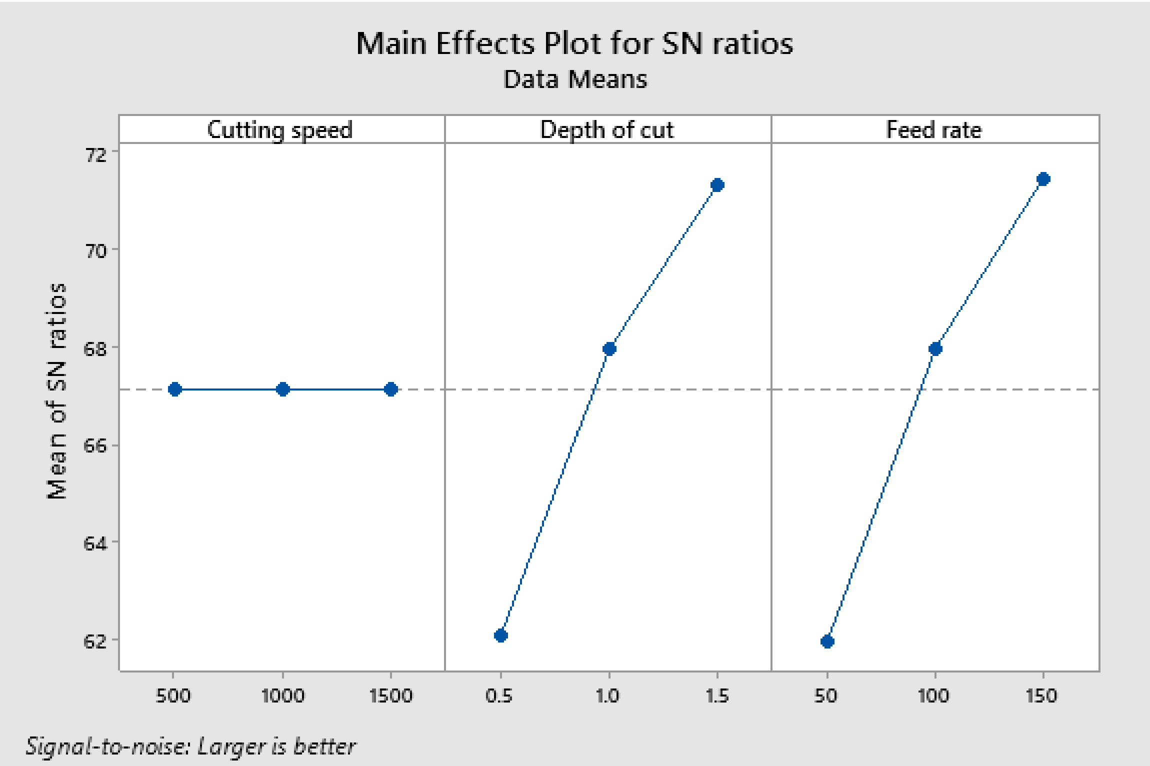


Figure 4. 4 Effect of Cutting parameter on Material Removal Rate

4.5.3 Effect of Cutting parameters on GRG

Fig 4.5 shows the main effect plots for S/N ratios of GRGs. To achieve maximum efficiency with better roughness and material removal rate the optimum cutting parameters are medium cutting speed, high depth of cut, and medium feed rate. This result is also stable with an optimum parameter of GRGs offered in Table 4.14.

