Comparative Study on the Advantages of Using Double Cutting Tool in the Conventional Turning Process of Cast Iron Material

Kalkidan Buzuneh Workineh

A Thesis Submitted to Department of Mechanical Engineering

School of Mechanical, Chemical and Materials 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

June 2022

Adama, Ethiopia

Comparative Study on the Advantages of Using Double Cutting Tool in the Conventional Turning Process of Cast Iron Material

Kalkidan Buzuneh Workineh

Advisor: Dr. Moera Gutu Jiru (Asst. prof)

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

June 2022
Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "Comparative Study on the Advantages of Using Double Cutting Tool in the Conventional Turning Process of Cast Iron Material" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Kalkidan Buzuneh Workineh	_________________	_________
Candidate	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Comparative Study on the Advantages of a Using Double Cutting Tool in the Conventional Turning Process of Cast Iron Material'' was prepared under my guidance by Kalkidan Buzuneh Workineh (PGR/21797/13) submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Manufacturing Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Moera Gutu jiru	__________________	_____________
Advisor	Signature	Date

APPROVAL SHEET

I, the advisors of the thesis entitled Comparative study on the advantages of a using double cutting tool in the conventional turning process of cast iron material and developed by Kalkidan Buzuneh Workineh; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into Comparative study on the advantages of a using double cutting tool in the conventional turning process of cast iron material the final version of the thesis.

Dr. Moera Gutu Jiru ____________ ___________

Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Kalkidan Buzuneh Workineh have read and evaluated the thesis entitled Comparative study on the advantages of a using double cutting tool in the conventional turning process of cast iron material 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. __________________________ ____________ ___________

Chairperson Signature Date

__________________________ ____________ ___________

Internal Examiner Signature Date

__________________________ ____________ ___________

External Examiner Signature Date

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

__________________________ ____________ ___________

Department Head Signature Date

__________________________ ____________ ___________

School Dean Signature Date

__________________________ ____________ ___________

Office of Postgraduate Studies, Dean Signature Date

ACKNOWLEDGMENT

Above all, I give special thanks to the Almighty God for everything of the merits is due to his gracious and merciful.

I want to express special thanks and gratitude to my Advisor Dr. Moera Gutu Jiru, Assistant professor in the Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University for his continuous support, guidance, comment, and suggestions throughout the thesis work time from starting up to end. His extreme energy, creativity, and excellent skills have always been a constant source of motivation for me. His involvement with originality has triggered and nourished the intellectual maturity that will help me today and tomorrow. I am proud to record that I had the opportunity to work with an exceptionally experienced doctor like him. He is a great person and one of the best mentors.

Special thanks to Mr. Abebe Balcha Manager of Operation Department at Rose Ethiopian iron and steel factory for their kind support and for providing the workshop facility to conduct the experimental work.

I am also grateful to Mr. Girmachew, department head, Mechanical Engineering Program in the School of Mechanical Chemical, Material and Chemical Engineering, for their support and contribution to the success of my thesis work.

Finally, my thanks go to my parents and all of the people who have supported me to complete the research work directly or indirectly.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

ACRONYMS

AA	Arithmetic Average
AISI	American Iron and Steel Institute
ANOVA	Analysis of Variance
BBD	Box-Behnken Design
CBN	Cubic Boron Nitride
CCD	Composite Central Design
CGI	Compacted Graphite Iron
CLA	Centre- Line Average
CNC	Computer Numerical Control
DoE	Design of Experimental
FEA	Finite Element Analysis
FEM	Finite Element Method
FGI	Flake Graphite Cast Iron
ISO	International Standard Organization
HSS	High Speed Steel
K_{IC}	Fracture Toughness
MQL	Minimum Quantity Lubrication
MRR	Material Removal Rate
OES	Optical Emission Spectroscopy
RSM	Response Surface Methodology
SEM	Scanning Electron Microscope
WC	Tungsten Carbide

ABBREVIATIONS

d_1	Primary depth of cut
d_1	Secondary depth of cut
et al.	And others
f	Feed
l	Chips length
Ra	Average surface roughness
R_q	Root-mean-square average
Rt	Maximum height of the profile
R_v	Maximum valley depth
R_z	Ten-point mean roughness
t	Chips thickness
Vc	Cutting speed

ABSTRACT

Today's quickly evolving new materials make it difficult for machining to attain the required surface finish. This thesis work looked at the science of using two single-point cutting tools at the same time to cut the material of the workpiece. A machined component's surface quality was examined with the effects of cutting speed, feed, and depth of cut. The impact of those cutting parameters resulted in increasing temperature, tool wear, and material removal rate. As a result of which surface roughness was investigated for different cutting parameters such as cutting speed (50, 70, 90) m/min, feed of (0.3, 0.525, 0.75) mm/rev, and depth of cut (0.3, 0.675, 1) mm for single tool turning while for double tool turning depth of cut (d_1 = 0.5, 0.75, 1, d_2 = 0.75, 1, 1.25) mm to improve productivity. The morphology of the chips was also investigated. The cutting parameters were optimized by turning process using the response surface methodology method. The surface roughness was selected as a response variable and the workpiece was estimated by using a surface roughness Profilometer. Besides, the cutting temperature in the tooltip was predicted using a digital thermometer and examined. The Box-Behnken design approach was incorporated to formulate the experiments and rigorous experimental analysis was performed. Analysis of variance (ANOVA) determined the influences of cutting parameters on the surface roughness. The results of variance presented that the influence of cutting speed, feed, and depth of cut were 51.33%, 22.58%, and 6.93% for double tool turning whereas for single tool turning 67.78%, 21.65%, and 1.6% respectively. The high surface finish attained at optimum cutting parameters (86.76 m/min, 0.3 mm/rev, and 1.75 mm) was 1.04 µm for double tool turning while for single tool turning was 1.11µm. (90 m/min, 0.3 mm/rev and 0.409 mm). For the selected cutting parameters in experimental results were observed that the material removal rate was increased by 55% during double tool turning than single tool turning. Similarly, the tool wear measured shows that total of 0.690 mm for single tool turning while it was reduced to 0.419 mm for double tool turning.

Keywords: *Cutting temperature, Tool wear, Surface Roughness, the Material removal rate*

CHAPTER-1

INTRODUCTION

1.1 Background of the Study

Metals are formed into a variety of shapes through various manufacturing processes. The non-cutting technique entails shaping metal without removing it and comprises operations such as rolling, spinning, extruding, drawing, and so on. Another way is to shape the metal by machining it by removing excess or undesired material from the workpiece material in the form of chips. Examples include turning, milling, planning, drilling, and so on. Metal cutting is one of the most exciting aspects of the industrial industry. To achieve the required shape of the component, appropriate dimensional tolerances, and a high surface gloss, machining is a crucial part of the production process (Pradeepkumar et al, 2015). Machining is the most versatile and accurate manufacturing technique, capable of producing a wide range of part geometries and geometric features.

One of the most essential material removal procedures is conventional machining. A lathe machine is a popular type of traditional machining that can perform a variety of machining operations such as turning, facing, counter-turning, tapering, boring, and chamfering. Metal cutting is carried out on a lathe by establishing relative motion between the workpiece and the cutting tool, in which the workpiece rotates and the cutting tool is made to move parallel to the workpiece's axis of rotation. When the maximum material removal rate and minimization of machining cost were critical, multi-tool machining is commonly used. Because turning is such a fundamental and crucial process, this research focuses on multi-tool turning (Kalkidan et al.2016)

Multiple tool Lathes were employed in high-volume material removal processes and provided with two or more carriages each carrying several single-point cutting tools operating simultaneously. The machining time was reduced because the carriages operate simultaneously. Higher cutting parameter values in turning provided an opportunity for increased productivity, but they also came with a higher risk of surface quality and tool life loss. In today's business, turning is a significant material removal procedure. At least one-fifth of all applications in metal cutting was turning operations. It's used to reduce the diameter of a work piece, usually to a specific size, and to give the metal a smooth surface (Saraswat et al., 2014).

The manufacturing industries are very much concerned with producing high-quality products in time at minimum cost. This research aims to investigate a comparative study on the advantages of a double tool over a single during the conventional turning of flake graphite cast iron material. The specific products from this cast iron are in the automotive industry (brake drums and disks, exhaust manifolds, cylinder heads, and especially engine blocks, including diesel engines). It was essential to optimize this material due to the quick-wear of components under dynamic load. In the present work, the models developed to predicate the product quality with the assistance of Response surface methodology, Design of experiments **(**Montgomery, 2017). The response surface methodology (RSM) was practical, accurate, and straightforward for implementation. The study of the most important variables affecting the quality characteristics and a plan for conducting such experiments is called the design of experiments (Myers et al, 2016).

The experimental data were used to develop mathematical models for second-order models using regression methods. The validity of the model is checked using an analysis of variance. RSM optimization procedure has been used to optimize the output responses of surface roughness. On selected material, a different trial with different parameters level is carried experiment, and finally, to verify the predicted value, a confirmation test is conducted based on an experiment. The research has completed a fractional experiment design that allows considering different levels of cutting parameters (cutting speed, feed rate, depth of cut) on the measured dependent variable. The ability to control the process for the better quality of the product is significant (Kassab and Khoshnaw, 2007).

1.2 Cast Iron- Structure and Constitution

Cast iron workpiece material is a metal with high hardness but also delicate qualities. Cast iron is a sort of metal that has been used for a long time and is one of the numerous metals discovered by humans. This metal is widely used, with cast iron engines accounting for over 80% of all vehicle engines. The eutectic iron and carbon alloy was cast iron. With a melting point of roughly 1200 degrees Celsius. The low melting point was advantageous since it was easily liquidated, reducing the need for fuel for the metal smelting process is more efficient and low cost (Lubis et al. 2020). Cast iron was a carbon alloy with carbon $\geq$ 2.11 wt% but also contained other important elements such as silicon, manganese, Sulphur, and phosphorous. The addition of these elements creates significant changes in the structure and properties. Theoretically, the carbon content of cast iron can lie between 2.11 % to 6.67 %. As higher carbon contents tend to make the cast iron more brittle, industrial cast irons have carbon normally in the range of 2.11% to 4.0% (Sandeep Kumar et al, 2012). Grey cast iron has some important properties that make it one of the most widely used cast materials. It has good vibration damping because of the dispersion of graphite. It has self-lubricating qualities and hence is Machinable. The price is low, and it is easy to cast even complicated structures. Its thermal conductivity is good because of the presence of graphite. Due to these reasons, it is often used in the automotive industry for components like cylinder heads, cylinder blocks, brake discs, etc. It is also used for machine tool bases (Sundaram, 2018).

1.2.1 Types of cast iron

The several variables, which lead to the different types of cast irons. Carbon content, alloying element, impurity content, cooling rate during and after freezing, and heat treatment after casting are all factors to consider. Based on the have very good machining qualities. A major reason for the continued large-scale use of cast iron in engineering was not only the low cost of the material and the casting process graphite morphology; there are several types of cast iron. The major two types can be gray iron with flake graphite and ductile iron, with nodular or spheroidal graphite. There was an intermediate type, called compacted graphite, which contains a fraction of nodular graphite, and the remaining graphite was in an irregular shape with undefined geometry **(**Muhmond, 2014).

- Grey cast iron (graphite in the form of a flake)
- Ductile iron/Nodular cast iron (graphite present in the form of spheres).
- Compacted graphite iron (contains a fraction of nodular graphite and the remaining graphite was in an irregular shape with undefined geometry).
- Malleable cast iron (graphite present in the form of nuggets).
- White iron (contains metastable cementite instead of graphite).

Flake graphite cast irons are considered but also the economics of machining the finished component. Because of their strong wear resistance and damping capabilities, flake graphite cast iron is utilized as mechanical components in bearings and brake shoes, among other things.

Table 1.1 Typical maximum turning speeds for flake graphite cast iron (Edward Trent &Paul Wright 2000)

Hardness	High-speed steel tools	Cemented carbide(WC-CO) tools	Ceramic (Alumina or silicon tools)
	Feed 0.75 mm/rev	Feed 0.75 mm/rev	Feed 0.75mm/rev
(BHN)	(m min^{-1})	(m min^{-1})	(m min^{-1})
115-200	40	120	450
150-200	25	90	400
200-250	20	70	250
250-300	12	55	180

1.3 Surface Roughness, Surface Finish, and Surface Integrity

The surface polish and integrity gained after machining determines the quality of machined surface components. The physical characteristics and chemical composition of the relevant surface and beneath layers determine the functional performance of any solid surface. Surface roughness, surface finish, and surface integrity are often used to describe the quality of the surface of manufactured objects produced by various machining processes. They are sometimes used interchangeably, but they are not identical. Roughness and finish both mean the same thing, but in different ways, whereas integrity is a broad concept that incorporates both of the previous two (Eugene et al., 1990).

1.3.1 Surface Roughness

Surface roughness is primarily determined by process variables such as tool geometry (nose radius, edge geometry, rake angle) and cutting circumstances (feed rate, cutting speed, and depth of cut) (Kumar et al., 2013). Surface roughness was more difficult to measure and track than physical size since it is influenced by a wide variety of situations. Some of these variables are within our control, while others are beyond our total control. Feed, cutting speed, tool shape, and tool setup are all controllable process parameters. Other variables like tool, workpiece and machine vibration, tool wear and deterioration, and workpiece and tool material variability are difficult to regulate (Rafai and Islam 2009). Cutting speed, feed, and depth of cut are all critical cutting characteristics to consider. Surface roughness is shown to decrease with increasing cutting speed and decreasing feed and depth of cut in most circumstances. Since these, cutting parameters will decide the type of chips, which we expect at the time of machining of a single constant material thus we have to analyze them for no such built-up edge chips formation.

Surface roughness is an important factor that determines the quality of a machined surface. It depends on many parameters such as cutting condition, machine tool vibration, cutting tool, and work holding devices. The cutting speed, feed, and depth of cut have a major influence on the surface roughness of the finished component. A lot of research work has been directed toward improving the surface quality of the machined component. The manufacturing industries are very much concerned about the quality of their products. They are focused on producing high-quality products in time at minimum cost. Surface roughness is one of the crucial parameters that have to be controlled within suitable limits for a particular process (Ranganath et al, 2014). It has been an important design feature and quality measure in the machining process. There are a large number of parameters that affect the surface roughness. These include cutting tool variables, workpiece material variables, cutting conditions, etc.

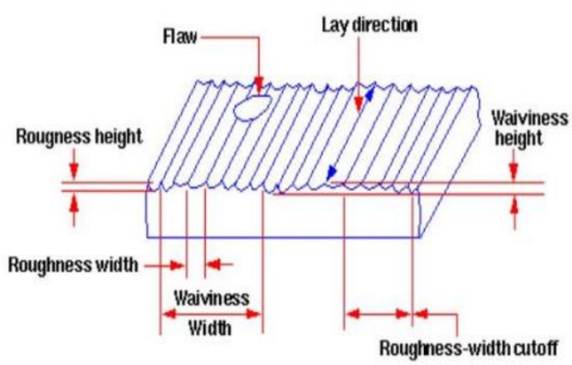


Figure 1.1 Surface characteristics and terminology (Vorbuger and Raja, 1990)

1.3.2 Surface Finish

Surface finish is one parameter of surface topography that indicates the smoothness of a solid surface. The surface finish determines the smoothness of a surface and it is essential in many situations, for instance, precision fits fastener holes, fatigue strength, wear resistance, and corrosion resistance improvement. The surface finishes are improved by decreasing the feed rate or by increasing the tool nose radius. It indirectly indicates the height and depth of asperities on the solid surface. No surface is perfectly smooth; even if it is perfectly smooth, it cannot be determined as every measuring instrument has a range of its capability. High surface finish is required in the fields of optics and electronics (lenses, mirrors), medical instruments, micro fluid (nozzle, channel, mixture), and material properties with high fatigue life wear resistance and toughness. There was different factor that determines surface finish such as feed, nose radius, cutting speed, depth of cut, feed rate, and workpiece hardness. However, the feed is a dominant factor (Kaladhar 2019 Kumar et al. 2018)

1.3.3 Surface Integrity

Surfaced integrity has a broad domain and consists of all surface topography parameters. Surface integrity is an enhanced condition of a surface produced in a machining or other surface generating condition that describes a geometric feature of the surface, physical properties, chemical properties, mechanical properties (residual stress, hardness, etc.), metallurgical properties (microstructure, phase transformation, etc.) and topological properties (surface roughness). The processes of enhancing surface integrity are such as strain hardening of surface, the introduction of compressive residual stress can increase fatigue life. Every surface generation or modification process is associated with the alteration of various properties including roughness, plastic deformation, micro cracking, phase transformations, micro-hardness, and residual stress (Rech, 2003 Lucca et al 2018).

1.4 Research Motivation

Many researchers have conducted experimental investigations in the machining process to add certain economical values by modifying various machine elements. Improving the surface quality of the machined product was one of the most common customer requests, and manufacturers must remain competitive. Without surface quality, it's difficult to talk about high production rates, long product life without defects, and mechanical qualities of materials like corrosion resistance and wear resistance. As a result, an experimental study work on machining with two tool-turning processes simultaneously has been presented to increase productivity, and extend tool life with optimum temperature generation, and surface roughness.

1.5 Problem Statement

In the metal manufacturing industry, machining is still the most commonly used method of product formation. In modern industry, one of the major goals is to manufacture at low cost and high-quality products in a short time. During machining of a different workpiece to get good quality of the product in a short time and to increase the rate of production, it should increase the depth of cut in the turning operation. However, the major problem in increasing the depth of cut is that it affects adversely the surface finish or quality of product and the life of the cutting tool. If cutting speed is reduced to enhance the tool life the material rate is also reduced and therefore, the production cost increases and the production rate is decreased. The concept of improving productivity rather to focus on different ways like using tools that are more cutting engaged simultaneous on cutting. Single point tool turning process of components; results in higher consumption of production time, lower production rate; poor tool life, more materials consumption, and less material removal rate. Therefore, the Multi-tool turning process is an important process, which can solve above listed problems. The multi-tool turning process will be carried out on a conventional lathe machine with necessary modifications. The experiments will be designed with the help design of the experiment (DoE) tool. The goal was to manufacture low-cost, high-quality products in a short time. Therefore, to full fill the above-mentioned goal, one has to focus on such a method, which will enhance the production rate by minimizing the machining time and at the same time will not affect the quality of the work finished.

1.6 Objective

1.6.1 General Objective

The main objective of this thesis is to investigate the advantage of double tool turning in the conventional turning process of cast iron material.

1.6.2 Specific Objective

The specific objectives are:

1. To optimize the cutting parameters (speed, feed, depth of cut) to maintain optimum productivity using Response Surface Methodology.
2. To determine the productivity in the multi-tool turning process while maintaining the required quality of surface finish
3. To analyze heat generated at the tool-chip interface in double tool turning.
4. To observe chip morphology during flake graphite cast iron

1.7 Significance of the Study

Productivity can be enhanced by the proper design of the cutting tool. At the same time, it is possible to enhance production rate and precision by simultaneous machining by more than one tool. This study has the following significance

1. To enhance the production rate
2. To enhance the precision of the product.
3. Obtain a better surface finish
4. Improve wear and corrosion resistance of parts
5. Helps to maintain the stability of dimensional accuracy
6. Increases the service life of the product, enables customer satisfaction, and increases market share. Furthermore, the study benefits the manufacturing industry (especially local industries like Rose Ethiopian Iron and Steel Industry and other machine shop industries).

1.8 Scope and Limitation of Studies

This study is limited to-

- ✓ Selected turning operations on lathe machine with its corresponding cutting parameters.
- ✓ Flake graphite cast iron and ceramic coated-carbide tool were selected for specimen and cutting tool materials respectively.
- ✓ Optimize and identify the most significant cutting parameters at which better surface finish is achieved during double and single tool turning of Flake Graphite Cast Iron 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 a dynamometer and difficulties to measure vibration frequencies.

1.9 Structure of the Thesis

1.9.1 Chapter One: Introduction

This chapter starts with giving a brief background about the machine, turning operation, optimization method, and cast iron. It includes the statement of problem, objective, scope, limitation, significance, beneficiaries, etc.

1.9.2 Chapter Two: Literature Review

Describes the general background of the Multi-tool Turning process, the idea and the principle of Multi-tool Turning processing, and a detailed literature review are presented. The related conventional single Turning process is also compared with the Multi-tool Turning process.

1.9.3 Chapter Three: Materials and Methods

Describes the general research design, material, tool design, manufacturing, and experimental condition. In addition, the experimental setup and procedures as well as testing procedures are also explained

1.9.4 Chapter Four: Results and Discussion

Explains results and discussion obtained from experimental observations. Characteristics of the production rate of single and double tool turning, macro and microscopically investigations, as well as the quality of the product were extensively discussed.

1.9.5 Chapter Five: Conclusion and Recommendations

Finally, a summary of the thesis work along with conclusions based on the findings was given in this chapter

CHAPTER- 2

LITERATURE REVIEW

2.1 INTRODUCTION

The following chapter looks at published studies on the turning process and how to optimize parameters. The experiment and the turning process, as well as hypotheses and facts, are all thoroughly explored. The paper covers a variety of optimization strategies for obtaining optimal results, with a focus on the Response Surface Method. Increased material removal rate with greater surface finish and high machining accuracy are the most pressing needs of current metal cutting operations. Its effects are often reduced in the metal cutting process by choosing the right process parameters. The selection of optimal cutting parameters is a very important issue for every machining process to enhance the quality of machined products, reduce machining costs, and increase the production rate.

To address these issues, the researchers develop models that attempt to replicate machining settings and create cause-and-effect correlations between various variables and desired product attributes. The description of each technique, together with its benefits and drawbacks, should aid both researchers and practitioners in selecting the approach that best suits their needs and unique requirements by offering concise yet adequate information. Different studies in the following part focus on the turning operation and show various results that improve the observed closeness in the results between experimental and predicted values in the turning operation.

2.2 Turning Operation

The turning operation was a basic metal machining operation that was frequently used in the metal cutting industry. During a turning operation, Metal was removed from the outer diameter of a revolving cylindrical workpiece during turning. It was used to reduce the diameter of the workpiece, usually to a specific size, and to give the metal a smooth surface. The workpiece was frequently turned, causing adjacent pieces to have differing diameters. The cutting tool was fed linearly in a direction parallel to the axis of the rotation. In a lathe machine tool, the turning operation was performed. The workpiece was held in a chuck fixed to the headstock of the lathe machine tool and was rotated at a fixed rotational speed. The cutting tool was advanced at a particular feed rate and a particular depth of cut to remove the material.

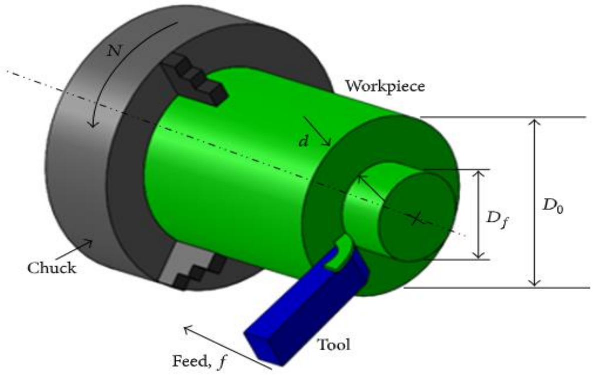


Figure 2.1 Turning operation (Sousa et al, 2017)

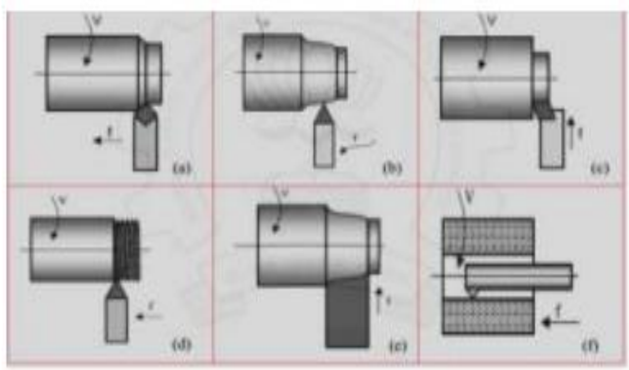


Figure 2.2 Turning Operations: (a),[straight turning, [b],Contour turning and Taper turning, [c],facing, [d], Thread cutting, [e], form turning and [f], boring (Sousa et al., 2017)

2.3 Concepts of double tool turning process

The prime requirement in any production process was to produce components at the minimum possible cost without affecting the overall quality of the component. To achieve this objective in metal cutting/metal machining many attempts have been made in several different ways; such as optimizing the tool life to minimize the production cost, maximizing the production rate to reduce the production cost, etc. If cutting speed is reduced to enhance the tool life material removal rate is reduced and therefore, the production cost increases. If we increased the cutting parameters to increase the production rate, it will affect the surface quality adversely. The new technique, which will enhance productivity without affecting the overall quality of the component using two single-point cutting tools works simultaneously for improving the production rate at the optimum surface finish. The additional cutting tool was fitted on the same tool post and mounted on the same carriage and lead screw as the first one. The following figure refers to the schematic representation of the two cutting tools working simultaneously on a single workpiece.

