PARAMETRIC OPTIMIZATION OF DRY TURNING OF Al6061-T6 ALLOY USING CNC MACHINE WITH CEMENTED CARBIDE TOOL

By: Lemlem Seboka Edecha

A Thesis Submitted To: The Department of Mechanical Engineering

School of Mechanical, Chemical and Material Engineering

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

Office of Graduate Studies

Adama Science and Technology University

January, 2024

Adama, Ethiopia

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DECLARATION

I declare that this thesis entitled ‘‘Parametric Optimization of Dry Turning of Al6061-T6 Alloy Using CNC Machine with Cemented Carbide Tool’’ is my own work and has not been submitted to any university for similar purpose. The references used in this thesis is duly recognized by proper citations.

Lemlem Seboka______ _______________ _____________

Name of student signature date

RECOMMENDATION OF ADVISORS

I, the advisor of this research, hereby certify that I have closely advised the student while developing this research and read the draft thesis entitled ‘‘Parametric Optimization Of Dry Turning of Al6061-T6 Alloy Using CNC Machine With Cemented Carbide Tool’’ prepared under my guidance by Lemlem Seboka Edecha. Therefore, I recommend the submission of the thesis to the department for further review and evaluation

Dr. Guteta Kabeta________________ ______________

Advisor Signature Date

APPROVAL SHEET

I, the advisors of the thesis entitled ‘‘Parametric Optimization of Dry Turning of Al6061-T6 Alloy Using CNC Machine with Cemented Carbide Tool’’ and developed by Lemlem Seboka Edecha, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Guteta Kabeta	________________	______________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Lemlem Seboka Edecha have read and evaluated the thesis entitled ‘‘Parametric Optimization of Dry Turning of Al6061-T6 Alloy Using CNC Machine With Cemented Carbide Tool’’ and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering

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ABSTRACT

In any machining process, it is most important to determine the optimal machining parameters to achieve the desired product quality. Therefore, it is essential to investigate the effect of cutting parameters on surface roughness in a machining operation to accomplish the desired quality of an item. In this research, optimization of effect of cutting parameter (cutting speed, feed rate and depth of cut) on output response variables such as surface roughness, tool wear, MRR and cutting temperature during dry turning of Al6061-T6 alloy by using CNC machine. The tool insert used in this experiment was cemented carbide. The specimen used was an Al6061-T6 alloy specimen that was 340mm long and 38mm in diameter. The Taguchi L9 orthogonal array was selected for the experiment design, and optimization based on signal-to-noise ratio has been applied. The analysis of variance (ANOVA) was found which parameters significantly affect the quality characteristic Surface roughness, cutting temperature and tool wear was measured by Vogel surface roughness tester, infrared thermometer and optical microscope respectively. Optimization of the turning parameters for lower tool wear, cutting temperature, surface roughness and higher material removal rate simultaneously using grey relational analysis (GRA). Analysis of variance shows that cutting speed was the most significant parameter followed by feed rate and depth of cut, affecting surface roughness by 61.23%, 18.89% and 15.4% respectively at the confidence level of 95%. Feed rate had a significant effect on the material removal rate (63.75%), followed by depth of cut and cutting speed at percentages of contribution of 30.1% and 3.12% respectively. The lower tool wear 0.051mm was obtained at high value of cutting speeds of 191 m/min, medium feed of 0.15mm/rev, and low depth of cut of 0.2 mm. The highest temperature (45.30°C) was observed for higher cutting parameter. The highest value of GRG was obtained with input parameters of feed 0.25 mm/rev, speed 191 m/min, and depth of cut 0.2 mm.

Keywords: *Dry machining, Aluminum6061-T6, ANOVA, Taguchi S/N-based optimization, tool wear, surface roughness, gray relational analysis*

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ABBREVIATIONS AND ACRONMYS

ANOVA	Analysis of variance
CNC	Computer Numerical Control
CVCF	Commercial vegetable cutting fluid
BUE	Build-up edge
d	Depth of cut
DOE	Design of experiment
DoF	Degree of freedom
F	Feed rate
GRG	Gray relational grade
HSS	High Speed Steel
MQL	Minimum Quantity Lubrication
MRR	Material removal rate
MSS	Mean sum of square
N	Spindle Speed
OA	Orthogonal Array
PVD	Physical Vapor Deposition
Ra	Average Surface roughness
RSM	Response surface methodology
SD	Standard deviation
S/N	Signal to noise ratio
SST	Total sum of square
SSTR	Treatment sum of square
T	Depth of cut
VB	Flank wear
v	cutting speed

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Machining is the commonly used method of all manufacturing technologies that involves the cutting metals to obtain the desired geometry with accurate dimensional tolerances and proper surface finish. Surface finish is one of the most important quality characteristics in manufacturing industries, which influences the performance of mechanical parts as well as production cost. In recent times, modern industries are trying to achieve high-quality products in a very short time with less operator input. For that purpose, the computer numerically controlled (CNC) machine tools with automated and flexible manufacturing systems have been implemented. In the manufacturing industries, various manufacturing processes adopted to remove the material from the work piece (Akhtar et al., 2021b). Out of these, turning is the most common method for metal cutting because of its ability to remove materials faster with reasonably good surface quality. Turning is the most common lathe machining operation. During the turning process, a cutting tool removes material from the outer diameter of a rotating workpiece. The main objective of turning is to reduce the workpiece diameter to the desired dimension. There are two types of turning operations, rough and finish. Rough turning operation aims to machine a piece to within a predefined thickness, by removing the maximum amount of material in the shortest possible time, disregarding the accuracy and surface finish. Finish turning produces a smooth surface finish and the workpiece with final accurate dimensions (Javidikia *et al.*, 2020).

Turning is a type of machining operation that involves a cutting tool removing material from a workpiece while it rotates around an axis. This operation is performed on a turning machine or lathe, a specialized tool that accommodates various geometries and materials. With turning, operators can achieve a good surface finish and manufacture parts with high tolerances. It’s a process that allows for the creation of internal and external surfaces, even contoured ones, with unparalleled precision (Abas *et al*., 2020a).

In a turning operation, it's a crucial task to select cutting parameters for achieving high cutting performance. Usually, the specified cutting parameters are determined by supported experience or by the use of a handbook. Cutting parameters are reflecting in surface roughness, surface texture and dimensional deviations of the product. Surface roughness which used to determine and evaluate the quality of a product is one of the main quality attributes of a turning product. Surface roughness is a measure of the technological quality of a product and an element that greatly influences manufacturing cost(Singh, 2021).

1.2 Overview of Surface Roughness

Surface roughness is the quantitative approach of determining the smoothness of a surface by measuring the height of peaks and depth of valleys over a fixed length and its important factor that determines the quality of a machined surface. The smoothness of a machined surface is determined by many factors such as cutting condition, machine tool vibration, cutting tool and work holding devices and cutting parameters (Sarker *et al*., 2018)

Surface roughness is a significant assess of component quality as it has a significant influence on the machining of components and production costs. Some analysis reveals that the surface factor is most vital need, along with geometric and dimensional aspects. In many machining operations, different parameters that affect the measured responses have been found. Choosing a high-speed CNC manufacturing process means lower costs, better performance and better quality also increased productivity with maximum production accuracy. In order to manufacture a quality product at lesser cost, all manufacturing enterprises are looking for lower roughness, tool wear and higher material removal rate. All measured outputs are the most important in the production process that should be considered. Therefore, the appropriate selection of technological parameters is imperative because they affect directly to the production process (Soren *et al.*, 2019).

However, the study and optimization of surface roughness is not as easy as determining any other variable. The study of surface Roughness is harder to achieve as it depends on both controllable and uncontrollable factors. The controllable variables include tool rake angle, feed rate, spindle speed, depth of cut etc. while wearing of tool, material friction, tool degradation etc. factors are much harder to control. Surface roughness of a machined product could affect several of the product’s features such as surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue(ADEDEJI *et al*., 2021).

Factors affecting surface roughness: whenever two machined surfaces come in contact with one another, the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the workpiece(He *et al*., 2018, Tulasi *et al.*, 2018) depend upon a number of factors such as:

(1) Vibrations;

(2) Material of the workpiece;

(3) Type of machining;

(4) Rigidity of the system consisting of machine tool, fixture cutting tool and work;

(5) Type, form, material and sharpness of cutting tool;

(6) Cutting conditions (machining parameters) i.e., Feed, speed and depth of cut

(7) Type of coolant used and

(8) The tool geometry.

(9) Some geometric factors which affect achieved surface finish which includes:

a) Nose radius b) Rake angle c) Side cutting edge angle, and d) Cutting edge.

Dry turning

Nowadays the use of cutting fluid in metal removal processes has lessened owing to its impact on the environmental, health hazards to the operator and stringent disposal procedures. Considering these drawbacks, industries are attempting to perform machining operations without cutting fluid called as "dry cutting". Dry cutting is exclusively used in industries namely automotive, aerospace, defense and marine industries (Mohan *et al.*, 2021). During dry cutting, the tool and the work material is subjected to increased friction and, subsequently rise in temperature at tool and work material interface. Dry turning is a machining operation in which work materials are machined using single point cutting tool (Dhanalakshmi and Rameshbabu, 2021).

Dry machining is applicable with regards to ecological advantage, as countries compel their industries to use mechanisms and legal guidelines for environmental safety and for their workers' safety and health regulations. They are safe for machinists and workshop people's health, no damage to body and is allergic reaction free, reduce thermal shock as a result offer improved tool life. Moreover, it removes cost of lubricant that have huge costs for machining (Yu et al., 2019).

Aluminum 6061-T6

Aluminium alloys are alloys which has Aluminium as the major or predominant metal. The common alloying elements are zinc, silicon, magnesium, iron, copper, tin and manganese. These additional elements to Aluminium enhance the workability, electrical conductivity, corrosion resistance and strength (Seçgin *et al.,* 2021). Aluminum alloys have high demand in many engineering applications because of their excellent mechanical properties. Any production activities can perform with main objectives of good surface quality and higher production rate. Metal machining process output is highly dependent on input variables, since small variations in one of the input variables results in a considerable change in the output variables (Gopal, 2021).

Aluminum 6061-T6 is a sub-category of the 6061 alloy, one of the most widely used aluminum alloy. Its gained widespread acceptance with in the fabrication of lightweight structure requiring a high strength- to -weight ratio and good corrosion resistance with great formability and weld ability. Some its application area air craft and aerospace industries, welded assemblies, marine frames, chemical equipment, electronic parts, fasteners, heat exchangers etc. Mayén *et al*. (2017). But on the other hand Al 6061 shows machining challenges on the base performance criteria like metallurgical aspect, chip formation, cutting tool wear, fatigue crack growth, lubrication strategy and formation of built up edge (BUE)and built up layer (BUL). Dry machining is applicable with regards to ecological advantage, as countries compel their industries to use mechanisms and legal guidelines for environmental safety and for their workers' safety and health regulations. They are safe for machinists and workshop people's health, no damage to body and is allergic reaction free, reduce thermal shock as a result offer improved tool life. Moreover, it removes cost of lubricant that has huge costs for machining(Yücel *et al.*, 2021).

Application of Al 6061-T6 alloy

Aluminum Sample Pack Round Bar 6061-T6 offers an inexpensive way to make sure you get the correct material for your project. 6061 is the most commonly used aluminum alloy in the world due to its positive characteristics. It is typically used in aerospace, automotive, cameras, couplings, marine hardware, electrical components, decorative hardware, structural applications, pins, brakes, pistons, valves, and bicycle frames (Gupta *et al*., 2023).

Automotive and aircraft alloys: In aerospace, 6061 aluminum bar was used for structural components, landing gear parts, and aircraft fittings, ensuring reliable performance even under extreme conditions. Aluminum such as 6111 is extensively use for the exterior or body panels of automotive. The automotive frames are produced from 5754 and 5182 aluminum formed sheets, 6063 or 6061 extrusion. Frames, wheels pistons, wheel hubs, cylinder heads and cylinder block are often made of aluminum 6061(Shin *et al*., 2017).

Marine application: Marine applications benefit from the corrosion-resistant properties of 6061 aluminum, making it suitable for boat fittings, marine hardware, and offshore structures such as piston, pistons, cylinder head, manifolds etc. Aluminum alloys are employing in the construction of boats and ships, other salt water-sensitive shore and marine application. These alloys are 6061, 6063, 5052, 5059, 5083, and 5086 aluminum alloys are used for that application (Park *et al*., 2015).

1.3 Research motivation

Surface quality has a great impact on dry turning performance because it improves corrosion resistance, fatigue strength, and creep life. The surface quality of the machined product is also one of the most specific customer requirements in machining, and it is critical to the growth of supplier competitors in the market.

In any manufacturing industries surface quality of machined product plays a vital role to increase the customers demand and the competitiveness between the manufacturers. Without surface quality it is difficult to talk about high production rate, long life of product without defect, crack formation and corrosion resistance. Surface roughness also affects many functional aspects of parts, such as coating, surface friction, and wear, the ability to disperse and hold lubricant, light reflection, load-bearing capacity, and fatigue resistance. Tool wear is another factor that affects surface quality, tool life, as well as end up wasting money. The only resolution to resolve this problem from root was by investigating a method to resolve those opposing problems at the same time and specify freedom for machinists and process engineers to prefer optimal input parameters. Therefore, the above reasons are the basic drivers of this work's inspiration.

1.4 Problem of Statement

Machining is one method of producing parts that are applicable in many machinery components and industries. The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of workpiece dimensional accuracy, surface roughness, tool wear, cutting temperature, high production rate (material removal) and increase the performance of the product with reduced environmental impact. Setting optimum condition such as cutting parameters (spindle speed, depth of cut and feed rate) are main challenges in machining industry which need experimental investigation. In turning, higher values of cutting parameter offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality, higher cutting temperature and shorter tool life, if there are improper process parameters is used.

Aluminum alloy 6061-T6 is widely used in various industries due to its excellent mechanical properties, including high strength, good corrosion resistance, and good weldability; it is difficult-to-machine material due to its low thermal conductivity and high chemical reactivity with cutting tools. Many people say that the desired cutting parameters are determined based on experience or by using a manufacturer's handbook, but this does not ensure that the selected cutting parameters gives optimal or near-optimal cutting performance. Furthermore, optimization of machining cutting parameters of machining aluminium materials are crucial to achieve good surface finish, improve cutting efficiency (minimum tool wear, low cutting temperature) and increase productivity.

1.5 Objectives of the study

1.5.1 General objective

The general objective of this thesis is parametric optimization of dry turning of Al 6061-T6 alloy using CNC machine with cemented carbide cutting to achieve the optimum machining condition.

1.5.2 Specific objectives

The specific objectives are;

1. To optimize the influence of cutting parameters on surface finish during dry turning process of dry turning of Al 6061-T6 alloy.
2. To evaluate material removal rate for different cutting parameters of dry turning of Al 6061-T6 alloy.
3. To analyze cutting tool wear for different cutting parameters of dry turning of Al 6061-T6 alloy.

4. To optimize the effect of cutting temperature for different machining parameters of dry turning of Al 6061-T6 alloy.

1.6 Significance of the study

This thesis mainly concentrates on studying effect of cutting parameters that affects surface finish, cutting temperature and tool wear during dry turning of Al 6061-T6 alloy is very important to produce high quality products and to obtain longer tool life. Presence and absence of cutting fluid have a great effect on general product qualities and tool life. This study will also be important to obtain optimum cutting parameters that produce high surface finish in dry turning. This dry turning operation aimed for reduce machining cost, for protecting the environment and health of the workers. Therefore, it has crucial benefits academically and practically for individual and other stakeholders. It adds more knowledge to the pre-existing researches on Al 6061-T6 alloys and their specific application on parts of aircraft, aerospace and marine manufacturing industries (pistons, valves, Frames, wheel hubs, cylinder heads and cylinder block).

1.7 Scope of the study

The scope of this study highly focused on experimental analysis of cutting parameter for surface roughness during dry turning on CNC of Al 6061-T6 alloy. This research work includes; investigate the variation of surface roughness with varying parameters. conduct experimental optimization of CNC dry turning, wear test, measure surface roughness and cutting temperature, optimize and identifying the most significant cutting parameters at which better surface finish is achieved during turning of Al 6061-T6 alloy.

1.8 Limitation of Studies

- This study is limited to: The scope of this study highly focused on experimental analysis of cutting parameter for surface roughness during dry turning of Al6061-T6 alloy by using a single cutting tool on the CNC lathe machine.
- Optimize and identifying the most significant cutting parameters at which better surface finish is achieved during single tool turning of Al6061-T6 alloy without considering

cutting tool geometry were studied, because considering the simultaneous effect of cutting parameters and tool geometry is very complex.

- The effect of cutting force and machine vibration on the surface roughness was not included because of difficulties to measure cutting forces without dynamometer and difficulties to measure vibration frequencies.

1.9 Structure of the Thesis

The thesis consists of five chapters that entitled in the experimental investigation and parametric optimization of dry turning of al6061-t6 alloy using CNC machine.

Chapter one: begins with an introduction, in which the background of the study is briefly pointed out, and definition, fundamental principles, machining process, and others.

Chapter two: A review of relevant research publications in the investigation to find out the cutting parameters on surface roughness, material removal rate, tool wear, and cutting temperature in a turning operation was presented. Available investigation of cutting parameters on surface roughness in turning operation models was studied to find the research gap in this chapter. The need for developing a new investigation of cutting parameters on surface roughness in turning the operation of Al 6061-T6 alloy has been justified.

Chapter three: discusses the materials and methodologies used in this research study. This includes detailed information about the workpiece and cutting tool used machines and equipment used, and the experimental procedure followed.

Chapter four: the main results of experimental studies and predictions was presented together with a detailed discussion. This chapter examines the effects of cutting parameters (spindle speed, depth of cut, and feed rate) on surface roughness, material removal rate, tool temperature and tool wear. Confirmation experiments are conducted to verify the results.

Chapter five: summarizes the optimization research work completed in this investigation, and future research directions are discussed.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Machinability is a term that describes the ease with which the material removal process can be conducted irrespective of machining type being considered. Machining is a general term that considers certain parameters usually described as output responses. In metal removal process, the output responses are mainly affected by appropriate choice of cutting parameters, so determining optimum cutting parameters is must to enhance surface quality, increase productivity and reduce machining cost (Srivastava *et al*., 2021c). To overcome this, many researchers have gone to a great length to conduct how these cutting parameters affect those output response, and suggest points at which optimum values were found. In this chapter, related literature studies on various topics on dry and the effect of cutting parameters on surface finish, tool wear, cutting temperature, and surface roughness were undertake in subsections.