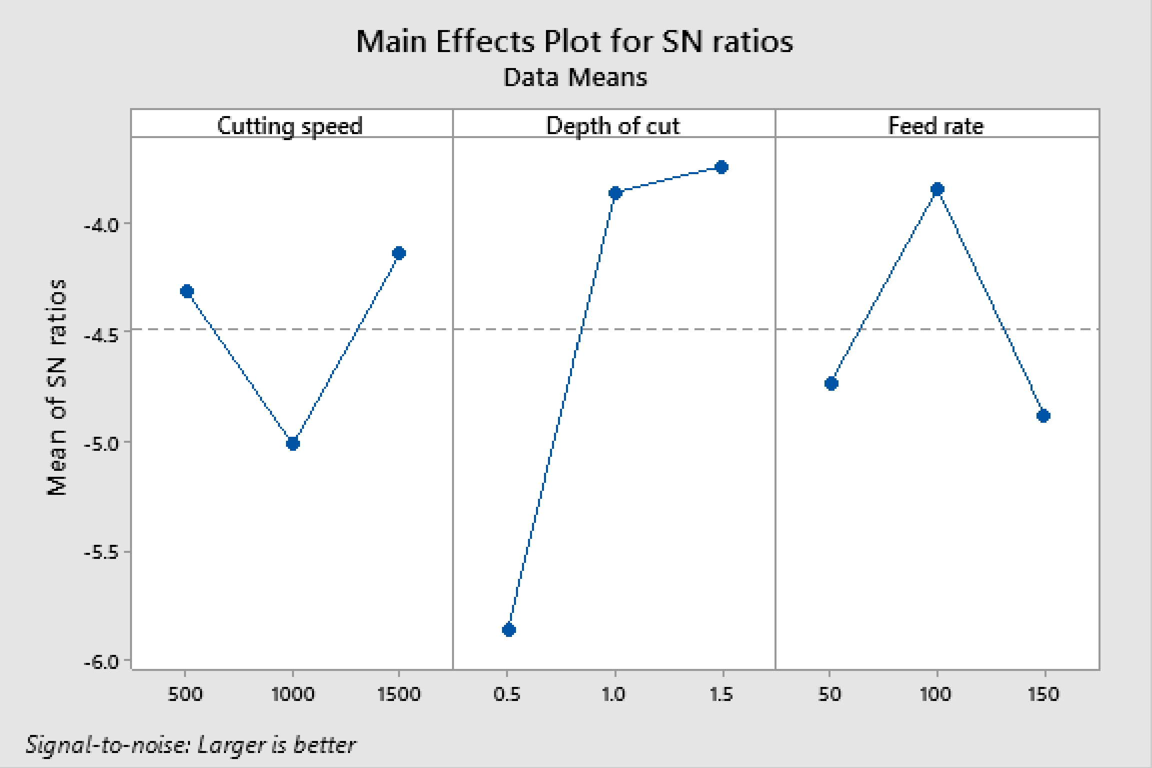


Figure 4. 5 Effect of cutting parameter in GRG

4.6 Interaction Plot for Grey relational Grade

Interaction plots are used to understand the behavior of one variable depending on the value of other variables. Interaction effects are analyzed in regression analysis, DOE, and ANOVA. This blog helped to understand the interaction plots and their effects, and the complications of the designs. But the interaction effects use a hypothesis test to determine whether the effect is statically significant. The plot displayed non-parallel lines that represent random sample error rather than an actual effect. P-values and hypothesis tests sorted out the real effects of the noise. Parallel lines have no interaction occurring. The more nonparallel the lines are, the larger the strong point of the contact. Wider line space indicates significant effects of interactions on the response, while narrow line spaces indicates less significances of parameter interactions [69].