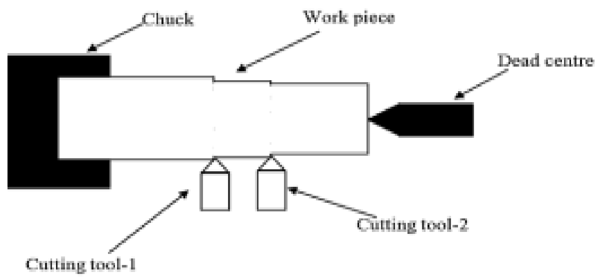


Figure 2.3 Schematic representation cutting tools mechanism (Pradeepkumar et al, 2015)

This project will investigate the use of two single-point cutting tools for simultaneous machining to increase the productivity of the turning process. A convectional lathe will change to accomplish a double tool turning procedure. A tool-holding fixture will be designed and installed on the lathe carriage. Cutting speed, feed, depth of cut, and distance between the two cutting tools are all process parameters in the double tool turning process.

Kalkidan et al (2016) studied the various possibilities of simultaneous machining in turning in several ways. The first was a schematic of cylindrical turning, drilling at the same time using a carriage-mounted turning tool and a tailstock-mounted drilling bit The second operation was a cylindrical turning procedure, which involved machining two features at the same time. It is common to have two tools moving with the same feed, however, it is feasible for these tools to move independently. The third illustration depicts a similar setup, except the tools are mounted on the opposite side of the cylindrical workpiece. This configuration equalizes the forces and improves precision. In other words, one tool serves as a follower rest for the other. The tool routes, on the other hand, are asynchronous. The final technique is two-tool synchronous machining. Both tools are direct across from each other here.

2.4 Analysis of Tooltip Temperature

The study of heat has become prominent in metal cutting as it has a very critical influence on machining processes. Any machining process involves three basic elements chip, tool, and workpiece. The heat developed among these elements cause a considerable effect on the machining performance.

Pradeep Kumar et al. (2015) addressed a concept on the rate of tool wear and the crater wear on the rake face of the cutting tool greatly influenced by the temperature at the chip-tool interface. The Tool-Chip interface is the region where maximum heat was generated among all the others. The maximum temperature occurs in the contact zone between chip and tool. In the entire heat generated, the chip carries 80% of total heat away and 10% transferred to the tool the remains 10% by the workpiece. During machining, a substantial amount of heat was created at three different positions from the cutting site. Almost all of the energy expended in plastic deformation was transformed into heat during cutting, causing a rise in the cutting zone's temperature. It can, to some extent, increase tool wear and, as a result, reduce tool life.

The plastic deformation and friction between the chip and the tool, as well as the tool, workpiece, and various cutting forces, all played a role in the temperature generation in the cutting zone. Because metal cutting involves a lot of plastic strain, practically all of the heat is transported to the chip, cutting tool, and workpiece, while only about 1% of the work is stored as elastic energy. The three sources of heat generation are

1. Shear-plane (AB), where the actual plastic deformation occurs
2. Tool-chip interface (BC), due to the friction between tool and chip
3. Tool-workpiece interface (BD), which occurs at the flank surface.

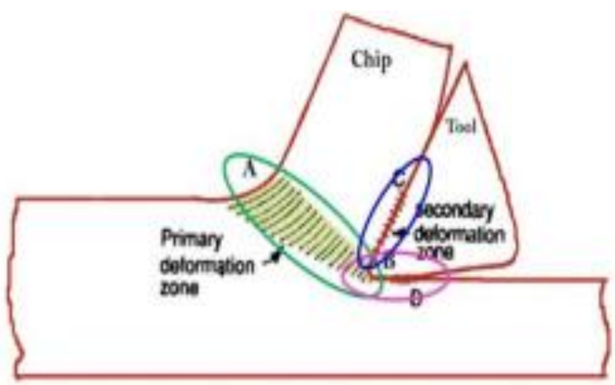


Figure 2.4 Sources of heat generation in metal cutting (Pradeep Kumar et al. 2015)

Dewes et al. (1999) measured the temperature during machining of hardened mold/die steel by using both tool work thermocouple and an Infrared camera. Interface temperature measured using the thermocouple when machining with the workpiece at 0°C was between 200-300 °C. The cutting temperature increased with cutting speed and it did not reduce at higher speeds.

The infrared technique indicated lower temperature than the thermocouple method with Value ranges of 68-390 °C.

The resultant heat of metal cutting is one of the limiting factors of machining processes. This phenomenon has adverse impacts on the manufactured tool, dimensional accuracy, tool wear, speed, and cost of production. On the other hand, the consumption of cutting fluid used in metal machining for a variety of reasons such as improving tool life, surface finish, and flushing away chips from the cutting zone, has become a health detriment to the operator as well as a contaminant into the environment.

Karpat and Ozel (2008) presented analytical and experimental validation of a thermal model when machining at a higher cutting speed with chamfered tools. The effect of cutting conditions, heat generation, and resultant temperature distribution at the tool and in the workpiece was investigated. The tool and work material pair is CBN and AISI 4340 steel. It has been observed that the temperatures increased with increasing uncut chip thickness. This also resulted in a decrease in friction factor. There are many detrimental effects of high cutting temperatures produced during machining. This further gets aggravated by increasing the cutting parameters such as cutting speed, feed, and depth of cut.

2.5 Study of Surface Roughness

Surface roughness is a measure of the surface finish of a product and an index of the product quality (Dash et al, 2012). It depends on many parameters such as cutting condition, machine tool vibration, cutting tool, and work holding devices. The cutting speed, feed, and depth of cut have a major influence on the surface roughness of the finished component. A lot of research work has been directed toward improving the surface quality of the machined component. Surface roughness refers to the small-scale fluctuations in a physical surface's height. It's calculated in a variety of ways, including the arithmetic mean and the center-line average.

Maximum peak (Ry), ten-point mean roughness (Ra), root-mean-square average (Rq), root-mean-square average (Rq), root-mean-square average (Rq), root-mean-square average (Rq), maximum peak (Rz), Rv is the maximum valley depth, Rt = Rq – Rv is the maximum profile height, and so on. Among them all, Ra is the most widely used roughness indicator. The arithmetic means value, often known as Ra, is a number that is calculated by multiplying two numbers together. The arithmetic average (AA) or CLA (Centre-Line Average) was originally known as AA (Arithmetic Average) or CLA (Centre-Line Average).The mean deviation from the centerline or datum line of a set of points. The datum line is drawn so that the sum of the regions beneath the profile above the datum equals the sum of the areas beneath the datum. Surface roughness was usually measured in microns (m) (Yashaswi 2014). Studies by (Sahin and Motorcu 2008) have shown that surface roughness was mostly dependent on feed rate, which is the dominating factor. (Mechlook 200) investigated the surface roughness, which is generally evaluated directly using instruments known as Profilometer. The Profilometer is a stylus probe instrument that uses a motor drive to move the stylus positioned in the pick-up unit across the machined surface. The selection of output is received and rectified by the pick-up, which is then amplified and the average roughness height is provided digitally. The Taylor Hobson Talysurf is one of the most prevalent forms of Profilometer. It works on the principle of carrier modulation.

2.6 Analysis of Tool Wear

Tool wear is a common occurrence in the machining process that has a considerable impact on the size of the product, its quality, the efficiency of the machining operation, production judgments, and financial feasibility. The wear of the insert has a significant impact on the machine economy (pand et al 2018) Cutting tool wear is influenced by tool material and shape, workpiece materials, cutting parameters (cutting speed, feed rate, and depth of cut), cutting fluids, and machine-tool characteristics, among other factors. Tool wear is usually a gradual process. In cutting tools, there are two types of wear zones: flank wear and crater wear. The most critical types of tool wear that were measured were flank and crater wear. Wear monitoring was most typically done with flank wear.

Kalidasan et al. (2016) Tool wear was found to be a primary factor influencing machining. It shows how much material is lost from the cutting tool during the machining process. The two most prevalent types of tool wear are flank wear and crater wear. The former is caused by the cutting tool rubbing against the machined surface, while the latter is caused by the chip sliding across the rake face of the cutting tool. The tool life, which was measured in minutes, was the amount of time it took for the tool to work satisfactorily. For multi-tool operations, the tool life was calculated for the highest production rate and lowest cost.

Tool failure patterns in multi-tool machining were described by Zompi et al. (1990), who employed probability theories to measure tool life. Analyze the multi-tool tool life distribution. Consider progressive wear and sudden tool breakage when evaluating the tool life distribution of multi-tool machining. For multi-tool and single-tool manufacturing machines, Sheikh et al. (1995) offered several tool replacement procedures. Because there has been very little research on tool wear in multi-tool turning, the current author conducted an experimental tool wear study on the double tool turning process. The turning tests were performed on a 200-mm-long cylindrical gray cast iron workpiece with a 0.5-mm depth of cut, 0.24-mm/rev feed, and a 1,210-rpm spindle speed. Eight passes were made to better understand cutting tool wear, and the workpiece diameter was lowered from 54 to 39 mm throughout the 330-second cutting time. The cutting speed was reduced from 201 to 148 m/min due to the diameter reduction. With the use of a toolmaker's microscope, tool flank wear was assessed after 2, 4, 6, and 8 passes during turning to comprehend the flank wear of both the front side and the rear side-cutting tool. The front side-cutting tool's flank wear is slightly higher than the rear side-cutting tool's since the rear-cutting tool had less friction.

Bagaber and Yusoff, (2001) also applied CCD, RSM, ANOVA, and DF for research of Austenitic stainless steel AISI 316 was turned with an uncoated carbide tool. The results indicated that feed rate and cutting speed are significant factors that influence surface roughness and tool wear, respectively. The surface roughness increases when cutting speed, and feed rate increase, while the tool wear increases with increasing the cutting speed, and depth of cut.

2.6.1 Tool Failure Modes

To minimize machining cost, it is not necessary only to find the most suitable cutting tool and work material combination, for a given machining operation, but also to reliably predict the tool life. Tool wear and tool life in machining are primarily determined by the following factors: tool geometry, tool materials, workpiece materials, cutting parameters, cutting condition, machine tool, and so on. It is important to identify the different tool failure modes to select appropriate operating conditions for machining.

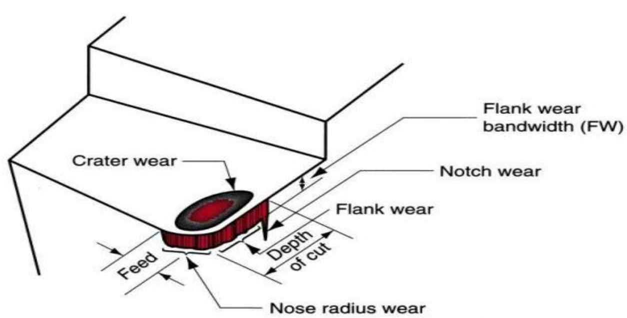


Figure 2.5 Principal location and types of wear *(*Edition and Groover, 1967*)*

The most widely researched tool failure modes are flank wear and crater wear

- Flank wear

Flank wear was mainly caused by friction between the flank face of the cutting tool and the machined workpiece surface and leads to loss of the cutting edge. High temperatures cause abrasive and/or adhesive wear, impacting the characteristics of tool materials as well as the surface of the work piece. The key wear mechanisms in flank wear are abrasion, diffusion, and adhesion. Flank wear is mechanically activated wear in cutting tools caused by the abrasive impact of the workpiece material on the cutting tools.

- Crater wear

Crater wear occurs due to the sliding action of the chip on the rake face of the cutting tool. The tool-chip interface temperature governs this mode of failure and the chemical affinity between the tool and the work piece materials. Crater wear is influenced by the same factors that affect flank wear. Diffusion, adhesion, and abrasion are the key wear mechanisms in crater wear of ceramic tools.

2.7 Material Removal Rate (MRR)

Understanding of material removal concept (MRR) in metal cutting is very important in the designing process and cutting tool selection to ensure the quality of the product. The material removal rate (MRR) in turning operations was the volume of material/metal that was removed per unit time in mm3/sec. For each revolution of the work piece, a ring-shaped layer of material was removed. Material removal rate (MRR) is the amount of material removed per time unit. It directly determines the productivity of the machining process as it is directly related to the amount of material removed per unit of time. In the machining process, high material removal means the removal of a large amount of material per a given time that maximize the production rate. However, a high production rate only does not mean economic machining because increasing material removal rate usually results in high surface roughness, high tool wear rate, and high tool tip temperature, which negatively affect the overall economy of the machining process. In this study, the following formula has been used to compute the material removal rate (Durga Bhavani, 2017).

2.9 Summary of literature review

Baker (2000) studied the fracture resistance of flake graphite cast iron. From the study, it can be concluded that the application of fracture mechanics to flake graphite cast iron was considered and it was shown that the fracture resistance can be characterized in terms of the fracture toughness (KIC) parameter. The micro mechanism of fracture was illustrated and shown the fracture resistance was controlled by the form and distribution of the graphite and by the strength of the steel-like matrix.

Venkatasubramanian & Baker (2000) carried out the fracture toughness of flake graphite cast iron having a range of eutectic call sizes and different matrix microstructure. Fracture toughness and tensile strength improve with decreasing cell size and rising matrix hardness, according to the findings.

Dewes et al. (2001) measured the temperature during machining of hardened mold/die steel by using both tool work thermocouple and an Infrared camera. Interface temperature measured using the thermocouple when machining with the workpiece at 0 °C was between 200-300 °C. The cutting temperature increased with cutting speed and it did not reduce at higher speeds. The infrared technique indicated lower temperature than the thermos couple method with Value ranges of 68-390 °C.

Chen (2001) discusses the cutting forces and surface finish while utilizing CBN tools to machine medium hardness steel. The issue that all industrialists face in reaching high productivity Surface roughness during the turning of Flake graphite cast iron is affected by the problem faced by all industrialists in producing high-quality goods with higher productivity in less machining time.

Diniz and Micaroni (2002) carried out other experiments in turning operations of AISI 1045 steel, also using coated carbide tools and cutting conditions typical of finishing operations. Their goal was to compare dry cutting with abundant fluid at different feeds, cutting speeds, and tool nose radii. Their main conclusion was that the operation with fluid always led to a longer tool life when compared with dry turning, but with the increase of the feed and tool nose radius, the tool life obtained in dry cutting becomes very close to that obtained with abundant fluid, which makes the use of dry turning of steel feasible.

Diniz et.al (2004) this work aim to seek conditions in which dry cutting was satisfactory compared with the flood of fluid (called here wet cutting) usually used. Showed that dry cutting cannot be used with a large depth of cut. But the main conclusion was that, if the tool material was changed to a more wear-resistant one, dry cutting can be used with results very similar to those obtained with a flood of fluid (wet cutting).

Boswell et.al (2007) Present a review identifying the effectiveness of minimum quantity lubrication (MQL) during conventional machining. Mechanical properties, quality, and type of the machine tool used in auxiliary tooling Surface roughness remain the main indicator of machined component quality as it was related to surface quality.

Kalidasan et.al (2009) the objective of this work is to make an experimental investigation on the distribution of cutting forces and feed forces on the front and rear cutting tools at various offset distances and different depths of cut during the Multi-tool turning process. It was found that the forces increased proportionately with the increase in depth of cut and the magnitude of increase of forces for front cutting tool and rear-cutting tool is different. The main aim of this work is to make an experimental study on the distribution of cutting forces in the Multi-tool turning process, particularly regarding two single-point cutting tools machining simultaneously, at different offset distances, and various depths of cut.

Tetsuya Uchimoto et al. (2010) investigated the feasibility of using the electromagnetic nondestructive evaluation method to characterize the shape and size of graphite in flake graphite cast iron. The conductivities and magnetic characteristics of flake graphite cast iron materials with varied graphite structures and matrices were measured and assessed systematically.

Li, (2012) presents the information on the development of a study on theoretical analysis and numerical simulation of tool wear all over the world. Focuses on the new development in predicting the tool wear evolution and tool life in orthogonal cutting with FEM simulations. shown that the simulations using a cutting tool with constantly updated rake face and flank face geometries are possible to predict the evolution of tool wear at any given cutting time from FEM simulations. In addition, a region of very low wear rates was observed close to the tool radius on the rake face side. It is found that tool wear is not formed by a unique tool wear mechanism but a combination of several tool wear mechanisms. Tool wear mechanisms in metal cutting include abrasive wear, adhesive wear, solution wear, diffusion wear, oxidation wear, etc.

Kalidasan, et al (2014 investigated the distribution of cutting forces and feed forces on the front and rear cutting tools at various offset distances and different depths of cut during the Multi-tool turning process. It was found that the forces increased proportionately with the increase in depth of cut and the magnitude of increase of forces for front cutting tool and rear-cutting tool is different.

A study titled "Surface Finish Monitoring in CNC Turning Using RSM and Taguchi Techniques" was delivered by Ranganath et al. in 2014. The results of an experimental examination of the effects of speed, feed rate, and depth of cut on surface roughness in CNC aluminum turning were described in this work (KS 1275). In CCD, the three parameters speed, feed rate, and depth of cut were chosen in the screening experiment. Taguchi and response surface methodology were developed using Minitab 15. The data were also analyzed using the same program. The Response surface methodology revealed the importance of all conceivable combinations of interactions and square terms, although Taguchi's technique usually only looks at three. This is since control factor interactions were aliased with their major effects. The time it took to perform trials with the response surface methodology technique was nearly double that of the Taguchi technique. The Response surface methodology's 3D surfaces might aid in visualizing the effect of parameters on response over the entire range indicated, whereas Taguchi's technique provided the average response value at a given level of parameters. The Taguchi technique did not have the optimization plot derived from the Response surface methodology. As a result, the response surface methodology is a more effective tool for optimization and can more accurately forecast the impact of factors on response.

Pradeep Kumar et al. (2015) addressed the concept of various sources of heat generation and its considerable effects on the life of the cutting tool and the quality of the machined parts and the distribution of the temperature in a different region. The study has also been conducted on the various aspects of heat generation, as it caused due to the cutting edge of the tool slides across the surface of the work and the paper focuses on various factors that influence the temperature generation. From the study, it can be concluded that heat distribution in the chip, workpiece, and tool is in the ratio of 80:10:10. Which shows the heat generated at the tool-chip interface is more and diverts to focus on that region.

Kalkidan et al (2016) evaluated the cutting forces and temperature in multi-tool turning of grey cast iron. It was observed that the temperature rise in the workpiece caused due to front and rear-cutting tools remained uninfluenced by the distance between the cutting tools and at the conditions, the rear-cutting tool experiences lesser force compared to a front tool, which reduces the friction. Kalidasan et.al (2016) studied the tool wear, machining accuracy, and chip-morphology with double tool turning. It was observed that the effective coefficient of friction of the rear tool was lesser than the front tool. The dynamic stiffness of the machining system was influenced by the compliance of headstock, tailstock, and carriage. Apart from this, the workpiece length, cutting tool, tool post, and working holding device such as chuck also affect the dynamic stiffness. The results confirmed the workpiece temperature was higher when the rear-cutting tool removed the material hen compared with the front-cutting tool. Under the experiment, the chips generated from the front cutting tool did not show any thermal effect and it was found that a higher depth of cut leads to higher diametral error.

Die souse et.al (2017) studied a review on the machining of cast irons. The machine parameter, characteristics, and properties, machinability were studied. White cast iron and CGI are not so easy to machine though, due to their high mechanical properties and presence of hard carbides in their microstructures that contribute to promoting abrasive wear and consequently reduction in the tool life. Nodular cast iron has low machinability when the chip breakability is the criterial due to the frequently continuous chip formation examined. They stated as coated cemented carbide remains the main tool material used for machining cast irons, in general, due to the good combination of hardiness, toughness, and costs.

Yadav (2017) developed a mathematical model and optimized the cutting parameters in the duplex turning process using a combined Taguchi-response surface Methodology hybrid approach. It was reported that the surface finishes improved significantly in the hybrid approach compared to the Taguchi method. It was reported that the conductivity and permeability of the flake graphite cast iron materials depend largely on their graphite structure rather than on the matrix.

Tariqul Islam et al. (2019) studied to determine the nature of heat generation and temperature distribution of different materials under different cutting tool feed. Both the heat generation and temperature due to different feed are found in terms of temperature variation. The result found through the numerical analysis suggested that temperature deviation increases with the cutting tool velocity but heat generation decreases with increasing the feed rate.

Sivaramakrishnaiah et al. (2019) studied numerical and experimental validation of chip morphology. Since experimental techniques for investigation, the chip morphology is expensive and time-consuming to overcome these difficulties used FEM (Finite element modeling) and simulation process as an effective tool to divination the effect of cutting variables. FEA simulation process model developed to divination the chip morphology and cutting forces in turning of Al-6061 with WC tool. It stated that numerical simulation process software is a reliable tool for divination chip morphology.

Table 2.1 Some Summary of Literature Review

S/N	Author Name	Operation and machine used	Materials used	Optimization Techniques used	Input parameters	Response variable	Results/most significant parameters
1	Kumaragurubaran *et.al*	Turning, CNC lathe	EN9 steel	Taguchi Design of Experiment	Feed Rate and Depth of Cut	Surface Finish	Feed rate
2	Prof. P.D. Kamble *et al*	CNC Lathe	EN8	Taguchi DOE	CuttingCondition, Speed, Feed, Depth of Nose Radius.	Surface Roughness, MRR	Spindle Speed
3	Choudhary *et al*	Turning	EN24T	Response surface methodology Surface roughness	Feed Rate and Depth of Cut	Surface roughness	Depth of cut
4	Singh	Ordinary lathe	EN8	Taguchi method	Spindle speed, feed rate, and depth of cut.	Surface roughness	Spindle speed
5	KALADHAR	Turning	AISI 202	ANOVA	Spindle speed, nose radius, and feed rate	Surface roughness	Feed rate and nose radius
6	Ashvin *J et al*	Turning	AISI 410	Response surface methodology	Nose radius feed rate and depth of cut	Surface roughness	Feed rate
7	Suresh *et al*	Turning	AISI 1030	Response surface methodology	Cutting speed, feed rate, and depth of cut	Tool wear, machining time, and surface roughness	Cutting speed
8	Paul, *et al*	Turning	AISI 4340	Taguchi DOE	Feed Rate and Depth of Cut	Surface roughness	Feed rate

9	Asilturk Ilhan *et.al*	Turning	AISI 4140	Taguchi Method	Feed Rate and Depth of Cut	Surface roughness	Feed rate
10	Asilturk Ilhan et. a	Turning	AISI 4140	Taguchi Method	Feed Rate and Depth of Cut	Surface roughness	Feed rate
11	M. Nalbant et.al	Turning	AISI 1030	Taguchi, S/N, ANOVA	insert radius, feed rate, and depth of cut	Surface roughness	Feed rate, insert radius
12	D. Singh	Ordinary lathe	EN8.	Taguchi method	Spindle speed, feed rate, and depth of cut	Surface roughness	Feed rate
13	Kirby et.al	Turning	S45C	ANOVA	Cutting speed, feed rate, and depth of cut.	Surface roughness	Feed rate

2.10 Research Gaps

Researchers have been fascinated by metal cutting due to its economic and technical importance. Among all the machining processes turning is a very widely used process. Many efforts have been directed toward improving the productivity of the process. A small increase in productivity can lead to a large amount of cost savings. Multi-tool turning process has got many advantages apart from increasing productivity. Therefore, the following aspects of multi-tool turning need to pay attention to:

- The machining performance depends on several parameters. Such, the cutting forces and temperatures generated during the process are of prime importance. In this aspect, a lot of research work has been done on the single tool turning process. Double tool turning remains a less explored area.
- The use of two tools simultaneously improves the product quality in the double tool turning process. The dimensional error and the tool wear in double tool turning is another domain where there is hardly any documented research work. It offers an ample scope to explore it.
- Surface roughness in double tool turning is an area that has received inadequate attention despite its ability to produce a good surface finish.
- Machining Time role in the improvement of productivity in the Multi-tool turning process.

CHAPTER- 3

MATERIAL AND METHODS

3.1 Introduction

This study was conducted to investigate the impact of surface roughness, improve productivity, and tool wear, and study the behavior of cutting parameters for flake graphite cast iron using both double and single tool turning machining processes. The details of the experimental procedures and material used for the study were provided in this chapter. All machines and instruments were discussed with supporting photographs and schematic diagrams.

3.2 Experimental Procedure

Figure 3.1 shows the overall stages for studies of an experimental investigation dry condition in the double tool turning process of flake graphite cast iron.