2.2 Dry turning

Dry machining is a machining process without the use of any cutting fluid during machining. According to (Soren *et al.*, 2019) metal fabrication industries are compelled to consider dry machining to enforce environmental protection laws for occupational safety and health regulations. The advantages of dry machining include non-pollution of the atmosphere (or water); no residue on the chip which reflected in reduced disposal and cleaning costs and no danger to health. Moreover, it offers machining cost reduction. But, in dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which causes higher temperatures, higher wear rates, and consequently, shorter tool life.

Javidikia *et al.* (2021) conducted experimental study using a statistical analysis tool on surface roughness obtained when turning AA6061-T6 under different environment (MQL, DRY and WET). Their results showed that feed rate was the most significant parameter on surface roughness (R_a) and the maximum height of the profile (R_t) for all the modes. Moreover, the optimization results showed that the feed rate in all the three modes approached its lowest value in the DOE equal to 0.07 mm/rev. They conclude that the smallest surface roughness parameter was achieved using DRY. (Khettabi *et al.*, 2017) machining performance is evaluated according cutting force, particle emission and the surface finish. Their experimental results showed that the MQL milling is interested in terms of force or surface finish but if the particle emission considered the dry machining is better.

Namlu *et al.* (2019) investigate machining of aluminum 6061 alloy under different conditions of dry, wet and MQL coolant/lubricant using HSS end mills. The resultant cutting forces were 48% lower than the dry condition and 44% lower than the wet condition. When compared to dry and wet conditions MQL cutting condition were founded to be best and more reliable condition because it is environmentally friendly, gives better surface finish and lower cutting forces. Pratheesh *et al*. (2019conducted optimal cutting parameters for machining AA6063 aluminium alloy of dry turning on a CNC machine. In this study following parameters like speed, feed and depth of cut was selected. ANOVA result shows that the influence of depth of cut is very high in obtaining the surface roughness of the finished product. From optimization the Spindle speed 1600 rpm, depth of cut 0.20 mm, feed 0.15 mm/rev is selected as the best design parameters by which we can obtain good surface finish. The optimized experimental runs show a much improved process performance. From optimization the Spindle speed 1600 rpm, depth of cut 0.20 mm, feed 0.15 mm/rev is selected as the best design parameters by which we can obtain good surface finish.

2.3 Effect of Cutting Parameters on Surface Roughness

Cutting speed: the cutting speed for aluminum alloys is determined by the workpiece and the limits of the machine tools. In experimental equipment and aerospace application, speeds up to 4600 m/min have been used (Soren *et al*., 2019).However, due to the limitation of caused by the spindle speed and the horsepower available, and also the parts dynamic balance, machining speed is rarely higher than 900 m/min and are often less than 300 m/min in some cases. In machining, cutting speed should be optimized to prevent time wastage and to reduce the temperature rise in the machined part. When the cutting speed increases from 30 m/min to 60 m/min, there is the possible reduction of build-up edge formation on the cutter, chips are likely to break more readily and improved finishing Samuel *et al.* (2021).

Cutting depth: The depth of cutting should be as large as possible taking into consideration the part strength, power of machine tool, chucking equipment and the quantity of stock to be removed to reduce the possible number of cuts. Cutting force increase as the cutting depth increases. The depth of the cut must be of limited value, to avoid distortion, slopping of the workpiece and unnecessary overloading of the machine (Soren *et al.*, 2019). In roughing, the cutting depth can be as high as 6.35 mm for small work. It can be as high as 38.10 mm for large and medium work. However, the depth of cut less than 0.635 mm is often recommended at the opposite end in finishing. At all time, all the cutting tools should be kept sharp and in good condition. The geometry of the tools must be carefully maintained within the required and standard requirement for aluminum alloys. Cutters are required to have the optimum flute numbers and standard spiral configuration for any application. In most applications, coarse spiral and a minimum number of flutes are more desired. Frictional heating and rubbing results from clogging and these can be reduced by ensuring that the flutes maintain a good surface finishing(Samuel *et al*., 2021).

Feeds and speeds: Feed usually depends on the rigidity and strength of the machine, the workpiece and also on the desired finishing. Light feed ranging from 0.05 to 0.15 mm/rev is required for finishing cuts while rough cuts may employ a feed ranging from 0.15 to 2.03 mm/rev. Correct feeds and speeds are required for any operation being carried out(Samuel *et al.*, 2021). High spindle speeds combined with slow feed rate can be seriously troublesome. Care must be taken in order not reduce feed below what is required especially when the cutter is tending towards or machining areas that require section changes. On pieces of equipment with multiple spindles, it is important to have enough net horse available to each of the spindles during heavy cuts (Struzikiewicz and Sioma, 2020).

Cutting force: At low speeds ranging from 30 to 60 m/min, aluminum alloys cutting for can widely be varied. The speed rises momentarily to peak values many times above the normal. The cutting force at higher speeds increases slight during the machining of some aluminum alloys such as 2011-T3 alloy but decreases for most alloys. The general effect of speed on cutting force is usually small. Increasing the cutting speed to about 300 m/min changes the cutting speed slightly. Above 300 m/min, the effect of speed is negligible. More heat is not produced as a result of the increase in speed, but the available time for removing the heat from the tool is shortened. Heat does not have any significant effect on the surface of high speed tools until the speed is above 215 m/min. These tools can be used for speeds beyond this limit, but for long tool life, carbide tools are recommended Samuel *et al.* (2021).

Support and clamping methods: The machine fixtures and support must be firm and have enough contact area and mass, to provide sufficient heat absorption capacity. The workpiece must be properly clamped to avoid part distortion or vibration. Any resulting deeper cuttings due to poor rigidity of the work could produce overheated areas. It is vital that the edge seal of the flat parts that being machine on vacuum chucks be positioned neatly the periphery to eliminate gapping and vibration at the outer edges(Junge *et al.*, 2022).

ADEDEJI *et al*. (2021) optimize cutting and cutting tool parameters as well as cutting tool parameters during turning operation of Al-Si alloy. The optimum setting of the control factors by main effects plots was found to be first level of speed (350 m/min), first level of Feed (0.200mm/rev), and first level of Depth of cut (0.2mm). This result is ideal when the prime requirement is to minimize surface roughness while machining Aluminum-Silicon alloy. As indicated by main effect plots for S/N ratio, the ideal conditions for least surface roughness (R a) are speed at level 2 (470 m/min), feed at level 2 (0.225 mm/rev), and depth of cut at level 3 (0.6 mm). El-Axir *et al.* (2017) study influence of turning variables and tool overhang on surface roughness parameters and residual stress induced to a 6061-T6 aluminum alloy due to machining. The surface roughness parameters was most affected by feed rate for different levels of tool overhang, speed and depth of cut, the average surface roughness considerably increases with an increase in feed rate.

Analysis and multi-response optimization of cutting process parameters of Aluminum alloy 6026-T9 in MQL and dry conditions. The type of insert used was a tungsten carbide, while the coolant was minimum quantity lubricant(MQL) vegetable oil (olive oil) performed at 150mL/hr. Based on analysis of variance (ANOVA) it is identified that the most significant cutting process parameters for surface roughness profile (Ra, Rq, Rz) under both dry and MQL conditions are the feed rate, while for the tool life are cutting speed and feed rate and for material removal rate is cutting speed followed by depth of cut and feed rate. However for MQL condition are cutting speed of 500m/min, the feed rate of 0.4mm/rev, depth of cut of 2mm, and positive rake angle of 15◦ (Abas *et al.*, 2020b).

Chauhan and Singh (2016) optimize cutting parameters during turning of aluminium alloy AA6063-T6 using tungsten carbide insert. The cutting parameters are nose radius, spindle speed, feed rate, and depth of cut. Based on the S/N analysis, the optimal process parameter for surface roughness are as follows: Nose radius level 4, spindle speed level 2 feed rate levels 1, and DOC at level 4, N4-S2-F1-D4.In single optimization technique for Ra the prediction result value 0.2508 µm and experiment result value 0.3014 µm. It is evident that the Nose radius is the most significant parameter for surface roughness in ANOVA study. 4-The highest S/N ratio in predicted result indicates that the optimization model is adequate.

Measurement of surface roughness is a crucial task in many engineering applications. It is a crucial quality attribute that may dominate the functional requirements of many components. It is an important factor in determining the quality of a machined surface. Cutting condition, vibration of the machine tool, cutting tool, and work holding mechanisms are some factors which affect surface roughness (Ulas *et al.*, 2020). To determine the effects of surface roughness and how they relate to the experimental parameters, a range of statistical studies were carried out. In those cases, a good result was obtained. Surface roughness is a property which defines the surface texture of a machined part (Aslantas *et al.*, 2020). This is an important output response to be studied because it shows the deviation of the machined surface from work piece material specifications.

2.4 Analysis of tool wear and cutting temperature

Wear can be defined as the damage or removal of material that a solid surface has undergone due to sliding, rolling, or impacting against another solid surface. It is not a material property, but rather a system response. Typically, wear is undesirable as it can lead to increased friction, and ultimately to material failure or loss of functionality. Thus, in order to reduce wear (and consequently friction) a thin film of lubricant is inserted between the rubbing surfaces (Pattnaik *et al*., 2018).

According to (Groover, 2020) tool life is defined as the length of cutting time that the tool can be used. Operating the tool until final catastrophic failure is one way of defining tool life. However, in production, it is often a disadvantage to use the tool until this failure occurs because of difficulties in re-sharpening the tool and problems with work surface quality. As an alternative, a level of tool wear can be selected as a criterion of tool life and the tool is replaced when wear reaches that level. Machining operations like turning, drilling, milling is accomplished using cutting tools. There are three possible modes by which a cutting tool can fail in machining process due to different conditions, which described as follows.

Fracture failure: this mode of failure occurs when the cutting force at the tool point becomes excessive, causing it to fail suddenly by brittle fracture.

Temperature failure: this failure occurs when the cutting temperature is too high for the tool material, causing the material at the tool point limit. In all machining processes, tool wear is a natural phenomenon, and it leads to tool failure. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality(Batista *et al.*, 2019). To effectively and safely machine these materials, high performance cutting tools that high hardness, high hot strength and high toughness are required coating technologies have developed rapidly to produce several types of coated tools for machining lighter nonferrous material such as Al 6061. Coating provided better results like longer tool life and better surface finish (Soren *et al*., 2019).

Tool wear always used as a lifetime criterion since it is easy to determine quantitatively.

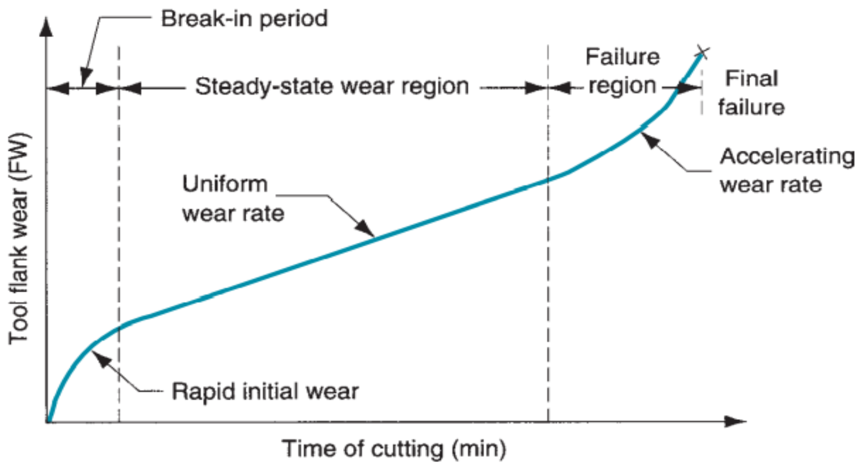


Figure 2. 1 Tool wears as a function of cutting time

Groover (2020)

Taylor tool life formula is as follows;

$$VT^n = C \qquad (2.1)$$

Where

- V is the cutting speed (m/min),
- T is the tool life (min)

- n is an exponent that depends on the cutting parameters and
- C is a constant.

The values of 'n' and 'C' depend mainly upon the tool work materials and the cutting environment (cutting fluid application).

According to the original Taylor tool life formula, the cutting speed is the only parameter that affects the life of the cutting tool. This is because this formula was obtained using high-carbon and high-speed steel tool material. With the further development of carbides and many other tool materials, it was found that the cutting feed and the depth of the cut are also significant (Groover, 2020). As a result, Taylor's tool life formula was modified to accommodate these changes as follows:

$$VT^n f^n t^b \tag{2.2}$$

Where t is the depth of cut (mm) and f is the feed (mm/rev). The exponents n, a, and b are to be determined experimentally for each of the cutting conditions.

Gutema *et al.* (2022)Studied critical machining properties and the experimentation to predict temperature rise using Al 6061 workpiece material and Al_2O_3 carbide coated cutting tool. The interaction effect diagram of RSM methodology revealed that cutting speed is the most significant factor, followed by rate of feed, cutting depth, and tool nose radius. multi-response optimization by desirability analysis shows that the minimum value of temperature rise parameters are 98.0 m/min cutting speed, 0.258 mm rate of feed, 0.893 mm cutting depth, and 0.84 mm tool nose radius. Usca *et al.* (2022) they conduct three different C/L conditions (cryo-LN_2, MQL and dry for 5140 steel, which is frequently use in gear manufacturing. They conclude determined a parallel relationship between surface roughness, flank wear, and cutting temperature. Experiment with cryo-LN_2 (Vc: 75 m/min and f_d: 0.15 mm/rev), the lower cutting temperature resulted in less cutting tool wear and, therefore, a higher surface quality.

Akgün and Kara (2021) focused on cutting force (F_c) and analysis of machined surface in CNC turning of AA 6061 alloy with uncoated and PVD-TiB_2 coated cutting inserts under dry cutting conditions based on Taguchi L18 array. The tool wear examination, a tendency to build up (BUE) formation was observed, and it was determined that it decreased with increasing cutting speed. Gupta *et al*. (2019) studied machining performance of Al 7075-T6 alloy, hybrid cooling and lubrication methods are applied to investigate the behavior of surface roughness and tool wear. Their experimental results showed that the tool wear can be reduced by 101–118% by using the right-most (cooling- lubrication) C/Ls and cutting parameters. Compared to the severe abrasion found in dry cutting, the N_2MQL and R-N_2MQL have reduced abrasion and existence of BUE over the tool rake surfaces results extending tool life. Akhil *et al.* (2016) investigate effects high cutting temperature are; rapid tool wear, formation of BUE, rapid corrosion, Induction of tensile residual stresses and micro cracks at the surface and sub surfaces which leads to dimensional inaccuracy and shorten tool life. They investigate that the optimum condition for obtaining maximum surface finish, with least rise in temperature at tool tip, is high cutting speed with low depth of cut and medium feed rate.

Debnath *et al.* (2016) Investigate influence of cutting fluid conditions and cutting parameters on surface roughness and tool wear in CNC turning process using Taguchi method out on mild steel bar using a TiCN + Al_2O_3 + TiN coated carbide tool insert. Cutting speed (43.1%) and depth of cut (35.8%) were the dominant factors influencing tool wear. However, application of cutting fluid (13.7%) showed a considerable contribution, while the feed rate gave the least contribution to tool wear. The optimum cutting conditions for desired surface roughness and tool wear were at a high level of cutting speed, medium level of depth of cut, low level of feed rate and low-flow high-velocity (LFHV) cutting fluid flow from the selected levels. According to Ahmad (2013) machining without the use of any cutting fluid so called dry machining is becoming increasingly more popular, especially in machining Al 6061 for the automotive application. This study deals with experimental investigation on the effect of dry machining on the tool wear by doing the comparative dry machining experiments using five commercial coated carbide available inserts: 3 PVD coated carbide inserts and 2 CVD coated carbide inserts. The results showed that the CVD coated carbides inserts have shown lower tool wear when compared to PVD coated carbide inserts.

Pan *et al.* (2021) study surface integrity of turned 6061 aluminum alloy using liquid nitrogen as cooling medium reduce the surface roughness, restrain the residual tensile stress and improve the surface micro hardness. Machining using cutting fluids has the advantage of better part quality and less tool wear. Yücel *et al.* (2021) focused on AA 2024 T3 Al alloy machined and various machinability indicators such as surface roughness, surface topography, maximum temperature and dominant tool wear mechanism under different cooling/lubrication strategies. Compared to dry machining, the base fluid MQL implementation helps to decline cutting temperature by

10.21%, while the MoS_2Nanoparticles doped MQL decreased the cutting temperature by 22.44% on average. The formation of BUE was significantly eliminated during NFMQL cutting. A less damaged cutting edge was obtained under NFMQL compared to both dry cutting and MQL environments.

2.5 Material removal rate (MRR)

Material removal rate (MRR) is the amount of material removed per time unit when performing machining operation. It is the indicator of how efficiently you are cutting and how profitable you are (Abas *et al.*, 2020b). The material removal rate to find out by using following relation:

$$MRR = V_C * V_f * d \tag{2.3}$$

Where V_c - cutting speed, V_f -are feed rate, d-Depth of cut

Parthiban *et al*. (2017)investigate experimentally the effect of Spindle speed, Feed rate and Depth of cut on the MRR and Surface roughness in Turning of AA 6061-T6. The Depth of cut plays a dominant role, this indicates that the high Spindle speed and minimum Depth of cut to achieve small surface roughness and Maximum MRR. When the process parameters, such as spindle speed, feed rate, and depth of cut, maintained at 1100 rpm, 1.16 mm/min, and 2 mm, the minimum Surface roughness and maximum MRR obtained from the study were 0.3879 m and 0.2926 mm, respectively. Warsi *et al.* (2019) determine optimum machining parameters during high-speed turning (up to 1500 m/min) of Al 6061 T6 alloy. The chosen machining parameters optimize the trade-off between three competing responses: specific cutting energy, material removal rate, and surface roughness. Analysis of variance results revealed cutting feed to be the most significant machining parameter affecting multi-objective function, followed by cutting speed and depth of cut. The proposed machining parameters resulted in reduction of specific cutting energy by 5% and an improvement of 33% in material removal rate while surface roughness remained unaffected.

