EXPERIMENTAL STUDIES AND OPTIMIZATION OF PROCESS PARAMETERS IN FACE MILLING USING RESPONSE SURFACE METHOD.

Thesis submitted in partial fulfilment of the requirement for the award of the degree of

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Submitted by

TAPAS DAS

Class Roll No. 002111202030

Exam Roll No. M4MEC23012

Under the guidance of

Prof. ABHISHEK MANDAL

Prof. DIPANJAN SAREN

DEPARTMENT OF MECHANICAL ENGINEERING

JADAVPUR UNIVERSITY

KOLKATA-700032, INDIA 2023

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

CERTIFICATE OF RECOMMENDATION`

This is to certify that **Mr. TAPAS DAS** has completed his thesis entitled "**EXPERIMENTAL STUDIES AND OPTIMIZATION OF PROCESS PARAMETERS IN FACE MILLING USING RESPONSE SURFACE METHOD**", under the supervision and guidance of **ABHISHEK MANDAL, DIPANJAN SAREN**, Jadavpur University, Kolkata. We are satisfied with his work, which is being presented for the partial fulfilment of the degree of Master of Mechanical Engineering, Jadavpur University, Kolkata-700032.

____

Prof. Abhishek Mandal
Thesis Advisor
Assistant Professor
Dept. of Mechanical Engineering
Jadavpur University, Kolkata-700032

____

Prof. Dipanjan Saren
Thesis Advisor
Assistant professor
Dept. of Mechanical Engineering
Jadavpur University, Kolkata-700032

____

HEAD, Dept. of Mechanical Engineering
Jadavpur University, Kolkata-700032

____

DEAN, Faculty of Engineering and Technology
Jadavpur University, Kolkata-700032

JADAVPUR UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY

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Tapas Das

Class Roll No. 002111202030

Exam Roll No. M4MEC23012

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CONCLUSION AND FUTURE SCOPE

List of Abbreviation

OVAT	One Variable at a Time
C.F.	Cutting force
Fx	Normal force
Fy	Feed force
Fz	Axial force
S.R.	Surface roughness
ap	Width of cut
ae	Depth of cut
f	Feed
Vc	Cutting speed
n	Spindle speed
WoC	Width of cut
DoC	Depth of cut
C.S.	Cutting speed
RPM	Revolution per minute
Ra	Avg. surface roughness
R_{rms}	Root means square surface roughness
CCD	Central composite design

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ABSTRACT

This thesis investigates the cutting forces and surface roughness in the face milling operation on Al6063 using a carbide tool. The effects of cutting parameters (cutting speed, feed rate, and depth of cut) on cutting forces and surface roughness are examined. The experiments are conducted on a horizontal milling machine with a carbide side and face milling cutter. Unlike traditional choices such as HSS tools or PCD tools, carbide, which are primarily designed for machining metals and alloys, are utilized in this study. In this experiment force measurement is done by Kistler tool dynamometer and surface roughness is measured by measured using a stylus-type profilometer called Talysurf. The results show that increasing cutting speed initially leads to an increase in cutting forces, but after a certain point, the forces start to decrease due to reduced tool workpiece interaction and workpiece softening caused by elevated temperatures. Higher feed rates and depth of cut result in increased cutting forces. Regarding surface roughness, an increase in cutting speed generally results in decreased roughness, indicating a smoother surface finish. However, an increase in feed rate and depth of cut shows an inverse relationship with surface roughness, leading to increased roughness values. The findings emphasize the importance of selecting appropriate cutting parameters to optimize cutting forces and surface roughness in face milling of Al6063. The use of carbide tools provides insights into their performance in machining AL6063. Future research can explore advanced tool materials or coatings to further improve the machining process and surface quality of Al6063.