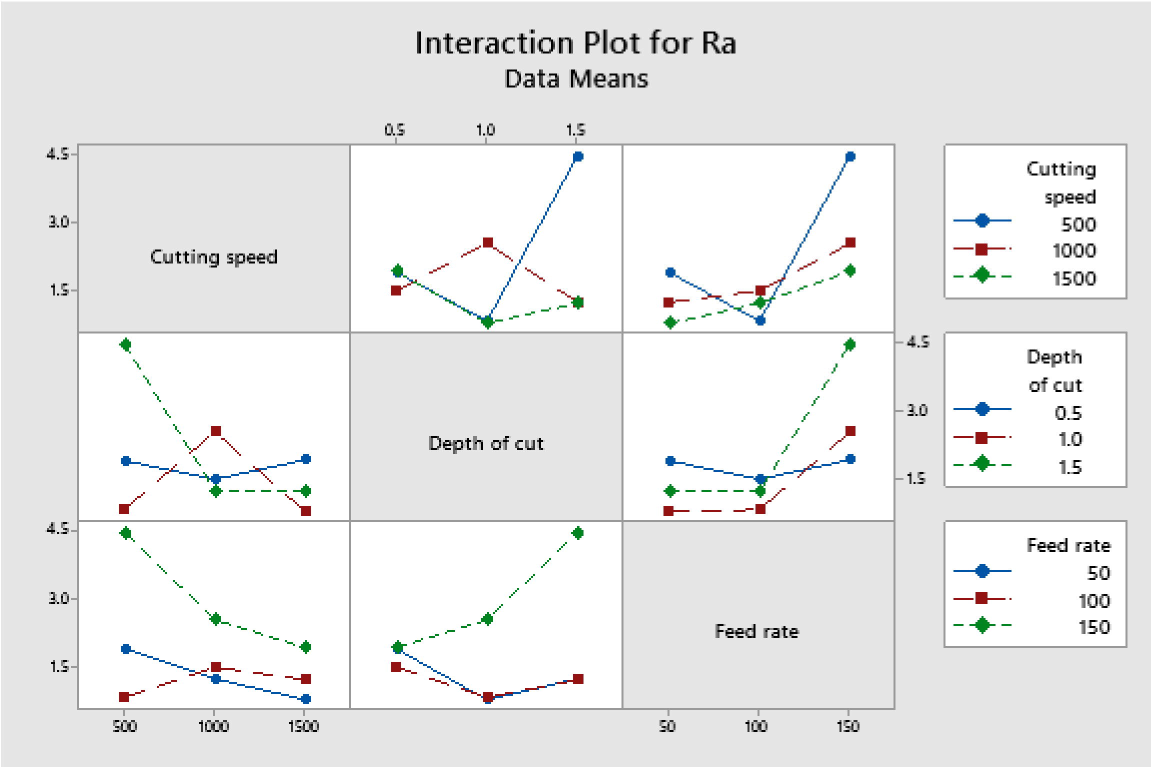


Figure 4. 6 Interaction plot for Surface roughness

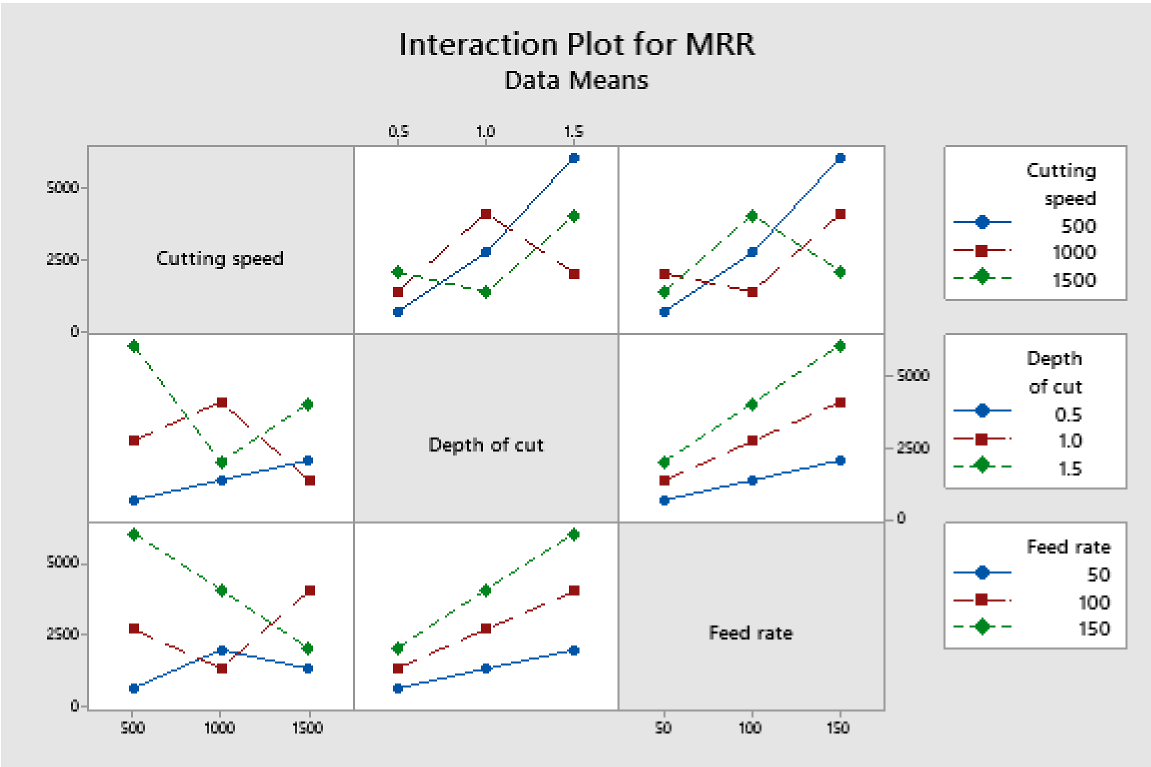


Figure 4. 7 Interaction plot for material Removal rate

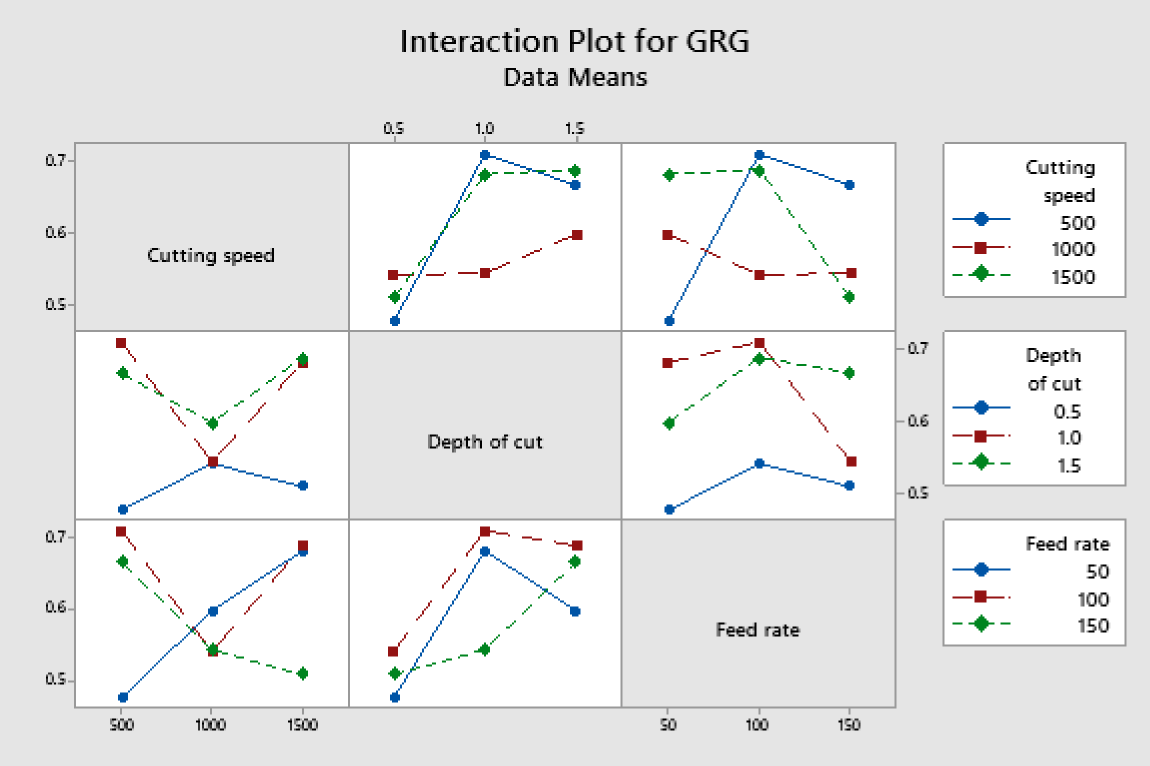


Figure 4. 8 Interaction plot for GRG

4.7 Analysis of Variance

The purpose of the ANOVA is to investigate which factors significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error [70]. The cutting parameters on the response variables i.e. surface roughness, material removal rate. ANOVA was used to investigate and model the relationship between a response variable and independent variables. It was also carried out to verify the factors which are spastically significant at 95% confidence level with the help of the P-value. The P-value which is less than or equal to 0.05 indicates the higher level of significance [67].

The estimated or predicted GRG(Y) at the optimum level of the machining parameter can be calculated by equation [67].

$$Y = Y_m + \sum_{i=1}^{q}(yi - Ym) \qquad 4.10$$

Where Y_m is the mean of GRGs all experimental runs, y_i mean of GRG at the optimal level of i^{th} parameter.

A confidence interval for the predicted mean of a confirmation run is calculated using equation

$$CL = \sqrt{Fa(1, fe)Ve(\frac{1}{neff} + \frac{1}{R})} \qquad 4.11$$