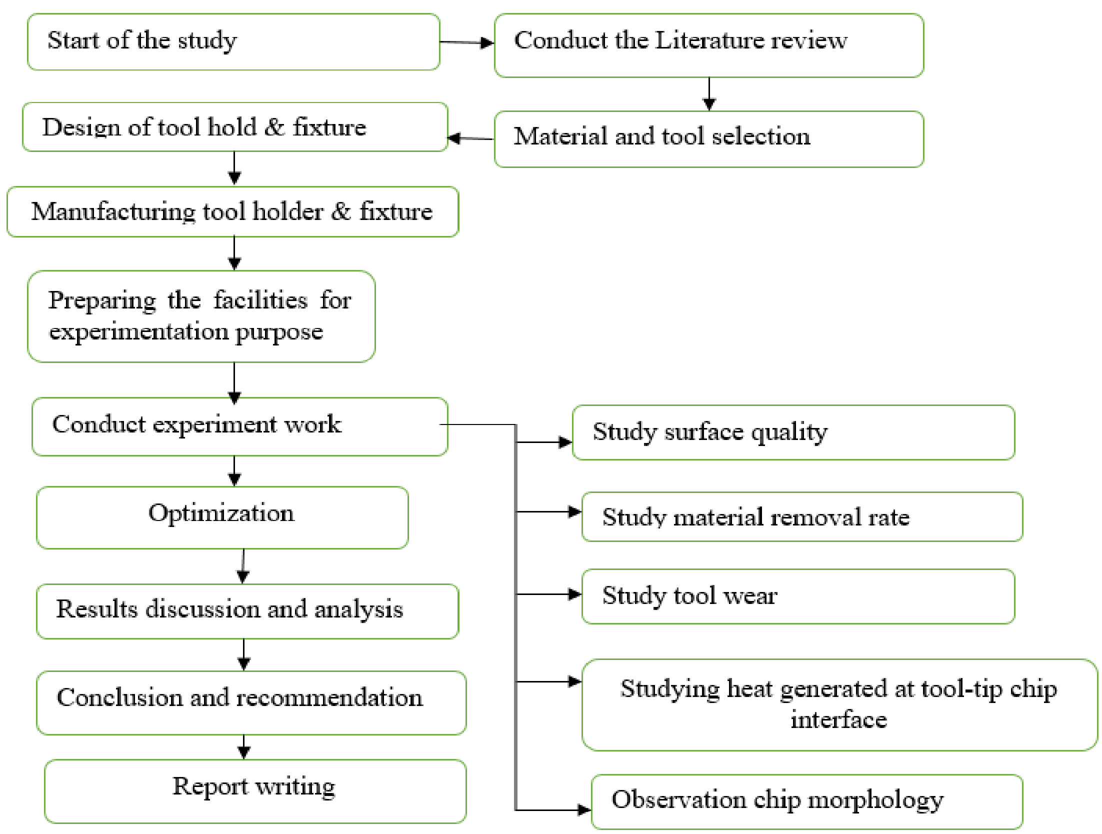


Figure 3.1 Experimental Procedure

3.3 Tool Fixture Designing and Manufacturing

For this experiment, the tool fixture was manufactured using mild steel. The tool fixture has (84*100*167) mm dimension, which was used for rigidly mounting onto the tool post of the lathe. The tool fixture has a grooved part to the dimension of 60*64 mm. The tooling fixture used in this experiment was manufactured from (84*101*167) mm dimension and M 13 hole on the top side of the plate. In addition, used to mount the lathe's tool post firmly. All dimensions are in mm.

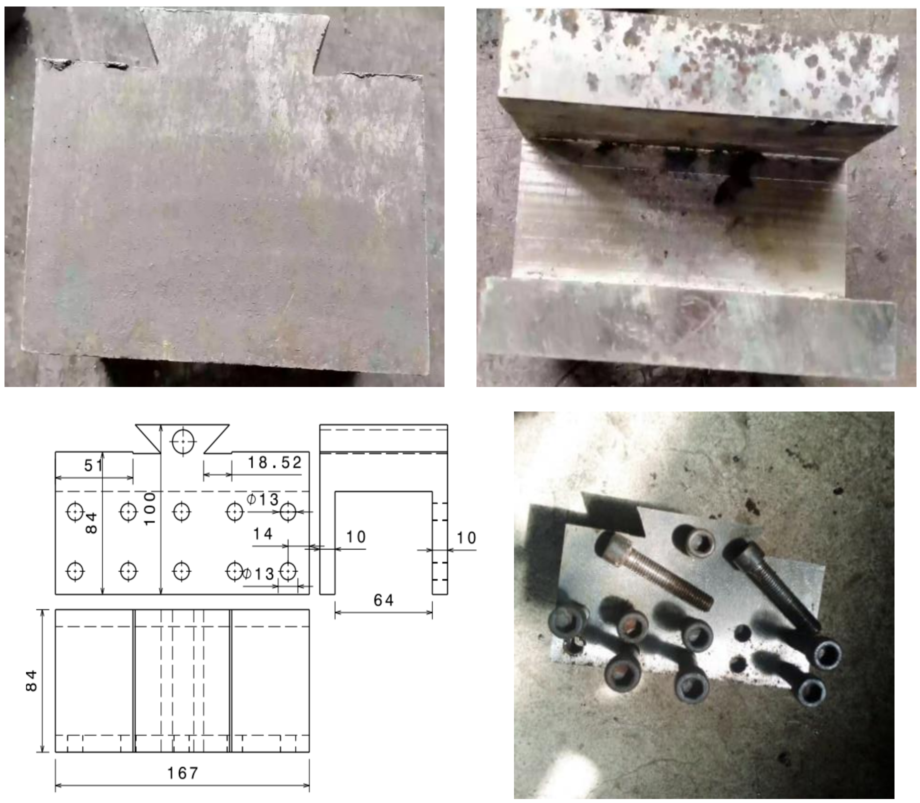


Figure 3.2 Photo of the tool fixture and detailed schematic of the tool fixture

The manufacturing process of tool fixtures was performed on lathe machines at Rose Ethiopian iron and steel factory. The Pasquino PF-300 lathe machine has an accuracy of 0.001 mm (1μm).

Figure 3.3 Pasquino PF 300 lath machine

3.4 Cutting Tool Holder and Fixture Modifications

The double tool turning process was carried out on a conventional lathe machine fitted with an attachment modified to accommodate required experiments. The lathe machine Tool post was used to mount the tool fixture in the right position. The double single-point Cutting tools were mounted on the manufactured tool fixture as shown in Figure 3.4.

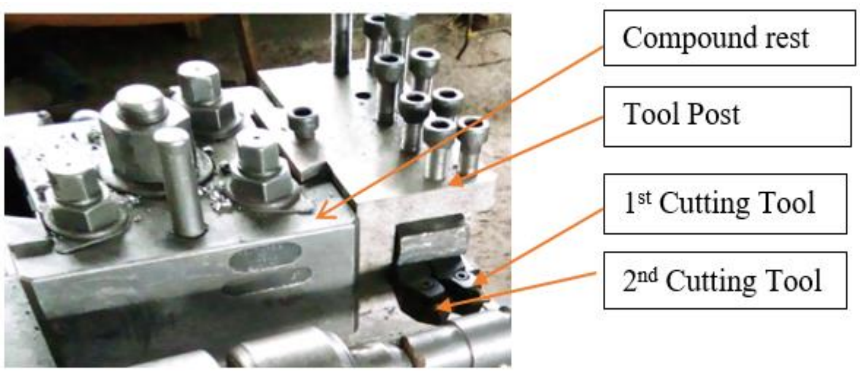


Figure 3.4 Lathe machine configurations

3.5 Materials

The materials employed in this investigation were flake graphite cast iron, which is frequently used in brake drums, clutch faces, and flywheels, among other cast iron applications. In many cases, the exceptional surface polish achieved removes the need for grinding. Because the chips are fragmented, cutting speeds can be increased without causing problems with chip control, etc. The cylindrical flake graphite cast iron workpiece used in the studies have a length of 500 mm and a diameter of 30 mm.

3.5.1 Analysis of Machining Parameters

Geometry and machining parameters both influence the turning process. The three principal adjustable machining parameters in a basic turning process, namely speed, feed, and depth of cut, are the focus of this research. Three parameters are shown in Figure 4. The combination of these three parameters results in material removal. Other input factors influence the output parameters, such as surface roughness and tool wear, but the latter are the ones that the operator can easily change during the operation (Maity, 2014).

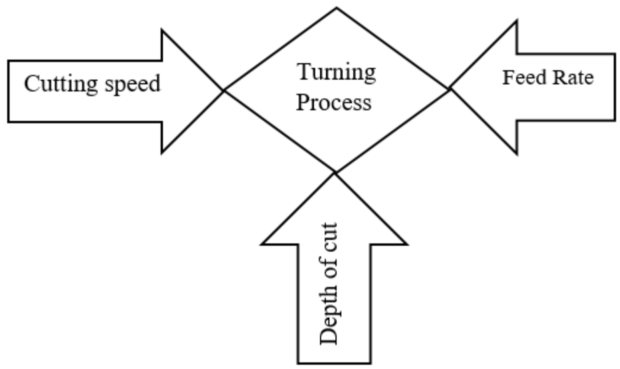


Figure 3.5 Factors affecting the turning process

3.5.1.1 Cutting Speed

The cutting speed was defined as the rate at which the uncut surface of the workpiece passes the cutting tool. It is often referred to as surface speed and was ordinarily expressed in m/min, though ft./min is also used as an acceptable unit (Maity, 2014). Cutting speed can be obtained from the spindle speed. The spindle speed is the speed at which the spindle, and hence, the workpiece, rotates. It was given in terms of the number of revolutions of the workpiece per minute i.e. rpm. If the spindle speed is „N" rpm, the cutting speed V c (in m/min) is given as:

$$v_c = \frac{\pi DN}{1000} \qquad (2.2)$$

where D = Diameter of the workpiece in mm

π, Pi: 3.14

3.5.1.2 Feed

Feed is the distance moved by the tooltip along its path of travel for every revolution of the workpiece. It was denoted as "f" and expressed in mm/rev. Sometimes, it is also expressed in terms of the spindle speed in mm/min as:

$$F_{m=fN} \qquad (2.3)$$

Where, f = Feed-in mm/rev, and N= spindle speed in rpm

3.5.1.3 Depth of cut

The distance between the newly machined surface and the uncut surface was defined as the depth of cut (d). It's the thickness of the material being removed from the workpiece, in other words. It can alternatively be described as the tool's depth of penetration into the workpiece, as measured from the workpiece surface before rotation. Due to the rotation of the work, the diameter after machining was reduced by twice the depth of cut, since this thickness was removed from both sides.

$$d = \frac{D_1 - D_2}{2} \quad (2.4)$$

Where, D1 = Initial diameter of job, and D2 = Final diameter of job

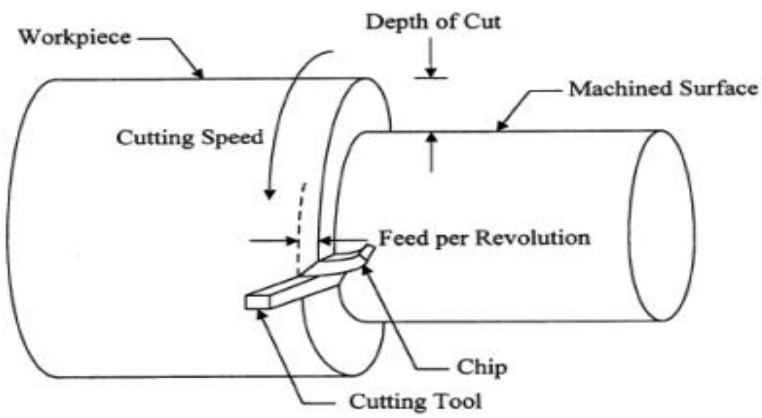


Figure 3.6 The adjustable machining parameters (Yang and Tarng 1998)

Table 3. 1 List of parameters and their levels for single tool turning

S. No	Cutting parameters	Symbol	Units	**Level**		
				Low	Medium	High
1	Cutting speed	Vc	m/min	50	70	90
2	Feed	f	mm/rev	0.3	0.525	0.75
3	Depth of cut	d	mm	0.35	0.675	1.0

Table 3. 2 List of parameters and their levels for double tool turning

S.No	Cutting parameters	Symbol	Units	**Level**		
				Low	Medium	High

	Cutting speed	Vc	m/min	50	70	90
	Feed	f	mm/rev	0.3	0.5	0.75
	Depth of cut 1	d_1	mm	0.5	0.75	1.0
	Depth of cut 2	d_2	mm	0.75	1	1.25

3.5.2 Properties of Workpiece Material

The machining behavior of flake graphite cast irons has been carefully considered. The inexpensive cost of the material and the casting process, as well as the economics of machining the completed piece, are primary reasons for cast iron's continued widespread use in engineering. Cast iron is machinable in practically all ways: tool wear is low, metal removal rates are high, tool forces are low, and power consumption is low. The machined cast iron's surface isn't very lustrous, yet it's ideal for various sliding interfaces. Even while milling at high rates, the chips are twisted as extremely small remains that can be voluntarily cleaned from the cutting region (Edward and Paul, 2000). The chemical composition of the material is in Table 3.1. As observed using Spectrometer in weight percentage.

Table 3.3 Chemical composition (wt %) of flake graphite cast iron

Element	Iron, Fe	Chromium, Cr	Nickel, Ni	Manganese, Mn	Silicon, Si	Carbon	Phosphorous, P	Sulphur, S
Wt %	92.5	0.136	0.01	0.352	1.371	4.5	0.003	0.18

3.5.3 Cutting Tool Materials and cutting condition

3.5.3.1 Cutting tool materials

Cutting tools are the main things to consider when choosing the cutting process of metal materials. The high hardness of material requires cutting tools that have high toughness to do the cutting. A cutting tool was any tool that was responsible for removing the excess material from the workpiece by direct mechanical abrasion and shear deformation (Dash, 2012). To perform an effective cutting operation, the cutter must be made from a material harder than the work material to be cut. In addition, the tool must be ready to withstand the heat generated during the machining process. According to (Schenider, 1989), an efficient cutting tool should have the following characteristics

a. Hardness: The tool material should be harder than the work material.
b. Hot hardness: The tool must maintain its hardness at elevated temperatures encountered during the machining process.
c. Wear Resistance: The tool should have served to its acceptable level of life before it wears out and needs to be replaced.
d. Toughness: The material should be strong enough to withstand shocks and vibrations. during interrupted cutting, the tool should not chip or fracture.

Ceramic coated-carbide tool was used in this study due to their improved properties like good thermal shock resistance, good high-temperature strength, creep resistance, low density, high hardness and wear resistance, electrical resistively, and better chemical resistance and ceramics are suitable coating materials for tools (Camuscu, 2006). The most commonly used ceramic coating is aluminum oxide (Al_2O_3). For turning, the cutting tool insert was used with ISO specification CNMG 120408. According to the orthogonal rake system of tool geometry definition, the used tool insert possessed -6°, -6°,6°,6°,15°,80°, and 0.8mm tool signature. These values are for inclination angle, orthogonal rake angle, orthogonal clearance of the principal flank, auxiliary orthogonal clearance, auxiliary cutting-edge angle, principal cutting-edge angle, and nose radius of tool insert, respectively. The main drawback of high-speed cutting is the rapid wear of cutting tools, which is caused by the high temperatures generated at the cutting zone. The high hot hardness, wear resistance, and chemical inertness of Al_2O_3based ceramic cutting tools make them suitable for high-speed cutting operations. Its toughness can be improved by embedding fine zirconia (ZrO_2) particles by an amount of 3-5% into the aluminum oxide matrix. Such a ceramic is called dispersion ceramic. White oxide ceramic is used in the rough machining of grey cast iron, nodular cast iron, and chilled cast iron (Sarma et.al. 2007 Camuscu, 2006).

Ezugwu and Tang (2011) compared the quality of machined surface in the turning of cast iron and nickel-based Inconel 718 alloy with round and rhomboid-shaped pure oxide (Al_2O_3 + ZrO_2) and mixed oxide (Al_2O_3 + Tic) ceramic tools. The test results showed that both round inserts and rhomboid-shaped tools give a better surface finish for both types of ceramics. Machining with the mixed oxide ceramic tools produced a better surface finish than with the pure oxide ceramic (Sarma, 2007).

Table 3. 4 The composition and properties of ceramic-coated carbide cutting tool

Cutting tool	Composition	Hardness (HV)	Thermal conductivity (W/m.k)	Transverse rupture strength (MPa)	Density (g/cm)	Young's modulus (GPa)
Ceramic coated carbide cutting	Al_2O_3 (96.5 %), ZrO_2 (3.5%)	2100	29	2150	11.6	530

3.5.3.3 Cutting condition

Cutting conditions play an important role in the efficient use of a machine tool. A dry-cutting environment was used for the experimentation process. The dry cutting process uses no coolant during machining. By the use of dry cutting, the costs of cutting fluid were alleviated. Cutting fluids have corrosive effects and are non-environmental-friendly. Dry cutting reduces machining costs and is environmental-friendly. In addition, inserts perform better at higher cutting temperatures achieved during dry cutting (Halim, 2008).

Dry machining represents a more valuable alternative, especially in terms of cost savings and environmental sustainability. It can provide a machine-tool flexibility and cost advantage if big sumps are not required.

3.6 Tools and Equipment Used

3.6.1 Lathe Machines

The work-piece material prepared was mounted and machined in a rigid and powerful conventional lathe machine. The double tool turning operations were conducted mainly on a conventional lathe machine, a model of PF-300 powered by a 7.5KW motor with a spindle speed range of 36 up to 2000 rpm.

Figure 3.7 Conventional lathe machine used for experimental study

3.6.2 Thermocouple

In this study, a digital thermometer device consisting of four-channel thermocouples was used for the temperature at the cutting tool insert end. This thermometer can be used to measure at most four different temperatures simultaneously. It has accurate measurement, quick response, stable performance, and simple operation.

Figure 3.8 Digital Thermometer Temperature Tester

3.6.3 Profilometer

The most practical method for assessing surface roughness is to measure it, which is defined as the irregularities left on the surface following the machining operation. Ra is the average roughness utilized in this investigation. The equipment used to measure the surface roughness was a contact type Model 657111, the reading distance range was 0.6mm and the maximum measuring range was 10μm. Surface roughness (Ra) data were collected at three different locations, and then the average values were calculated. Figure 3.10 was shown the surface roughness tester device.

Figure 3.9 Surface roughness tester device

3.6.4 Spectrometers

Optical Emission Spectroscopy (OES) Q2ION –Bruker analysis is a rapid method for determining the elemental composition of a variety of metals and alloys. For this experiment was used for identifying the chemical composition of workpiece material.

Figure 3.10 Spectrometer machine tool, result in the display window

3.6.5 Scanning Electron Microscope [SEM]

Scanning electron microscope (SEM) produces high resolution, high magnification images by scanning the surface of a specimen with a focused beam of an electron. A model of JCM-6000 Plus scanning electron microscope was used to scan the wear of the cutting tool.

Figure 3.11 Scanning electron microscope

3.7 Research Methodology

The experimental work would be carried out employing Flake graphite cast iron as the work-piece material. The method of specimen preparation, the design of experiments procedure, the selection of a proper design, analysis of variance, and methods for measuring tool wear, cutting temperature, surface roughness, material removal rate, and chip formation observation would all be discussed under research methodology.

3.7 Specimen Preparation for Turning Operation

The workpiece materials used for this study is flake graphite cast iron on a conventional lathe machine, which, is highly used in the application of the automotive industry. For both single tool turning and double tool turning using the same workpiece material for both experimental studies. The experiment was conducted on the convectional lathe machine with different combinations of turning process parameters.

This workpiece, with a dimension of 30x500mm (30mm diameter and 500mm in length) was prepared for each single and double tool turning. A 50 mm length of the workpiece was clamped in the chuck and rough turning was carried up to the length of 450 mm. Cleaning the samples of surface contamination, such as dust, grease, or any other soluble organic particles, so that there will be no adverse effect on the results. The work material was centered and cleaned by removing a 5 mm depth of cut from the outside surface to remove rust before the actual machining process. One end of the workpiece was held in a chuck and the other end was supported by a tailstock. After the turning operation finished, the specimen was taken for measurement. Then fifteen experiments with each cut length of 25 mm and the selected depth of cut for both single and double tool turning would be operated with different turning parameters for experimental study with different cutting parameters.

3.8 Experimental Setup

The experiments had performed in a conventional lathe machine and the cutting tool used was a ceramic-coated carbide tool. The detailed information on chemical composition and mechanical properties is provided in Table3.1 and Tables3.2 respectively and specification of 500mm in length and 30mm Flake graphite cast iron diameter was prepared for both double tool and single tool turning process under dry machining conditions. The experiment is made in the Rose Ethiopian Iron and Steel Factory in Addis Ababa.

Figure 3.12 Experimental setups

3.9 Experiment plan

The experiment was performed to investigate the effect of input parameters on response. The design of the experiment (DOE) has a significant effect on the approximate accuracy and cost of the response surface. The experiment of fifteen runs was randomized by using the Design of Experiment. DOE was evaluated as the response to the model fitted. The design data was evaluated by running the fifteen samples through turning operation and calculating the measuring of the surface roughness using a Profilometer. For both double tool and single tool turning using the same workpiece material for experimental study under dry cutting conditions.

3.10 Design of Experiment

DoE has been implemented to select manufacturing process parameters that could result in a better quality product. The methods of design such as

- Taguchi's method
- Response surface methodology
- Factorial designs

RSM could help in visualizing the effect of parameters on response in the entire range. It is a better tool for optimization and better predicts the effect of parameters on response and the optimization plot is the feature. Design of experiments (DOE) was a structured method that was used to identify relationships between several input variables and output responses. DOE techniques were employed before, during, and after the regression analysis to evaluate the accuracy of the model. With the help of DOE, the resources needed to experiment can be optimized (Halim, 2008). A few methods used as DOE was Taguchi Method, Response Surface Method, and Factorial Designs. Under this study, Response Surface Methodology focused on the ensuing study. Among this method, the Response Surface Methodology focused during the ensuing study.

3.10.1 Response Surface Methodology

RSM was one of the design experiment techniques used for optimal parameter setting. ANOVA, Surfaces plots analysis, and optimal values for experiments conducted based on the experimental data can be evaluated. A collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery et al., 1997). RSM can be defined as a statistical method that uses quantitative data from appropriate experiments to determine and simultaneously solve multi-variable equations correlating the dependent parameters(response) such as cutting force, power consumption, surface roughness, and tool life with independent parameters (input variables). Cutting speed, feed rate, and depth of cut, in a turning process. The graphical representations of these equations are called response surfaces, which can be used to describe the individual and cumulative effect of the input variables on the response and to determine the mutual interactions between the input variables and their subsequent effect on the response (Ranganath et al 2014). *To* observe the most influential process parameters in the turning process, namely cutting speed, feed, and depth of cut each at three levels considered in the case of this thesis.

For these reasons, RSM, based on BB-DOE, was selected. Therefore, it is used in this work to model, predict, and optimize the parameter. As a mathematical and statistical technique, it was developed for the treatment of problems involving a response of interest as a function of several variables. It is one of the ways machining process modeling and analysis can achieve to facilitate its optimization. For the "n" number of measurable input variables, the response surface was defined as ((Halim, 2008).

$$Y = f(x_1, x_2, x_3, x_4 \ldots x_n) + \varepsilon \tag{3.1}$$

Where, $x_1 \ldots x_n$ are the independent input parameters and $\boldsymbol{\varepsilon}$ is the random error

Y is the output or response variable which has to be optimized.

In a turning operation with three input variables, the response function written as:

$$Y = f(x_1, x_2, x_3) + \varepsilon \tag{3.2}$$

Where, x_1 = logVc, x_2 = log f, and x_3 = log d. Y = log parameter and ε is the random error

If the response can be well modeled by a linear function of the independent variables, the equation can be written as:

$$Y = b_0 + b_{1x1} + b_{2x2} + b_{3x3} \cdots\cdots\cdots b_{nxn} \pm \varepsilon \tag{3.3}$$

However, if a curvature appears in the system, then a higher-order polynomial such as the quadric model below the equation may be used.

$$Y = \ b_0 + \sum_{i=1}^{n} bixi + \sum_{i=1}^{n} bijx^2 i + \sum_{i<j}^{n} bijxj \tag{3.4}$$

Where Y is the corresponding response and xi (1, 2… n) is the independent input parameters. The terms b_0, b_1, b_2, and so on are the second-order regression coefficients. The second term contributes to the linear effect, the third term contributes to the higher-order effects, and the fourth term contributes to the interactive effects of the input parameters. The values of the coefficients are estimated by using the responses collected (Y_1, Y_2 …...) through the design points (n) by applying the least square technique. This equation can be rewritten in terms of the three variables:

$$Y = b_0 + b_{1x1} + b_{2x2} + b_{3x3} + b_{11x1^2} + b_{22x2^2} + b_{33x3^2} + b_{12x1x2} + b_{13x1x3} + b_{23x2x3} \tag{3.5}$$

The objective of using RSM is not only to investigate the response over the factor space but also to locate the region of interest where the response reaches its optimal or near-optimal value. A careful study of the response surface model provides a combination of factors giving the best response.