CHAPTER 1:

INTRODUCTION

The field of machining processes has witnessed significant advancements in recent years, driven by the ever-increasing demand for superior machining performance and improved product quality. Among various machining operations, face milling holds immense significance in the manufacturing industry, as it enables the removal of large amounts of material from a workpiece to achieve the desired shape and surface finish. In the context of face milling, understanding the cutting forces and surface roughness becomes crucial for optimizing machining parameters and ensuring the desired product quality.

This thesis aims to investigate the cutting forces and surface roughness in the face milling (down milling) operation of two distinct materials: Al6063 alloy and magnesium and silicon as the alloying elements. The utilization of these materials is prevalent in various industrial sectors due to their desirable properties, such as lightweight, high strength-to-weight ratio, thermal conductivity, and wear resistance. The choice of carbide tool as the cutting tool further adds simplicity to the machining process due to its unique characteristics.

The primary objective of this research is to explore the relationship between cutting forces and surface roughness in the face milling operation of Al6063 alloy and magnesium and silicon as the alloying elements Al6063, with specific emphasis on down milling. The investigation will involve comprehensive experimental studies, where a range of machining parameters, including cutting speed, feed rate, and depth of cut, will be systematically varied to observe their effects on cutting forces and surface roughness.

The collected data will be analyzed and interpreted to identify the key factors influencing the machining performance and surface quality. The outcomes of this research will provide valuable insights into the machining behaviour of Al alloy and magnesium and silicon as the alloying elements Al6063 in face milling operations, thereby aiding in the optimization of machining parameters for enhanced productivity and quality.

Furthermore, the findings will contribute to the existing body of knowledge concerning the application of Carbide tools in the machining of these materials. this thesis seeks to bridge the gap in understanding the relationship between cutting forces, surface roughness, and machining parameters in the face milling operation of Al alloy and magnesium and silicon as the alloying elements Al6063. The research findings will benefit manufacturing industries, particularly those involved in the production of components using these materials, by facilitating the development of efficient machining strategies and improving overall product quality.

Table 1.1 Chemical composition of Al6063

Constituent element	**Minimum** (% by weight)	**Maximum** (% by weight)
Aluminium (Al)	97.5%	99.35%
Magnesium (Mg)	0.45%	0.90%
Silicon (Si)	0.20%	0.60%
Iron (Fe)	0	00.35%
Chromium (Cr)	0	00.10%
Copper (Cu)	0	00.10%
Manganese (Mn)	0	00.10%
Titanium (Ti)		00.10%
Zinc (Zn)		00.10%
others		00.15%

1.1 Composite and AA 6063

1.1.1 composite

Composites are materials that consist of two or more distinct components that are combined to create a new material with unique properties. The components can be any combination of materials, but are typically composed of a matrix material and a reinforcement material. The matrix material serves as a bonding agent that holds the reinforcement material together, while the reinforcement material a provides additional strength, stiffness, and other desirable properties to the composite material.[1]

1.1.2 How to make composite?

Composite materials are typically made by combining two or more different materials to create a new material with improved properties. The basic process for making a composite material involves the following steps:

1. Material Selection: The first step in making a composite material is to select the materials that will be combined to create the composite. The materials can be of different types, such as fibres, matrix materials, and additives, and are selected based on their properties, such as strength, stiffness, toughness, weight, and cost.
2. Preparation: The next step is to prepare the materials for the manufacturing process. The Fibers, which provide the strength and stiffness, may need to be cut or chopped to the desired length, while the matrix material, which binds the fibres together, may need to be

liquefied or dissolved to a specific viscosity. Additives, such as pigments or flame retardants, may also be mixed in at this stage.