Where $Fa(1, fe)= F0.05(1,2)=18.51$ from (tabulated), $neff = 0.77786, R = 1$ and $Ve = 0.02733$ (mean square error)

The confidence interval of the predicted mean of the confirmation run is ± 0.198.

4.7.1 ANOVA for Surface Roughness

From Table 4. 9 for surface roughness, the feed rate has the maximum influence with 57.65% of contribution, followed by cutting speed 18.71% contribution and depth of cut 12.00% contribution. Other interactions have small effect on surface roughness and the errors only 11.64%. From the results the residual error is less than 15% percent so the outcome is acceptable.

Table 4. 16 ANOVA table for surface roughness

Analysis of Variance							
Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cutting speed	2	1.9	18.71%	1.9	0.9501	1.61	0.383
Depth of cut	2	1.219	12.00%	1.219	0.6093	1.03	0.492
Feed rate	2	5.853	57.65%	5.853	2.9267	4.95	0.168
Error	2	1.181	11.64%	1.181	0.5907		
Total	8	10.154	100.00%				

4.7.2 ANOVA for material Removal rate

Table 4.13 presents the percentage contribution of effect on material removal rate. It was clearly observed that the Feed rate contributes 47.36%, Depth of cut 45.12% and Cutting speed 3.76% have important influence on material removal rate. The cutting speed has minimum significance in material removal rate.