The Box-Behnken (BBD) was selected for the design of the turning experiment. Analysis of variance (ANOVA) was used to validate the developed models and to predict the effect of selected factors A, B, and C on the response characteristics Ra. Optimization of the coded and actual response functions, Ra (A, B, C), subject to constraints as determined by the limits of the factors A, B, and C, was performed as appropriate using a standard optimization technique. The

RSM was implemented in the Minitab software version 18. The response surface method is a sequential process, and the methodology used for the modeling can be summarized, as shown in the figure below:

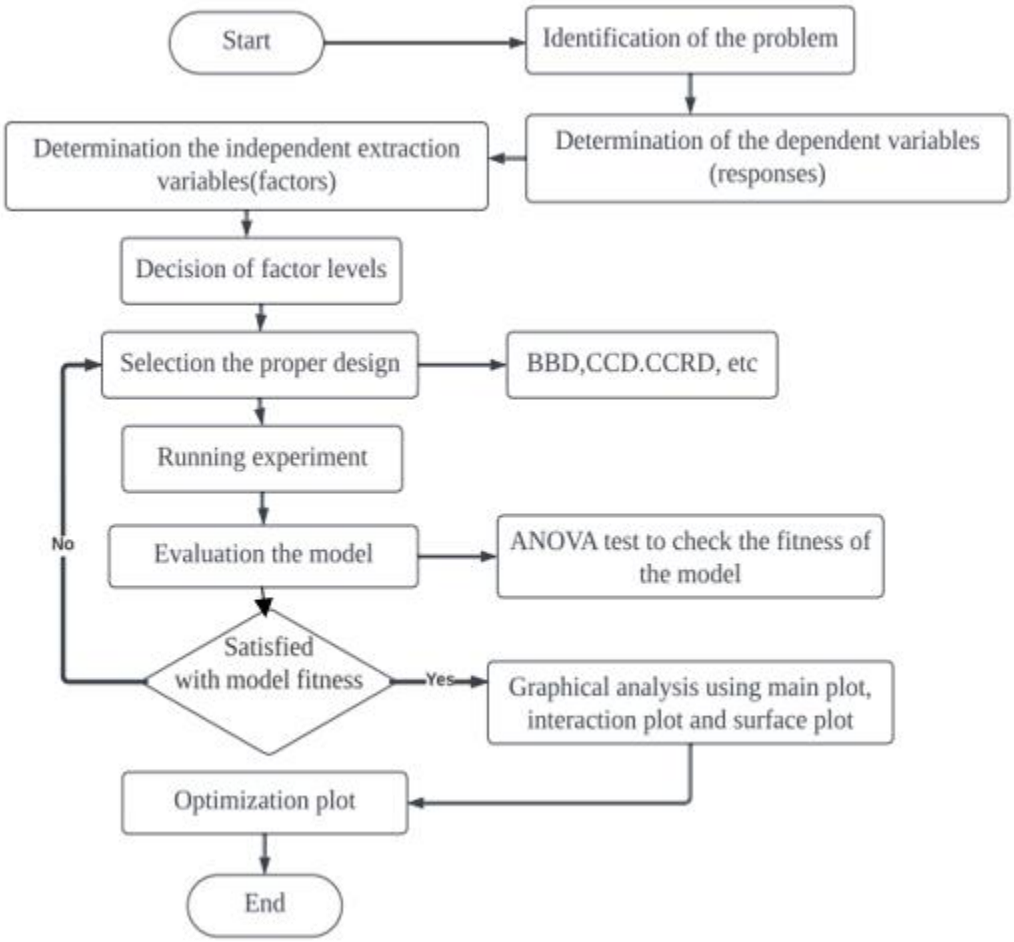


Figure 3.13 Outline of response surface methodology used

3.11 Surface Roughness Measurement

The quality of the surface made using conventional and non-conventional machining is important because a smooth surface reduces the chances of surface scratches caused by wear and corrosion. Likewise, the superiority of a part made by turning operation can affect the performance of the surface for wear and corrosion safeguard. The surface profiles of all samples were quantitatively analyzed to determine the statistical standard parameter of average roughness, Ra by using mark surface. The roughness of a surface cannot be easily cleared by a single parameter. It’s a basic property of the surface and every test condition was repeated at least three times at different new locations on a rod bar surface to make certain the repeatability and reproducibility of the result. In this study, after the turning process of flake graphite cast iron with different cutting parameters, the centerline average surface roughness was measured by a surface contact Profilometer.

3.12 Measurement of Material Removal Rate (MRR)

The material removal rate is the amount of material removed per unit time and ultimately determines machining productivity in roughing operations and production of large batches, the material removal rate needs to be maximized (Mozammel et al.,2018). In the present investigation, the following formula has been used to compute the material removal rate.

$$MRR = Vc \ x \ f \ x \ ap \qquad \textbf{(3.6)}$$

Where MRR = Material removal rate,

f = feed (mm/rev),

Vc = cutting speed (m/min), and

ap = total depth of cut (mm).

3.13 Studying Cutting Temperature

The friction between the rake face of the cutting tool and chip causes heat generation in the secondary shear deformation zone whereas the friction between the tool flank and the machined surface causes heat generation in the tertiary shear deformation zone. Higher cutting temperature adversely affects the tool life and decreases the wear resistance and hardness of the cutting tool, which causes poor surface finish and dimensional inaccuracy of the machined surface. Therefore, it is important to maintain a lower cutting temperature during the machining process. Measures the temperature of the cutting tooltip during dry machining of flake graphite cast iron in a single and double cutting tool turning operation was used digital thermometer temperature tester. During measuring the cutting tool tip temperature first, insert the two tips of wire into the thermocouple then make to hold it to both cutting tool materials. In this study, the temperature generated at the cutting tool tip was measured for each of fifteen experiments using a digital thermometer temperature tester shown in figure 3.12

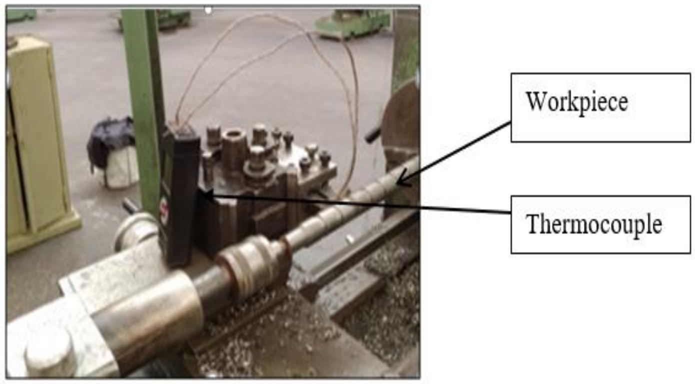


Figure 3.14 Tooltip temperature measurement setup

3.14 Tool Wear Study

Surface roughness, cutting temperature, surface integrity, and other machinability characteristics are frequently dependent on and affected by tool wear. Many variables influence it, including tool material, coating application, cutting speed, feed, cutting depth, and cooling environment. Using a Scanning electron microscope, the impact of all of these characteristics is examined.

3.15 Chip Formation Observation

Chip creation and removal are critical in cutting procedures with a spatially constrained cutting zone, such as drilling, reaming, milling, and all turning operations on automatic lathes. The orthogonal cutting depiction is the best way to see the specifics of the chip manufacturing process. Chip formation was viewed as a two-dimensional process in a plane perpendicular to the cutting edge in the orthogonal model (Mohammadi, 2008). The cutting tool penetrates the work material during the machining process, causing it to bend elastically and subsequently plastically. The material begins to flow as soon as the tool-induced shear stress reaches or exceeds the shear strength of the work material in the shear zone. The distorted work material generates a chip that flows across the face of the cutting tool, depending on the tool geometry. Shear stresses are created in the secondary shear zones by friction between the tool's contact planes and the underside of the chip or the new workpiece surface. Generally, the main type of chip that can be formed is fragmented chips. The chips are formed as very small rubbish, which can voluntarily be cleared from the cutting area even when machining at very far above the ground speeds. It is to some amount dirty and sandy action; throw a fine scatter of graphite into the air, so that fortification for factory employees may be necessary. Like when cutting other supplies, there is a great differentiation between the behavior of cast iron when sheared on the shear plane and at the tool work interface. The most significant feature is that coming apart on the shear plane occurs at very common intervals, initiated by the graphite flakes. The chip is thus composed of very small remains a few millimeters in the piece. Because the chips are not continuous, the length of making contact with the rake face is very short. The chips are skinny and the cutting force and power utilization are near to the ground. The cutting force is low also because graphite flakes are very weak. One flake may lengthen a significant way across the shear plane.

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Introduction

The point of the study was to see how different cutting parameters affected the surface quality, material removal rate, tool wear, tooltip temperature, and chip morphology of Flake graphite cast iron during single and double tool turning under dry conditions. The results of each experiment were thoroughly discussed in this chapter. The experiment's design was utilized to determine the best cutting settings and the ones that had the most impact on surface finishing.

For each double and single tool turning, all fifteen trials were undertaken with varying cutting parameters but with a constant length of cut of 500mm and a diameter of the workpiece prepared for experimental investigation of 30mm. This experimental investigation of the turning process of flake graphite cast iron during dry machining operations were carried out at various cutting speeds (50, 70, 90) m/min at feeds of (0.3, 0.525, 0.75) mm/rev, and with the first and second depths of cut of (0.5, 0.75, 1.0) mm, and (0.75, 1.0, 1.25) mm for double tool turning, while for single tool turning was (0.35, 0.675 and 1.0) mm.

For the experiment, the cutting parameters for double tool turning and single tool turning were optimized individually on a typical lathe machine. Figure 4.1 shows a sample of flake graphite cast iron after turning under both machining settings. This part tries to convey the details of the study's results and debate.

Figure 4.1 Samples after turning process for both operations

The surface roughness of these two components was examined, and the findings were assessed. The results demonstrate that the component turned with the Single Tool turning method has a higher Ra value. As a result, the surface finish obtained in the component turned using multi-tool turning was superior to the surface finish obtained in the component produced using the traditional turning method. Because two cutting tools were simultaneously engaged with the workpiece in double tool turning.

4.2 Optimization of Cutting Parameters

The focus of the work was on the investigation and optimization of turning cutting parameters for flake graphite cast iron using the Response surface methodology. Box-Behnken Design (BBD) method comes under the Response surface methodology. In RSM, box-Behnken design (BBD) is one of the prominent techniques to minimize the number of experiments and obtain quadratic interactions between selected factor pairs. A Box-Behnken design is an experimental design, useful in response surface methodology, for building a second-order (quadratic) model for the response variable and few runs. The response surface design is better, as it generates a second-order quadratic model of regression, which is a better predictive model than a first-order quadratic model. In this work, BBD has been applied for the experimental investigation.

4.3 Analysis of Surface Roughness

Analysis of Surface Roughness Measurements of surface roughness (Ra) data were taken at three different locations, on the machined surface using a surface roughness tester (Profilometer), and the average values were recorded. The measured experimental results of mean values of surface roughness for each trial experiment are illustrated in Table 4.3 and Table 4.4 for both single tool turning and double tool turning respectively. Optimization of the cutting parameters for both turning processes has been performed separately. For surface roughness analysis, the smaller-the-better performance characteristics were used. Therefore, in this case, Average Surface Roughness (Ra) was defined as:

$$Avg.Ra = \frac{R1+R2+R3}{3} \tag{4.1}$$

Where $Ra \rightarrow$ Average surface roughness

$$\left.\begin{matrix} R1 \\ R2 \\ R3 \end{matrix}\right\} \rightarrow first, second\ and\ third\ trial\ test\ of\ surface\ roughness\ vaue$$

In ANOVA, the 95% confidence level was chosen to determine the effect of cutting parameters on the surface roughness of machined parts.

Table 4.1 Data generated from the turning experiment (Single tool turning)

S. No	Input process parameters			Surface roughness(μm)			Avg. Ra (μm)
	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Meas.1	Meas.2	Meas.3	
1	50	0.300	0.675	1.410	1.520	1.420	1.450
2	50	0.750	0.675	1.490	1.570	1.710	1.590
3	50	0.525	0.35	2.110	2.150	1.790	1.850
4	50	0.525	1.00	2.060	1.95 0	2.000	2.020
5	50	0.300	0.350	1.370	1.500	1.450	1.440
6	70	0.750	0.350	1.650	1.910	1.390	1.650
7	70	0.525	0.675	1.370	1.50	1.450	1.440
8	70	0.750	1.00	1.500	1.690	1.610	1.60
9	70	0.300	1.00	1.430	1.510	1.350	1.430
10	70	0.525	0.675	1.330	1.540	1.450	1.440
11	90	0.300	0.350	1.090	1.140	1.100	1.110
12	90	0.300	0.675	1.370	1.250	1.280	1.300
13	90	0.525	0.350	1.140	1.160	1.170	1.150
14	90	0.525	1.00	1.120	1.200	1.130	1.150
15	90	0.750	0.675	1.200	1.340	1.300	1.280

Table 4.2 Data generated from the turning experiment (Double turning)

S. No	Input process parameters			Surface roughness(μm)			Avg. Ra (μm)
	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Meas.1	Meas.1	Meas. 1	
1	50	0.300	1.750	1.350	1.490	1.440	1.420
2	50	0.750	1.750	1.790	1.910	1.730	1.810
3	50	0.525	1.250	1.290	1.790	1.600	1.560
4	50	0.525	2.250	2.200	1.910	1.890	2.000

5	50	0.525	1.750	1.250	1.420	1.590	1.420
6	70	0.750	1.250	1.370	1.820	1.550	1.580
7	70	0.525	1.750	1.360	1.240	1.580	1.420
8	70	0.750	2.250	1.730	1.610	1.790	1.710
9	70	0.300	2.250	1.090	1.120	1.120	1.110
10	70	0.525	1.750	1.530	1.330	1.370	1.410
11	90	0.300	1.750	1.040	1.040	0.930	1.040
12	90	0.300	1.250	1.170	1.1300	1.150	1.150
13	90	0.525	1.250	1.150	1.310	1.290	1.250
14	90	0.525	2.250	1.140	1.130	1.210	1.160
15	90	0.750	1.750	1.120	1.140	1.250	1.170

Tables 4.1 and 4.2 data show the maximum and minimum values of average surface roughness during the experimental investigations for both double and single cutting tool turning operations.

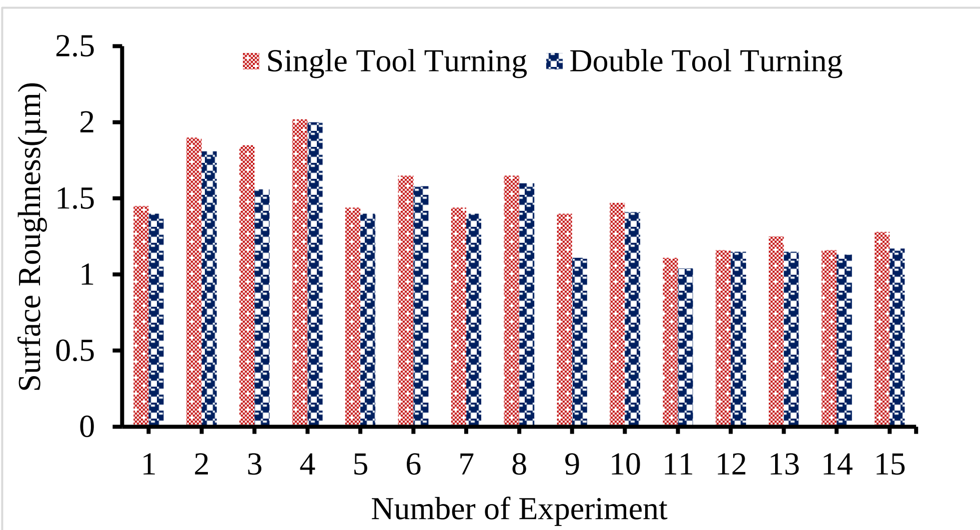


Figure 4.2 Number of experiments Vs Average surface roughness

For double and single tool turning, the minimum surface roughness was found to be 1.04m and 1.11m, respectively, while the low surface finish was determined to be 2.00m and 2.02m. As a result, the surface finish obtained in the component turned using multi-tool turning is superior to that obtained in the component produced using the traditional turning method. During the double tool, turning surface roughness improved by 6.73%. Because two cutting tools were simultaneously engaged with the workpiece in double tool turning.

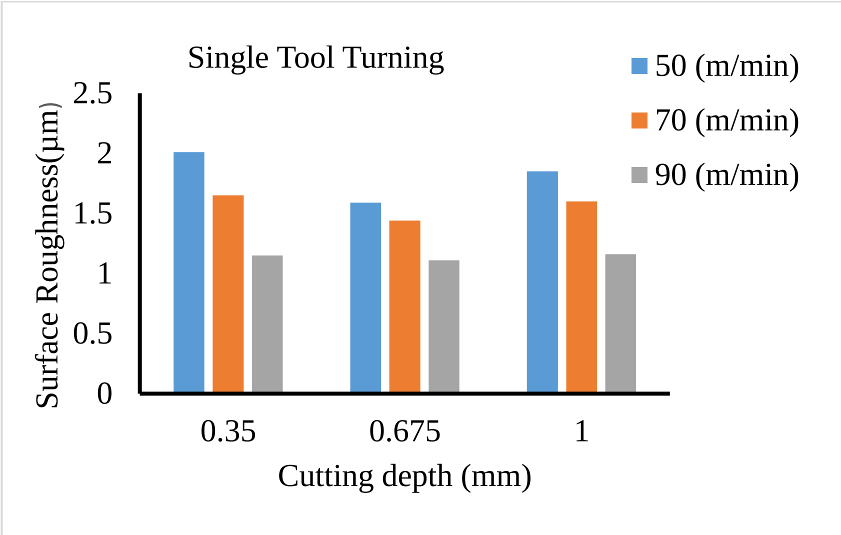


Figure 4.3 Variation of surface roughness with respect to cutting depth at various cutting speed for single tool turning

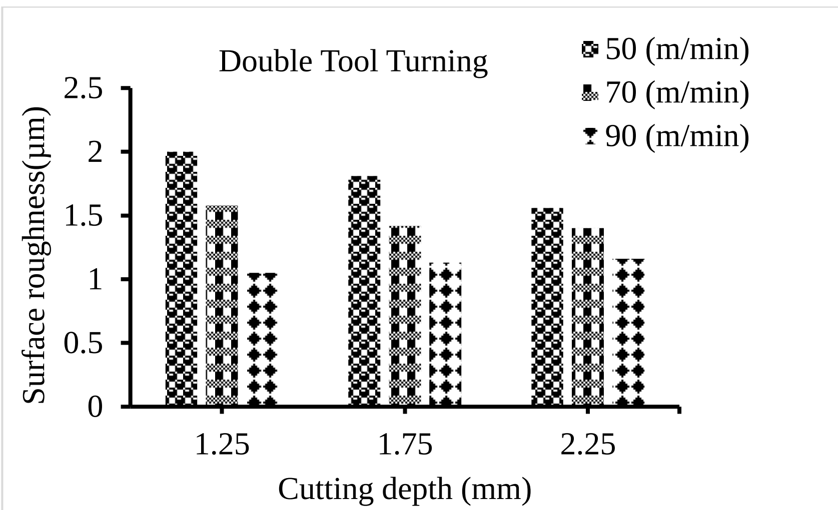


Figure 4.4 Variation of surface roughness with respect to cutting depth at various cutting speed for double tool turning

As illustrated in Figures 4.3 and 4.4, the least value of Ra was achieved when Vc and a_p, were 90 m/min and 0.35 mm and 90 m/min and 1.25 mm for both single tool turning and double tool turning respectively. The greatest value of Ra was achieved in the case of cutting speed and depth which were 50 m/min and 1.00 mm and 50 m/min and 2.25 mm for both single tool turning and double tool turning respectively. The surface roughness decreased with the increasing cutting speed at different cutting depths. On the one hand, the surface roughness decreased with cutting speed. Similarly, surface roughness increased with cutting depth increased.

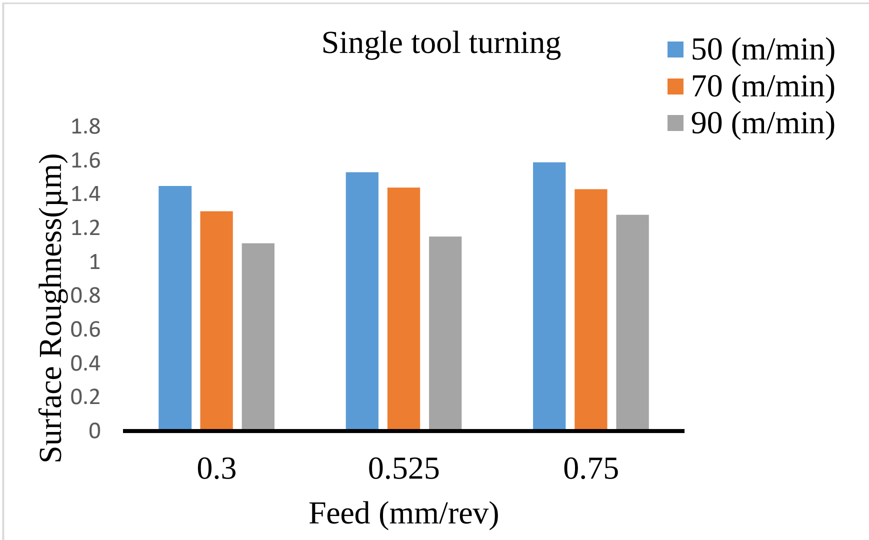


Figure 4.5 Variation of surface roughness with respect to feed rate at various cutting speed for single tool turning

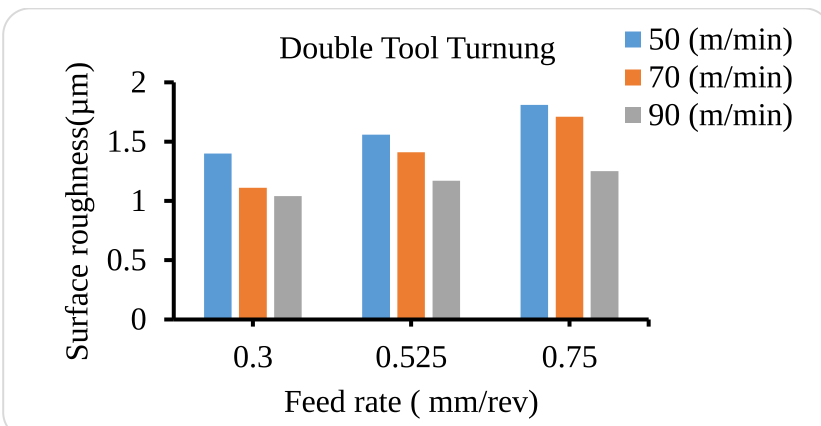


Figure 4.6 Variation of surface roughness with respect to feed rate at various cutting speed for single tool turning

Cutting parameters have a direct impact on surface roughness, as Figures 4.5 and 4.6 show for both double and single tool turning, surface roughness appears to rise with rising feed rate. from this study effect of cutting parameters on surface roughness of flake graphite cast iron at low depth of cut and feed rate and high spindle speeds.

4.3.1 Analysis of Variance

The ANOVA is where the descriptive statistics and statistical tests are presented. In general, look for low p-values to identify important terms in the model. The p-values to determine if the model explains a significant portion of the variance. Table 4.5 and 4.6 shows ANOVA results for the linear [A, B, C] quadratic [A2, B2, C2] and interactive [(A × B), (A × C), (B×C)] factors. The sum of squares is used to estimate the square of deviation from the mean. Mean squares are estimated by dividing the sum of squares by degrees of freedom. F-value, which is a ratio between the regression mean square and the mean square error, is used to measure the significance of the model under investigation concerning the variance of all the terms, including the error term at the desired significance level. P-value or probability value is used to determine the statistical significance of results at a confidence level. In this study, the significance level of $\alpha = 0.05$ is used, i.e., the results are valid for a confidence level of 95%. Table 4.5 and 4.6 shows the p-values and the significance levels for each source of variation. If the p-value is less than 0.05, then the corresponding factor (source) has a statistically significant contribution to the response variable. If the p-value is more than 0.05, then it means the effect of a factor on the response variable is not statistically significant at a 95% confidence level.