3. Mixing: The prepared materials are then mixed together to create a uniform blend. The mixing process can vary depending on the materials being used and the desired properties of the final composite. For example, for Fiber-reinforced composites, the Fibers are typically mixed with the matrix material to create a resin system that wets out the Fibers.
4. Molding: Once the composite material has been mixed, it is molded into the desired shape. There are several different molding techniques that can be used, such as compression molding, injection molding, and filament winding, depending on the properties and geometry of the final composite. In compression molding, the material is placed in a mold and heated and compressed to create the desired shape. In injection molding, the material is injected into a mold under high pressure. In filament winding, fibers are wound around a mandrel in a specific pattern to create a hollow structure.
5. Curing: After molding, the composite material is cured to harden the material and create the desired properties. Curing can be done through a variety of methods, such as heat, pressure, or chemical reactions, depending on the materials being used and the desired properties of the final composite. The curing process may also involve post-curing, which can further improve the mechanical properties of the composite.
6. Finishing: Finally, the composite material may be finished with surface treatments, coatings, or other enhancements to further improve its properties and appearance. For example, the surface of the composite may be polished or painted, or a protective coating may be applied to improve durability and resistance to damage.

   the process for making a composite material can be complex and involves several different steps, each of which is critical to creating a final product with the desired properties. The specific process used will depend on the materials being used, the desired properties of the final product, and the intended application of the composite material

1.1.3 Types of Composites

There are several types of composites, each with their own unique properties and applications. Here are some common types of composites:

1. Metal Matrix Composites (MMCs): MMCs consist of a metal matrix reinforced with fibers or particles of materials such as ceramic or carbon. They are strong, stiff, and have good thermal conductivity, making them useful for high-temperature applications such as automotive and aerospace.

2. Polymer Matrix Composites (PMCs): PMCs are the most widely used type of composite, and consist of a polymer matrix reinforced with fibers such as carbon, glass, or aramid. They are lightweight, strong, and have good resistance to corrosion and fatigue. PMCs are used in a wide range of applications, including aerospace, automotive, and sports equipment.
3. Ceramic Matrix Composites (CMCs): CMCs consist of a ceramic matrix reinforced with fibers such as carbon or ceramic. They are lightweight, strong, and have good resistance to high temperatures and wear. CMCs are used in applications such as aerospace, defense, and energy.
4. Natural Fiber Composites (NFCs): NFCs are composites made from natural fibers such as bamboo, hemp, or flax, and a polymer matrix. They are biodegradable, renewable, and have a low carbon footprint, making them a sustainable alternative to traditional composites. NFCs are used in applications such as furniture, construction, and automotive.
5. Sandwich Composites: Sandwich composites consist of a lightweight core material sandwiched between two face sheets made of materials such as aluminum or carbon fiber. They are lightweight, stiff, and have good resistance to impact and fatigue. Sandwich composites are used in applications such as marine, aerospace, and wind energy.

1.1.4 Advantages and Disadvantages of Composite

Advantages

1. High Strength to Weight Ratio: Composite materials are made by combining two or more materials with different properties to create a new material that has improved properties. For example, carbon fiber reinforced polymer (CFRP) composites are made by combining carbon fiber and a polymer resin. The resulting material has a much higher strength-to-weight ratio than either carbon fiber or polymer resin alone. This makes it ideal for use in lightweight structures that require high strength, such as aircraft components, sports equipment, and racing cars.
2. Corrosion Resistance: Composite materials are highly resistant to corrosion because they do not contain metal. Metals can corrode when they come into contact with moisture and oxygen in the air, but composites do not have this problem. This makes them ideal for use in marine and offshore applications, as well as in corrosive industrial environments.
3. Design Flexibility: Composite materials offer designers a high degree of flexibility in terms of shaping and forming. They can be molded into complex shapes and structures using a variety of manufacturing techniques, such as filament winding, pultrusion, and resin

infusion. This allows designers to create components that are both lightweight and strong, while also being aerodynamic and aesthetically pleasing.