Table 4. 17 ANOVA table for Material removal Rate

Analysis of Variance							
Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cutting speed	2	890509	3.76%	890509	445255	1	0.5
Depth of cut	2	10686112	45.12%	10686112	5343056	12	0.077
Feed rate	2	11215552	47.36%	11215552	5607776	12.59	0.074
Error	2	890509	3.76%	890509	445255		
Total	8	23682682	100.00%				

4.7.3 ANOVA for GRG

Depth of cut has greater significant effects on the Grey relational Grades (GRG) followed by feed rate and cutting speed. The results shows that Depth of cut 65.26% contributions, feed rate 13.05% contributions and Cutting speed 12.09% contributions. The percentage of error is 9.59%.

Table 4. 18 ANOVA table for GRG

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cutting speed	2	0.006804	12.09%	0.006804	0.003402	1.26	0.442
Depth of cut	2	0.036714	65.26%	0.036714	0.018357	6.8	0.128
Feed rate	2	0.007339	13.05%	0.007339	0.003669	1.36	0.424
Error	2	0.005398	9.59%	0.005398	0.002699		
Total	8	0.056254	100.00%				

4.8 Optimum parameter

A grey relational grade obtained from the grey relational analysis was used to optimize the process parameters of machining Al-6061 with 10% TiB_4 composite. The optimum level of cutting parameters were cutting speed 1500rpm, Depth of cut 1.5mm and feed rate 100mm/min. The results tabulated in table 4.19.

Table 4. 19 Optimum Result

Experiment No.	**Cutting speed (rpm)**	**Depth of cut (mm)**	**Feed rate (mm/min)**	**Surface finish R_a (μm)**	**Material Removal Rate (MRR) (mm^3/min)**
9	1500	1.5	100	1.24	4062.375

Using Grey relational analysis optimal setting of process parameters for performance characteristics is $A_3B_3C_2$. Corresponding predicted values are confirmed experimentally. Surface roughness (1.24 μm) is achieved with a material removal rate of (4062.375mm^3/min). The average grey relational analysis using Taguchi method depth of cut followed by feed rate and depth of cut are most influential factors for surface roughness and material removal rate in turning process.

CHAPTER Five: Conclusion, Recommendation and Future Work

5.1 Conclusion

Aluminum 6061 with 10% Titanium di boride reinforcement was fabricated by using the stir casting method. The mechanical properties of the composite tensile test, hardness test, and impact test were evaluated experimentally. The resulting processes are optimized using the ANOVA technique for minimizing the component factors. The following conclusions are drawn:

- ✓ Al 6061 with 10% TiB_2 is fabricated by using the stir casting method; the stir casting method is a good fabrication process for metal matrix composites. By using a scanning electron microscope, the morphology of TiB_2 was checked; its shape was irregular, and the size was observed up to 200X magnification.
- ✓ Al 6061 with 10% TiB_2 has a mechanical property i.e. tensile test (208MPa), hardness test by Rockwell hardness tester the results was (74.9HRH), and finally the Impact result was (311.67KJ/m^2).
- ✓ In CNC turning of Al 6061-TiB_2 composite the minimum surface roughness (0.8µm) was obtained at higher cutting speed 1500rpm, medium depth of cut at 1mm and low feed rate 50mm/rev.
- ✓ Maximum material removal rate (4.475mm^3/min) was obtained at low cutting speed 500rpm, high depth of cut 1.5mm and high feed rate 150mm/min.
- ✓ From the analysis of variance (ANOVA) for surface roughness it was found that the feed rate contribution percentage of 57.65%, cutting speed 18.71% and Depth of cut 12.00% have significant influence on the surface roughness. This shows feed rate is the most significant factor on surface finish. Other interactions have small effect on surface roughness and the errors only 11.64%. From the results the residual error is less than 15% percent so the outcome is acceptable.
- ✓ From the analysis of variance the contributions for maximum material removal rate was feed rate 47.36%, depth of cut 45.12% and cutting speed 3.76%. This result shows that cutting speed has a lower effect on material removal rate than the other cutting parameters.

- ✓ The ANOVA Grey relational grade of the combination result shows that Depth of cut 65.26% contributions, feed rate 13.05% contributions and Cutting speed 12.09% contributions. The percentage of error is 9.59%.
- ✓ The optimal combination process parameters for the work piece under consideration with minimum surface finish and maximum material removal rate was obtained at cutting speed 1500rpm, depth of cut 1.5mm, and feed rate 100mm/min.
- ✓ Generally increasing feed rate, depth of cut and cutting speed increases material removal rate which increases production rate but also increase risk of deterioration of surface quality.