Table 4.3 Analysis of variance results for single tool turning

Source	Sum of Squares	Df	Mean square	F-value	P-value	Contribution%
Model	0.891918	9	0.099102	48.7	0.000	98.87
A-Cutting speed	0.610513	1	0.610513	300.01	0.000	67.68
B-Feed rate	0.195312	1	0.195312	95.98	0.000	21.65
C-Depth of cut	0.014450	1	0.01445	7.1	0.045	1.60
A^2	0.001920	1	0.001298	0.64	0.461	0.21
B^2	0.006000	1	0.006283	3.09	0.139	0.67
C^2	0.000698	1	0.00698	0.34	0.584	0.08
AB	0.0388025	1	0.038025	18.69	0.008	4.22
AC	0.016900	1	0.016900	8.3	0.035	1.87
BC	0.0008100	1	0.008100	3.98	0.103	0.9
Residual	0.010175	5	0.002035			1.13
Total	0.9020393	14				

Table 4.4 Analysis of variance results for double tool turning

Source	Sum of Squares	Df	Mean square	F-value	P-value	Contribution%
Model	0.929083	9	0.929083	79.21	0.000	99.30
A-Cutting speed	0.480200	1	0.480200	368.44	0.000	51.33
B-Feed rate	0.211250	1	0.211250	162.08	0.000	22.58
C-Depth of cut	0.064800	1	0.064800	49.72	0.001	6.93
A^2	0.000107	1	0.000003	0.00	0.966	0.01
B^2	0.0007016	1	0.004741	3.64	0.115	0.75
C^2	0.036310	1	0.036310	27.86	0.003	3.88
AB	0.008100	1	0.008100	6.21	0.055	0.87
AC	0.048400	1	0.048400	37.14	0.002	5.17
BC	0.072900	1	0.072900	55.93	0.001	7.79
Residual	0.006517	5	0.001303			0.7
Total	0.936293	14				

The Model F-value of 5.61 and 79.26 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB and AC, and A, B, C, C^2, AC, and BC are significant model terms for both single and double tool turning respectively. Values greater than 0.0500 indicate the model terms are not significant. The percentage contribution of each term is also shown in this table. Cutting speed (A) was found to be the most significant factor for Ra, which explains the 67.68% (for single tool turning) and 51.33% (for double tool turning) contribution of the total variation. The next contribution to Ra comes from the feed rate with a contribution of 21.65% and 22.58% for single and double tool turning respectively. Goutam et al., 2014 conducted several experiments on Ti-6Al-4V alloy machining and established the relationship between speed of cut and roughness then found that the cutting speed was the most influential factor affecting surface roughness and flowed by feed rate. Cui et al., 2022, used chip formation, cutting force, and surface quality to examine the influence of cutting parameters on cutting performance. Using analysis of variance, the effect of cutting parameters on cutting force and surface roughness was examined (ANOVA). Cutting depth had the most clear effect on cutting force, whereas cutting speed had the most significant effect on surface roughness, according to the findings. The cutting speed, quadratic [A^2, B^2, C^2], and interactions [BC] and A^2, B^2, and AB are do not have statistical significance for both single and double tool turning respectively because they have a much lower level of contribution and their p-value is more than the confidence level.

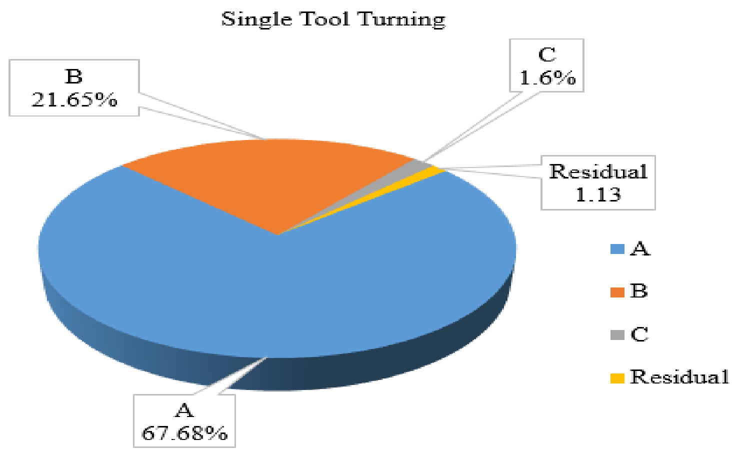


Figure 4.7 Percentage contribution of cutting parameters on surface roughness for single tool turning

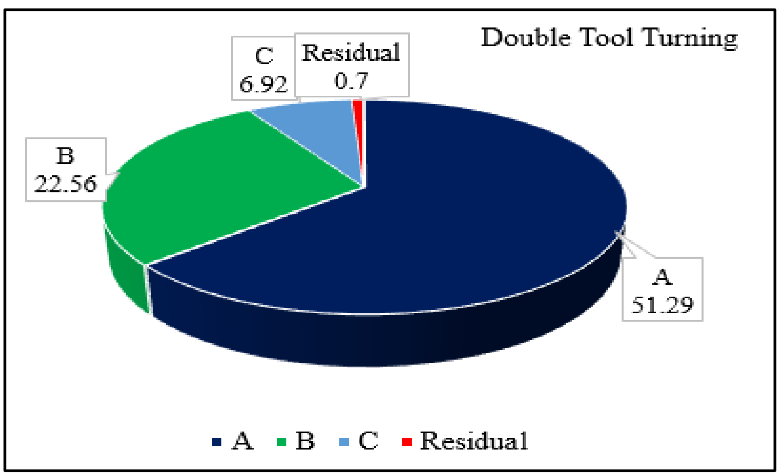


Figure 4.8 Percentage contribution of cutting parameters on surface roughness for double tool turning

4.3.2 Fit Statistics

Table 4.5 Fit Statistics summary for single tool turning

R^2	0.996
Adjusted R^2	0.9889
Predicted R^2	0.9367

Table 4.6 Fit Statistics summary for double tool turning

R^2	0.9930
Adjusted R^2	0.9805
Predicted R^2	0.9296

The other important term was the coefficient of determination R^2, which was defined as the ratio of the explained variation to the total variation and a measure of the degree of fit. As R^2 approaches unity, the response model fitness with the actual data improves. The value of R^2 = 0.99.6 in the case of single tool turning indicates that the model explains 99.6% of the total variations and for double tool turning R^2 = 0.9930 it indicates 99.30% of total variations. This means that the regression model provides a complete between the dependent and independent variables.

4.3.3 Parametric Influence on Surface Roughness

Theoretically, surface roughness is a function of feed rate and nose radius. However, in practice, cutting speed, depth of cut, and tool wear also affect surface roughness. Since the inserts used in the experiments have identical nose radius values, the effect of nose radius was not investigated in this study.

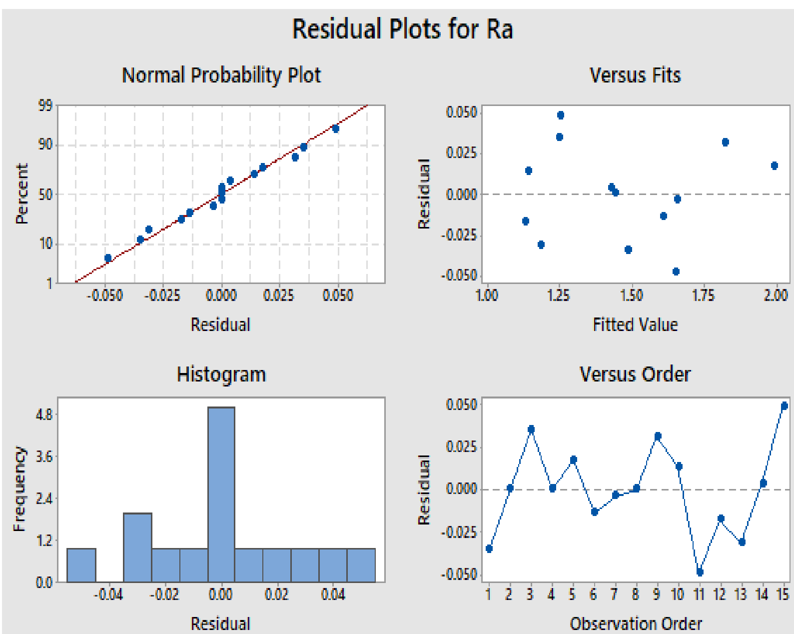


Figure 4.9 Residual plots of Surface Roughness for single tool turning

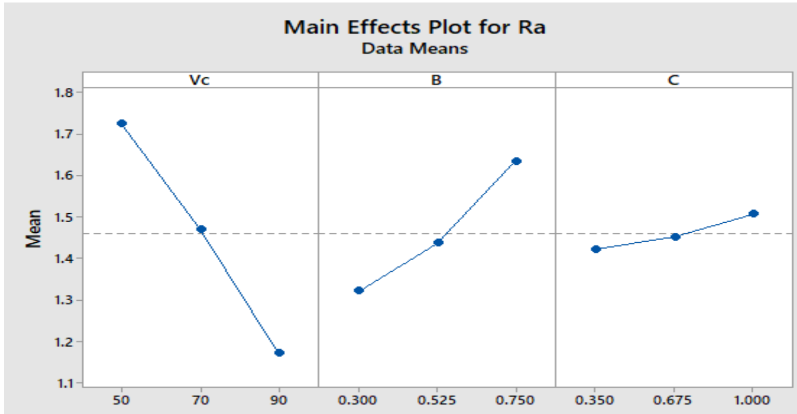


Figure 4.10 Main effects plot for mean Surface Roughness for single tool turning

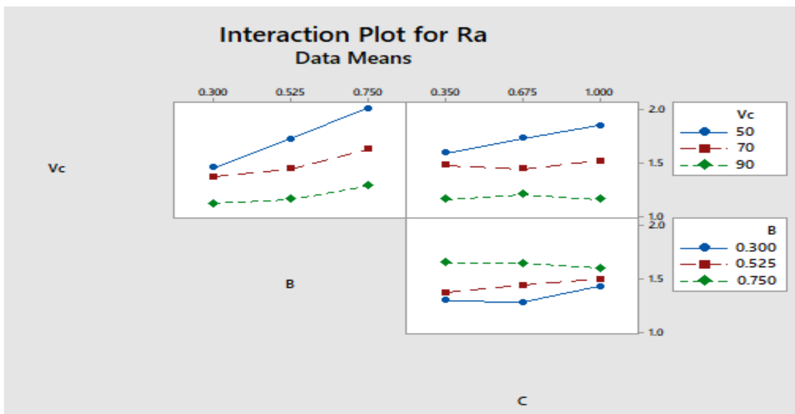


Figure 4.11 Interaction plot of surface roughness for single tool turning

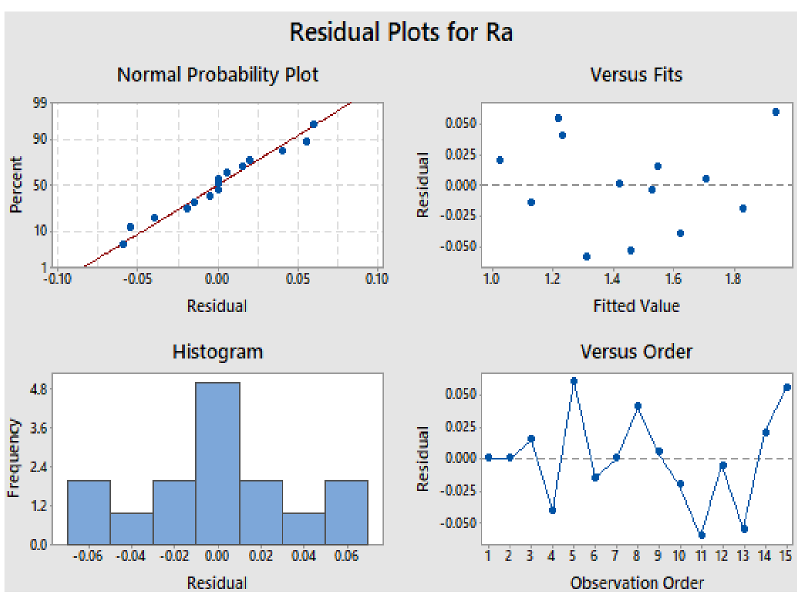


Figure 4.12 Residual plots of Surface Roughness for double tool turning

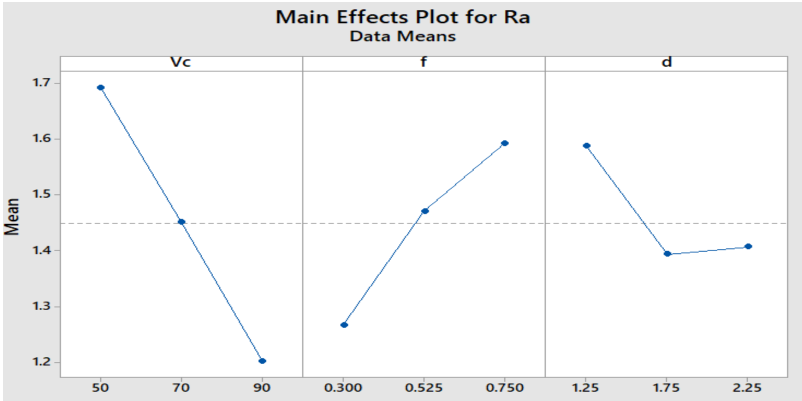


Figure 4.13 Main effects plot for mean Surface Roughness for double tool turning

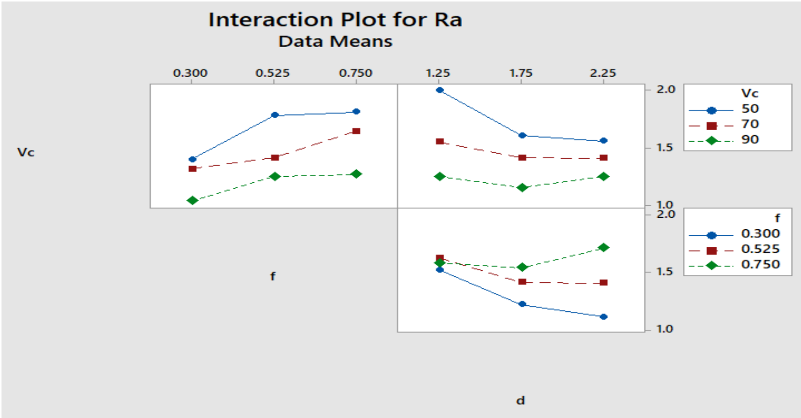


Figure 4.14 Interaction plot of surface roughness for double tool turning

Figure 4.10 and 4.13 shows the plot of the main effects of cutting speed, depth of cut, and feed rate parameters on the surface roughness in a single tool and double tool turning processes respectively. It was clearly shown that the feed rate and cutting speed significantly affect the surface roughness (Ra) for both Single and double Tool Turning. The cutting speed was found more significant factor affecting the (Ra). The surface roughness was apparently to a decreased trend with a decrease in feed rate because of the depth of cut shared between the two tools in the case of the double tool turning Process. On the other hand, as the cutting speed increased, the surface roughness decreased. Therefore, to obtain a low value of surface finish on the machined part, the feed rate should be set at low possible, and the cutting speed should be set as high as possible. This improved from this study by applying two tools at a time to minimize the depth of cut, which causes more feed. Figure 4.10 also proves that the cutting speed has more influence on surface roughness than feed rate in double tool turning.

4.3.4 Surface roughness optimization using response surface methodology

In RSM, the approach of desirability function analysis was proposed by (Derringer and Suich, 1980). The selection of optimum cutting conditions has always been a challenge in machining. Low surface roughness values can be achieved by adjusting cutting conditions with the help of appropriate optimization methods. Therefore, the process parameters are defined in the standard optimization format to be solved by optimization algorithms. The optimal response plot is generated using MINITAB software.

Response optimization: Ra

Table 4.7 Parameters for single tool turning

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Target	0.999	1.11	2.01	1	1

Table 4.8 Parameters for double tool turning

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Target	0.936	1.04	2	1	1

Table 4.9 Starting Values for single tool turning

Variable	Vc	f	D
Setting	50	0.3	0.35

Table 4.10 Starting Values for double tool turning

Variable	Vc	f	D
Setting	50	0.3	1.25

Desirability is simply a mathematical method to find the optimum. Desirability is an objective function that ranges from zero outside of the limits to one at the goal. The numerical optimization finds a point that maximizes the desirability function. The desirability of 1.00 means the goals were easy to reach and better results may be available. Consider making the goals more difficult or adding new criteria for less critical responses and even factors. The ultimate goal is not to maximize the desirability value. The factor settings that result in the highest desirability scores indicate there is an island of acceptable outcomes. It is quite possible for there to be multiple islands (local optima) to explore. Table 4.13 and 4.14 shows the optimized parameters for both single and double tool turning.

Table 4.11 Optimized solution for single tool turning

Solution	Vc (m/min)	f (mm/rev)	d (mm)	Ra Fit	Composite Desirability
1	90	0.3	0.350	1.1183	0.990783

Table 4.12 Optimized solution for double tool turning

Solution	Vc (m/min)	f (mm/rev)	d (mm)	Ra Fit	Composite Desirability
1	86.7677	0.3	1.75071	1.03992	0.999210

Optimal machining parameters obtained are cutting speed of 86.7677 m/min at a feed rate of 0.3 mm/min and 1.75071mm depth of cut for double tool turning and for single tool turning at cutting speed 90 m/min, feed 0.3 and 0.35 depth of cut. The value is completely dependent on how closely the lower and upper limits are set relative to the actual optimum. The goal of optimization is to find a good set of conditions that will meet all the goals, not to get to a desirability value of 1.0. Now since the desirability value is 0.9999210, which is very close to 1.0.

Table 4.13 Optimized surface roughness for single tool turning

Response	Fit	SE Fit	95%Cl	95%Pl
Ra(µm)	1.1183	0.0478	(0.9954,1.2411)	(0.9494,1.2872)

Table 4.14 Optimized surface roughness for double tool turning

Response	Fit	SE Fit	95%Cl	95%Pl
Ra(µm)	1.0399	0.0277	(0.9686,1.1112)	(0.9229,1.1569)

Figure 4-15 and 4.16 shows the surface roughness optimization plots for cutting parameters Each column of the graph corresponds to a factor. Each row of the graph corresponds to the response. Each cell of the graph shows how the response changes as a function of one of the factors, while all other factors remain fixed. The numbers displayed at the top of a column show the current factor level settings and the high and low settings of a factor in the experimental design.

The composite desirability (D) is displayed in the upper left corner of the graph. The label above composite desirability refers to the current setting and changes interactively with the factor settings. The optimal response plot is generated using MINITAB software. The vertical lines inside the graph represent current optimal parametric settings. The horizontal dotted lines represent the current response values.

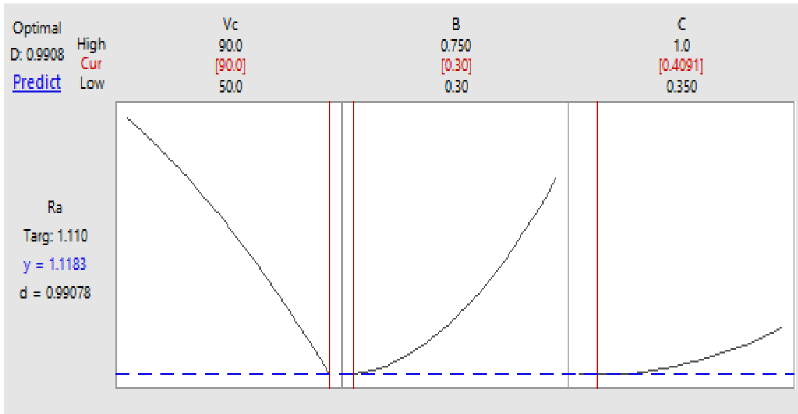


Figure 4.15 Response optimization plot for surface roughness for single tool turning

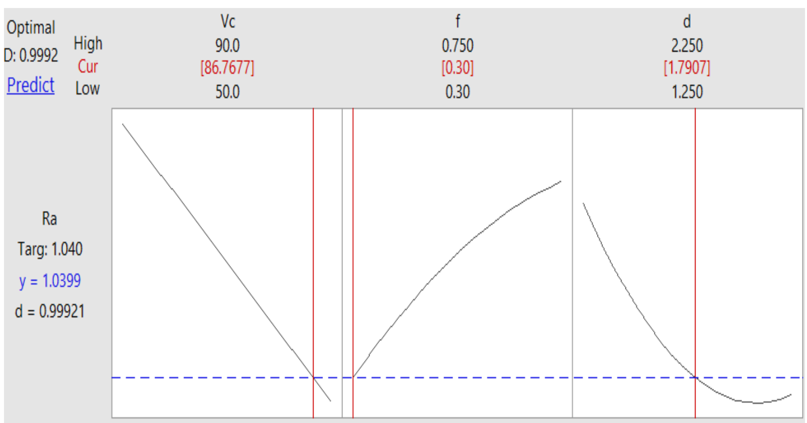
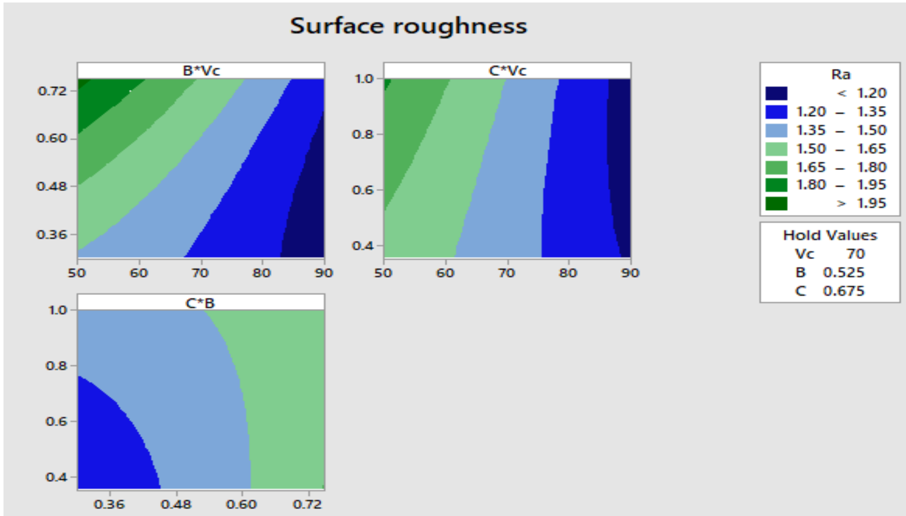


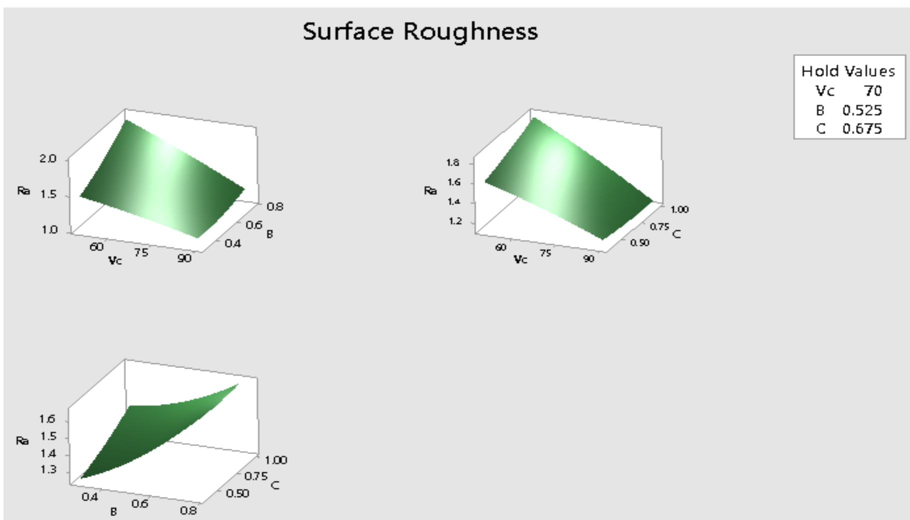
Figure 4.16 Response optimization plot for surface roughness for double tool turning

4.3.5 The interaction contour plot

The 2D, and 3D surface, and contour plots for the respective cutting parameters and surface roughness are shown in Figures 4.17 and 4.18. However, this plot is useful to find the optimum values of cutting speed and feed rate at a particular value of surface roughness and depth of cut. These 3D surface plots can be used for estimating the surface roughness values for any suitable combination of the input parameters, namely cutting speed, feed rate, and depth of cut.