4. Fatigue Resistance: Composite materials have excellent fatigue resistance because they are made up of multiple layers or plies of material. Each layer is oriented in a different direction, which helps to distribute stress evenly throughout the material. This makes it much more resistant to fatigue than traditional materials like metals, which tend to fail after repeated stress cycles.
5. Thermal Resistance: Composite materials have excellent thermal resistance because they are made up of materials that have different thermal expansion coefficients. This means that they do not expand or contract as much as metals when exposed to high temperatures. This makes them ideal for use in hightemperature applications such as engine components, exhaust systems, and industrial machinery.

composite materials offer a range of advantages that make them ideal for a wide variety of applications. Their high strength-to-weight ratio, corrosion resistance, design flexibility, fatigue resistance, and thermal resistance make them an attractive alternative to traditional materials in many industries.

Disadvantages

While composite materials offer a number of advantages, there are also some disadvantages to consider. Here are some of the main disadvantages of composite materials:

1. Cost: Composite materials can be more expensive than traditional materials such as metals and wood. The manufacturing process for composites can be complex and require specialized equipment and techniques, which can drive up the cost of production.
2. Brittle: While composites are generally strong, they can be brittle and prone to cracking or breaking under impact or other high-stress conditions. This can make them less suitable for applications where impact resistance is critical.
3. Environmental Impact: The production of composite materials can have a negative environmental impact. The use of resins and other chemicals can release harmful pollutants into the air and water, and the disposal of composite waste can also be a challenge.
4. Limited Repairability: Unlike traditional materials such as wood or metals, composite materials can be difficult to repair if they become damaged. Repairs often require specialized skills and equipment, which can be expensive.

5. Susceptibility to UV Light: Some composite materials can be susceptible to damage from UV light. This can cause them to degrade and become discolored over time, particularly when exposed to sunlight or other sources of UV radiation.

Overall, while composite materials offer many advantages, there are also some limitations to consider. The cost of production, brittleness, environmental impact, limited repairability, and susceptibility to UV light are all factors that need to be taken into account when considering the use of composites in different applications.

1.1.5 Aluminium Alloy Al-6063

Al-6063 contains magnesium and silicon as the main alloying elements. The composition standardization of the alloys is maintained by The Aluminium Association. Al-6063 possesses good mechanical properties and is heat treatable and weldable. Table 1 details the chemical composition of the selected material. This alloy is most commonly used for extrusions as complex shapes can be formed much easily. Few applications include window frames, door frames, roofs, and sign frames. The extensive use of the material in architectural applications elicited the idea of performing a study on providing a suitable solution for the machining of Al-6063 with the least effect on the environment, irrespective of demand. For this study, a circular work material of dimensions 50 mm × 25 mm is taken for machining. Based on the literature survey, the TiCN end mill cutter is taken as the cutting tool material with a Rockwell hardness of 88. The cutter selected is of 25 mm diameter with a total length of 74 mm. To avoid the effect of vibration and chatter while machining, an overhung length of 25 mm is maintained throughout the process.

1.2 Milling machine

1.2.1 Milling machine

Milling is a machining operation that involves the removal of metal through the use of a rotating milling cutter. A milling machine is a machine tool that cuts metal which is fed against a rotating multipoint cutting tool. The workpiece is commonly held in a vice or similar device clamped to a table that can move in three perpendicular directions. The multiple cutting edges of cutting tool revolve with high speed and eliminate metal at a very fast rate. As a result, one of the most significant machines in the workshop is the milling machine. All operations can be carried out with excellent precision with milling machine [7].

In milling machine, the workpiece is rigidly clamped on the table of machine and revolving multi-tooth cutter is positioned and clamped along the spindle axis. The cutter revolves at a normal speed and the workpiece is fed through it slowly. The work can be fed in three directions: longitudinal, vertical and cross direction. The cutter teeth remove the metal from the work surface, resulting in the required shape.