Singh *et al.* (2017)study the effect of input parameters i.e. spindle speed, feed rate and depth of cut of aluminum alloy 6351 on the surface roughness and material removal rate by using Taguchi technique. Feed (P=0.055) is the most effective parameter on the surface roughness followed by speed (P=0.552) and depth of cut (0.963) being recorded as the least effective parameter. Also feed (P=0.005) have greatest impact on material removal rate, further speed (P=0.010) makes the second largest contribution and depth of cut (P=0.233) shows the least contribution towards material removal rate. It is observed that feed rate is the most influencing factor for metal removal rate (MRR) and surface roughness followed by depth of cut and speed. Srivastava *et al*. (2021a) optimize input process parameters of the turning process in the machining of Aluminum 7075-T651 with a tungsten carbide insert. The input machining parameters are cutting speed, feed, and depth of cut for the output response parameters cutting force, feed force, radial force, material removal rate, and surface roughness of the workpiece. For the cutting force the optimal setting is the speed at 715 rpm, feed rate at 0.08 mm/rev, and depth of a cut at 0.1 mm. For radial force the optimal setting is the speed at 715 rpm, feed rate at 0.08 mm/rev, and depth of a cut at 0.5 mm. For the MRR, the optimal setting is the speed at 715 rpm, feed rate at 0.12 mm/rev, and depth of a cut at 0.5 mm. For the surface roughness, the feed is the most significant factor with the contribution of 26.60%, followed by the speed with 17.74% contribution.

2.6 Optimization Techniques

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

2.7 Design of Experiment

Taguchi method is one of the easiest statistical approaches to optimization of input parameters for the determination of the optimum outputs. Taguchi method is one of the important tools used in the industry to shortage product design, develop time and produce lower product costs. In the Taguchi approach, optimization, data analysis and the prediction of the optimum results are provided by the objective function, which is called signal to noise ratio (S/N). Signal factors represent system control inputs. Noise factors represent variables, which are expensive or difficult to control Akhtar *et al.* (2021b). The S/N ratios generally used are: the nominal the better, the-lower-the-better and the-larger-the-better. Different parameters affect the response to a different degree. Using analysis of variance (ANOVA) the relative effect of the different parameters is determined. S/N ratio and ANOVA provide determining of the optimum cutting parameters for the response (Bindhushree *et al*., 2021). Taguchi design of experiments converts the usual design into a robust design. This design allows understanding and providing the interaction of factors affecting the output parameters. Taguchi analysis uses orthogonal array (OA) of experiments that give set of appropriate number of experimental trials. These orthogonal arrays reduce the number of trial experiments (Abas *et al*., 2020a).

2.8 Summary of Literature Review

For a variety of materials, many researchers have identified the optimum cutting parameter; however, the same methodology has not yet employed. According to the literature reviewed above and summarized in, most researchers focused on determining how cutting speed, feed rate, tool geometry, and depth of cut affect surface roughness, material removal rate, cutting temperature, cutting force, and tool wear when turning various materials under various conditions (dry, minimum quantity lubrication (MQL) and wet).

2.9 Grey relational analysis

S/N ratio method is adopted for optimization of turning parameters for single objective response variable. In many cases, objective of some response variables may be maximum or minimum value. In the present study, higher MRR is required to achieve maximum productivity, whereas lowest cutting force, tool wear, machining temperature and surface roughness are required for better service life of the finished component. To address this issue, multi-objective optimization techniques are necessary to satisfy all response variables objective with optimal parameters conduction. Grey relational analysis (GRA) is the multi-objective response optimization technique, which developed by Deng in 1989 (Khan et al., 2020). GRA commonly used for calculating the performance of variability of complex optimization problems with insufficient data. In the GRA, compare the original sequence and comparable sequence with the help of grey relational grade.

The influence of the cutting parameters while turning aluminum 7075 is known through ANOVA and Grey relational analysis. The maximum material removal rate, minimum tool wear and surface roughness are selected as the quality targets. The percentage contribution of cutting speed at stage 1 is ranked one because of its high influence over material removal rate, tool wear and surface roughness. From the response table of the Grey relational analysis, speed is the strongest factor among the other parameters used on the multi performance characteristics. The optimal combination of machining parameters is v1, f1, d2. This study effectively accomplished the grey relational analysis for optimum machining parameters for the turning operation of Aluminum(Sharma et al., 2021). Experimentations are conducted on CNC Spinner Lathe machine. AISI 4340 steel is selected as workpiece material. Three different types of Cutting tool are considered for the study. Grey Relational Analysis and Taguchi Philosophy together are used to optimize the process. As per the Taguchi method L27, Orthogonal Array (OA) is finalized for the experimentation. For the computation of the response table and ANOVA table, the Taguchi based data Analysis is used. Quality characteristic Surface Roughness and Tool Wear are optimized to 0.958 um and 0.0401 mm respectively (Surya et al., 2019b).

(Sharma et al., 2021) Grey relation analysis is applied for the optimization value. From this research work author find optimum value of experimental process parameter, which is feed, speed, and depth of cut with the help of GRG. In this research work we consider the minimum surface roughness and maximum MRR. GRG is the foremost process for calculate the optimum value with minimum time. Prediction of GRA shows the noteworthy increment of 16.629 (14.55 %) in Material Removal Rate (MRR) and a noteworthy reduction of 0.148 (8.9%) in Surface Roughness.

Table 2. 1 Summary of literature review

No	Authors Journal name, volume, issue & year	Material and operation	Cutting parameters/ Working Conditions and Response(s)	Method or techniques
1	Gupta *et al*. (2019) The International Journal of Advanced Manufacturing Technology (2019) 101:55–69	Al 7075-T6 alloy (round bar, length 100 mm, diameter 32 mm) was used for turning	Effect of cutting speed and feed rate, at different C/Ls (hybrid cooling and lubrication), the surface roughness, tool wear, and chips.	Ranque–Hilsch vortex tube (RHVT) N2MQL 3D topographic analysis

2	Garcia *et al.* (2019b) Journal of the Brazilian Society of Mechanical Sciences and Engineering (2019) 41:317	AA6082-T6 length 168 mm, diameter 100 mm) was used for turning	Optimization of cutting parameters (cutting speed, depth of cut and feed rate) under dry and RQL conditions on surface roughness	Box–Behnken design of experiments ANOVA
3	Yücel *et al.* (2021) journal of materials research and technology, Volume 9, Issue 5, 2020, pp. 10386-10400	Al 2024 T3 alloy of 65 mm diameter and 270 mm length	Cutting speed, feed rate, depth of cut under dry and MQL condition on cutting edge, cutting temperature	Taguchi's L27 orthogonal ANOVA
4	ADEDEJI *et al.* (2021) Journal of Multidisciplinary Engineering Science and Technology (JMEST) ISSN: 2458-9403	Turning operation on Conventional lathe machine with HSS cutting tool of aluminum alloy (Al-Si)	Optimization of cutting parameters (cutting speed, depth of cut and feed rate) on surface roughness and MRR	Taguchi's L27 Orthogonal Array ANOVA
5	Abas *et al.* (2020b) Journal of material research and technology Volume 9, Issue 5, September–October 2020	Aluminum alloy 6026-T9 with cutting tungsten carbide tool	optimization and analysis of Machinability of cutting speed, feed rate, depth of cut, and positive rank angle, under MQL and dry conditions on surface roughness, tool life and material removal rate	Taguchi orthogonal array (L_{16}) ANOVA Desirability
6	Chauhan and Singh (2016)International Journal of Engineering Research	AA6063-T6 aluminum alloy rod was cut 50 mm length per piece and 25.4 mm	Optimization of cutting speed, feed rate, depth of cut and nose radius under aluminum alloy dry cutting condition on surface	Taguchi ANOVA Regression analysis

	& Technology (IJERT) IJERTV5IS110345 Vol. 5 Issue 11, November-2016	diameter used for turning operation with material using coated carbide by using CNC machine	roughness.	
7	Pratheesh *et al*. (2019) International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9, Issue-2, December 2019	AA6063 T6 having a diameter of 28mm and 100mm in length was prepared for turning operation with Carbide insert CNMG cutting tool by using CNC machine	Optimization of effect of cutting parameter (Feed, Cutting Speed, Depth of Cut) during dry turning operation on surface roughness	Taguchi OA ANOVA
8	Singh *et al.* (2017)International Research Journal of Engineering and Technology (IRJET) e-ISSN: Volume: 04 Issue: 08 | Aug -2017	Aluminum alloy 6351 having length (L) =70 mm and Diameter (D) =30 mm for turning operation on CNC machine	effect of input parameters i.e. spindle speed, feed rate and depth of cut on the surface roughness and material removal rate,	ANOVA, S/N Ratio
9	Chauhan and singh (2019) International Journal of Engineering Research & Technology (IJERT)	Aluminium alloy Al6063-T6 using tungsten carbide insert by using CNC machine.	optimize cutting parameters during (nose radius, spindle speed, feed rate, and depth of cut) on surface roughness	Taguchi orthogonal array (L_{16}) ANOVA
10	Srivastava *et al.* (2021a) Production Engineering Archives	Aluminum Alloy 7075-T651 of a cylindrical bar of 300 mm length and 60mm	Experimental Investigation and Optimization of Machining turning Parameters in parameters a (cutting speed, feed, and depth	Taguchi OA ANOVA

	2021, 27(4),296-305	diameter for turning operation with tungsten Carbide Insert (Uncoated) cutting tool.	of cut) for the output response parameters cutting force, feed force, radial force, material removal , and surface roughness	

2.9 Research gap

Studying experimental investigation and parametric optimization of dry turning of Al 6061-T6 alloy is very important due to challenges in machining in terms of surface quality of machined parts, cutting temperature, tool life etc. In the above literature survey of cutting parameters for lathe machine and milling machine like cutting speed, feed, depth of cut, tool geometry, and work piece material, which affect the desired output including, surface finish, tool wear, tool life and performance are studied. However there were no parametric optimizations of dry turning of Al 6061-T6 on output response variables, (tool wear, cutting temperature, surface roughness and MRR) during turning operation on CNC machine with cemented carbide cutting tool. Therefore, the intention of this research is to add a new contribution on:

- Identifying the optimum cutting parameters at which surface finish is good enough, tool wear is low, and material removal is optimal to bridge the gap between quality and productivity in hard turning of Al 6061-T61043 alloy.
- Studying the tooltip temperature which is very important for recent studies.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

Experimental study was conducted to optimize cutting parameters on surface roughness, tool wear, cutting temperature, material removal rate and residual stress during dry turning of Al6061-T6 by using cemented carbide cutting tool. This chapter aims to present the details of the experimental procedures and material used for the study. All machines and equipment were presented with supporting photographs and schematic diagrams.

3.2 Experimental Procedure

The general procedures of experimental investigations and optimization of cutting parameters in turning process of Al 6061-T6 was shown in Figure 3.1. Input process parameters are the workpiece material, machining parameters which was defined on the specific machine tool and turning inserts which are located and clamped into a corresponding tool holder.

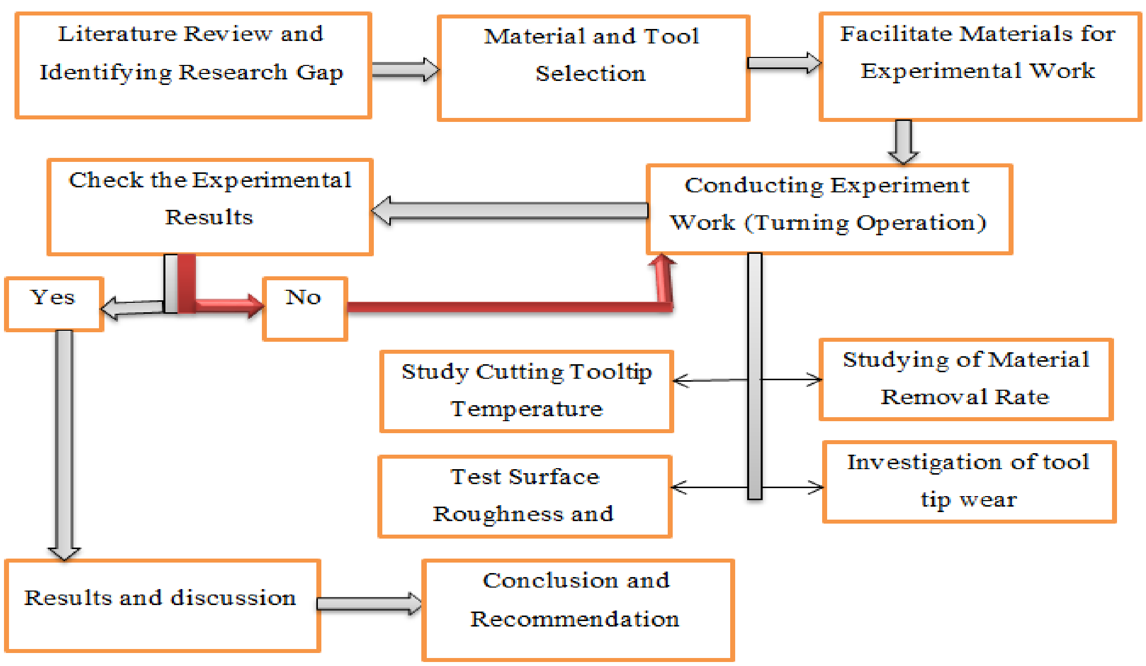


Figure 3. 1 experimental procedure

3.3 Material selection and composition

This study was performed to investigate the cutting parameters on surface roughness using turning operation of Al 6061-T6 alloy. Aluminum alloy 6061-T6 was selected under dry machining conditions for turning operations by using a CNC lathe machine. Al 6061-T6 alloy used for turning operations have diameter of 38mm and 150mm of length is used, machining was conducted at dry machining condition. AA6061-T6 alloy has gained widespread acceptance in the fabrication of lightweight structures requiring a high strength-to-weight ratio and good corrosion resistance. AA6061-T6 is widely used in numerous engineering applications including transport and construction, where superior mechanical properties such as tensile strength and hardness are essentially required. It can use for a variety of interior parts in cars, in railway carriages, pipelines, furniture or in trucks. The work piece material was Al6061-T6 alloy, detail chemical composition listed in table below.

Figure 3. 2 Aluminum round bar

The chemical compositions of Al6061-T6 were tested using spectrometry shows in figure 3.3 which is known as Oxford Instruments PMI-MASTER Smart. The specific chemical composition of Al6061-T6 used for experimental study was shows in Table 3.1.

Figure 3. 3 Spectroscopy Material Compositions

Table 3. 1 Chemical Composition of Al 6061-T6

Component	Al	Cr	Cu	Si	Mg	Fe
Wt. (%)	95.8-98.6	0.04-0.35	0.15-0.14	0.4-0.8	0.8-1.2	Max. 0.7

3.4 Cutting Tool Selection

A cutting tool is any tool that wants to remove metal from the workpiece using shear deformation. To perform an effective cutting operation, the cutter made from a material harder than the work material to cut. The tool must be ready to withstand the heat generated during the machining process. The tool must have a specific geometry (known as tool geometry) for effective cutting and smooth surface finish (Junge et al., 2020). In this selecting of cutting tool single-point cutting tools, cemented carbide tool insert recommended with chemical composition of (65% W, 14 % Ti, 9 % Co and 12 % C) was used in this experimental study**.** The ceramic tool is very hard, resistant to wear withstand chemical decomposition at elevated temperature and they exhibit excellent advantages such as producing good surface finish, economical in nature, fracture resisting strength, good chemical inertness, high compressive strength, thermal shock resistance, high stability against abrasive particle, high resistance to mechanical stress, ability to maintain its shape at elevated cutting temperature, wear resistance with a wide range of high-speed finishing operations and the high removal rate in machining of aluminium alloy materials (Uddin et al., 2021). Table below shows the properties of cemented carbide tool insert material.

Table 3. 2 Properties of Cutting Tool

Hardness (HV)	Thermal conductivity (W/m.k)	Rupture strength(MPa)	Density(g/cm^3)	Young's modulus(MPa)
1500	25	1860	11.6	480

Figure 3. 4 Cemented Carbide Cutting Tool

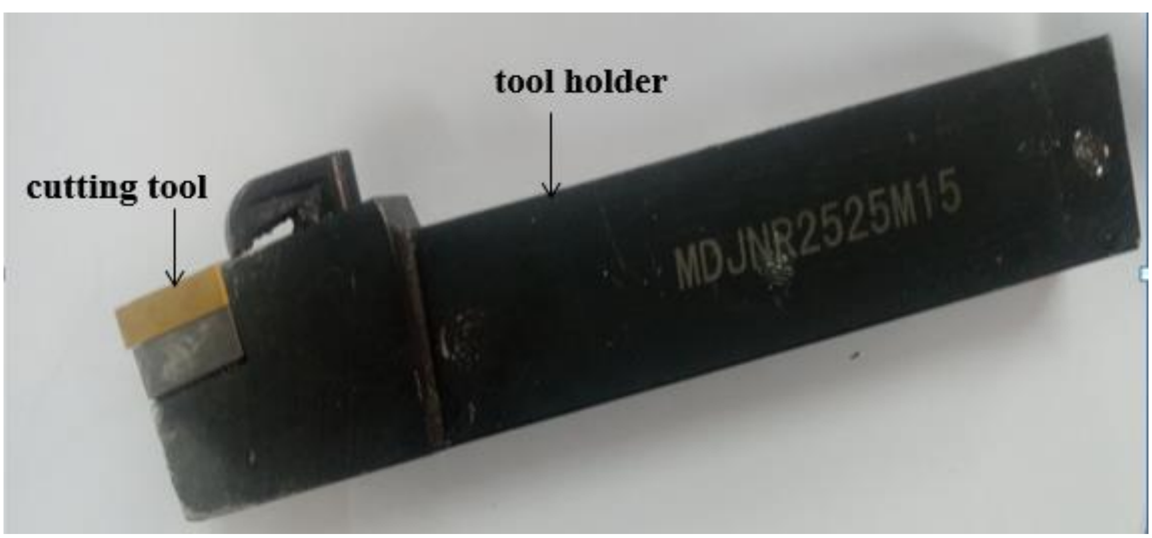


Figure 3. 5 Tool Holder

3.5 Tools and Equipment

3.5.1 Turning machine and response measurement

Lathe machine is a machine which rotates a workpiece about axis of rotation, while holding cutting tool stationary in order to conduct various machining including turning, facing, drilling and some other functions and was founded in a variety of sizes and designs. The type of control that is offered can classify turning machines. A conventional lathe requires the operator to control the motion of the cutting tool during the turning operation. Turning machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) lathe and they operate turning process according to a program that is preprogrammed, these types of lathes are preferable as they offer very high precision Akhtar et al. (2021a). An experimental design for machining was conducted on CNC dry turning operation based on input variables of turning parameters (cutting speed, feed rate and depth of cut) and L9 orthogonal array will be used for machining, the surface roughness, cutting temperature, tool wear and material removal rate (MRR) was recorded. CNC machine was conducted due to its low cost, improve productivity and quality requirements. CNC lathe used for turning process is shown on Figure 3.6