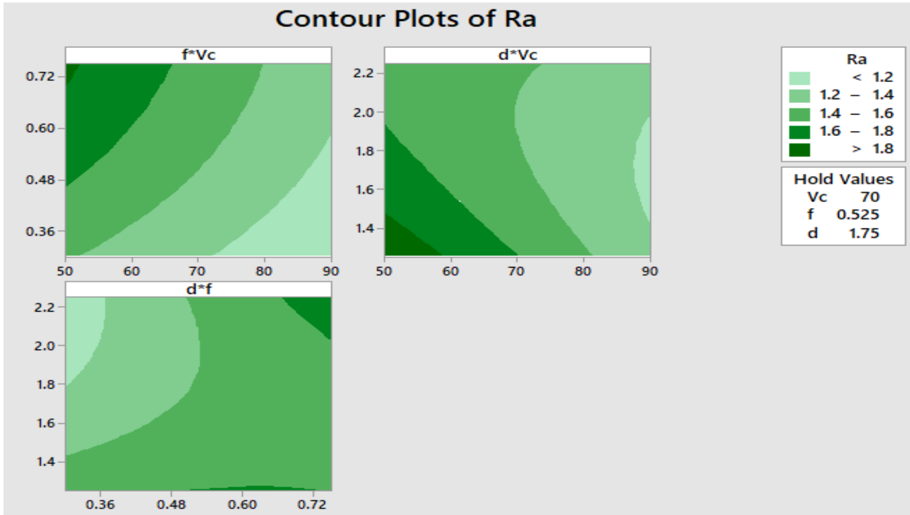


A) 2D view

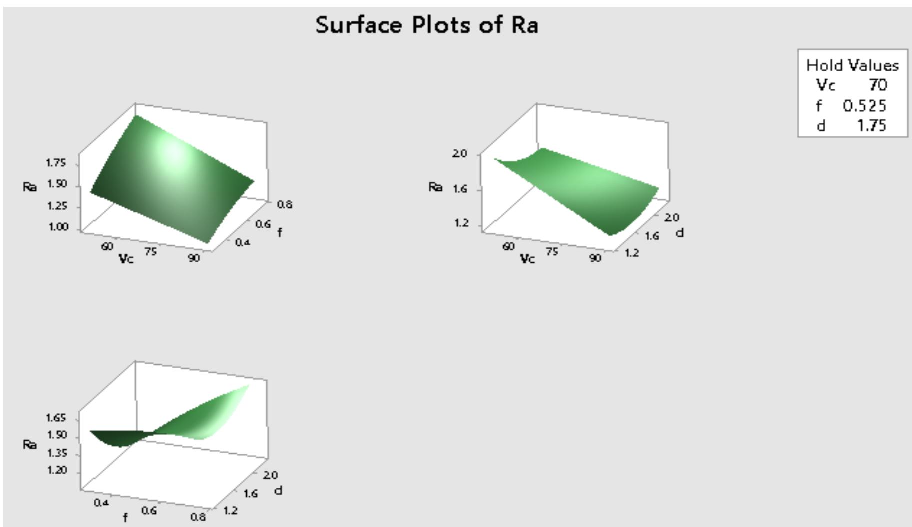


B) 3D view

Figure 4.17 Surface and contour plot of Ra for varying cutting speed, feed, and depth of cut at (A) 2D view and (B) 3D view for Single tool turning



A) 2D



B) 3D

Figure 4.18 Surface and contour plot of Ra for varying cutting speed, feed, and depth of cut at (A) 2D view and (B) 3D view for Double tool turning

4.4 Analysis of Material Removal Rate

Material removal rate (MRR) was the amount of material removed per time unit, directly aiming at the process productivity. The double tool turning method played a significant role to remove a high volume of material rate and can give approximately double the production rate of the single tool turning method. Based on the equation for material removal rate, the material removal rate of double tool turning processes was calculated as follows with compare of the single tool turning process. The material removal rate can be calculated by using equation (3.6).

The number of materials removed during the turning process of flake graphite cast iron for each experiment was determined and listed in Table 4.15 and Table 4.16 for both double and single tool turning. In the present investigation, the following formula has been used to compute the material removal rate.

Material Removal Rate (MRR) = Vc x f x ap,

Where Vc: -Cutting speed

f: -feed

d: - depth of cut.

Table 4.15 Experimental result for MRR for Single tool turning

Single tool turning				
Exp.No	Cutting Speed (m/min)	Feed (mm/rev)	Depth-1 (mm)	MRR (mm^3/sec)
1	50	0.3	0.35	87.5
2	50	0.3	0.675	169.75
3	50	0.525	1.00	437.50
4	50	0.525	0.675	295.512
5	50	0.75	1.0	625
6	70	0.3	0.35	122.5
7	70	0.3	1.0	350
8	70	0.525	0.35	214.37
9	70	0.525	0.675	413.43
10	70	0.75	0.35	297.5
11	90	0.3	0.35	157.5
12	90	0.3	0.675	306.75
13	90	0.525	0.675	531.563
14	90	0.525	1.0	787.50
15	90	0.75	0.35	393.75

Table 4.16 Experimental result for MRR for Double cutting tool turning

Exp. No	Speed (m/min)	Feed (mm/rev)	Depth -1 (mm)	Depth-2 (mm)	MRR (mm^3/sec)
1	50	0.3	0.75	1	437.5
2	50	0.75	0.75	1.0	1093.5
3	50	0.525	0.5	0.75	546.88
4	50	0.525	1	1.25	984.38
5	70	0.525	0.75	1	1071.88
6	70	0.75	0.5	0.75	1093.75
7	70	0.525	0.75	1	1071.88
8	70	0.75	1.00	1.25	1968.75
9	70	0.3	1.00	1.25	787.5
10	70	0.525	0.75	1.00	1071.79
11	90	0.3	0.750	1.00	787.5
12	90	0.3	0.5	0.75	427.5
13	90	0.525	0.50	0.75	984.38
14	90	0.525	1.0	1.25	1771.875
15	90	0.75	0.75	0.1	1968.75

As observed in Table 4.15 and Figure 4.16 material removal rate is affected by cutting speed, feed, and depth of cut. While increasing cutting parameters, the material removal rate was increased. The higher the cutting parameters the higher the material removal rate achieved. This can be justified by the relation shown in equation (3.6). Material Removal Rate (MRR) was important for increasing the productivity of machining operations by increasing the number of chips removed from the machined workpiece or product. The material removal rate increased as the cutting settings were raised. The higher the cutting parameters, the faster the material was removed.

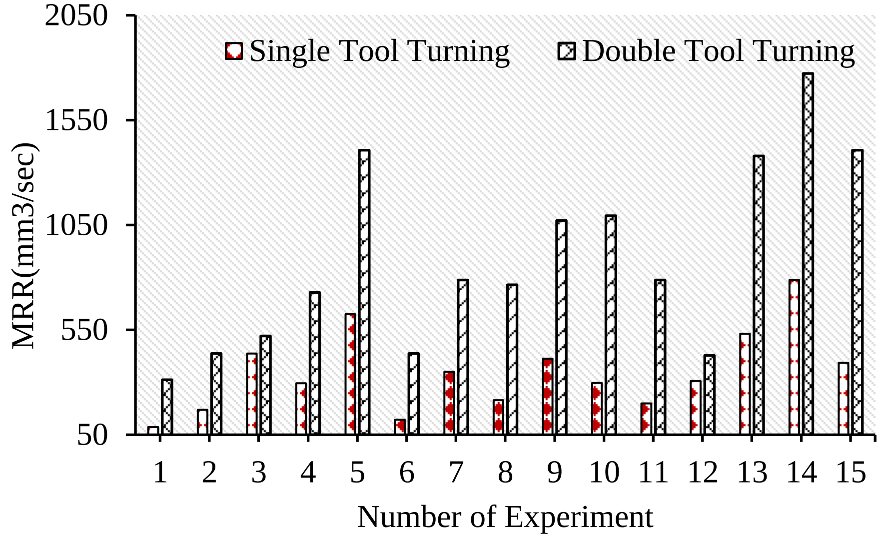


Figure 4.19 Material removal rate Vs Number of Experiment for both double and single tool turning

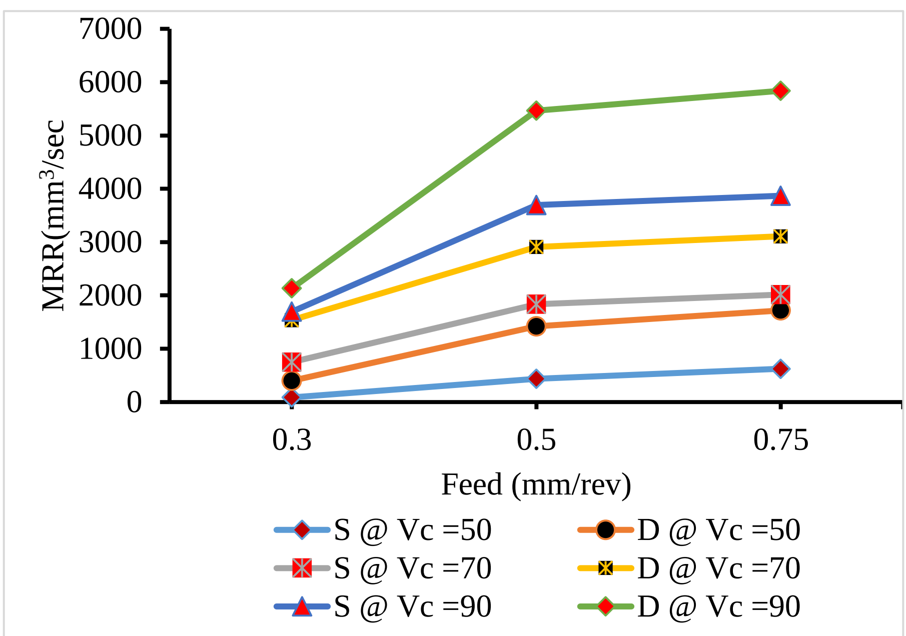


Figure 4.20 Material Removal Rate vs. Feed for both double and single tool turning

These cutting parameters, on the other hand, have an impact on the machined part's surface quality, tool wear, and cutting temperature. The cutting parameters must be controlled due to the above-mentioned issues. As a result, machining parameter optimization was critical. The material removal rate obtained at the optimum cutting parameters, which were 787.5 mm^3 /sec and 158.122 mm^3 /sec for both double and single cutting tools, was based on experimental results. Both increased surface smoothness and material removal rate were accomplished because the optimum cutting speed for the greatest surface finish was at the highest-level values. A higher material removal rate in machining does not imply cost-effectiveness because it affects tool life, surface integrity, and overall machining efficiency. However, cost-effective machining will be achieved with optimal parameters such as reduced tool wear, increased tool life, excellent surface finish, and low cutting temperature. Figure 4.20 indicates the influence of feed rate on material removal rate.

As shown in Figure 4.20, double tool turning produced the greatest results for chip removal from bulk material. As a result, the materials removal rate in double tool turning increased more rapidly than in single tool turning as cutting parameters were increased. The productivity of double tool turning was much increased because the removal rate was high without harming the science of machining.

4.4.1 Optimization of Material Removal Rate

The optimization of a single tool and double tool turning process parameters such as removal rate (MRR) during machining of work material flake graphite cast iron for given values of machining parameters like cutting speed, feed, and depth of cut was carried out using the statistical tool Minitab. The response surface methodology (Box-Behnken Design) was used to optimize the result and to determine the optimum level of input process parameters for the best value of material removal rate. The optimum value of cutting speed, feed, and depth of cut has been determined to predict the best material removal rate. The adequacy of the model was also tested by analysis of variance test (ANOVA).

A three-factor three-level was considered in each factor at three widely spaced levels. Three variables were considered for an experimental design for flake graphite cast iron. Tables 4.17 and 4.18 were three levels of process parameters for single and double tool turning, respectively.

Table 4.17 Machining parameters and their levels (Single tool turning)

Process Parameters	Lever - 1	Lever - 2	Lever -3
Cutting speed(m/min)	50	70	90
Feed(mm/rev)	0.3	0.525	0.75
Depth of cut(mm)	0.35	0.675	0.75

Table 4.18 Machining parameters and their levels (Double tool turning)

Process Parameters	Lever - 1	Lever - 2	Lever -3
Cutting speed(m/min)	50	70	90
Feed(mm/rev)	0.3	0.525	0.75
Depth of cut(mm)	1.25	1.75	2.25

4.4.2 Model summary statistics

Table 4.19 Model summary statistics for single tool turning

R^2	99.43%
Adjusted R^2	98.4%
Predicted R^2	90.84%
PRESS	681904

Table 4.20 Model summary statistics for double tool turning

R^2	99.83%
Adjusted R^2	99.52%
Predicted R^2	97.39%
PRESS	124380
S	40.2988

The test of significance of MRR has been carried out using a quadratic model. The results of the quadratic model for MRR are given in Tables 4.19 and 4.20 for both single and double tool turning. The value of R^2 and adjusted R^2 for double and single tool turning are 99.83%and 99.52% and 99.43% and 98.4% respectively. This means that the regression model provides a complete between the dependent and independent variables. The associated p-value for the model is $p < 0.05$(95% confidence) indicating that the model is considered to be statistically significant. Hence, the model was found to be adequate. It was also seen from the Table that p-values, the main effect of process parameters were much more significant.

Table 4.21 Analysis of variance results for single tool turning

Source	Sum of Squares	Df	Mean square	F-value	P-value	Contribution %
Model	739844	9	82205	96.43	0.000	99.43
A-Cutting speed	144605	1	144605	169.63	0.000	19.43
B-Feed rate	207025	1	207025	242.85	0.000	27.82
C-Depth of cut	317007	1	317007	371.86	0.000	42.60
A^2	860	1	848	0.99	0.364	0.12
B^2	992	1	848	0.99	0.364	0.13
C^2	886	1	886	1.04	0.355	0.12
AB	26417	1	26417	30.99	0.003	3.55
AC	12939	1	12939	15.18	0.011	1.74
BC	29113	1	29113	34.15	0.002	3.91
Residual	4262	5	852			0.57
Total	744106	14				

Table 4.22 Analysis of variance results for double tool turning

Source	Sum of Squares	Df	Mean square	F-value	P-value	Contribution %
Model	4757896	9	528655	325.53	0.000	99.83
A-Cutting speed	832271	1	832271	512.48	0.000	17.46
B-Feed rate	618862	1	618862	381.07	0.000	12.98
C-Depth of cut	1883836	1	1883836	1160.00	0.000	39.53
A^2	17262	1	4500	56.98	0.001	1.42
B^2	67537	1	92528	0.99	0.364	0.13
C^2	343365	1	343365	211.43	0.000	7.2
AB	236167	1	236167	145.42	0.000	4.96
AC	294495	1	294495	181.34	0.000	6.18
BC	464102	1	464102	285.78	0.000	9.74
Residual	464102	5	1624			0.17
Total	4766016	14				

Figure 4.22 and 4.25 showed the main effects of cutting speed, depth of cut, and feed rate parameters on Material Removal Rate (MRR) for single and double tool turning. The Depth of

Cut followed by feed rate more significant parameter than cutting speed in controlling the MRR during single tool turning while double tool turning depth of cut followed by cutting speed is more significant than feed rate. As the depth of cut increases, MRR also increased, this was mainly due to more volume of chips generated during machining. The optimum of MRR was obtained at a feed rate of 0.3 mm/rev, depth of cut of 1.75mm, and cutting speed of 90 m/min in double tool turning while at a feed rate of 0.3 mm/rev, depth of cut of 0.35 mm and cutting speed of 90 m/min in single tool turning. Figures 4.21 and 4.24 depicted the normal probability of residuals for MRR. It was observed from the result that the residual values were normally distributed in a straight line hence the model was adequate. The optimized machining parameters were well proved.

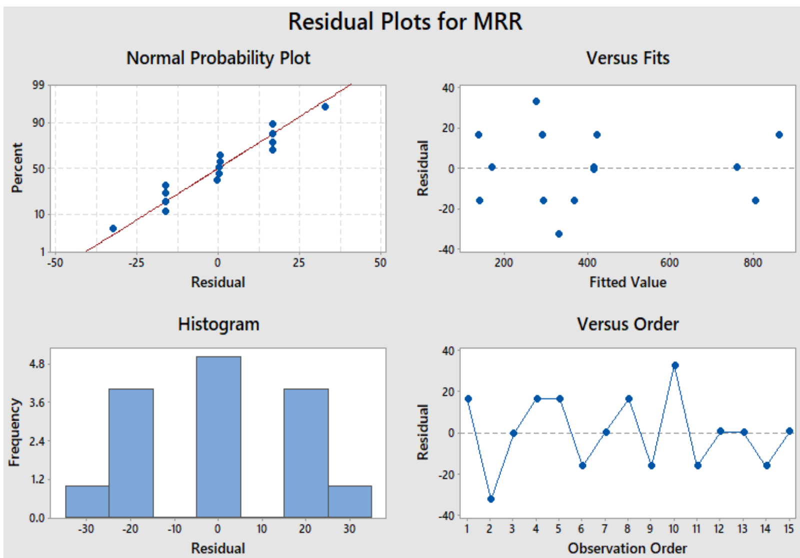


Figure 4.21 Residual plots for Material Removal Rate of single tool turning

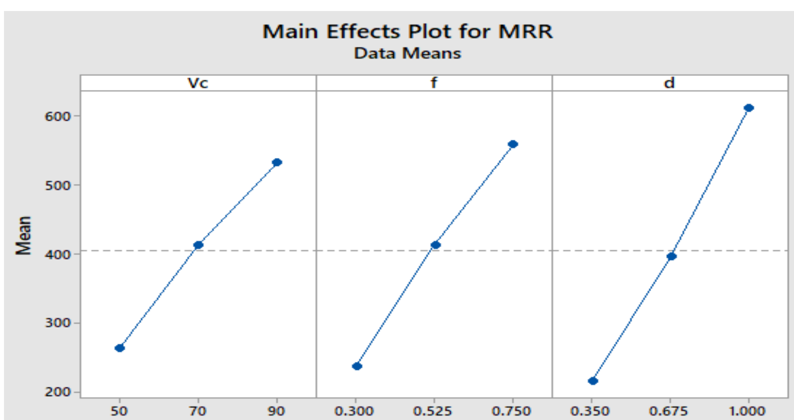


Figure 4.22 Main Effects plot Material Removal Rate for single tool turning

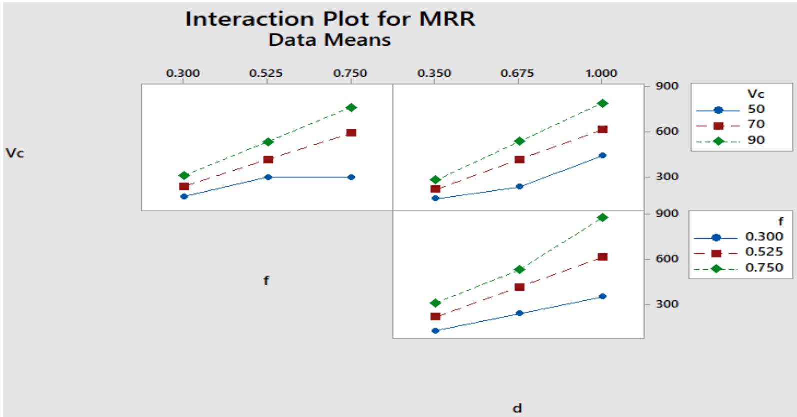


Figure 4.23 Interaction plot of Material Removal Rate for single tool turning

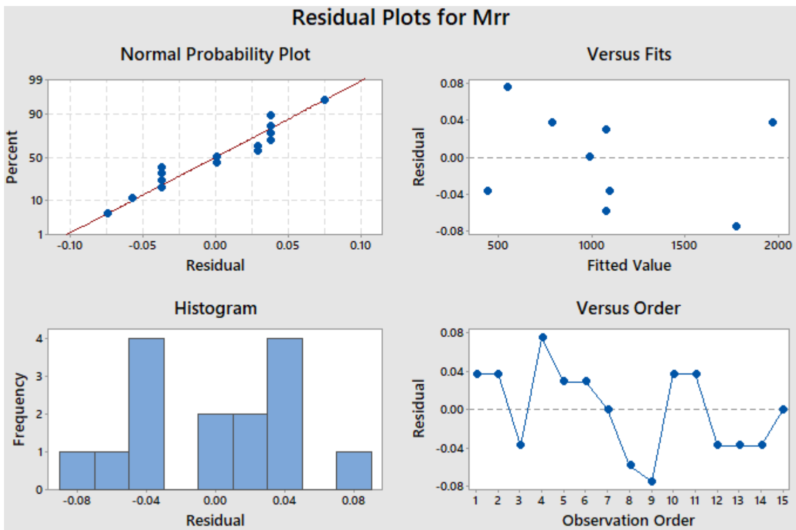


Figure 4.24 Residual plots for Material Removal Rate of double tool turning

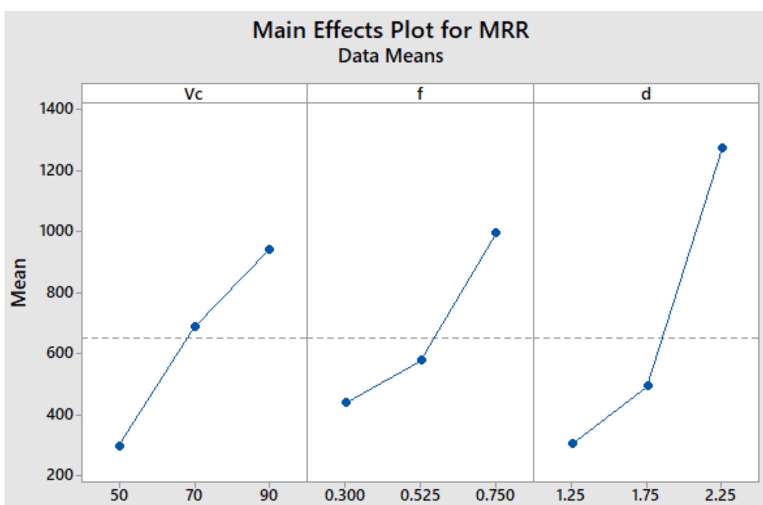


Figure 4.25 Main Effects plot Material Removal Rate for double tool turning

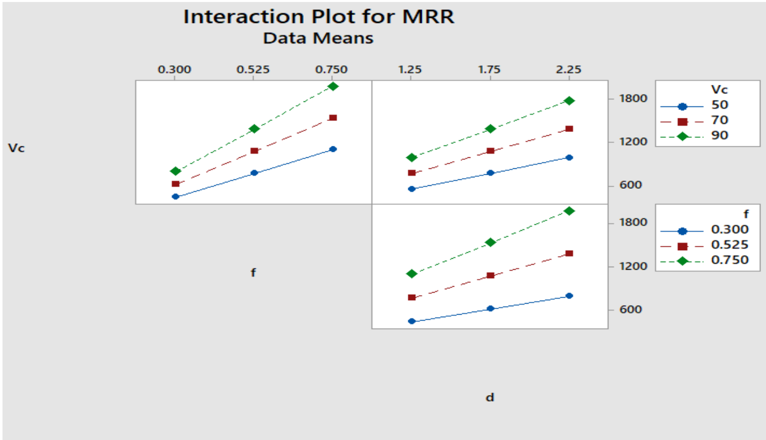


Figure 4.26 Interaction plot of Material Removal Rate for double tool turning

(Jaharah et al., 2009) similarly obtained this phenomenon where the depth of cut is significantly affecting the MRR produced, followed by the cutting speed and feed rate. Besides, (Ghani et al., 2002) investigated that the surface finish of the work part was not influenced by the tool wear; however, it was influenced by the increase in cutting speed, feed rate, or depth of cut.

4.4.3 Material Removal Rate Optimization Using Response Surface Methodology

The optimal response plot is generated using MINITAB software.

Response Optimization: Ra

Table 4.23 Parameters for single tool turning

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Target	122.5	157.5	875	1	1

Table 4.24 Parameters for double tool turning

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Target	437.5	787.5	1968.75	1	1

Table 4.25 Starting Values for single tool turning

Variable	Vc(m/min)	f(mm/min)	d(mm)
Setting	50	0.3	0.35

Table 4.26 Starting Values for double tool turning

Variable	Vc(m/min)	f(mm/min)	d(mm)
Setting	50	0.3	1.25

The desirability of 1.00 means the goals were easy to reach and better results may be available. The factor settings that result in the highest desirability scores indicate there is an island of acceptable outcomes.

Table 4.27 Optimized solution for single tool turning

Solution	Vc (m/min)	f (mm/rev)	d(mm)	MRR Fit (mm^3/sec)	Composite Desirability
1	90	0.3	0.35	158.122	0.999133

Table 4.28 Optimized solution for double tool turning

Solution	Vc (m/min)	f (mm/rev)	d(mm)	MRR Fit (mm^3/sec)	Composite Desirability
1	90	0.3	1.75	787.381	0.999666

The value is completely dependent on how closely the lower and upper limits are set relative to the actual optimum. The goal of optimization is to find a good set of conditions that will meet all the goals, not to get to a desirability value of 1.0.

Table 4.29 Optimal machining parameters for single tool turning

Variable	Vc(m/min)	f(mm/rev)	d(mm)
Setting	90	0.3	0.35

Table 4.30 Optimal machining parameters for double tool turning

Variable	Vc(m/min)	f(mm/rev)	d (mm)
Setting	90	0.3	1.75

The optimal machining parameters obtained are a cutting speed of 90 m/min at a feed rate of 0.3 mm/min and 0.35 mm depth of cut for single tool turning where at a cutting speed of 90 (m/min), a feed rate of 0.3 (mm/rev) and depth of cut are 1.75 mm for double tool turning.