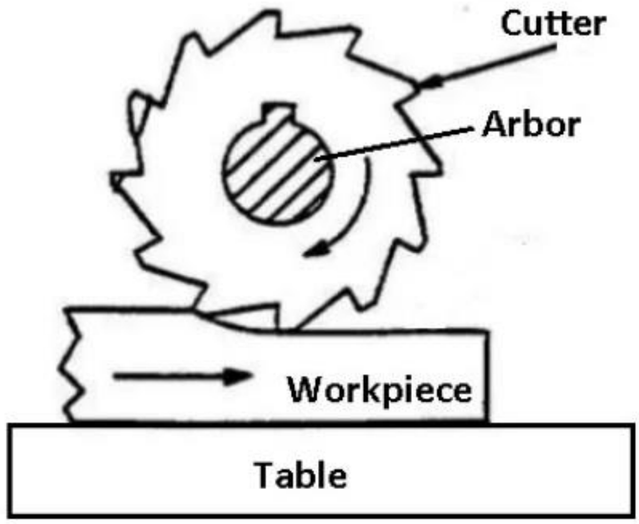

Figure 1.1 Principle of milling machine

Following are the different types of milling machines:

The column and knee milling machine is the most common form of milling machine for general shop operations. The table is supported by the knee-casting, which is in turn supported by the main column's vertical slides. The column's knee is vertically movable, allowing the table to be adjusted up and down to accommodate work of varying heights. The construction of fixed bed type is massive, heavy, and inflexible. The construction of the table mounting distinguishes these milling machines from column and knee milling machines. The table is directly attached to the ways of a fixed bed. There are no provisions for transverse or vertical adjustment; therefore, the table can only reciprocate at a right angle to the spindle axis. It is categorized as simplex, duplex, or triplex depending on whether the machine has a single, double, or triple spindle head. Planer type milling machine is also known as a "Plano-Miller." It is a huge machine with vertical and transversely movable spindle heads that is utilized for heavy-duty tasks. It resembles a planer and works similarly to a planning machine. The cutters are carried by a cross rail that may be raised or lowered on this equipment. The saddles and their heads are all supported by rigid uprights. This configuration of many cutter spindles allows for the machining of a variety of work surfaces. As a result, it achieves a significant reduction in production time. Milling machines with non-conventional designs have been created for specific applications. This machine contains a spindle that rotates the cutter and allows the tool to be moved in multiple directions. In milling machine, numerical Control technology was developed in the mid-twentieth century. The functioning of the machine tool is controlled by the NC control system through the use of specially coded instructions (combination of alphabet, digit and symbols). NC systems are integrated and permanently hooked into the control unit and perform a predetermined logical purpose. Around 1972, a real boom occurred with the introduction of CNC. Modern CNC systems use a specialized microprocessor with memory registers that store a variety of routings capable of manipulating logical functions. Due to this adaptability, it enables such widespread adoption of technology in contemporary industry. CNC stands for computer numerical control, a computer-assisted procedure for controlling general-purpose machines using instructions generated by a processor and stored in a memory system. The main advantages of CNC machines are following that high repeatability, precision, high volume production and the ability to produce complex contours/surfaces, job change flexibility, automatic tool settings, less scrap, increased safety, reduced paper work, faster prototype production and reduced lead times. As a result, it is utilized in a variety of applications including aircraft and automobile components, dies and molds, pipe and shaft manufacturing, turbine and pump manufacture and so on. Additionally, there are certain disadvantages such as high setup costs, professional operators, computers and required programming skills as well as onerous maintenance. In industry, a variety of CNC machines are utilized, the most common of which being CNC machining centers, vertical machining centers (VMCs) and CNC lathes. Milling is a widely used procedure in the die and mold business. Milling has evolved as a process with new automated machinery and processes being used to continuously produce the highest quality product. The workpiece is stationary while the tool rotates during the CNC milling process. The rotating tool with several cutting blades works over the workpiece to create a plane or straight surface throughout this machining operation. Milling tools have also evolved significantly from uncoated high-speed steel tools to the widely used coated tools, owing to the increased tool life.