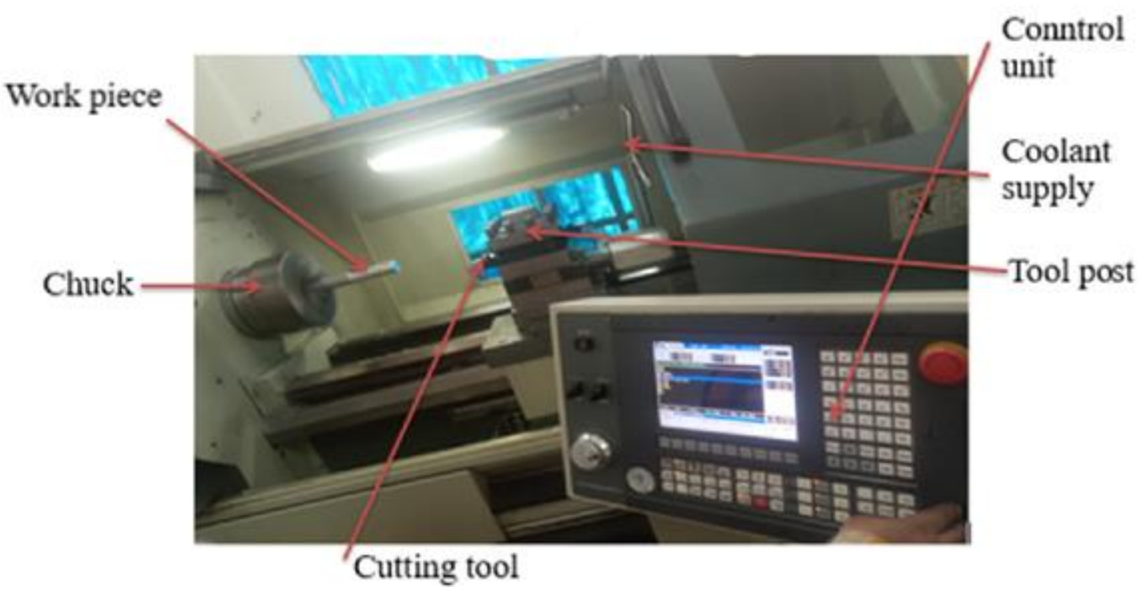


Figure 3. 6 CNC machine

CNC set up program

Experiment No.5

```
%2651
T0101
M03 S1400
G00 X38 Z2
G01X37.6 Z-150 F120
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.3

```
%2651
T0303
M03 S1200
G00 X38 Z2
G01X36.9 Z-190 F300
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.1

```
%2651
T0505
M03 S1200
G00 X38 Z2
G01X36.5  Z-30 F120
G01 X40
G00 80
```

Experiment No.4

```
%2651
T0202
M03 S1400
G00 X38 Z2
G01X37.3 Z-120 F140
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.6

```
%2651
T0404
M03 S1400
G00 X38 Z2
G01X36.7  Z-60 F350
G01 X40
G00 80
G00 Z300
M05
M30
```

```
G00 Z300
M05
M30
```

Experiment No.9

```
%2651
T0606
M03 S1600
G00 X38 Z 2
G01X37.7 Z-140 F400
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.8

```
%2651
T0707
M03 S1600
G00 X37.7 Z 2
G01X37.5 Z-120 F240
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.7

```
%2651
T0808
M03 S1600
G00 X37.5  Z 2
G01X37.1Z-90 F160
G01 X40
G00 80
G00 Z300
M05
M30
```

Experiment No.2