Table 4.31 Optimized material removal rate for single tool turning

Response	Fit	SET Fit	95%Cl	95%Pl
MRR	158	234	(-442, 758)	(-623, 939)

Table 4.32 Optimized material removal rate for double tool turning

Response	Fit	SET Fit	95%Cl	95%Pl
MRR	787.381	0.059	(787.23,787.532)	(787.137, 787.625)

The optimized Material removal rate obtained is MRR 158 (mm^3/sec) and 787.381(mm^3/sec) for single and double tool turning respectively. The desirability value is 0.999133 and 0.99966, which is very close to 1.0.

The composite desirability (D) was displayed in the upper left corner of the graph. The label above composite desirability refers to the current setting and changes interactively with the factor settings. The optimal response plot was generated using MINITAB software. The vertical lines inside the graph represent current optimal parametric settings. The horizontal dotted lines represent the current response values.

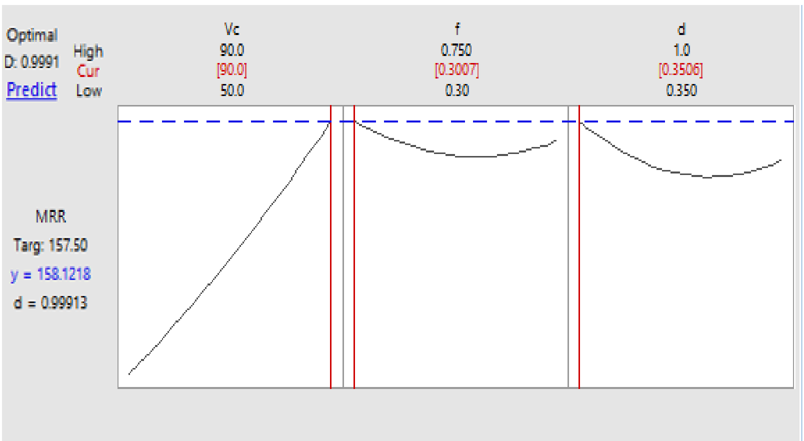


Figure 4.27 Response optimization plot Material Removal Rate for single tool turning

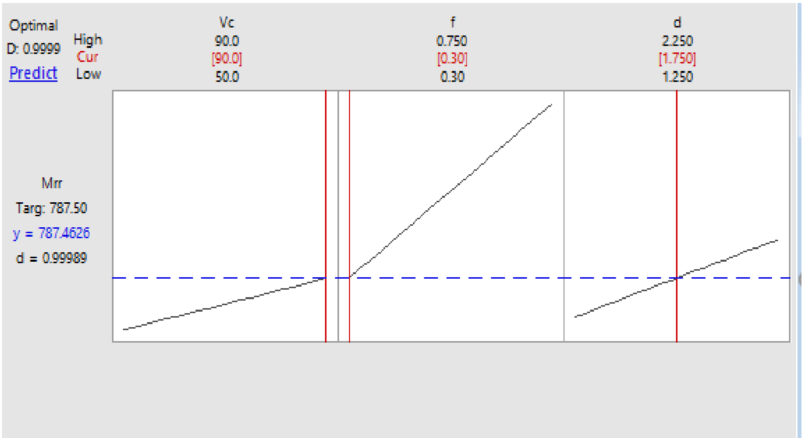
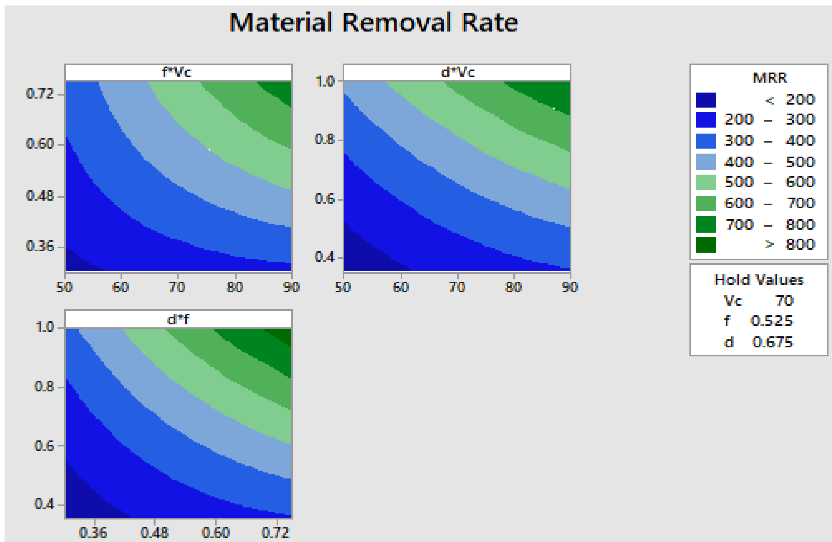


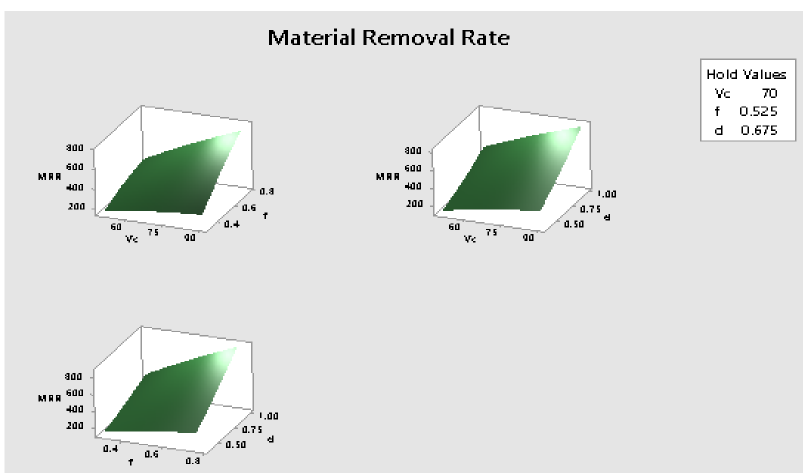
Figure 4.28 Response optimization plot Material Removal Rate for double tool turning

4.4.4 The interaction contour plot

The 2D, 3D surface, and contour plots for the respective cutting parameters and Material Removal Rate are shown in Figures 4.29 and 4.30. However, this plot is useful to find the optimum values of cutting speed and feed rate at a particular value of Material Removal Rate and depth of cut. These 3D surface plots can be used for estimating the MRR values for any suitable combination of the input parameters, namely cutting speed, feed rate, and depth of cut.

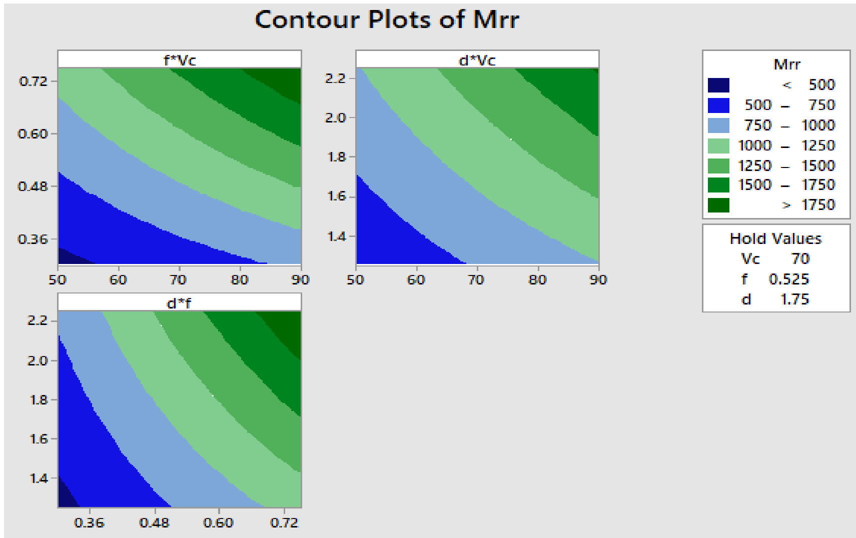


A) 2D view

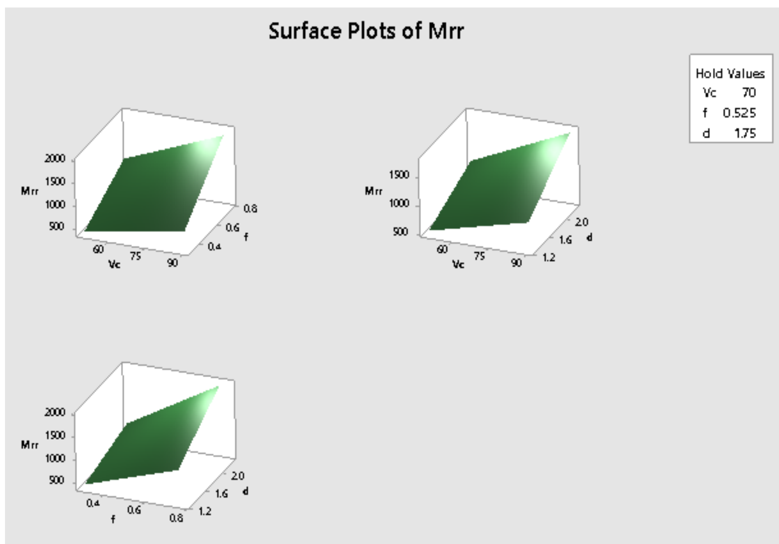


B) 3D view

Figure 4.29 Surface and contour plot of MRR for varying cutting speed, feed, and depth of cut at (A) 2D view and (B) 3D view for Single tool turning



A) 2D View



B) 3D View

Figure 4.30 Surface and contour plot of MRR for varying cutting speed, feed, and depth of cut at (A) 2D view and (B) 3D view for double tool turning

4.5 Analysis of temperature

To determine the temperature difference between double and single tool turning, an experiment was done. The heat was generated during the turning process due to friction between the cutting tool and the workpiece. The amount of heat generated during machining varies depending on the type of workpiece material, cutting parameters, and machining conditions. The temperature at the tooltip was moderate when turning flake graphite cast iron with a ceramics-coated carbide tool. For each experiment run, the workpiece surface temperature was determined using a digital thermocouple. Tables 4.33 indicate the workpiece's greatest surface temperature at the cutting zone for each run of the experiment.

Table 4.33 The measured temperature at the tooltip for the Double cutting tool

Exp. No.	Cutting speed (m/min)	Feed (mm/rev)	Depth-1 (mm)	Depth-2 (mm)	Averg. T (^oC)	
					Tool-1	Tool-2
1	50	0.30	0.75	1.00	35.8	38.9
2	50	0.75	0.75	1.00	37.3	40.2
3	50	0.525	0.50	0.75	42.1	45.4
4	50	0.525	1.00	1.25	46	51
5	70	0.525	0.75	1.00	49.7	54.3
6	70	0.75	0.50	0.75	51.9	57.6
7	70	0.525	0.75	1.00	55	59.3
8	70	0.50	1.00	1.25	60.1	64.2
9	70	0.30	1.00	1.25	69.3	73.7
10	70	0.525	0.75	1.00	74.2	77.3
11	90	0.30	0.50	0.75	71.4	75.2
12	90	0.30	0.75	1.00	67.3	69.9
13	90	0.525	0.50	0.75	68.7	70.3
14	90	0.525	1.00	1.25	72	76.3
15	90	0.75	0.75	1.00	75	79

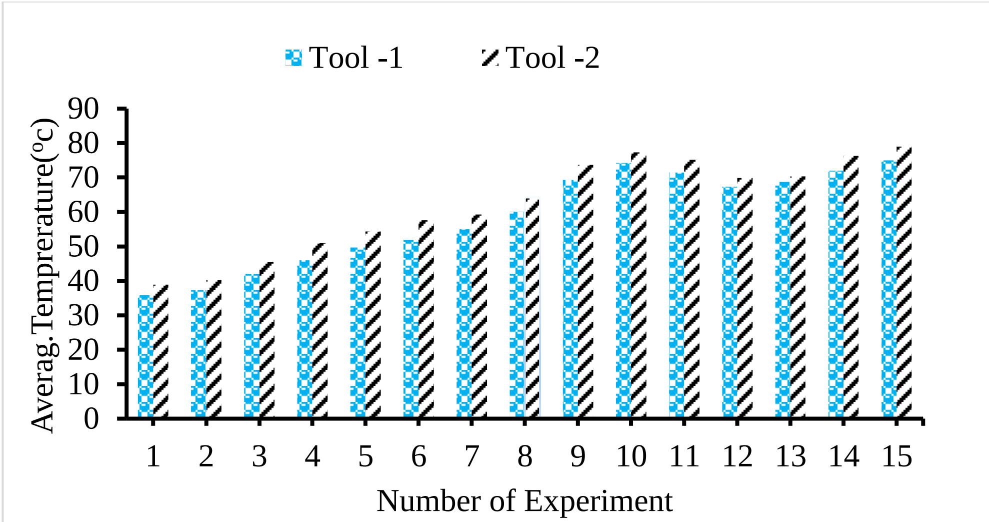


Figure 4.31 Temperature values Vs Number of an experiment for 1st and 2nd cutting tool

The tooltip temperature measurements were taken as the average, as shown in Table 4.33. In experiment number twelve, the optimum average temperature for the first cutting tool was 67.3 ^{0}C and 69.9 ^{0}C for the second cutting tool. The machining parameters were 90 m/min cutting speed, 0.3 mm/rev feed, 0.75 mm first depth of cut, and 1.0 mm second depth of cut. At a low cutting speed (50 m/min), the minimum temperature for the first and second cutting tools was 35.8 and 38.9 ^{0}C, respectively. As a result of the increased cutting speed, the tooltip temperate generated increases. The same can be seen in Figure 4.31.

4.6 Analysis of Cutting tool wear

The experiment was conducted for both double tool and single tool turning to analyze the cutting tool wear differences at high surface roughness. The mechanism of tool wear at the tooltip was presented based on the image taken by using SEM at 150x magnification. As shown in Figures 4.32 up to 4.34; the tooltip of the cutting tool inserts in double tool turning process tests was carried out at a cutting speed of 50 m/min, feed of 0.525 mm/rev, and depth of cut at 1.00 mm, 1.25 mm were investigated to understand the flank wear of the 1st and 2nd cutting tools. For a single tool turning at a cutting speed of 50 m/min, feed of 0.525 mm/rev, and depth of cut 1.00 mm, Flank wear occurs on the flank of the tool with a depth of 0.419 mm, 0.474mm, and 0.69 mm for T_1, T_2, and single tool turning respectively. It was created due to rubbing between the newly generated work surface and the flank face of the cutting tool adjacent to the cutting edge.

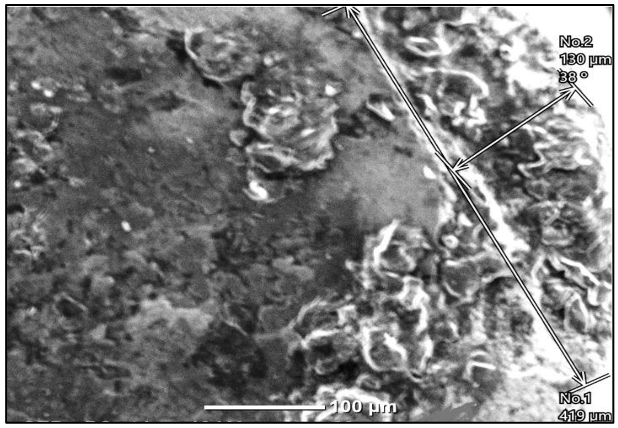


Figure 4.32 Tool wear of the 1st cutting tool at 150X magnification (50 m/min cutting speed, 0.525 mm/rev feed, and 1.00 mm depth of cut)

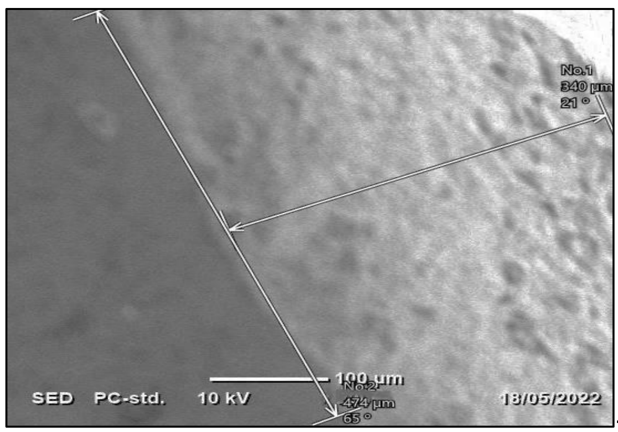


Figure 4.33 Flank wear of the 2nd cutting tool at 150X magnification (50 m/min cutting speed, 0.525 mm/rev feed, and 1.25 mm depth of cut)

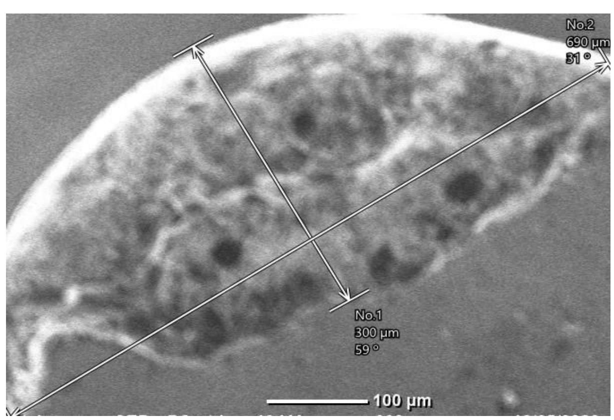


Figure 4.34 Flank wear of the Single cutting tool at 150X magnification (50 m/min cutting speed, 0.525 mm/rev feed, and 1.00 mm depth of cut)

In this study, experimental data shows that the flank wear in double tools at T_1, T_2, and Single Tool turning are (0.419, 0.474, and 0.690) mm. Abrasive wear was identified as the dominant mode. Machining by the leading 1st cutting tool raises the workpiece temperature. This temperature rise promotes diffusion wear while reducing abrasion wear. Tool wear was less for measured values for double tool turning. This was between reduced temperature and shared cutting force between the two cutting tools engaged together. As the surface roughness got high, the tool wear was high which justifies that an improved surface finish can reduce the tool wear. Therefore, optimized cutting parameters resulted in low tool wear, high tool life, high surface finish, economical machining, etc.

4.7 Observation of Chip Morphology

Chip formation has become a technology in its own right, which has shown significant development over the last few decades of machining. Chip formation and its resultant morphology are not only affected by the cutting parameter selected but also influenced by the cutting tools and inserts. The main type of chips formed during machining flake graphite cast iron is fragmented chips. The chips are formed as very small rubbish, which can voluntarily be cleared from the cutting area even when machining at very far above the ground speeds. It is to some amount dirty and sandy action; throw a fine scatter of graphite into the air, so that fortification for factory employees may be necessary, in dry turning operation of this study. The figure shows the chips formed in the dry turning process of flake graphite cast iron for all fifteen different experiments conducted in this study. Due to the presence of graphite element in the cast iron, alloy the chips produced were discontinuous type as shown in Figure.

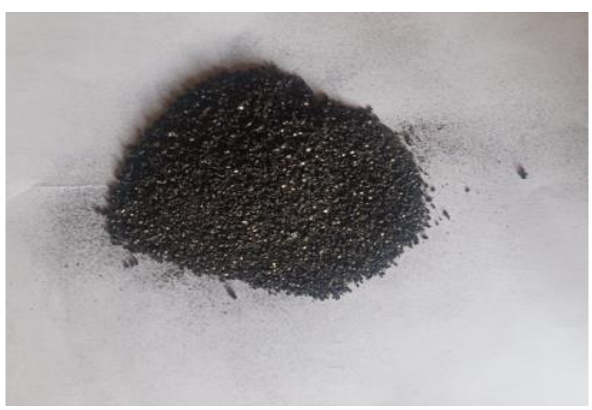


Figure 4.35 chip formed during machining of flake graphite cast iron.

CHAPTER -5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this thesis, experimental work on a single tool and double tool turning was carried out using a conventional lathe machine on a flake graphite cast iron workpiece. The effect of cutting parameters such as cutting speed, feed, and depth of cut were investigated. The results on surface roughness, cutting temperature, tool wear, and material removal rate were investigated. In addition, chip morphology was studied using image analysis for chip removal analysis. The productivity improvement with the use of a double tool for a single tool turning operation was estimated using optimization analysis. The experimental results were compared to the predicted Cutting parameters and productivity improvement parameter factors for the double tool turning process. Cutting temperature, cutting tool wear, surface roughness, material removal rate, and chip formation were evaluated for both double and single tools. The production rates generated by the single tool and double tool turning processes were compared. The following conclusions were taken from the analysis outcomes.

1. In comparison to traditional turning, surface roughness was reduced in specific machining conditions. A superior surface finish can be attained at a lower production cost and improved by 6.73% during double tool turning with suitable process parameter selection.
2. When working with flake graphite cast iron in dry conditions, a high cutting speed, low feed rate, and low cut depth are beneficial for achieving minimal surface roughness.
3. Tool wear of double tool is lesser as compared to the single tool turning. Lesser tool wear contributes to increased production levels.
4. Because both the first and second cutting tools were cutting at the same time, the machining time was reduced, and material removal rates were increased by 55 % in double tool turning compared to single tool turning which improved productivity.
5. Overall, double-tool turning provides much better performance than single-tool turning. However, it requires a change in the design of the lathe and an appropriate selection of process parameters.

5.2 Recommendation

The double-tool turning process is covered in this chapter. A study of multi-tool turning machining performance could help enhance productivity even more. Soft computing approaches can also be used to forecast other characteristics such as cutting force and tool wear. However, a large amount of experimental data is required. Experiments in metal cutting were time-consuming and complex. This problem can be solved by augmenting experimental research with FEM multi-tool machining simulations, which can provide speedy and accurate results. In comparison to experimental research, it also saves material, manpower, and time. To take advantage of both methodologies, a hybrid model integrating FEM and soft computing methods might be used.

SPECIAL ACKNOWLEDGEMENT

This research work is funded by Adama Science and Technology University under the grant number ASTU/SM-R/593/22, Adama, Ethiopia.

REFERENCE

Abhang, L. B., and Hameedullah, M. (2012). Optimization of machining parameters in steel turning operation by Taguchi method. Procedia Engineering, 38, 40-48.

Aggarwal, A., Singh, H., Kumar, P., & Singh, M. (2008). Optimizing power consumption for CNC turned parts using response surface methodology and Taguchi's technique—a comparative analysis. Journal of materials processing technology, 200(1-3), 373-384.

Asiltürk, I., & Akkuş, H. (2011). Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. *Measurement*, *44*(9), 1697-1704.

Aouici, H., Yallese, M. A., Chaoui, K., Mabrouki, T., and Rigal, J. F. (2012). Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization. Measurement, 45(3), 344-353.

B. Kumaragurubaran1, and P Gopal1, T Senthil Kumar, M Prasanna Mugunthan1 and N H Mohamed Ibrahim(2013) “Optimization Of Turning Parameters Of En-9 Steel Using Design Of Experiments Concepts” International Journal Of Mechanical Engineering And Robotics Research, Vol. 2, No. 3, ISSN 2278 – 0149, pp 183-189.

Baker, T. (1998). The fracture resistance of flake graphite cast iron. *International Journal of Materials in Engineering Applications*, *1*(1), 13–18. https://doi.org/10.1016/0141-5530 (78)90003-1

Bagaber SA and Yusoff AR (2019). Multi-objective optimization of cutting parameters to minimize power consumption in dry turning of stainless steel 316. J Clean Prod; 157: 30–46.

Boswell, B., Islam, M. N., Davies, I. J., Ginting, Y. R., & Ong, A. K. (2017). A review identifying the effectiveness of minimum quantity lubrication (MQL) during conventional machining. The International Journal of Advanced Manufacturing Technology, 92(1), 321- 340.

Camuscu, N., (2006). Effect of cutting speed on the performance of Al2O3-based ceramic tools in turning nodular cast iron. Materials and Design, 27, 997-1006.

Chen, W. (2000). Cutting forces and surface finish when machining medium hardness steel using CBN tools. International Journal of Machine Tools and Manufacture, 40(3), 455–466. https://doi.org/10.1016/s0890-6955 (99)00011-5

Cui, Z., Ni, J., He, L., Guan, L., Han, L., & Sun, J. (2022). Investigation of chip formation, cutting force, and surface roughness during orthogonal cutting of polytetrafluoroethylene. *Journal of Manufacturing Processes*, *77*, 485–494. https://doi.org/10.1016/j.jmapro.2022.03.031

Chattopadhyaya, S., Sharma, A., Chaudhary, V., & Rohan, R. (2021, March). Analysis of Elastic Deflection of Single Point Cutting Tool and Optimization of Cutting Speed in Turning Operation by Using MADM Method. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1104, No. 1, p. 012017). IOP Publishing.