1.2.2 Types of milling process

Milling process has basically broad classification. The milling process performed may be grouped under following separate headings

1. Peripheral milling
2. Face milling
3. End milling

Peripheral Milling

It is a milling cutter operation that produces a machined surface parallel to the cutter's axis of rotation. Peripheral milling is classified as;

1. Up milling
2. Down milling

Up milling

When the feed direction of the cutting end mill tool is against the direction of rotation of the end mill tool at the point of engagement, this is referred to as up milling, as illustrated in figure 1.2. Up milling causes the chip load on teeth to progressively grow from zero to maximum at the point of contact. At the start of tool-workpiece engagement, teeth rub against the workpiece's surface resulted in improving the surface finish. Tool contact with the workpiece during engagement may result in unwanted work hardening as a result of the high temperature generated. Machining by up milling may result in distortion due to the upward cutting force if the workpiece has a thin cross section. The contact point generates considerable heat as a result of the progressive accumulation of chip load during up milling.

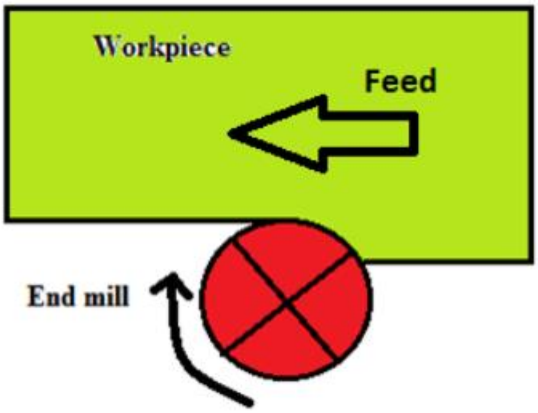

Figure 1.2 Up milling

Down milling

When the feed direction of the cutting end mill tool is parallel to the cutter rotation direction at the point of disengagement, this is referred to as down milling, as seen in figure 1.3. Down milling gradually reduces the chip load on teeth from maximum to zero at the point of contact. Because there is little contact between the tool and the workpiece during engagement, there is less risk of work hardening. There is little danger of distortion during down milling a workpiece with a thin cross section. Additionally, there is less probability of heat development at the contact site in down milling than in up milling. Although the tendency for chip welding is reduced in down milling, chip re-deposition on the completed surface occurs frequently. In general, down milling is suited for a wide variety of metal processing operations due to its low deflection and high surface polish.

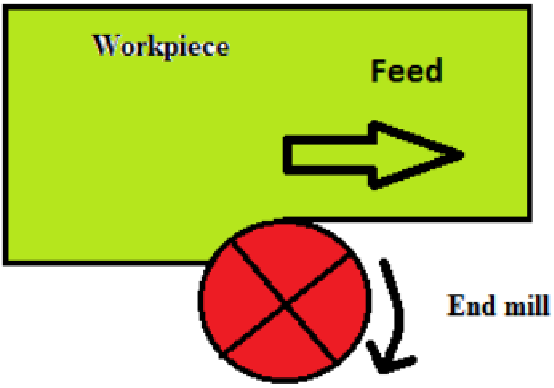

Figure 1.3 Down milling

Face Milling

A milling cutter performs this procedure to generate a flat-machined surface perpendicular to the rotation axis of the cutter. The peripheral cutting edges of cutter do the real cutting, while the face cutting edges conclude the job by removing a little quantity of metal from the work area. End Milling End milling is the combination of peripheral and face milling. The end milling is the operation of producing a flat surface which may be vertical, horizontal or at an angle in reference to the table surface. The end mill operation is shown in figure 1.4. The end milling cutters are also used for the production of slots, grooves or keyways. A vertical milling machine is more suitable for end milling operation.