5.2 Recommendations

When conducting a turning operation for the machining of Al-TiB_2 composite higher cutting speeds, a higher depth of cut, and a medium feed rate of the cutting parameters are recommended to achieve better machined surface quality and higher material removal rate simultaneously.

5.3 Future Work

There are a lot of machining parameters that have significant influence in machining of Al 6061- TiB_2 composite. Some of suggested future works which could not addresses in this works are listed below.

- ✓ This study was limited in surface finish and material removal rate. So for future which needs a study about chip morphology
- ✓ In this study the machinability of Al 6061-TiB_2 composite has been studied, this can be further extend other response parameters like machining time and tool rear rate.

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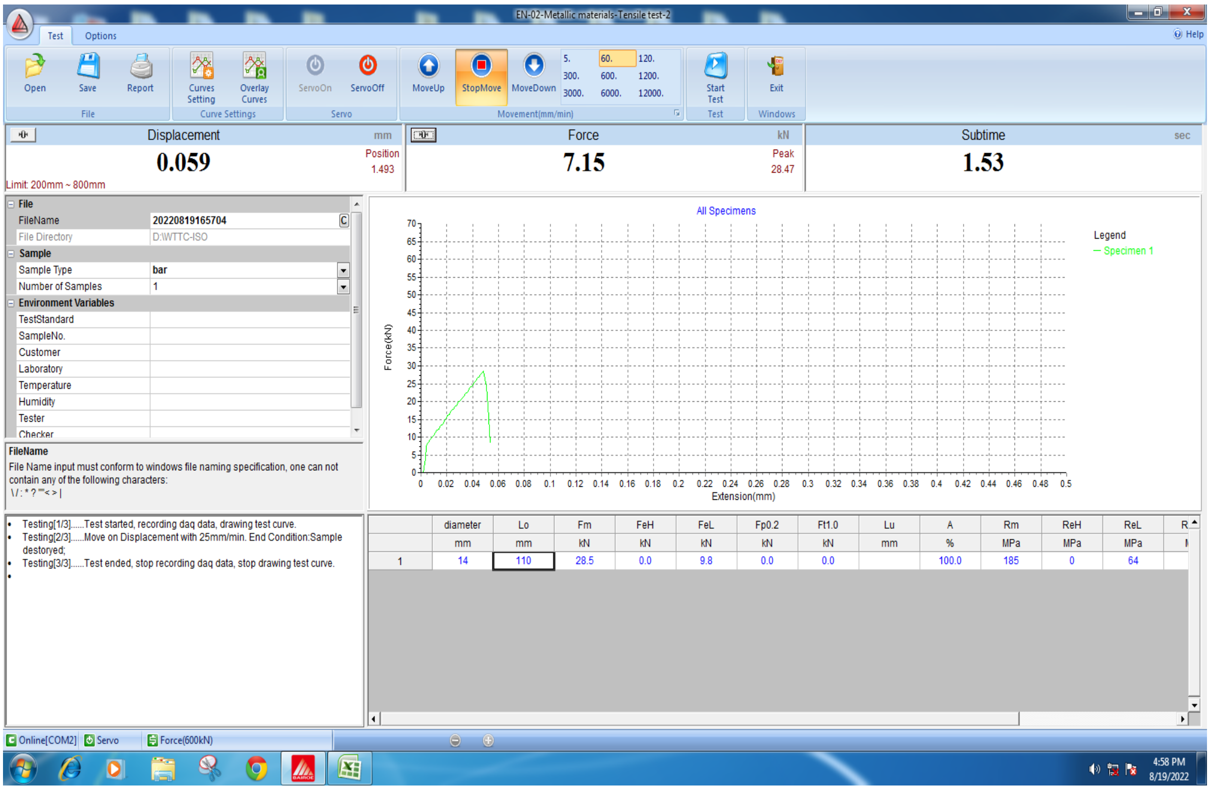
APPENDIX A: Chemical composition of Al6061 result (wt. %) In Spectrometer