Goutam, M., Giriyapura, C., Mishra, S. K., & Gupta, S. (2014). Titanium allergy: a literature review. *Indian journal of dermatology*, *59*(6), 630.

Halim, M.S.B., (2008), "Tool Wear Characterization of Carbide Cutting Tool Insert in a Single Point Turning Operation of AISI D2 Steel," B.Tech. Thesis, Department of Manufacturing Engineering, University Teknikal Malaysia Mekala.

Jaharah, A. G., Rodzi, M. N. A. M., Rahman, A. A., Ab Rahman, M. N., & Hassan, C. C. (2009). Machinability of FCD 500 ductile cast iron using coated carbide tool in dry machining condition. *International Journal of Mechanical and Materials Engineering*.

Kalidasan, et al (2014) ''Preliminary Experimental Investigation on Multi-Tool Turning Process. 8th BSME International Conference on Thermal Engineering AIP Conf. Proc. 2121, 140007-1–140007-6; https://doi.org/10.1063/1.5115958

Kalidasan, R., Senthilvelan, S., Dixit, U., & Vaibhav, J. (2016). Double tool turning: machining accuracy, cutting tool wear, and chip-morphology. International Journal of Precision Technology, 6(2), 142. https://doi.org/10.1504/ijptech.2016.07818

Kaladhar, M. (2019). Evaluation of hard coating materials performance on machinability issues and material removal rate during turning operations. Measurement, 135, 493-502.

Kamble, P. D., Waghmare, A. C., Askhedkar, R. D., & Sahare, S. B. (2017). Multi-objective optimization of turning parameters considering spindle vibration by Hybrid Taguchi Principal Component analysis (HTPCA). *Materials Today: Proceedings, 4*(2), 2077-2084.

Kassab, S. Y., and Khoshnaw, Y. K. (2007). The effect of cutting tool vibration on surface roughness of workpiece in dry turning operation. Engineering and Technology Journal, 25(7), 879-889.

Karpat, Y., & Özel, T. (2008). Analytical and thermal modeling of high-speed machining with chamfered tools. Journal of Manufacturing Science and Engineering, 130(1).

Kumar, S. R., & Kulkarni, S. K. (2017). Analysis of hard machining of titanium alloy by Taguchi method. Materials Today: Proceedings, 4(10), 10729-10738.

Kumar H, Mohd. Abbas, Aas Mohammad, Hasan Zakir Jafri (2013), Optimization of cutting parameters in CNC Turning, International Journal of Engineering Research and Applications (IJERA), Vol. 3, Issue 3, pp. 331-334,

Kirby, E. D., Zhang, Z., Chen, J. C., & Chen, J. (2006). Optimizing surface finish in a turning operation using the Taguchi parameter design method. *The International Journal of Advanced Manufacturing Technology*, *30*(11), 1021-1029.

Li, B. (2012). A review of tool wear estimation using theoretical analysis and numerical simulation technologies. International Journal of Refractory Metals and Hard Materials, 35, 143–151. https://doi.org/10.1016/j.ijrmhm.2012.05.006

Lucca, D. A., Brinksmeier, E., & Goch, G. (1998). Progress in assessing surface and subsurface integrity. CIRP Annals, 47(2), 669-693.

Lubis, s. Y., rosehan, r., handoko, d., & komala, w. (2013). Analisa perhitungan biaya pembubutan baja AISI 4340 menggunakan pahat keramik. *Jurnal kajian teknologi*, *9*(2).

Mia, M., Dey, P. R., Hossain, M. S., Arafat, M. T., Asaduzzaman, M., Ullah, M. S., & Zobaer, S. T. (2018). Taguchi S/N based optimization of machining parameters for surface roughness, tool wear, and material removal rate in hard turning under MQL cutting conditions. *Measurement*, *122*, 380-391.

Montgomery, D.C., Design, and Analysis of Experiments, Wi1ey, New York, 4th ed., 1997 Myers, R. H., Montgomery, D. C., and Anderson-Cook, C. M. (2016). Response surface methodology: process and product optimization using designed experiments. John Wiley and Sons.

Montgomery, D. C. (2017). Design and analysis of experiments. John Wiley and sons.

Mechlook, n.d, "Surface Finish-Direct Measurements," from http://www.mechlook.com/surface-finish-direct-instrument-measurements/

M.pradeepkumar et al (2015). A Review on Heat Generation in Metal Cutting. International Journal of Engineering and Management Research, Muhmond, H. M., & Fredriksson, H. (2013). Relationship between inoculants and the morphologies of MnS and graphite in gray cast iron. *Metallurgical and Materials Transactions B*, *44*(2), 283-298.

Panda, A., Sahoo, A. K., Rout, A. K., Kumar, R., & Das, R. K. (2018). Investigation of flank wear in hard turning of AISI 52100 grade steel using multilayer-coated carbide and mixed ceramic inserts. *Procedia Manufacturing*, *20*, 365-371.

Raman Kumar, Paramjit Singh Bilga, Sehijpal Singh "Multi-objective optimization using different methods of assigning weights to energy consumption responses, surface roughness, and material removal rate during rough turning operation" Journal of Cleaner Production 164(2017) pp 45-57.

Ranganath M. S, Vipin, (2014) "Experimental Investigation and Parametric Analysis of Surface Roughness in CNC Turning Using Design of Experiments", International Journal of Modern Engineering Research, Vol. 4, Issue 9,

Ranganath M. S, Vipin, (2014) "Experimental Investigation and Parametric Analysis of Surface Roughness in CNC Turning Using Design of Experiments", International Journal of Modern Engineering Research, Vol. 4, Issue 9,

Ranganath M S, Vipin, Harshit (2014) Optimization of Process Parameters in Turning Operation Using Response Surface Methodology: A Review

Rech, J., & Moisan, A. (2003). Surface integrity in finish hard turning of casehardened steels. International Journal of Machine Tools and Manufacture, 43(5), 543-550.

Sahin Y. and Motorcu A.R., (2008), "Surface roughness model in machining hardened steel with cubic boron nitride cutting tool," International Journal of Refractory Metals and Hard Materials, 26(2), pp. 84-90.

Saraswat, N., Yadav, A., Kumar, A., & Srivastava, B. P. (2014). Optimization of cutting parameters in turning operation of mild steel. *International review of applied engineering research*, *4*(3), 251-256.

Sen, a., & dewangan, dr. S. (2016). Experimental examination and optimization on quality and productivity in turning operation. Ijariie-issn (o)-2395-4396.

Sivaramakrishnaiah, M., Nandakumar, P., & Rangajanardhana, g. (2019). Numerical and experimental validation of chip morphology. International journal of advanced research in engineering & technology, 10(2). https://doi.org/10.34218/ijaret.10.2.2019.049

Sharma, V. S., Dhiman, S., Sehgal, R., & Sharma, S. K. (2008). Estimation of cutting forces and surface roughness for hard turning using neural networks. Journal of Intelligent Manufacturing, 19(4), 473-483

Sousa, V. F., & Silva, F. J. (2020). Recent advances in turning processes using coated tools A comprehensive review. *Metals*, *10*(2), 170.

Sundaram, D. (2018). The Effect of Solidification time and Cooling rate on the Ultimate tensile Strength of Grey Cast Iron.

Tang, L., Sun, Y., Li, B., Shen, J., & Meng, G. (2019). Wear performance and mechanisms of PCBN tool in dry hard turning of AISI D2 hardened steel. *Tribology International*, *132*, 228-236.

T. Uchimoto, T. Takagi, T. Abe,(2010), Electromagnetic nondestructive evaluation of graphite structures in flake graphite cast iron, Materials Transactions, 51 1114-1119

Thiele Jr, E. W., Kundig, K. J., Murphy, D. W., Soloway, G., & Duffin, B. (1999). Comparative machinability of brasses, steels, and aluminum alloys: CDA's universal machinability index. SAE transactions, 362-371.

Trent, E. M., & Wright, P. K. (2000). *Metal cutting*. Butterworth-Heinemann.

Venkatasubramanian, T. V., & Baker, T. J. (1998). Fracture toughness of flake graphite cast iron. Metals Technology, 5(1), 57–61. https://doi.org/10.1179/mt.1978.5.1.57

Vorburger, T.V., J.Raja. (2000). Surface finish Metrology. Michigan Technological University, Volume 3, Issue 10, pp57-67.

Yashaswi A. (2014). Optimization of machining parameters in a turning operation of austenitic stainless steel to minimize surface roughness and tool wear. Journal of Manufacturing Science and Engineering, 130(1).

Yadav, R. N. (2017). A hybrid approach of Taguchi-Response Surface Methodology for modeling and optimization of Duplex Turning process. Measurement, 100, 131–138. https://doi.org/10.1016/j.measurement.2016.12.060

Zompi, A., Levi, R. and Ravignani, G.L. (2000) Multi-tool machining analysis, part 1: tool failure patterns and implications. ASME Journal of Engineering for Industry. 101: 230

Zhu, D., Zhang, X., & Ding, H. (2013). Tool wear characteristics in the machining of nickel-based superalloys. *International Journal of Machine Tools and Manufacture*, *64*, 60-77.236.

APPENDIX

Journal of Manufacturing Processes

Comparative study on the Advantages of Double Tool Turning than Single During Conventional Turning

--Manuscript Draft--

Manuscript Number:	
Article Type:	Full Length Article
Keywords:	machining; surface finish; temperature; optimization
Corresponding Author:	Moera Gutu, Phd Adama Science and Technology University ETHIOPIA
First Author:	Moera Gutu, Phd
Order of Authors:	Moera Gutu, Phd
	Kalkjidan Buzune
	Raga Silash
Abstract:	The effect of cutting speed, feed, and depth of cut on surface quality of a machined component were investigated. The impact of those cutting parameters resulted in increasing temperature, tool wear, and material removal rate. As a result of which surface roughness was investigated for different cutting parameters such as cutting speed (50, 70, 90) m/min, feed of (0.3, 0.525, 0.75) mm/rev, and depth of cut (0.3, 0.675, 1) mm for single tool turning while for double tool turning depth of cut (d1 = 0.5, 0.75, 1, d2 = 0.75, 1, 1.25) mm to improve productivity using this new machining technology. The cutting parameters were optimized by turning process using the response surface methodology method. The surface roughness was selected as a response variable and the workpiece was estimated by using a surface roughness Profilometer. The Box-Behnken design approach was incorporated to formulate the experiments and rigorous experimental analysis was performed. Analysis of variance (ANOVA) determined the influences of cutting parameters on the surface roughness. The results of variance presented that the influence of cutting speed, feed, and depth of cut were 67.68%, 21.65%, and 1.60% for double tool turning whereas for single tool turning 51.33%, 22.58%, and 6.93% respectively. The high surface finish attained at optimum cutting parameters (86.76 m/min, 0.3 mm/rev, and 1.79 mm) was 1.04 μm for double tool turning while for single tool turning was 1.11μm. (90 m/min, 0.3 mm/rev and 0.409 mm). For the selected cutting parameters in experimental results were observed that the material removal rate was increased by 55% during double tool turning than single tool turning.
Suggested Reviewers:	
Opposed Reviewers:	

Box-Behnken Design

Design Summary

Factors:	3	Replicates:	1
Base runs:	15	Total runs:	15
Base blocks:	1	Total blocks:	1

Center points: 3

Design Table (randomized)

Run	Blk	A	B	C
1	1	-1	0	-1
2	1	-1	1	0
3	1	0	0	0
4	1	0	1	-1
5	1	0	1	1
6	1	1	0	1
7	1	-1	-1	0
8	1	-1	0	1
9	1	0	-1	-1
10	1	1	-1	0
11	1	0	-1	1
12	1	0	0	0
13	1	1	1	0
14	1	1	0	-1
15	1	0	0	0

For Single Tool Turning

Response Surface Regression: Ra versus Vc, B, C

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.891918	98.87%	0.891918	0.099102	48.70	0.000
Linear	3	0.820275	90.93%	0.820275	0.273425	134.36	0.000
Vc	1	0.610513	67.68%	0.610513	0.610513	300.01	0.000
B	1	0.195312	21.65%	0.195312	0.195312	95.98	0.000
C	1	0.014450	1.60%	0.014450	0.014450	7.10	0.045
Square	3	0.008618	0.96%	0.008618	0.002873	1.41	0.343
Vc*Vc	1	0.001920	0.21%	0.001298	0.001298	0.64	0.461
B*B	1	0.006000	0.67%	0.006283	0.006283	3.09	0.139
C*C	1	0.000698	0.08%	0.000698	0.000698	0.34	0.584
2-Way Interaction	3	0.063025	6.99%	0.063025	0.021008	10.32	0.014
Vc*B	1	0.038025	4.22%	0.038025	0.038025	18.69	0.008
Vc*C	1	0.016900	1.87%	0.016900	0.016900	8.30	0.035
B*C	1	0.008100	0.90%	0.008100	0.008100	3.98	0.103
Error	5	0.010175	1.13%	0.010175	0.002035		
Lack-of-Fit	3	0.010175	1.13%	0.010175	0.003392		0.013
Pure Error	2	0.000000	0.00%	0.000000	0.000000		
Total	14	0.902093	100.00%				

Response Optimization: Ra

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Target	0.999	1.11	2.01	1	1

Starting Values

Variable	Setting
Vc	50
B	0.3
C	0.35

Solution

Solution	Vc	B	C	Ra Fit	Composite Desirability
1	90	0.3	0.409091	1.11830	0.990783

Multiple Response Prediction

Variable	Setting
Vc	90
B	0.3
C	0.409091

Response	Fit	SE Fit	95% CI	95% PI
Ra	1.1183	0.0478	(0.9954, 1.2411)	(0.9494, 1.2872)

For Double Tool Turning

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.929083	99.30%	0.929083	0.103231	79.21	0.000
Linear	3	0.756250	80.83%	0.756250	0.252083	193.41	0.000
Vc	1	0.480200	51.33%	0.480200	0.480200	368.44	0.000
f	1	0.211250	22.58%	0.211250	0.211250	162.08	0.000
d	1	0.064800	6.93%	0.064800	0.064800	49.72	0.001
Square	3	0.043433	4.64%	0.043433	0.014478	11.11	0.012
Vc*Vc	1	0.000107	0.01%	0.000003	0.000003	0.00	0.966
f*f	1	0.007016	0.75%	0.004741	0.004741	3.64	0.115
d*d	1	0.036310	3.88%	0.036310	0.036310	27.86	0.003
2-Way Interaction	3	0.129400	13.83%	0.129400	0.043133	33.09	0.001
Vc*f	1	0.008100	0.87%	0.008100	0.008100	6.21	0.055
Vc*d	1	0.048400	5.17%	0.048400	0.048400	37.14	0.002
f*d	1	0.072900	7.79%	0.072900	0.072900	55.93	0.001
Error	5	0.006517	0.70%	0.006517	0.001303		
Lack-of-Fit	3	0.006450	0.69%	0.006450	0.002150		0.015
Pure Error	2	0.000067	0.01%	0.000067	0.000033		
Total	14	0.935600	100.00%				

Fits and Diagnostics for All Observations

Obs	Ra	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	2.0000	1.9600	0.0313	(1.8796, 2.0404)	0.0400	2.22	14.81	0.750000
2	1.4200	1.4167	0.0208	(1.3631, 1.4702)	0.0033	0.11	0.10	0.333333
3	1.4200	1.4167	0.0208	(1.3631, 1.4702)	0.0033	0.11	0.10	0.333333
4	1.7100	1.6875	0.0313	(1.6071, 1.7679)	0.0225	1.25	1.34	0.750000
5	1.1100	1.0925	0.0313	(1.0121, 1.1729)	0.0175	0.97	0.96	0.750000
6	1.2500	1.2500	0.0313	(1.1696, 1.3304)	0.0000	0.00	0.00	0.750000
7	1.5600	1.5600	0.0313	(1.4796, 1.6404)	0.0000	0.00	0.00	0.750000
8	1.2700	1.2525	0.0313	(1.1721, 1.3329)	0.0175	0.97	0.96	0.750000
9	1.2500	1.2900	0.0313	(1.2096, 1.3704)	-0.0400	-2.22	-14.81	0.750000
10	1.0400	1.0175	0.0313	(0.9371, 1.0979)	0.0225	1.25	1.34	0.750000
11	1.5800	1.5975	0.0313	(1.5171, 1.6779)	-0.0175	-0.97	-0.96	0.750000
12	1.5200	1.5425	0.0313	(1.4621, 1.6229)	-0.0225	-1.25	-1.34	0.750000
13	1.4000	1.4175	0.0313	(1.3371, 1.4979)	-0.0175	-0.97	-0.96	0.750000
14	1.4100	1.4167	0.0208	(1.3631, 1.4702)	-0.0067	-0.23	-0.20	0.333333
15	1.8100	1.8325	0.0313	(1.7521, 1.9129)	-0.0225	-1.25	-1.34	0.750000

Response Optimization: Ra

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Target	0.936	1.04	2	1	1

Starting Values

Variable	Setting
Vc	50
f	0.3
d	1.25

Solution

Solution	Vc	f	d	Ra Fit	Composite Desirability
1	86.7677	0.3	1.79071	1.03992	0.999210

Multiple Response Prediction

Variable	Setting
Vc	86.7677
f	0.3
d	1.79071

Response	Fit	SE Fit	95% CI	95% PI
Ra	1.0399	0.0277	(0.9686, 1.1112)	(0.9229, 1.1569)

Multiple Response Prediction for Material removal rate for single tool turning

Response Surface Regression: MRR versus Vc, f, d

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	739844	99.43%	739844	82205	96.43	0.000
Linear	3	668637	89.86%	668637	222879	261.44	0.000
Vc	1	144605	19.43%	144605	144605	169.63	0.000
f	1	207025	27.82%	207025	207025	242.85	0.000
d	1	317007	42.60%	317007	317007	371.86	0.000
Square	3	2738	0.37%	2738	913	1.07	0.440
Vc*Vc	1	860	0.12%	848	848	0.99	0.364
f*f	1	992	0.13%	848	848	0.99	0.364
d*d	1	886	0.12%	886	886	1.04	0.355
2-Way Interaction	3	68469	9.20%	68469	22823	26.77	0.002
Vc*f	1	26417	3.55%	26417	26417	30.99	0.003
Vc*d	1	12939	1.74%	12939	12939	15.18	0.011
f*d	1	29113	3.91%	29113	29113	34.15	0.002
Error	5	4262	0.57%	4262	852		
Lack-of-Fit	3	4262	0.57%	4262	1421		0.000
Pure Error	2	1	0.00%	1	0		
Total	14	744106	100.00%				

Fits and Diagnostics for All Observations

Obs	MRR	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI	Cook's D
1	153.1	136.8	25.3	(71.8, 201.8)	16.3	1.12	1.15	0.750000	0.37
2	295.3	328.0	25.3	(263.0, 393.0)	-32.6	-2.24	-158.80	0.750000	1.50
3	412.4	413.1	16.9	(369.8, 456.4)	-0.7	-0.03	-0.03	0.333333	0.00
4	306.3	289.9	25.3	(224.9, 354.9)	16.3	1.12	1.15	0.750000	0.37
5	875.0	858.7	25.3	(793.7, 923.7)	16.3	1.12	1.15	0.750000	0.37
6	787.5	803.8	25.3	(738.8, 868.8)	-16.3	-1.12	-1.15	0.750000	0.37
7	168.8	168.7	25.3	(103.8, 233.7)	0.0	0.00	0.00	0.750000	0.00
8	437.5	421.2	25.3	(356.2, 486.2)	16.3	1.12	1.15	0.750000	0.37
9	122.5	138.8	25.3	(73.8, 203.8)	-16.3	-1.12	-1.15	0.750000	0.37
10	307.8	275.1	25.3	(210.1, 340.1)	32.6	2.24	158.80	0.750000	1.50
11	350.0	366.3	25.3	(301.3, 431.3)	-16.3	-1.12	-1.15	0.750000	0.37
12	413.4	413.1	16.9	(369.8, 456.4)	0.3	0.01	0.01	0.333333	0.00
13	759.4	759.4	25.3	(694.4, 824.4)	-0.0	-0.00	-0.00	0.750000	0.00
14	275.6	291.9	25.3	(226.9, 356.9)	-16.3	-1.12	-1.15	0.750000	0.37
15	413.4	413.1	16.9	(369.8, 456.4)	0.3	0.01	0.01	0.333333	0.00

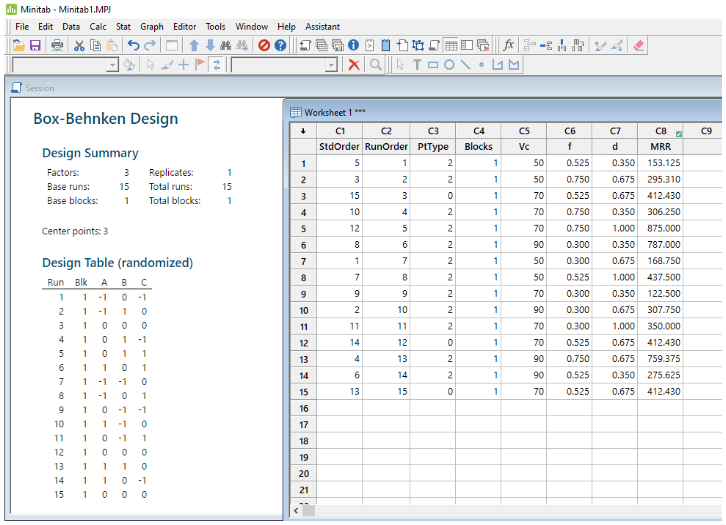
Response Optimization: MRR

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Target	122.5	157.5	875	1	1

Starting Values

Variable	Setting
Vc	50
f	0.3
d	0.35



Minitab - Minitab1.MPJ

File Edit Data Calc Stat Graph Editor Tools Window Help Assistant

Session

Box-Behnken Design

Design Summary

Factors:	3	Replicates:	1
Base runs:	15	Total runs:	15
Base blocks:	1	Total blocks:	1

Center points: 3

Design Table (randomized)

Run	Blk	A	B	C
1	1	-1	0	-1
2	1	-1	1	0
3	1	0	0	0
4	1	0	1	-1
5	1	0	1	1
6	1	1	0	1
7	1	-1	-1	0
8	1	-1	0	1
9	1	0	-1	-1
10	1	1	-1	0
11	1	0	-1	1
12	1	0	0	0
13	1	1	1	0
14	1	1	0	-1
15	1	0	0	0

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	StdOrder	RunOrder	PtType	Blocks	Vc	f	d	MRR	
1	5	1	2	1	50	0.525	0.350	153.125	
2	3	2	2	1	50	0.750	0.675	295.310	
3	15	3	0	1	70	0.525	0.675	412.430	
4	10	4	2	1	70	0.750	0.350	306.250	
5	12	5	2	1	70	0.750	1.000	875.000	
6	8	6	2	1	90	0.300	0.350	787.000	
7	1	7	2	1	50	0.300	0.675	168.750	
8	7	8	2	1	50	0.525	1.000	437.500	
9	9	9	2	1	70	0.300	0.350	122.500	
10	2	10	2	1	90	0.300	0.675	307.750	
11	11	11	2	1	70	0.300	1.000	350.000	
12	14	12	0	1	70	0.525	0.675	412.430	
13	4	13	2	1	90	0.750	0.675	759.375	
14	6	14	2	1	90	0.525	0.350	275.625	
15	13	15	0	1	70	0.525	0.675	412.430	
16									
17									
18									
19									
20									
21									

Material removal rate for double tool turning

Response Surface Regression: MRR versus Vc, f, d

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	4757896	99.83%	4757896	528655	325.53	0.000
Linear	3	3334968	69.97%	3334968	1111656	684.52	0.000
Vc	1	832271	17.46%	832271	832271	512.48	0.000
f	1	618862	12.98%	618862	618862	381.07	0.000
d	1	1883836	39.53%	1883836	1883836	1160.00	0.000
Square	3	428165	8.98%	428165	142722	87.88	0.000
Vc*Vc	1	17262	0.36%	4500	4500	2.77	0.157
f*f	1	67537	1.42%	92528	92528	56.98	0.001
d*d	1	343365	7.20%	343365	343365	211.43	0.000
2-Way Interaction	3	994763	20.87%	994763	331588	204.18	0.000
Vc*f	1	236167	4.96%	236167	236167	145.42	0.000
Vc*d	1	294495	6.18%	294495	294495	181.34	0.000
f*d	1	464102	9.74%	464102	464102	285.78	0.000
Error	5	8120	0.17%	8120	1624		
Lack-of-Fit	3	7717	0.16%	7717	2572		0.073
Pure Error	2	403	0.01%	403	201		
Total	14	4766016	100.00%				