```
%2651
T0909
M03 S1200
G00 X37.1 Z 2
G01X36.8 Z-60 F180
G01 X40
G00 80
G00 Z300
M05
M30
```

3.5.2 Surface roughness measurement

Surface roughness is the most decisive parameter in machining process, as it’s considered as basis of the product quality. It measures the refined inadequacy of the surfaces. The quality of the surface made using CNC machine is important because a smooth surface (better finished components) reduces the chances of surface damage caused by wear, corrosion, improves fatigue strength, creep failure, increase the productivity & economics of the industry (Bedada et al., 2021).

Surface roughness was measured by Surface contact profilometer roughness tester known as VOGEL Surface Roughness Tester with 65711 model which is digital surface roughness tester as shown in Figure 3.7. This surface roughness tester displays roughness value in micro meter (µm). The measuring range of VOGEL Surface Roughness Tester 65711 is 0.02µm to 10µm. A stylus attached to the detector unit of tester was traced the minute irregularities of work-piece surface. The vertical stylus displacement during the trace was processed and digitally displayed on the liquid crystal display of instrument.

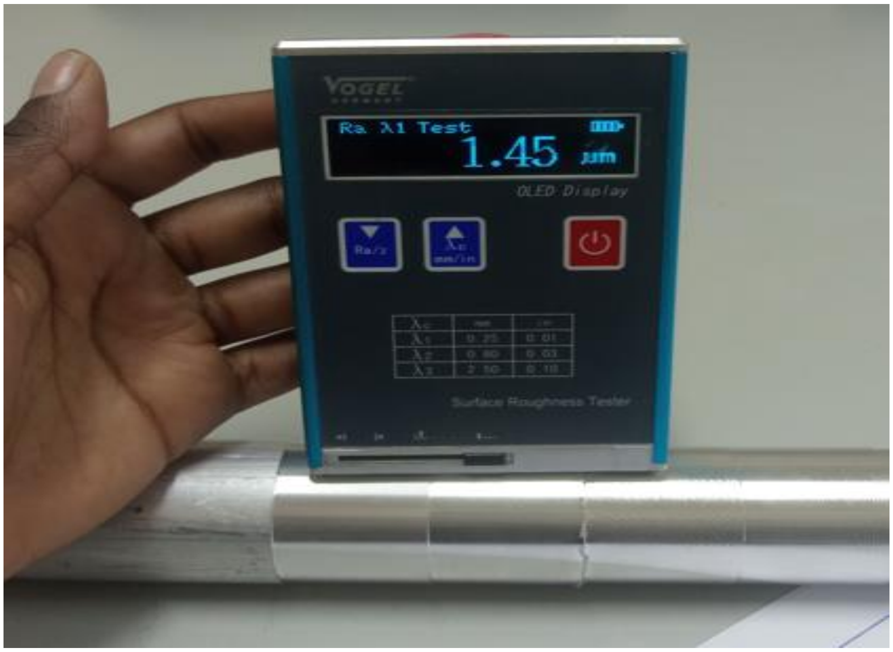


Figure 3. 7 Vogel (Surface-roughness testing equipment)

3.5.3 Tool Wear Measurement

After each experimental run of turning Al6061-T6 alloy, the tool insert was withdrawn and the tooltip wear and tool wear pattern were analyzed using an optical microscope (Model- Huvitz HR – 300 series, Dimension 540 × 670 × 850 mm) with a magnification range of 10x and 20x. Microscope used for testing is showed on below figure.

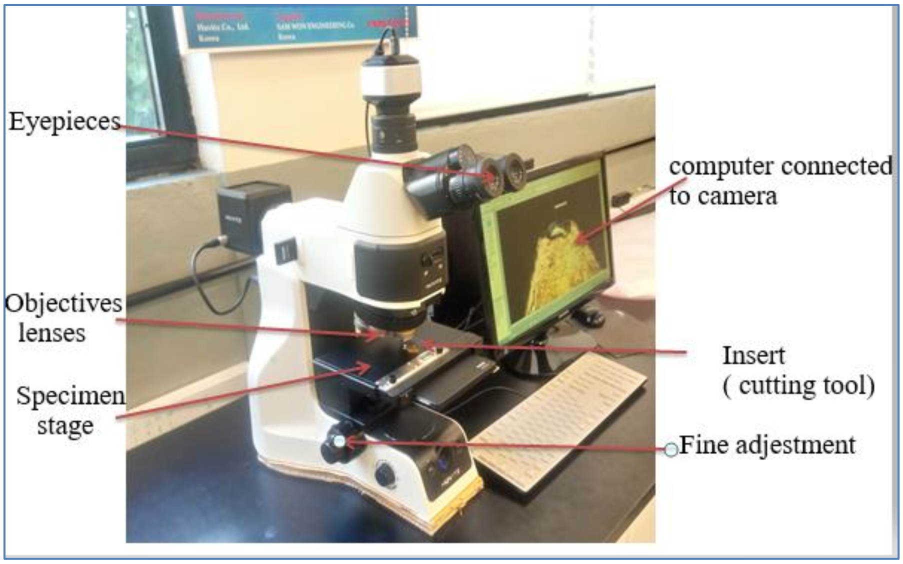


Figure 3. 8 optical microscope

The flank wear patterns mostly involve visible microgrooves because of the abrasive wear mechanism. This abrasive wear is caused by high stresses induced at the tool–workpiece interface during turning which resulted in plastic deformation of the tool which leaded ridges and microgrooves to be formed on the flank face. (Zhang et al., 2023)Additionally, it is also observed that narrow ridges, and grooves due to surface plastic deformation are clearly found on the flank face. Ridges and grooves formed on the flank and rake face of the tool was because of the plastic deformation of surface asperity and adherence of chip particles and it leads to the formation of ridges and fine grooves on the machined surface indicating the occurrence of abrasive wear. Chip adhesion and tooltip chattering is also seen on the flank face of cutting tool.

3.5.4 Temperature measurement

To measure and analyze the relationship between cutting parameters, tool wear and temperature, the infrared thermometer was used to capture tool tip temperature. The temperature of cutting zone was measured during the machining time of every run. The basic working principle of infrared thermometer is, to measures the surface temperature of an object. The unit optics sense emitted, reflected, and transmitted energy, which is collected and focused onto a detector. The unit electronics translate the information into a temperature reading which is displayed on the unit (Cichosz et al., 2023). In units with a laser, the laser is used for aiming purposes only. By holding the meter by its handle grip and pointing it towards the surface to be measured. Pull and hold the trigger to turn the meter on and being tested. While continuing to push the trigger the laser pointer is concentrated at the cutting zone. Release the trigger and the hold display will appear on the LCD indicating that the reading is being held. Infrared thermometer used for the temperature measurement was shown as in Figure 3.9 bellow.

Figure 3. 9 Infrared thermometer

3.5.5 Cutting condition

Dry cutting environment was used for an experimentation process. Dry cutting process is one that uses no coolant during machining. By the use of dry cutting, cost of cutting fluid was alleviated. Cutting fluids have corrosive effects and non-environment friendly. Dry cutting reduces machining cost, protect safety and health of operator and is environment friendly. Also, inserts perform better at higher cutting temperatures achieved during dry cutting.

3.5.6 Measurement of Material Removal Rate (MRR)

The material removal rate is the volume of material removed per unit time which ultimately determines machining productivity. In roughing operations and production of large batches, the material removal rate needs to be maximized. However, in finishing operations, it affects surface roughness, tool life, cutting temperature, and the overall economy of the machining process. In turning process for achieving low surface roughness, low tool wear, low tooltip temperature, usually low cutting parameters are applied, as MRR is usually low for finishing as reported by

Srivastava et al. (2021b). In the present investigation, the following formula has been used to compute the material removal rate.

$$MRR = V * f * d \tag{3,1}$$

Where:

- f is feed rate mm/rev
- V is spindle speed in m/min
- d is depth of cut in mm for each turn

3.6 Selection of Process Parameter

In turning process, the important task is to select cutting parameters for achieving high cutting performance. For experimentation purpose, cutting parameters for given material will be selected depending on knowledge found from the literature, according to the recommendations of tool manufacturer, manufacturer's handbook recommended for the tested material, current industrial practice, and experience(Wei et al., 2020, Sharif, 2022, Surya et al., 2019a).

Table 3. 3 Levels of parameters and their range used for an experiment

No.	**Process parameter**	**Levels**			**Units**
1	Cutting speed	1200	1400	1600	(rpm)
2	Feed rate	0.1	0.15	0.25	(mm/rev)
3	Depth of cut	0.2	0.3	0.4	(mm)

3.7 Design of Experiment

The design of experiments (DOE) technique is a very powerful tool, which will permit us to carry out the modeling and analysis of the influence of process variables on the response variables. In the design of the experiment, the Taguchi method is mostly used to optimization of machining parameters because it is a problem-solving tool that can improve the performance of the product, process design, decrease the experimental time, reduce the cost, and find out significant factors in a shorter time. The response variable is an unknown function of the process variables, which are known as design factors or independent variables(Krishnan et al., 2023), Tamizharasan et al. (2019). The experiment will conducted by varying the cutting parameters such as (cutting speed, feed rate, depth of cut), and the cutting parameters was split into different level values. To observe the most influential cutting parameters of Al 6061-T6 turning process each cutting parameters at three levels was considered in the case of this study. These level values of control factors were selected based on knowledge found in the literature, experience, and according to the recommendations of a tool manufacturer. These levels were then oriented according to the Taguchi L9 orthogonal array (OA) which is shown in Table 3.5. Taguchi based orthogonal array has the property of reducing the number of experiments without affecting the outcome significantly Patel et al. (2020).

The following are steps related to the Taguchi-based experiments:

- State the problem
- Determine the objective
- Determine the response and its measurement
- Identify factors influencing the performance characteristic
- Separate the factors into control and noise factors
- Determine the number of levels and their values for all factors
- Identify control factors that may interact
- Select the Orthogonal Array
- Assign factors and interactions to the columns of OA
- Conduct the experiment
- Analyze the data
- Interpret the results
- Select the optimal levels of the significant factors
- Predict the expected results
- Run a confirmation experiment

Taguchi uses the S/N ratio to measure the quality characteristics deviating from the desired value and it offers three categories of signal to noise ratio as follows;

Nominal is the best characteristics,

$$\frac{S}{N} = 10log\frac{\bar{Y}^2}{S^2} \quad (3.2)$$

Smaller is the better characteristic,

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} {Y_i}^2\right] \quad (3.3)$$

Larger is the better characteristics,

$$\frac{S}{N} = -10\log(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{Y_i}^2}) \quad (3.4)$$

Here Y = observation n = total number of observation, $\bar{Y}$ = the average of observed data, S^2 = the variation of Y and Yi = ith response.

- Larger is the better is suitable for determining the profit, material removal rate, production rate etc.
- Smaller is the better is appropriate for surface roughness, cutting temperature, MRR etc.
- Smaller is the better is applicable for current.

The S/N ratio was calculated for surface roughness in each of the nine trial conditions to see the effect of each parameter on the response in dry turning conditions. Thus, the L9 orthogonal array delivered by Minitab 18 to make further experimentations as shown in Table 3.5 and this array specifies nine experiments.

3.8 Selection of Orthogonal Array

The cutting experiments were carried out on a CNC lathe machine by using ceramic insert tools with selected cutting parameters within three levels given in Table 3.4. The selection of a specific orthogonal array was based on the number of levels of various factors using Taguchi method. Here, to conduct the experiments 3 factors each at 3 levels were selected.

Nine different samples were manufactured with different parameters and at different levels for dry turning. Now the Degree of Freedom (DOF) can be calculated by the formula as given below.

For OA;

$$DOF = a - 1 \quad (3.5)$$

$$DOF = \mathrm{P} * (\mathrm{L} - 1) \quad (3.6)$$

DF =3∗ (3−1) =6 ≈$L9$

Where, DOF is degree of freedom, P is number of factors, L is number of levels

DOF = 3*(3-1) = 6.Therefore, 8>6; i.e. DOF of OA is greater than DOF of the experiments. However, the total number of experiments of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus, the L9 orthogonal array delivered by Minitab 18 to make further experimentations as shown in Table 3.5 and this array specifies nine experiments. The steps to go through are as follows:

- Selection of factors to be evaluated
- Selection of number of levels
- Selection of appropriate orthogonal array
- Conduct the experiment and analyze the results

Table 3. 4 Orthogonal array of experimental design for machining

S.No.	Parameters		
	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	1200	0.1	0.2
2	1200	0.15	0.3
3	1200	0.25	0.4
4	1400	0.1	0.3
5	1400	0.15	0.4
6	1400	0.25	0.2
7	1600	0.1	0.4
8	1600	0.15	0.2
9	1600	0.25	0.3

3.9 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) was found which parameters significantly affect the quality characteristic. In the analysis of variance, the percentage contribution of each control factor was used to measure the corresponding effects on the performance characteristics.

In the analysis of variance, the percentage contribution of each control factor was used to measure the corresponding effects on the performance characteristics. ANOVA results indicate whether there was statistically significance in difference or not in output characteristics Kumar et al. (2020). ANOVA analysis involves when α values is below 0.05 is significant and above 0.05 is not significant. Percent contribution measures the percentage contribution of each model term relative to the total sum of squares.

From analysis of variance percentage contribution of each influential parameter was calculated by the following formula:

$$P = \frac{\text{SSTR}}{\text{SST}} * 100 \tag{3.7}$$

Where,

- P: Percentage contribution of individual factor
- SS: Sum of squares or treatment sum of squares
- SST: Total sum of squares

3.10 Grey Relational Analysis

The multiple performance characteristics include material removal rate (MRR), surface roughness (Ra), cutting temperature and tool wear. Three important machining parameters; namely cutting speed, feed rate and depth of cut are considered as the input process parameters (Pandey et al., 2022). In this study, material removal rate denoted as higher-to-better performance characteristics and is calculated using Eq.3.8. Besides, cutting temperature, surface roughness and tool wear were considered as lower-the-better performance characteristic and are determined by Eq3.9.

Step-I (Normalization of the data) Here, the data is normalized to escape the cause of its various units and variability. Here, all the data is scaled in between 0 to 1 numerical values, which is termed as its range. The data are normalized based on three criteria (Kamble et al., 2021).

A higher-the-Better criterion (HB) Here, the targeted value of real sequence is infinity. The data to be normalized in their original sequential set by using the formula as expressed below:

$$Y_i(m) = \frac{Y_i^{\wedge}(k) - minY_i^{\wedge}(m)}{maxY_i^{\wedge}(m) - minY_i^{\wedge}(m)} \tag{3.8}$$

Lower-the-better criteria (LB) Here, the data is to be normalized in their original sequences by using the formula as expressed below:

$$Y_i(m) = \frac{maxY_i^{\wedge}(m) - Y_i^{\wedge}(m)}{maxY_i^{\wedge}(m) - minY_i^{\wedge}(m)} \tag{3.9}$$

Step-II (calculation of grey relational coefficients ψ_i (m)) Here, firstly the deviation sequence value "Δ_{0i} " between $Y_0\ (m)$ and $Y_i\ (m)$ is determined out by using the formula as expressed below:

$$\Delta_{0i} = \|Y_0\ (m) - Y_i\ (m)\| \tag{3.10}$$

The $\psi_i(m)$ (grey relational coefficients) is calculated as:

$$\psi_i(m) = \frac{\Delta_{min} + \theta\Delta_{max}}{\Delta_{0i} + \theta\Delta_{max}} \tag{3.11}$$

Where $Y_0\ (m)$ and $Y_i\ (m)$ are the absolute and comparability sequences respectively; Δ_{max} and Δ_{min} are the maximum and minimum of ' Δ_{0i} ' between $Y_0\ (m)$and $Y_i\ (m)$ respectively; 'θ' is the identification coefficient and its value lies between 0 and 1.

Step-III the *GRG* (grey relation grade) is calculated as:

$$GRG_i = \frac{1}{n}\sum_{m-1}^{n} GRG_i\,(m) \tag{3.12}$$

Where n is the total number of response factors, and GRG is calculated *GRG* value. *GRG* values show the correlation between reference and comparability sequence. In this case, all the response factors have been considered with equal important. But, as it is impractical in real life, the overall grey relational grade with different weightage is computed as

$$\mathrm{GRG_i} = \frac{\sum_{\mathrm{m-1}}^{\mathrm{n}} \mathrm{w_m}\,\psi_{\mathrm{i}}(\mathrm{m})}{\sum_{\mathrm{m-1}}^{\mathrm{n}} \mathrm{w_m}} \tag{3.13}$$