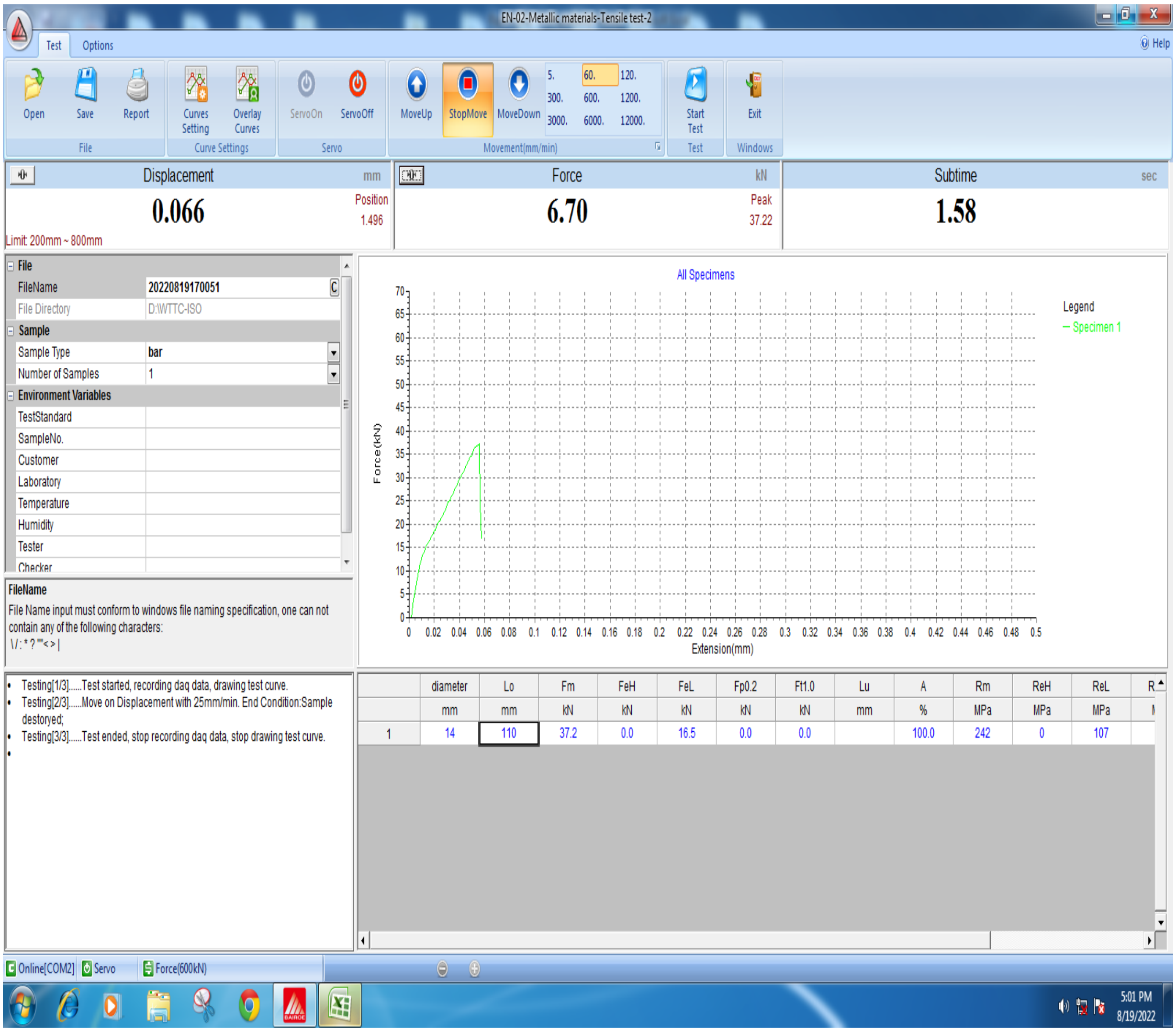
Average	Element	Burn 1	Burn 2	[illegible] 3	Burn 4	Burn 5	Burn 6
98.02	Al %	99.06	99.09	93.83	99.04	99.05	
0.0134	Si %	< 0.0020	< 0.0020	0.0670	< 0.0020	< 0.0020	
0.803	Fe %	0.0655	0.0721	> 3.00	0.0993	0.0976	
0.269	Cu %	0.183	0.196	0.585	0.191	0.192	
0.0843	Mn %	0.0738	0.0744	0.123	0.0763	0.0739	
0.385	Mg %	0.390	0.321	0.532	0.362	0.322	
0.0566	Zn %	0.0281	0.0336	0.155	0.0271	0.0395	
0.162	Cr %	0.130	0.132	0.285	0.133	0.132	
0.0049	Ni %	< 0.0030	< 0.0030	0.0246	< 0.0030	< 0.0030	
0.0091	Ti %	0.0061	0.0075	0.0148	0.0085	0.0086	
< 0.0005	Be %	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	
0.0120	Ca %	< 0.0005	< 0.0005	> 0.0250	< 0.0005	< 0.0005	
0.0049	Li %	0.0048	0.0048	0.0055	0.0048	0.0048	
0.0191	Pb %	< 0.0050	< 0.0050	0.0929	< 0.0050	< 0.0050	
0.0167	Sn %	< 0.0050	< 0.0050	0.0837	< 0.0050	< 0.0050	
0.0032	Sr %	0.0032	0.0031	0.0035	0.0032	0.0031	