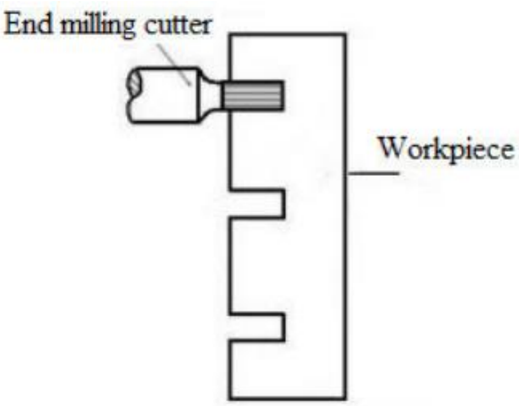

Figure 1.4 End milling operation

1.2.3 Milling Machine Operations

Milling is a machining technique that involves advancing a cutter into a workpiece and removing material with rotary cutters. This can be accomplished by adjusting the direction of one or more axes as well as the cutter head speed and pressure. Milling encompasses a wide range of procedures and machinery from small individual pieces to large -scale gang milling operations. The various types of milling machine operations are as follow: Plain milling operation, face milling operation, side milling operation, straddle milling operation, angular milling operation, gang milling operation, form milling operation, profile milling operation, end milling operation, saw milling operation, milling keyways,grooves and slot, gear milling, helical milling, cam milling and thread milling.

1.2.4 Specific terms in milling process:

As shown in figure 1.5, various specific terms are discussed in following:

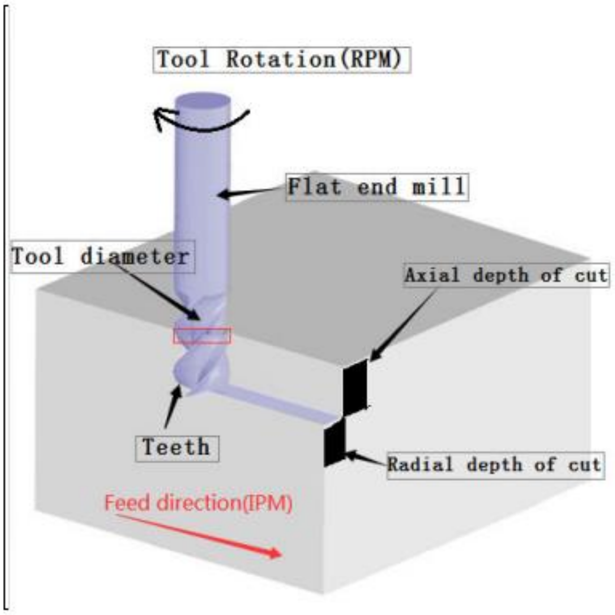

Figure 1.5 Specific terms in end mill

Cutting speed, V_c: It indicates the surface speed at which the cutting edge of cutting tool machines the workpiece.

$$V_c = \frac{\pi . D_c . n}{1000} \text{ m/min}$$

Where Dc is cutting diameter at cutting depth and n is spindle speed

Feed, V_f: It is the feed of the tool in relation to the workpiece in distance per unit time related to feed per tooth and number of teeth in the cutter.

$$f_z = \frac{V_f}{n.Z_c}$$

Where n is spindle speed, Zc is number of effective teeth and fz is feed per tooth.

Depth of cut: The depth of cut is the difference between the uncut and the cut surface in axial direction.

Radial depth of cut: The depth of the tool in the workpiece along its radius as it performs a cut. If the radial depth of cut is smaller than the radius of the tool, the tool is only partially engaged, resulting in a peripheral cut. When the radial depth of cut equals the diameter of the tool, the cutting tool is fully engaged and making a slot.

1.2.5 Importance of milling machining

The milling cutter performs a rotary movement (primary motion) and the workpiece a linear movement (secondary motion). The milling technique is used to produce, mainly on prismatic components, flat, curved, parallel, stepped, square and inclined faces as well as slots, grooves, threads and tooth systems.

CNC Milling (also known as computer numerical control milling) is a method of manufacturing that utilizes pre-programmed software to control machining tools. Digital instructions are first of all fed into the computer, which then automatically operates the machine to create the components that match the specifications.