Where $\mathrm{GRG_i}$ the overall GRG (for ith experiment); ψ_{i}(m: the GRG coefficient of mth parametric characteristics' in ith run; $\mathrm{w_m}$: the weightage corresponding to their mth factors.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Introductions

Experimental work was conducted to study the effect of cutting parameters, such as spindle speed, feed rate and depth of cut, on the surface roughness, tool wear, material removal rate, tool temperature of Al6061-T6 alloy during the dry-turning process. The experiment was carried out on a CNC lathe machine using ceramic insert cutting tool. Nine experiments were performed to identify the optimum condition. During and after machining operation, measurements were taken for each of the end responses, statistical analysis was made to get the optimum parameters according to the requirements and the main effects were identified. The diameter of the workpiece prepared for experimental work is 38mm and 340mm length. The outcome results for each experiment were discussed in this chapter in detail.

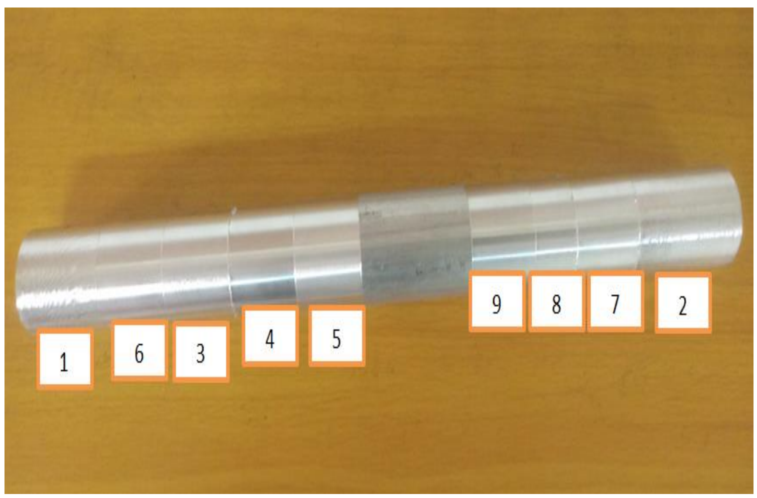


Figure 4. 1 Sample after turning process

The response results from experimental investigation carried out by orthogonal array were analyzed using Taguchi methods were to identify the optimum cutting parameters and the most influential cutting parameters on surface finishing. Specimens were prepared based on L9 orthogonal array and the S/N ratios are calculated using MINITAB 18 software. The S/N ratio for "smaller is better" is used to identify the optimum parameters because a smaller surface roughness is desired. The design of the experiment was used to identify the optimum cutting parameters and to identify the most influential parameters. This section presented the details of the result and discussion used for the study. Furthermore, predictive and optimization models are discussed with supporting photographs and schematic diagrams.

4.2 Result Values Obtained from Turning Experiment

Data collection plays a significant role in the statistical analysis of any field, as it decides the progression of the analysis to the best or worst. A proper and suitable data collection leads to better results from the analysis. In such a focus, it was very much essential to choose a well suitable data collection technique for the analysis.

Table 4. 1 Experimental result of TC, MRR, Ra and tool wear at different cutting parameter

Exp. No.	Spindle speed (rpm)	Cutting speed (m/min)	Feed (mm/rev)	D (mm)	T_c (^oC)	MRR (mm^3/min)	Ra (μm)	Tool wear (μm)
1	1200	143	0.1	0.2	27.86	2860	1.79	0.1060
2	1200	143	0.15	0.3	29.30	6435	1.88	0.1070
3	1200	143	0.25	0.4	32.47	14300	2.01	0.1200
4	1400	167	0.1	0.3	34.50	5010	1.76	0.0980
5	1400	167	0.15	0.4	40.80	10020	2.03	0.1065
6	1400	167	0.25	0.2	36.90	8350	1.92	0.0890
7	1600	191	0.1	0.4	43.70	7640	1.65	0.1070
8	1600	191	0.15	0.2	41.84	5730	1.57	0.0510
9	1600	191	0.25	0.3	45.30	14325	1.74	0.0780
Max.	1600	191	0.25	0.4	45.30	14325	2.03	0.0510
Min.	1200	143	0.1	0.2	27.86	2860	1.57	0.1200

4.3 Measurement of surface roughness

The average mean value of surface roughness for each factor i.e. cutting speed (A), feed (B), and depth of cut (C) are calculated using the design of experiments. Table 4.2 presents the experimental results of surface roughness (Ra) values for each specimen and their mean values.

Table 4. 2 Experimental results and signal to noise ratio of surface roughness

Exp. No.	Spindle speed (rpm)	Cutting speed (m/min)	Feed (mm/rev)	D (mm)	Ra (μm)	S/N ratios
1	1200	143	0.1	0.2	2.01	-5.06
2	1200	143	0.15	0.3	1.79	-5.48
3	1200	143	0.25	0.4	1.88	-6.06
4	1400	167	0.1	0.3	1.92	-4.91
5	1400	167	0.15	0.4	1.76	-6.15
6	1400	167	0.25	0.2	2.03	-5.67
7	1600	191	0.1	0.4	1.74	-4.35
8	1600	191	0.15	0.2	1.57	-3.92
9	1600	191	0.25	0.3	1.65	-4.81
	Average performance mean value				**1.82**	**-5.16**

4.3.1 Response Tables and Analysis of Mean

The mean value of surface roughness for each factor i.e. Cutting speed (A), Feed (B), and Depth of cut (C) at each level are obtained and the result is listed in response Table 4.3. An example calculation is shown for factor B (feed):

$S/N_{B1} = \frac{1.79+1.76+1.65}{3} = 1.73$

$S/N_{B2} = \frac{1.88+2.03+1.57}{3} = 1.83$

$S/N_{B3} = \frac{2.01+1.92+1.74}{3} = 1.89$

Table 4. 3 Response table for mean effects plot for smaller is better of surface roughness

level	Parameter		
	Cutting speed	Feed rate	Depth of cut
	A	B	C
1	1.893	**1.733**	**1.760**
2	1.903	1.827	1.793
3	**1.653**	1.890	1.897
Delta	0.250	0.157	0.137
Rank	**1**	**2**	**3**

The control factor's main effect plot for means of surface roughness values variations is as shown in Figure 4.2 The result taken from the above data shows as smaller is better is selected for surface roughness value output.

$Delta = (Maximum\ mean - Minimum\ mean)$

The factor with the greatest effect on the mean from Table 4.3 shows cutting speed (Delta = 0.250, Rank = 1). The factor with the least effect on the mean is a depth of cut (Delta = 0.137, Rank = 3). Since the main effect plots for means is helpful for adjusting the mean on better value. Those parameter levels with better surface finish value of specimens that means **A3B2C1**will be taken as a possible parameter combination for better values. The significant factors in the order increasing by affecting surface roughness are depth of cut, feed rate and cutting speed as it's seen in Table 4.3.

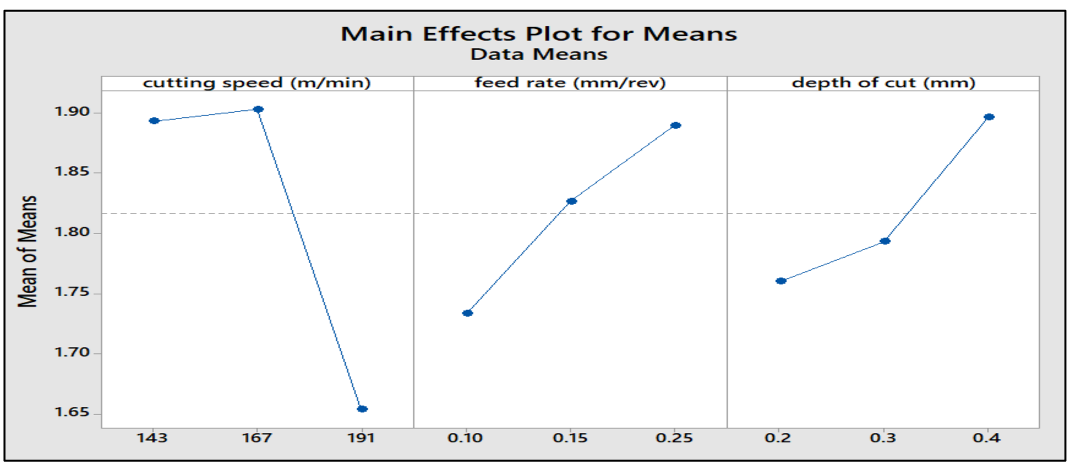


Figure 4. 2 Main effect plots for means surface roughness

As observed from Figure 4.2 that within the scope of this investigation the minimum point in the graph for each turning parameter was the optimum conditions. The minimum point for cutting speed was at level three, to feed the minimum point on this graph was at level one and for a depth of cut is at level one. This is due to the identified optimum turning parameter was at high cutting speed, medium feed, and low depth of cut which is A3B2C1.

4.3.2 Interaction Effect

Combined effect was clearly shows that a variation of surface roughness at different cutting parameters. Figure 4.3 shows the effect of cutting speed on surface roughness at a different feed. As increasing cutting speed from 143m/min to 167 m/min the surface roughness also increased at constant feed of 0.15 mm/rev. But at 0.25mm/rev feed the surface roughness was decreased with increasing cutting speed from 143m/min to 167m/min and then cutting speed was further increased to 191m/min the surface roughness value was decreased at 0.1mm/rev, 0.15 mm/rev and 0.25mm/rev. The result indicated that by increasing cutting speed, the surface finish can be improved because at higher cutting speeds more strain energy is available for the work-piece which leads to continuous and easy removal of the material. Hence the Ra values were found to decrease with increased in cutting speed Similar result has been discussed by Garcia *et al.* (2019a).When the turning was performed at a low cutting speed, a subsurface material fracture occurs, which contributes to increasing surface roughness; by increasing the cutting speed this effect disappears. The reason for decreased surface roughness was for reduced wear, low tooltip temperature, and friction as well as getting the product with high quality.

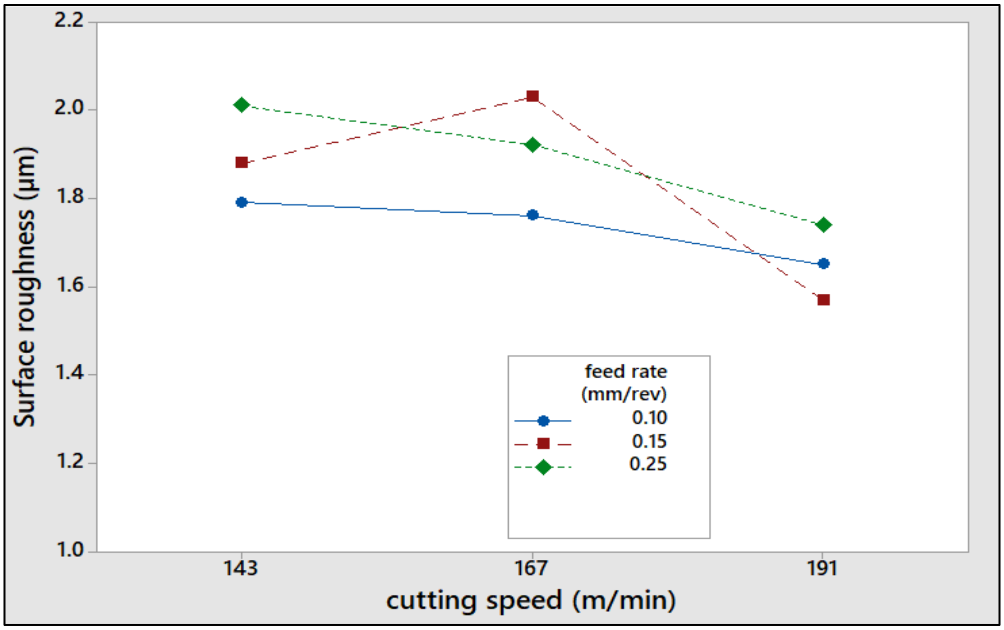


Figure 4. 3 shows the effect of cutting speed on surface roughness at different feed rate

Higher feed rates mean more material in contact with the cutting tool hence higher cutting force evolution which caused in the appearance of the vibration, which leads to high surface roughness. As observed from Figure 4.3 shows that the effect of feed, and cutting speed on surface roughness (Ra) when feed was increased to 0.25mm/rev surface roughness was also increased at cutting speed of 143m/min and 191m/min, but decreased at cutting speed of 167m/min. At feed increased from 0.1mm/rev to 0.15mm/rev the value of surface roughness also increased at cutting speed of 143m/min and167m/min this is because higher feed rates also caused in increasing the cutting temperature, which leads to the appearance of the tool wear hence undesired surface roughness the same work has been obtained by (Khrouf *et al.*, 2022).

4.3.3 Effect of depth of cut on Surface Roughness

As the depth of cut increasing from 0.2 mm to 0.3 mm, as shown in Figure 4.4, the surface roughness decreased to1.76µm at cutting speeds of 167 m/min but increased to 1.88µmat cutting speed 143m/min and to 1.74µm at cutting speeds of 191 m/min. When depth of cut further increased to 0.4 mm the value of surface roughness increased to 2.01µm and 2.03µmat cutting speeds of 143m/min and 167m/min respectively. Because at higher depths of cut, higher cutting forces were demanded to remove the bigger amount of the material. Increasing of cutting forces leads to the appearance of the machine tool vibration which affects negatively the surface roughness. The results showed that optimum (minimum) surface roughness was achieved at minimum depth of cut (0.15 mm).

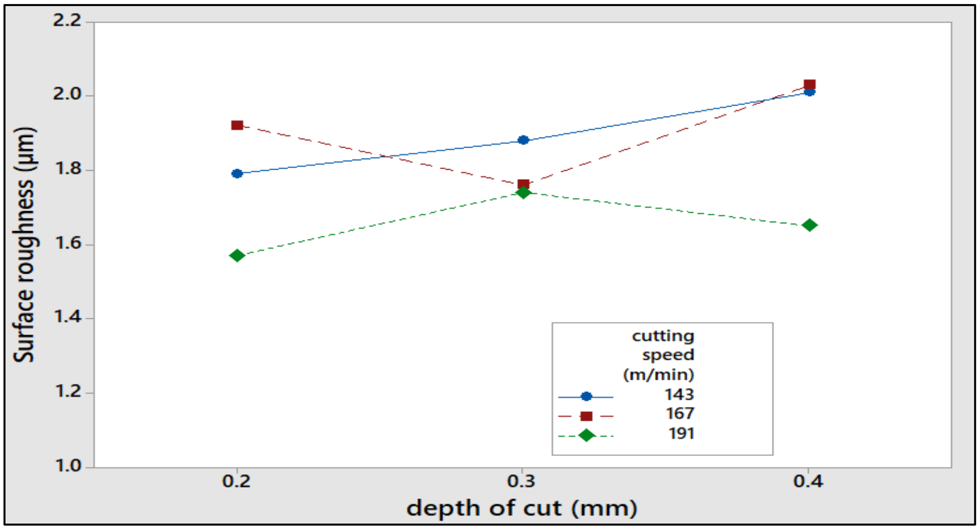


Figure 4. 4 shows the effect of depth of cut on surface roughness

The variation of surface roughness with respect to the cutting parameters indicated that the surface roughness fluctuated for various cutting speed, feed rate, and depth of cut. The reason for decreased surface roughness was for reduced wear, low tooltip temperature, and friction as well as getting the product with high quality. As observed from the result surface roughness was better at high spindle speed, so the influence of cutting speed on surface roughness was highly significant the same results has been obtained Abebe et al. (2021).

4.3.4 Performance at Optimal Levels of the Mean Value of surface roughness

For predicting the optimum response, three factors of parameters are selected by the small mean value. A3B2C1 is the optimum level of parameters mean value for surface roughness value. To find out the predicted value of the responses (surface roughness value) the following linear regression equation is used:

$$\mathrm{Yopt} = \mathrm{m} + (\mathrm{mA3} - \mathrm{m}) + (\mathrm{mB1} - \mathrm{m}) + 9(\mathrm{mC2} - \mathrm{m}) \tag{4.1}$$

Where, m is average performance mean value for surface roughness, mA3 is optimum level value for parameter A, mB1 is optimum level value for parameter B, mC2 is optimum level value for parameter C.

$$\text{Yopt} = 1.82 + (1.653 - 1.82) + (1.733 - 1.82) + (1.760 - 1.82)$$

$\text{Yopt} = 1.51$ (Predict mean value for surface roughness value)

4.3.5 Analysis of S/N Ratios for surface roughness

The Taguchi method uses the S/N ratio to measure the variations of the surface roughness value in experimental design. The equations used for calculating the signal to noise ratios are based on the characteristics of the response variables being reported. In this experimental work, the response variables are smaller-the-better. Table 4.2 presents the calculations of S/N ratios for surface roughness values results using the design of experiments. And Table 4.4 presents the response table for a signal to noise ratios for smaller is better for this study. Example of calculation for response table for a signal to noise ratio for factor C (Depth of cut) is as follows:

$$S/N_{C1} = \frac{-5.06+(-5.67)+(-3.92)}{3} = -4.88$$

$$S/N_{C2} = \frac{(-5.48)+(-4.91)+(-4.81)}{3} = -5.07$$

$$S/N_{C3} = \frac{(-6.06)+(-6.15)+(-4.35)}{3} = -5.53$$

Table 4. 4 Response table for signal to noise ratios smaller is better of surface roughness

Level	Parameters		
	Cutting speed	Feed rate	Depth of cut
1	-5.535	**-4.772**	**-4.880**
2	-5.575	-5.184	-5.068
3	**-4.360**	-5.514	-5.521
Delta	1.216	0.741	0.641
Rank	1	2	3

$$\text{Delta} = \text{Maximun}\,\frac{S}{N}\text{ ratio} - \text{minimum }\frac{S}{N}\text{ ratio}$$

By looking at the surface roughness response in Table 4.3 and the main effect plot for the signal to noise (S/N) ratios, the cutting speed weight percentage has the greatest effect (Delta = 1.216, Rank = 1), the factor with the second effect on the S/N ratio is feed (Delta = 0.741, Rank = 2) and the least effect on the (S/N) ratio was the depth of cut (Delta = 0.641, Rank = 3). The optimal parameter combination is A3B2C1, for increasing the surface quality of Al 6061-T6.The control factor's main effect plot for the surface roughness S/N ratio shown in Figure 4.5.

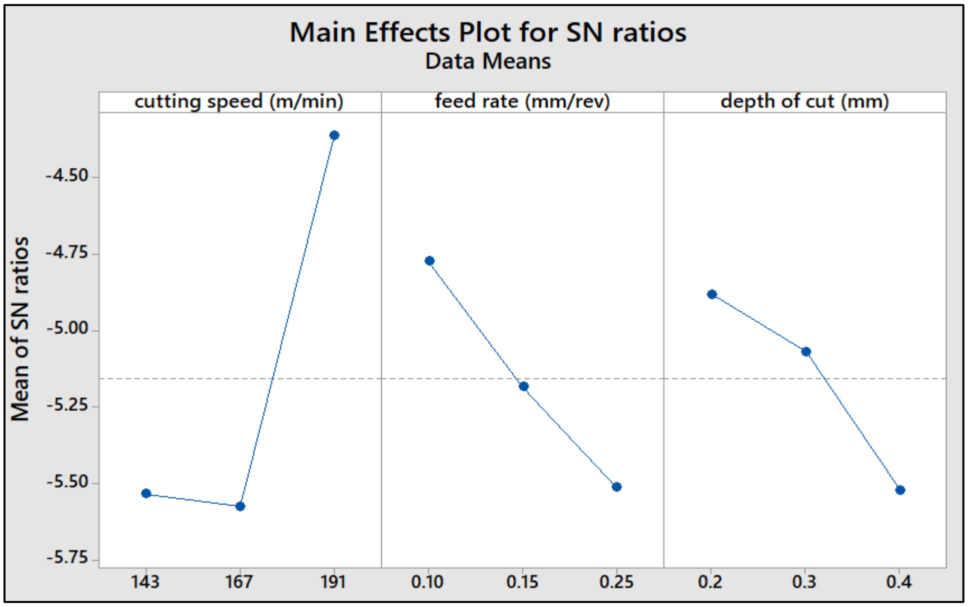


Figure 4. 5 Main effects plot for S/N ratio of surface roughness

The numerical value of the maximum point in each graph shows the best value of that particular parameter at that level. They also indicated the optimum conditions in the range of the experimental conditions. The most effective parameter to enhance the surface roughness is the cutting speed weight percentage when compared with other cutting factors and depth has the least effect on the surface roughness. Since, S/N ratio used for this study is smaller was better and smallest S/N ratio was selected as it shown in the Figure 4.5.

4.3.6 Prediction of Performance at Optimal Levels of S/N Result

For predicting the optimum response approximately, three factors of parameters are selected by low S/N ratio value. A3B1C2was the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response (surface roughness value) linear regression equation 4.2 was used:

$$\text{Yopt} = \text{m} + (\text{mA3} - \text{m}) + (\text{mB1} - \text{m}) + (\text{mC2} - \text{m}) \qquad (4.2)$$

$$\text{Yopt} = -5.16 + (-4.360 - (-5.16)) + (-4.772 - (-5.16)) + (-4.880 - (-5.16))$$

$\text{Yopt} = 3.69$ (Predict S/N value for surface roughness).

4.3.7 Analysis of Variance (ANOVA)

For Surface Roughness Analysis of variance (ANOVA) was used to identify the most significant factors which affects the surface roughness of the machined part. It was calculated and reported in Table 4. 4 Percent contributions for each factor were calculated by equation 4.3.

$$P(\%) = \frac{SSTR}{SST} * 100 \qquad 4.3$$

Where

- ✓ DOF is degree of freedom
- ✓ SST is total sum of squares
- ✓ SSTR is treatment Sum of squares
- ✓ MSE is mean square error and
- ✓ F is F- Ratio calculated by using Minitab 18 software.

Table 4. 5 Analysis of variance for surface roughness value

Source	DOF	SSTR	MSE	F	P	Percent contribution	Significance e (α= 0.05)
Cutting speed	2	0.12	0.06	14.90	0.063	61.23%	Highly significant
Feed rate	2	0.037	0.018	4.62	0.178	18.89%	significant
Depth of cut	2	0.03	0.015	3.78	0.209	15.4%	Less significant
Residual error	2	0.008	0.004			4.1%	
Total	8	0.196				100%	

Table 4.5 presents surface roughness percentage contribution variation of factors A, B and C; where factors represents cutting speed, feed and depth of cut respectively. It was observed that cutting speed factor has statistical and physical significance on the surface roughness value during turning operation of Al 6061-T6 at 95% of level of confidence.