Appendix B: Tensile test result graph

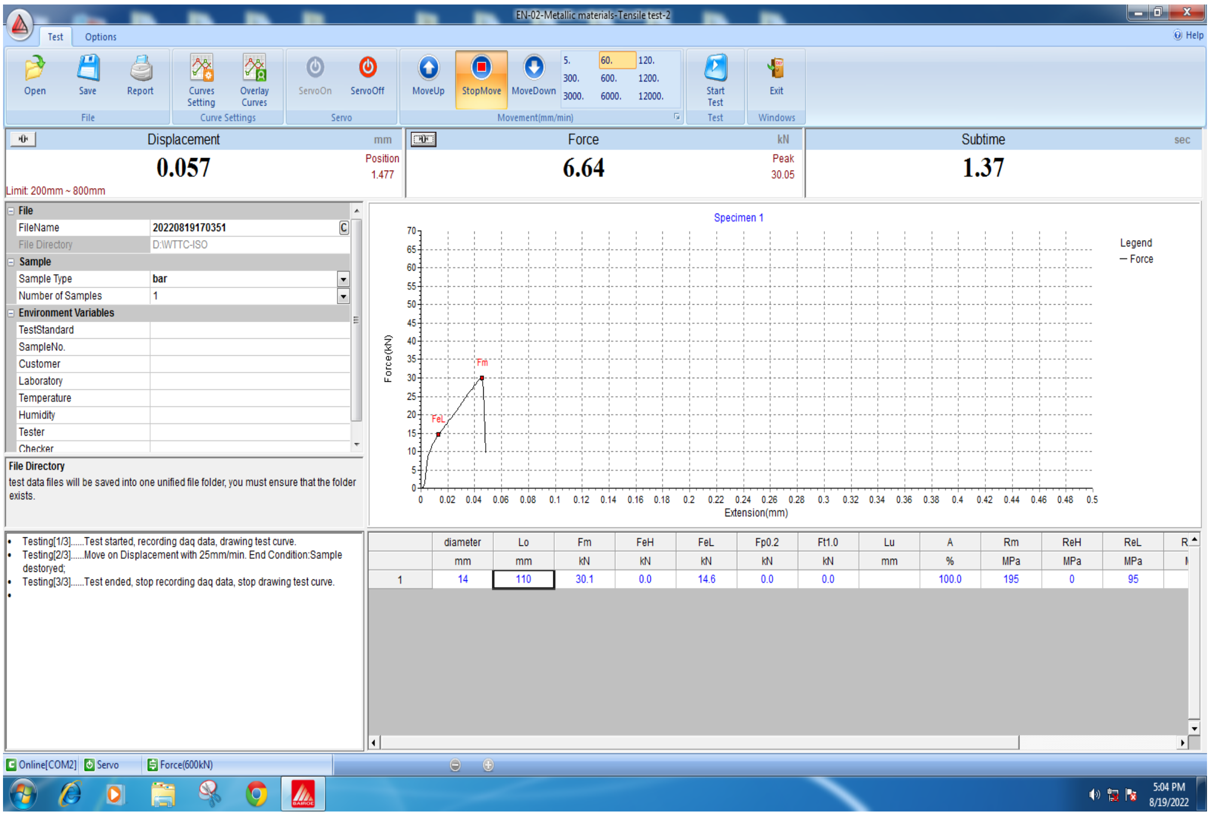
Sample 1



Sample 2


EN-02-Metallic materials-Tensile test-2
Displacement
0.066
Force
6.70
Peak
37.22
Subtime
1.58
All Specimens
Force(kN)
Extension(mm)
Legend
Specimen 1
FileName
20220819170051
Testing[1/3].....Test started, recording daq data, drawing test curve.
Testing[2/3].....Move on Displacement with 25mm/min. End Condition:Sample destoryed;
Testing[3/3].....Test ended, stop recording daq data, stop drawing test curve.
diameter 14
Lo 110
Fm 37.2
FeH 0.0
FeL 16.5
Fp0.2 0.0
Ft1.0 0.0
A 100.0
Rm 242
ReH 0
ReL 107

Sample 3


EN-02-Metallic materials-Tensile test-2
Displacement
0.057
Force
6.64
Peak
30.05
Subtime
1.37
Specimen 1
Force(kN)
Extension(mm)
Testing[1/3].....Test started, recording daq data, drawing test curve.
Testing[2/3].....Move on Displacement with 25mm/min. End Condition:Sample destoryed;
Testing[3/3].....Test ended, stop recording daq data, stop drawing test curve.

Appendix C: Hardness Test Result