It is clearly observed that the cutting speed 61.22% , feed 18.89% and depth of cut 15.4% have significant influence on the surface roughness of Al 6061=T6 of specimens. Therefore, cutting speed has significant effect on surface roughness of Al 6061- T6 in dry turning process.

Controlling the cutting speed for machining materials like Al 6061-T61will help to get good surface finish, economical machining time, less tool wear, low cutting temperature, and optimum material removal rate.

4.3.8 Determining the Optimum Condition

From the Table 4.3 and Table 4.4, it's clearly observed that cutting speed weight percentage at optimum level value of 191m/min, feed optimum level value 0.15mm/rev and depth of cut optimum level value 0.2mm makes the response S/N ratio values smaller. Therefore, the optimum processing parameters signal to noise (S/N) ratio was selected.

Table 4.6 presents the optimum parameters setting selected for surface roughness obtained from the design of experiment and experimental results. The selected optimum parameters in this study were at higher cutting speed, at medium feed and at minimum depth of cut which, is at A3B2C1.

Table 4. 6 Optimum parameters setting levels and their values

Controllable factors	**Level selected**	**Value of level**	**Rank of affecting the response**
Cutting speed	3	191	1
Feed rate	2	0.15	2
Depth of cut	1	0.2	3

4.4 Material Removal Rate analysis and discussion

Material removal rate (MRR) is the amount of material removed per unit time. The material removal rate can be calculated by using equation (3.1). While increasing cutting parameters, the material removal rate was increased. This can be justified by the relation shown in equation (3.1). On the other hand, these cutting parameters also affect the surface quality of the machined part, tool wear, and cutting temperature. Due to the above-mentioned reasons, the cutting parameters are needed to be limited. Therefore, the machining parameter optimization is highly necessary.

As observed from Table 4.7 below material removal rate was maximum at experiment number nine (Vc = 191m/min, f = 0.25mm/rev and d = 0.3mm) and minimum material removal rate was obtained at experiment number one (Vc = 143m/min, f =0.1mm/rev and d1 = 0.2mm). Material Removal Rate (MRR) is important for increasing the productivity of machining operations by increasing the amount of chips removed from the machined workpiece or product.

Table 4. 7 Experimental results for mean and signal to noise ratio of material removal rate

Exp. No.	Spindle speed (rpm)	Cutting speed (m/min)	Feed (mm/rev)	D (mm)	MMR (mm^3/min)	S/N ratios
1	1200	143	0.1	0.2	2860	-69.13
2	1200	143	0.15	0.3	6435	-76.17
3	1200	143	0.25	0.4	14300	-83.11
4	1400	167	0.1	0.3	5010	-74
5	1400	167	0.15	0.4	10020	-80
6	1400	167	0.25	0.2	8350	-78.43
7	1600	191	0.1	0.4	7640	-77.66
8	1600	191	0.15	0.2	5730	-75.16
9	1600	191	0.25	0.3	14325	-83.12

The higher cutting parameters the higher the material removal rate achieved. In machining, a higher material removal rate doesn’t mean economical because it affects tool life, surface integrity, and the overall machining economy. However, the economical machining was achieved at optimized parameters for which tool wear is less, tool life is more, surface finish was good, and cutting temperature was low. Since the optimum cutting speed at which best surface finish obtained was at highest level values, both improved surface finish and material removal rate was achieved.

4.4.1 Effect of Feed Rate on Material Removal Rate

Effect of feed rate on material removal rate is shown on Figure 4.6 it was observed that as feed rate increased at constant cutting speed and depth of cut. The highest material removal rate was achieved at highest feed rate of 0.25 mm/rev and smallest material removal rate was found at lowest feed rate which is 0.1 mm/rev. Since the optimum cutting speed at which best surface finish obtained is at highest level values, both improved surface finish and material removal rate was achieved. Increased feed rates mean more material in contact with the cutting tool which resulted in higher cutting force to remove material at faster rate. The higher feed rates promote the axial movement of the cutting tool resulting in shifting of the cutting tool to new location at a faster rate thereby increasing MRR the same work has been obtained by (Rahman *et al.*, 2021).The economical machining will be achieved at optimized parameters for which tool wear was less, tool life is more, surface finish is good, cutting temperature was low From Figure 4.6 it was observed that material removal rate increased as cutting speed increases. From experimental investigation it was observed that with too slow a cutting speed, time were lost for the machining operation, resulted in low material removal rate or production rates.

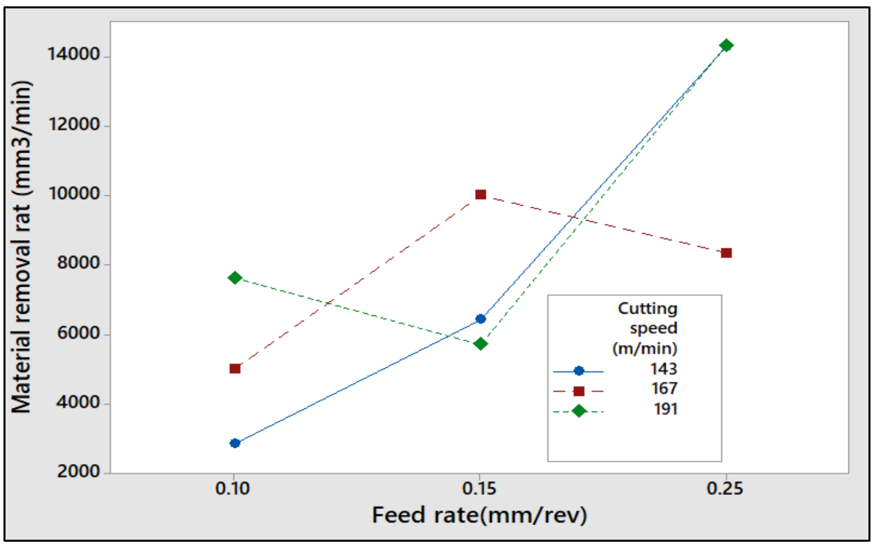


Figure 4. 6 Effect of feed on MRR

4.4.2 Effect of Depth of Cut on Material Removal Rate

As observed from Figure 4.6 when depth of cut is increased from 0.2mm to 0.3mm the material removal rate was increased at 0.1mm/rev and 0.25mm/rev feed but decreased at 0.15mm/rev. And depth of cut further increased to 0.4mm the material removal rate was increased at 0.1mm/rev, 0.12mm/rev and 0.25mm/rev. from figure 4.6 concluded that, at feed of 0.1mm/rev the amount of material removal rate was continuously increased.

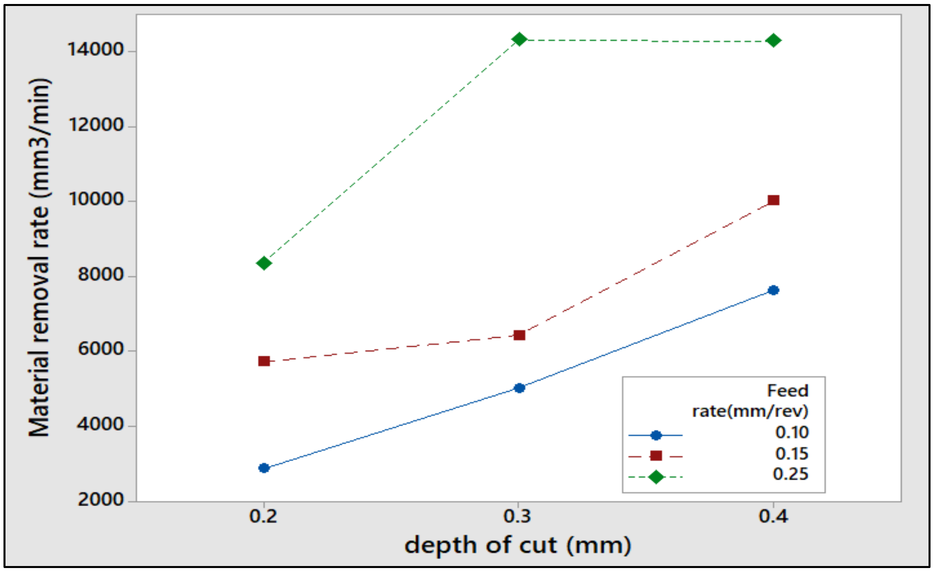


Figure 4. 7 Effect of depth of cut on MRR

As observed from the analysis material removal rate was affected by cutting speed, feed, and both depth of cut. While increasing cutting parameters, the material removal rate was increased. The higher cutting parameters the higher the material removal rate achieved similar result has been discussed by (Alemayoh *et al.*, 2023). This can be justified by the relation shown in equation (3.1). Maximum material removal rate obtained the optimum material removal rate is at experiment number nine (14325mm^3/min) at this trial the value of cutting parameters were 191m/min cutting speed, 0.25mm/rev feed, 0.3mm depth of cut

4.5 Analysis of Tooltip Temperature

During machining, heat was generated due to friction between tool-work and tool chip interface. The quantity of heat produced varies with the type of material being machined and cutting parameters used. Observations and measurements during experimental work confirmed that heat was generated due to friction forces at the tooltip interface. Table 4.8 presents the recorded temperature for various cutting parameters at tooltip during the finish turning process, using an infrared radiation thermometer. The workpiece highest cutting temperature at the cutting zone for each run of the experiment was also shown in Table 4.8. It is evident that the workpiece highest surface temperature was recorded in run number 9 with depth of cut 0.3mm, at feed rate of 0.25mm/rev and spindle speed of 191m/min in dry turning conditions. It was evident from the experiments that the inserts maintained minimum cutting temperatures at minimum depth of cut, feed rate and spindle speed values. In addition, there was a big chance that built-up edge (BUE) was developed at higher spindle speed, resulting in more dull cutting edges on the tool and consequently, higher cutting temperatures.

Table 4. 8 Experimental results for mean and signal to noise ratio of temperature at tool tip

Exp. No.	Spindle speed (rpm)	Cutting speed (m/min)	Feed (mm/rev)	D (mm)	Cutting temperature (^{0}C)	S/N ratios
1	1200	143	0.1	0.2	27.86	-28.89
2	1200	143	0.15	0.3	29.30	-29.34
3	1200	143	0.25	0.4	32.47	-30.23
4	1400	167	0.1	0.3	34.50	-30.76
5	1400	167	0.15	0.4	40.80	-32.21
6	1400	167	0.25	0.2	36.90	-31.34
7	1600	191	0.1	0.4	43.70	-32.40
8	1600	191	0.15	0.2	41.84	-31.98
9	1600	191	0.25	0.3	45.30	-33.12

As observed from table 4.8 the maximum of temperature (45.3^{0}C) was founded at high cutting speed of (191 m/min), the feed rate of 0.25mm/rev. The minimum temperature of (27.86^{0}C) was obtained at low cutting speed (143 m/min). Therefore, the increase in cutting speed leads to an increase in tooltip temperate generated due to high friction at the tool-work interface similar result has been obtained by (Ping et al., 2021). The cutting temperature in the cutting tooltip depends greatly on the friction between tool workpiece materials and which resulted to undesirable temperature in the cutting tool which leads rapid wear of cutting tool materials by softening of the tooltip. It accelerated flank wear and crater wear of cutting tool by plastic deformation and finally leads to tool breakage.

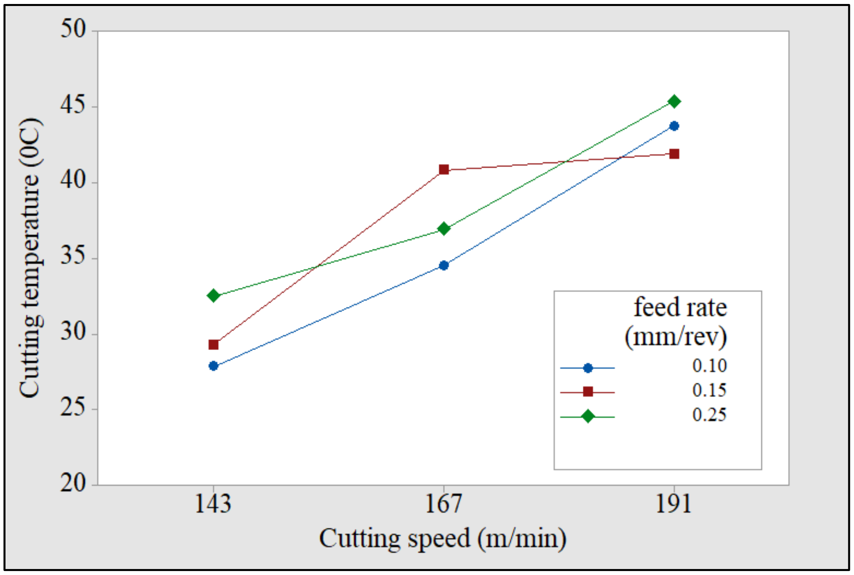


Figure 4. 8 Effect of Cutting Speed on Cutting Temperature

It is observed from Figure 4.8 the cutting temperature increases as cutting speed increases with corresponding feed due to high friction at the tool-work interface. But at feed rate of 0.1mm/rev nearly constant temperature was generated.

Figure 4.9 shows the effect of feed rate on the material removal rate. It was observed that with an increase in feed rate the cutting temperature increases similar result has been discussed by (Soren et al., 2019). The maximum tooltip temperature measurement of 45.3^{0}C was resulted using infrared thermometer at 0.25 mm/rev feeds, and cutting speed of 191 m/min. As feed rate increased from 0.15mm/rev to 0.25mm/rev cutting temperature increased to 32.47^{0}C, 45.3^{0}C at cutting speed of 143m/min and 191m/min respectively, but temperature decreased to 36.6^{0}C as feed rate increased at cutting speed of 167 m/min.

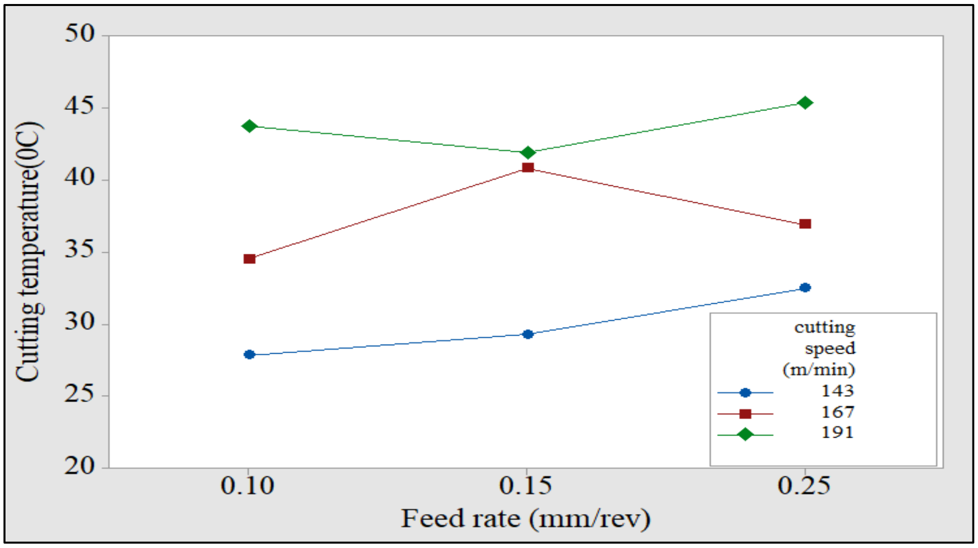


Figure 4. 9 Effect of Feed Rate on Cutting Temperature

As observed from Figure 4.10 an increase in depth of cut leads to cutting temperature increment. The obtained optimum cutting parameter of the depth of cut of 0.1mm the minimum cutting temperature of 27.86^{0}C was achieved. The tooltip temperature increases due to more heat was generated or concentrated in a small area and low thermal conductivity of workpiece material the same result has been reported by (Luo et al., 2020).

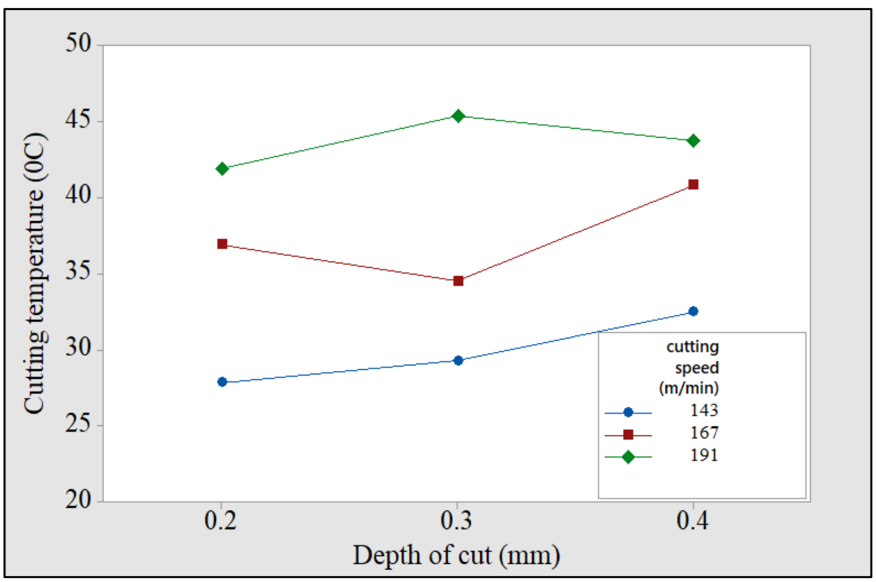


Figure 4. 10 Effect of Depth of Cut on Cutting Temperature

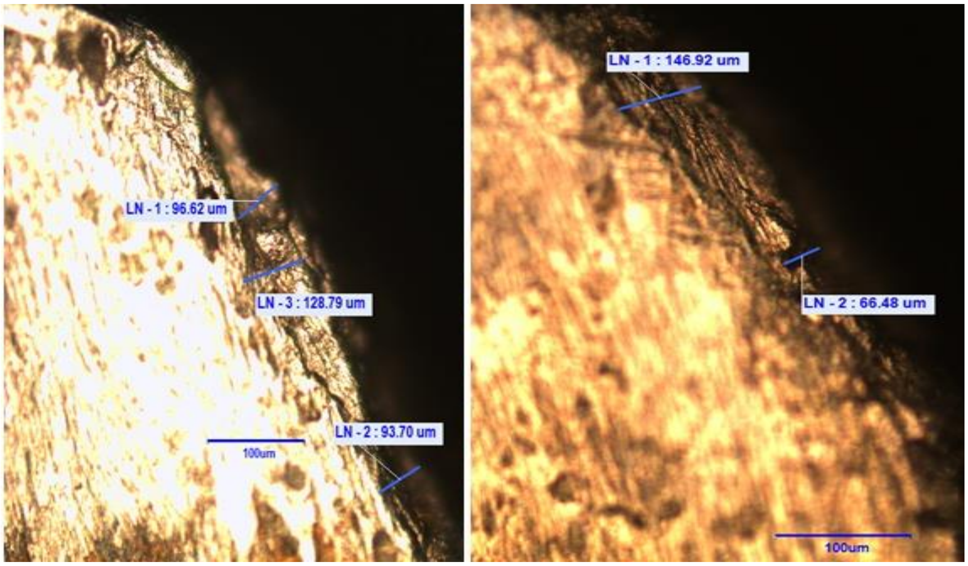
During the turning of aluminium, the temperature of the interaction area of the cutting tool and workpiece becomes high. The temperature affects not only the rate of wear of the cutting tool but also the integrity of workpiece surface such as residual stress, hardness, and surface roughness as reported by (Soren et al., 2019)

Generally, the three machining parameters was found to be a dominant effect on tooltip temperature and the result of experimental outcomes gives a good clue about the values of tooltip temperature achieved, as well as the effect of some cutting parameters.

4.6 Analysis of tool wear

Experimental investigation done while dry turning of Al 6061-T6 alloy and data acquired from optical microscope showed that two types of wear which are flank and crater wear observed. Crater wear is defect generated due to high temperature change that was instigated on rake face due to the severe contact between chip and cutting tool and it is observed that Crater wear does not directly affect the surface integrity of the workpiece as it occurs on tool and chip interface, instead of tool work interface. But flank wear occurs on tool-work interface which is seen to directly affect surface quality of machined surface and flank wear gradually changes the geometry of cutting tool.

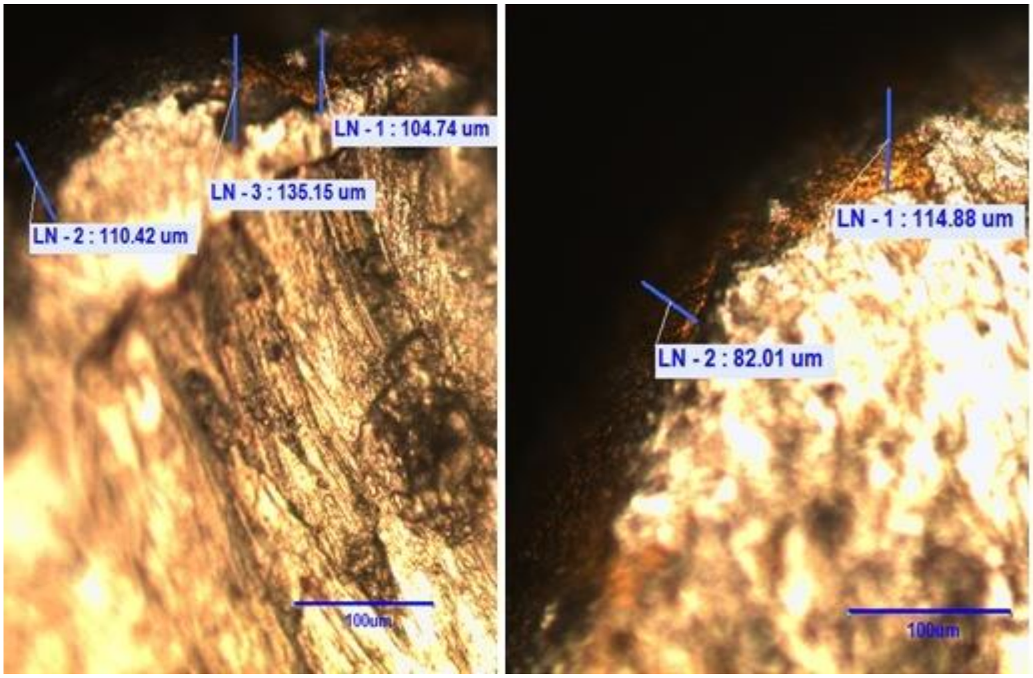
The mechanism of tool wear in tooltip has been presented based on the image taken by using optical microscopy at 10x magnifications as can been shown in Figures below. The photographic images of the tooltip of the cutting tool inserts have taken at different cutting parameters. The pattern of tool wear is different at different cutting parameters and their combinations. This is due to the effect caused by the cutting speed; feed rate and depth of cut gives different wear patterns under different parameters values.



a) Exp. 1 N=1200rpm,f=0.1mm/rev, d=0.mm **b)**Exp.2 N=1200rpm, f=0.25mm/rev, d= 0.3mm

Figure 4. 11 Optical image of the tool tip wear of experiment 1 and 2 at different cutting parameter

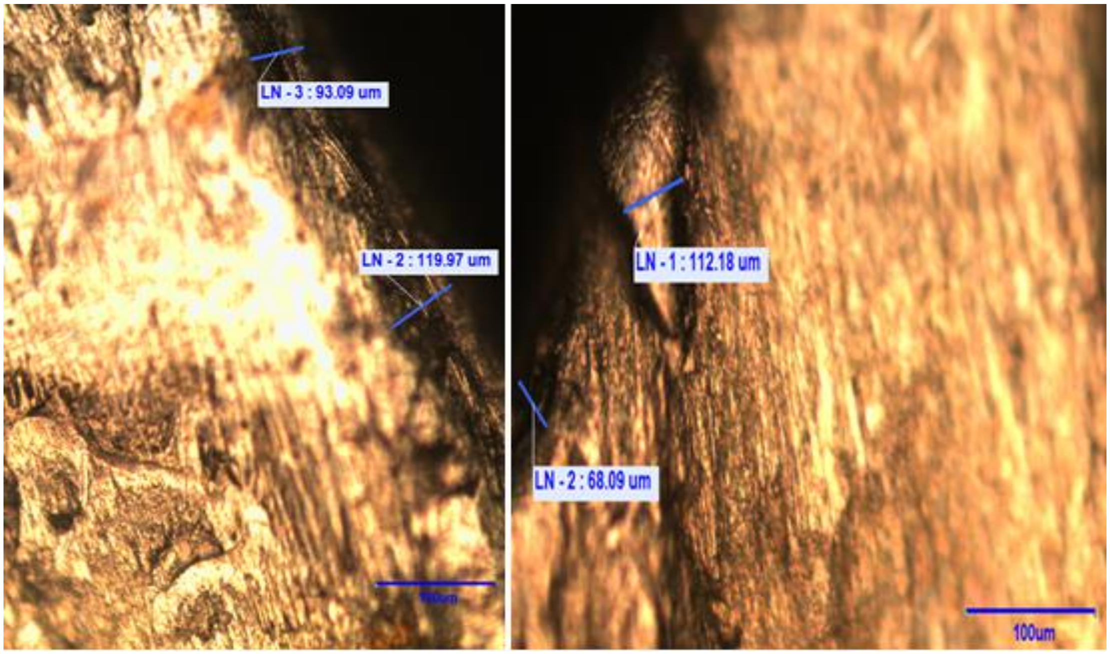
Figure 4.11 shows the nature of tooltip wear. The tooltip lost some materials approximately in macrons. Lines or groove marks are found in the cutting tooltip. The loss of some materials and the occurrence groove marks on tooltip are the features of the micro chipping and abrasive wear mechanism respectively the same result was obtained by (Batista Ponce et al., 2018). Likewise, tooltip wear measurement values for experiment 1 and experiment 2 are 0. 1060μm, and 0.1070μm respectively were attained.



c) Exp. 3 N= 1200 rpm, f=0.15mm/rev, d= 0.4mm**d)**Exp.4 N=1900rpm, f=0.1mm/rev, d=0.3mm

Figure 4. 12 Optical image of the tool tip wear of experiment 3 and 4 at different cutting parameter

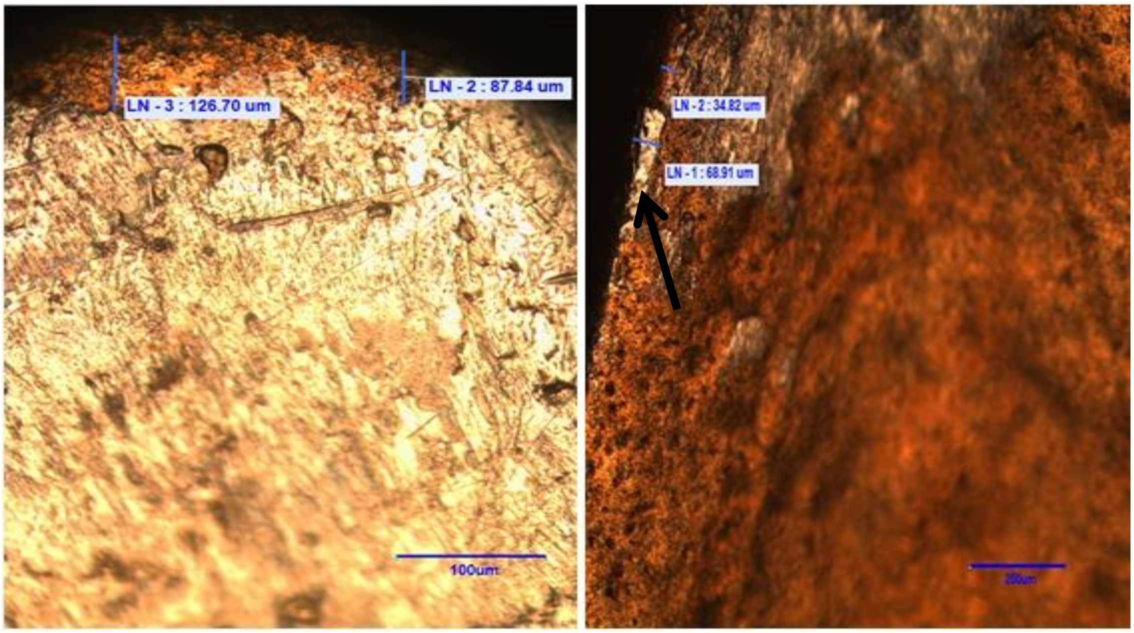
Figure 4.12 is an observation of optical microscope image of tooltip during turning of Al 6061-T6 alloy for experiment 3 at, V = 143 m/min, f= 0.15 mm/rev, and d = 0.4 mm and for experiment 3 at, V = 143 m/min, f= 0.167mm/rev, and d = 0.3 mm, at 10x magnification. The tooltip wear of experiment 3 of 0.1200µm and experiment 4 of 0.0980µm was observed, and it is an indication of high friction at the tool- work interface due to low cutting speed produce high tool wear the same work has been reported by (Sharif and Manufacturing, 2022) un stability of machine tool, and high thermal stress, etc. The abrasion wear was the dominant wear mechanism, based on image analysis.



e) Exp. 5 N=1900rpm, f=0.25mm/rev, d=0.4mm**f)** Exp. 6 N=1900rpm, f=0.15mm/rev, d=0.2mm

Figure 4. 13 Optical image of the tool tip wear of experiment 5 and 6 at different cutting parameter

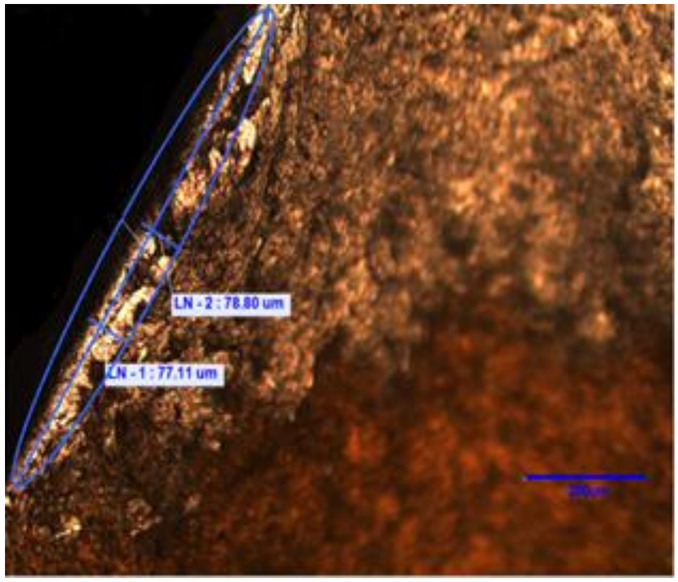
As observed from Figure 4.13 there is a formation of lines or groove marks in the cutting tooltip at 10x magnification using an optical microscope. These groove marks are produced due to the movement of the workpiece materials against the cutting tool and it is the features of the abrasive wear mechanism. Also, the cutting tooltip experiences significant mechanical stress and thermal stress due to friction at the tool work interface which can induce tool wear. In the same way, tooltip wear measurement values of tool tip wear for experiment 5 of 0.1065µm, and for experiment 6 of 0.0890µm respectively were accomplished. As reported by (Ping *et al.*, 2021) high tool tip wear is an indication of tool wear by thermal stress, which causes the softening of tooltip by plastic deformation.



g) Exp.7 N=2150rpm, f=0.1mm/rev, d=0.4mm**h)** Exp.8 N=2150rpm, f=0.25mm/rev, d=0.2mm

Figure 4. 14 Optical image of the tool tip wear of experiment 7 and 8 at different cutting parameter

As observed from Figure 4.14 there is ridges, lines, or groove marks in the cutting tooltip. These groove marks or ridges are produced due to the movement of the hard workpiece materials against the cutting tool and it is the features of the abrasive wear mechanism. At the same time, as reported by (Pattnaik et al., 2018) the cutting tool experiences significant mechanical stress and thermal stress due to friction at the tool-work interface which can induce tool wear. The tool wear of the tooltip of the optimum combination of cutting parameters (trial 8) which are cutting speed of 191 m/min, feed 0.25 mm/rev, and depth of cut of 0.2mm. When analyzing the image, it can be concluded that the optimized cutting parameters can resulted in the lowest tool tip wear of 0.0510μm was observed.



i) Exp. 9 N=2150rpm, f=0.15mm/rev, d=0.3mm

Figure 4. 15 Optical image of the tool tip wear of experiment 9 at different cutting parameter

In the same way, Figure 4.15 shows the tooltip lost some materials, and groove marks are found in the cutting tooltip. The loss of some materials and the occurrence marks on tooltip is the features of the micro chipping and abrasive wear mechanism respectively the same result was obtained by (Zhang et al., 2023).Also, tooltip wear measurement values of tool tip wear of 0. 1200μm was attained. Generally, as observed from figure 4.11 to figure 4.15 gradual wear, abrasive wear, ridges, lines, or groove marks, tool tip chattering occurs due to rubbing between the newly generated work surface and the flank face adjacent to the cutting edge, instability of machine tool, and high thermal stress, thermal stress, which causes the softening of tooltip by plastic deformation.

Table 4. 9 experimental results for mean and signal to noise ratio of tool wear measurement

Exp. No.	Spindle speed (rpm)	Cutting speed (m/min)	Feed (mm/rev)	D (mm)	Tool wear (µm)	S/N ratios
1	1200	143	0.1	0.2	0.1060	19.49
2	1200	143	0.15	0.3	0.1070	19.41
3	1200	143	0.25	0.4	0.1200	18.42
4	1400	167	0.1	0.3	0.0980	20.17
5	1400	167	0.15	0.4	0.1065	19.45
6	1400	167	0.25	0.2	0.0890	21.01
7	1600	191	0.1	0.4	0.1070	19.41
8	1600	191	0.15	0.2	0.0510	25.84
9	1600	191	0.25	0.3	0.0780	22.16

It can be observed from Figure that many lines, ridges and groove marks are observed on the flank face for cutting parameters that give poor surface roughness due to increase of friction at tool-work interface and the motion relative to the surface of hard particles trapped at the interface, which shows that the prominent wear mechanisms on the flank face are the abrasive wear observed the same work has been presented by (Okokpujie *et al.*, 2018).

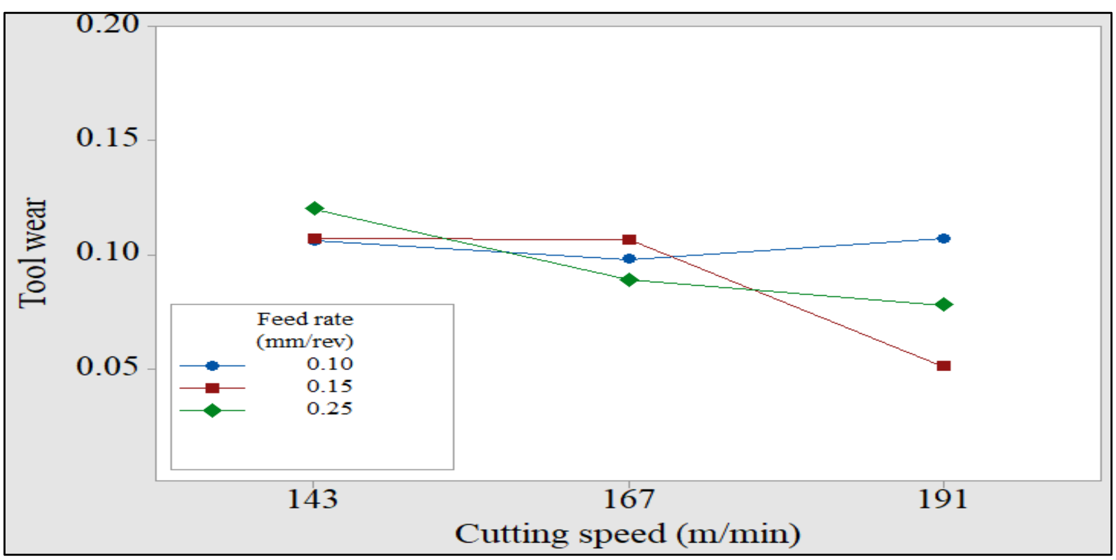


Figure 4. 16 Effect of Cutting Speed on Tool Wear

From analysis of surface roughness, it was observed that surface roughness mainly depends on cutting speed followed by depth of cut and feed rate, Increase in cutting speed leads to increase in the surface roughness which makes the poor machined surface and the augmentation in speed represents the higher straining of chips which encourages higher cutting forces and temperature. This high temperature softens the material and facilitates material adhesion over the machined surface which increased the average surface roughness and increased tool wear. It is also observed from study that blunted cutting edge caused by tool wear enhances the surface uniformity and increases the surface roughness at the same time.

4.7 Grey Relation Analyses (GRA)

GRA relation analysis is applied for the optimization in which multi variable is converted into a single variable. In this calculation we consider the material removal rate maximized, tool wear and surface Roughness has minimized.

Step-1 Data pre-processing is the method of shifting experimental results from original sequence to comparable sequence. Whereas the original data were normalized in the range of 0 and 1 by using formula from equation 3.8 for MRR and equation 3.9 for surface roughness, tool wear and cutting temperature to avoid the effect of response variable units and minimize the variability. This is called the grey relational generating

Table 4. 10 normalization of result

Experimental result					Normalization data			
Exp. No.	T_c	MRR	Ra	Tool wear	T_c	MMR	Ra	tool wear
1	27.86	2860	1.79	0.1060	1	0	0.522	0.203
2	29.30	6435	1.88	0.1070	0.917	0.312	0.326	0.188
3	32.47	14300	2.01	0.1200	0.736	0.998	0.043	0
4	34.50	5010	1.76	0.0980	0.619	0.188	0.587	0.319
5	40.80	10020	2.03	0.1065	0.258	0.625	0.000	0.196
6	36.90	8350	1.92	0.0890	0.482	0.479	0.239	0.449
7	43.70	7640	1.65	0.1070	0.092	0.417	0.826	0.188
8	41.84	5730	1.57	0.0510	0.198	0.250	1.000	1.000
9	45.30	14325	1.74	0.0780	0	1	0.630	0.609
Max.	45.30	14325	2.03	0.0510	1	1	1	1
Min.	27.86	2860	1.57	0.1200	0	0	0	0

Step-2 for each experiment deviation sequence is calculated using equation 3.10 shown in table 4.11

Table 4. 11 Normalization of data and deviation sequences of different response variables

Normalizing data					Deviation sequence			
No.	Tc	MRR	Ra	Tool wear	Tc	MRR	Ra	Tool wear
1	1	0	0.522	0.203	0	1	0.478	0.797
2	0.917	0.312	0.326	0.188	0.083	0.688	0.674	0.812
3	0.736	0.998	0.043	0	0.264	0.002	0.957	1.000
4	0.619	0.188	0.587	0.319	0.381	0.812	0.413	0.681
5	0.258	0.625	0.000	0.196	0.742	0.375	1.000	0.804
6	0.482	0.479	0.239	0.449	0.518	0.521	0.761	0.551
7	0.092	0.417	0.826	0.188	0.908	0.583	0.174	0.812
8	0.198	0.250	1.000	1.000	0.802	0.750	0.000	0.000
9	0	1	0.630	0.609	1	0	0.370	0.391
Max	1	1	1	1	1	1	1	1
Min	0	0	0	0	0	0	0	0

Step-3 GR Coefficient, GRG and rank is calculating as surface Roughness, cutting temperature, tool wear and MRR. Grey relational coefficient (GRC) is applied to normalize data after deviation sequence for distributing experimental result in the best and worst condition according to important of response variables. Grey relational coefficient was calculated using equation 3.11. GRG is an average of grey relational coefficient corresponding to each response variable; it was calculated using equation 3.12. GRG value indicates the level of relationship between the original sequence and comparable sequence. If the two sequences settle at same points, then their GRC is 1 and consequently, their GRG is equal to 1the same result was obtained by (Kannan et al., 2020).

Table 4. 12 Results of gray relational coefficient and Grey Relational Analysis of different response variables

	Deviation sequence				gray relational coefficient					
NO.	Tc	MRR	Ra	Tool wear	Tc	MRR	Ra	Tool wear	GRG	RANK
1	0	1	0.478	0.797	1	0.333	0.511	0.385	0.557	4
2	0.083	0.688	0.674	0.812	0.858	0.421	0.426	0.381	0.522	5
3	0.264	0.002	0.957	1.000	0.654	0.996	0.343	0.333	0.582	3
4	0.381	0.812	0.413	0.681	0.568	0.381	0.548	0.423	0.480	7
5	0.742	0.375	1.000	0.804	0.403	0.571	0.333	0.383	0.423	9
6	0.518	0.521	0.761	0.551	0.491	0.490	0.397	0.476	0.463	8
7	0.908	0.583	0.174	0.812	0.355	0.462	0.742	0.381	0.485	6
8	0.802	0.750	0.000	0.000	0.384	0.400	1	1.000	0.696	1
9	1	0	0.370	0.391	0.333	1	0.575	0.561	0.617	2
Max	1	1	1	1	1	1	1	1.000		
Min	0	0	0	0	0.333	0.333	0.333	0.333		

All the experimental runs were then ranked from 1 to 9 with respect to their corresponding GRG values. Optimum run is identified with highest GRG value and is ranked number 1. GRG ranking of the experimental runs is shown in Table 4.12 Experiment 8 displayed the highest value of GRG with input parameters of feed 0.25 mm/rev, speed 191 m/min, and depth of cut 0.2 mm under dry condition. GRG mean has been used to identify the optimum parameters for the experiments performed as reported by (Denkena et al., 2020). The response table for the means of grey relational grade is shown in table 4.13.

Table 4. 13 Response Table for Means for Gray relational analysis

Level	cutting speed(m/min)	feed rate(mm/rev)	depth of cut(mm)
1	0.5537	0.5073	0.5720
2	0.4553	0.5470	0.5397
3	0.5993	0.5540	0.4967
Delta	0.1440	0.0467	0.0753
Rank	1	3	2

In this work the outputs are MRR, tool wear, surface roughness and cutting temperature. In these responses MRR should be maximized, tool wear, surface roughness and cutting temperature should be minimized. Table 4.13 from the analysis of experimental results it is clear that the parameters for machining of Al6061-T6 achieved highest GRG at run 8. Hence v3f3d1can be considered as optimal parameters for the expected output.

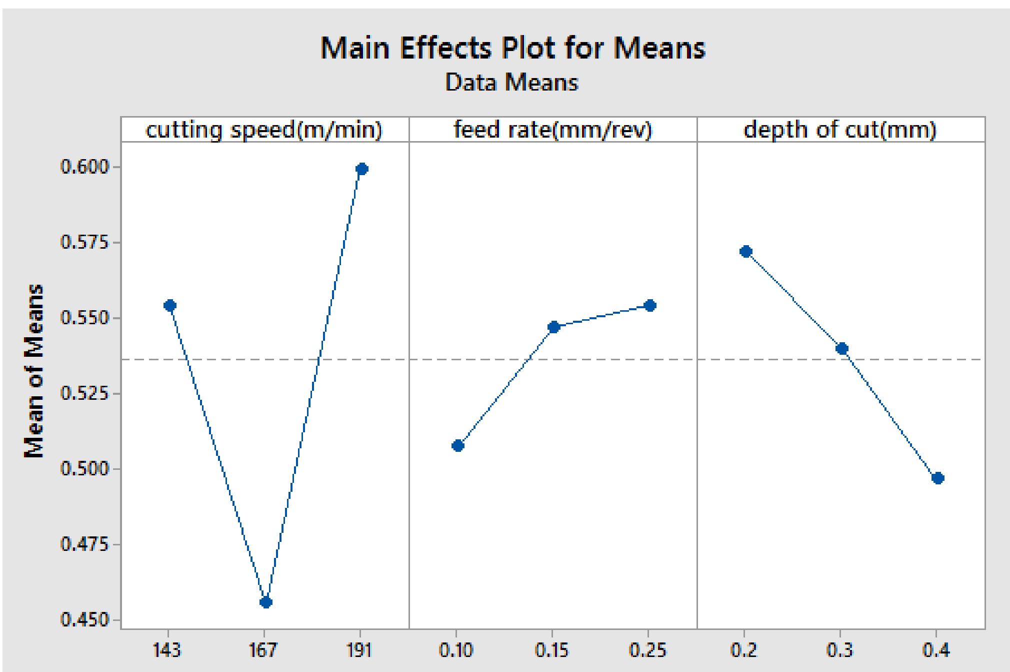


Figure 4. 17main effect plots for means for gray relational analysis

Figure 4.17 shows various combinations of machining parameters and the resulting performance. From the main effect plot, we can understand that the grey relational grade increases with the increase of spindle speed. Regarding the feed rate, it decreases for the first values, then increases for the second and third value. GRG increases with a decrease in the depth of cut. For speed at stage 3, feed at stage 3 and depth of cut at stage 1 the average grey grades are high. Which means average grey grade high at cutting speed of 191m/min, feed rate 0.25mm/rev, depth of cut 0.2mm these stages have high influence on the output responses, MRR, tool wear, cutting temperature and surface roughness while turning Al6061-T6 alloy the same result is obtained by (Agebo *et al.*, 2023). Table 4.13 From the analysis of this table, it could be concluded that cutting speed followed by depth of cut and feed rate, are significantly affecting the grey relational grade.

4.7.1 Selecting optimal parameter for output response variables

The best experimental run was obtained in experiment 8 with the value of GRG 0.696 with the input parameters of speed 191m/min, feed 0.25 mm/rev, and depth of cut 0.2 mm for all output response variables (surface roughness, MRR, tool wear and cutting temperature). presents the optimum parameters setting selected for gray relational analysis obtained from the design of experiment. The selected optimum parameters in this study were at higher cutting speed and feed and at minimum depth of cut.

Table 4. 14 Optimum parameters setting levels of output response variables (Ra, MMR, Tc and tool wear)

Turning parameter	selected Level	Value of level	Rank of GRG
Cutting speed	3	191	1
Feed rate	3	0.25	2
Depth of cut	1	0.2	3

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The current study was focused on experimental investigation and parametric optimization during dry turning of Al6061-T6 alloy by using CNC machine with cemented carbide cutting tool. Taguchi L9 orthogonal array and signal-to-noise ratio method was used for optimization of input parameters such as cutting speed, feed and depth of cut. The results indicated that cutting parameters influence surface roughness, cutting temperature material removal rate and tool wear. The role of each factor was identified by the analysis of variance (ANOVA). Therefore, based on the experimental results and successive analysis, the following conclusions are drawn:

- Surface roughness decreased at higher spindle speeds, and it was increased by the increased of the feed rate and depth of cut for dry turning.
- In dry turning of Al 6061-T6 alloy the minimum value of surface roughness 1.57μm was obtained at the high cutting speed 191 m/min and medium feed rate 0.15mm/rev and lower depth of cut 0.2mm.
- Analysis of variance (ANOVA) shows that cutting speed was the most significant parameter for surface roughness followed by feed rate and depth of cut affecting by about 61.23%, 18.89% and 15.4 % respectively.
- Based on experimental results, the arithmetical mean roughness of the surface was in the range Ra = 1.57 – 2.03, this means that by an appropriate choice of the input process parameters exceptionally high quality of a machined surface can be obtained, but worse quality as well.
- Increasing in cutting parameters (depth of cut, feed rate and spindle speed) was resulted in increasing in cutting temperature.
- Cutting speed got the most significant influence on cutting temperature followed by depth of cut at the confidence level of 95% within the specific test range. Its percentage contribution in cutting temperature was 88.38% and 6.08% during dry turning of Al6061-T6.
- There was also substantial amount of change on material removal rate which is proportional to productivity as it ranges MRR = 2860-14325mm$^{3/}$min. Effect of the

optimal input parameters on the optimal output responses was identical to that for experimental researches and they were cross checked.

- The turning of Al6061-T6alloy achieved better surface finish and lower tool wear, at high value of cutting speeds of 191 m/min, medium feed of 0.15mm/rev, and low depth of cut of 0.2 mm.
- Further on, a cutting insert flank wear covers the range of wear = 0.051-0.120mm, which implied appropriate combination of the input process parameters can result in sizable change on wear of cutting insert. This might result in product quality and costs.
- The best experimental run was obtained in experiment 8 with the value of GRG 0.696 with the input parameters of speed 191m/min, feed 0.25 mm/rev, and depth of cut 0.2 mm for all output response variables

5.2 RECOMMENDATION

Based on the results and conclusions of this study, forwards the following recommendations:

- In this study Al 6061-T6 has been used. This can be further extended to other materials types to study the effect of cutting parameters on the surface roughness under the same condition of hard turning parameters.
- The study can be extended by various parameters and their interactions and the mechanical properties studies can also be carried out.
- The metal fabrication, automotive and spare part manufacturing industries can use the optimized turning parameters for dry, MQL and wet turning of Al 6061-T6 alloy to achieve the product with minimum surface roughness.

5.3 FUTURE WORK

As a future research work, any interested person will carry out the following:

- In this research, only three parameters have been studied in accordance with their effects, the further researches can be carried out to study the effects of tool geometry like Nose Radius, Rake Angle, coating materials, lubricants on the surface roughness, cutting temperature, MRR, tool wear and residual stress.
- Future research work may be directed towards applying responded surface methodology and genetic algorithm to further fine-tune the optimization of cutting parameters, which

was beyond the scope of this research, as it was mainly focused towards the identification of most significantly influencing factors.

- Study the effect of different cutting tools with similar cutting parameters.

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