Continuous Usage

CNC milling machines do not need to take breaks like human workers. Once the instructions have been details as input into the computer and the machining begins, the manufacturing can take place throughout the task is completed. This constant usage has completely transformed the industry and provided manufacturers with a way to drastically reduce their costs and improve productivity. Large projects that once might have taken weeks or even months to complete can now be completed in a matter of days or hours. This means they are able to make a good economics in a shorter space of time without drastically increasing their costs.

Consistency

One of the greatest advantages of CNC milling is that the same components over and over again in huge volumes can be produced. These manufactured parts will be exactly the same size, shape and dimensions that mean everything will be created to match the right specifications every single time. Even the most skilled workers will not be able to create the exact same components time and again. Instead, there will likely be tiny differentiations with each part.

Reduced Test Runs

A lot of test runs are required in traditional machining methods to ensure that the produced components will be matched the specifications or not. This is because the operator will need to familiarize themselves with the process needed to manufacture the component and may make several mistakes in their first few attempts.

CNC milling machines have ways of avoiding these numerous test runs. They can use visualization systems that enable the operator to see what will happen after the tool passes will finish, meaning the engineer will get a good idea of whether the component is going to match the specifications beforehand.

Design Retention

Once a design has been successfully loaded into the computer system and a perfect prototype created to ensure that everything is exactly as it should be, the software can easily retrieve the instructions whenever required again.

These instructions ready on file means that there is no need to start from initial point when the components need manufacturing again. This master file also ensures that regardless of outside circumstances, such as a change of machine operator, the CNC milling process can continue uninterrupted. Additionally, there is no need to keep up with versions of the design that might exist on paper, a disc, flash drive, another computer or anywhere else.

Capability

When used in conjunction with advanced computerized design software, CNC milling can be created output components that simply cannot be replicated by manually operated machine, no matter the skill level of the engineers. CNC machines can be produced components of any size, shape, texture or quantity that is needed, without any hassle or stress.

1.3 Cutting tools

1.3.1 Classification of cutting tools

Despite the fact, the basic shape of a cutting tool changes widely depending on the type of activity. Every cutting tool must have a wedge-shaped section with a sharp cutting edge that can cut material smoothly, as it is supposed to perform. Now, a cutting tool can have one or more main cutting edges that work together in a single pass to cut material.

Cutting tools are categorized in a variety of ways, the most frequent of which is by the number of major cutting edges that are involved in the cutting activity at the same time[8]. Cutting tools can be divided into two classes based on this classification, as shown below.

- Single point cutting tool
- Multi point cutting tool

A multi-point cutting tool contains more than two main cutting edges that simultaneously engage in cutting action in a pass. The number of cutting edges present in a multi-point cutter may vary from two or more.

Advantages of multi-point cutting tool

* Chip load on each cutting edge is considerably reduced since the overall feed rate or depth of cut is evenly divided among all cutting edges. As a result, a higher feed rate or depth of cut can be used to improve material removal rate and hence productivity.

* The force acting on each cutting edge is greatly reduced due to the dispersion of chip load. Occasionally, one component of cutting force is automatically eliminated or lowered.

* During machining, no part of the cutting edge is in constant contact with the work piece; instead of engagement and disengagement occur frequently. This allows enough time for heat to dissipate from the tool body, protecting the cutter from overheating and plastic deformation. As a result of the intermittent cutting action, the tool temperature rises at a slower rate.

* Tool wear rate is reduced as a result of shorter engagement times and less heat generation within the tool body. As a result, the tool life is increased.

1.3.2 Coated cutting tool

The coatings that are now being investigated function exceptionally well while machining hard materials. These coatings are gaining traction in the industry, with very positive results in terms of increased performance and tool life. Coatings enhance the quality of the tool's surface and extend its life. They significantly minimize cutting forces, cutting temperatures and tool wear, making them an extremely attractive option for the machining sector.

Direct contact between the tool steel workpiece and the cutting tool can be avoided successfully by coating on cutting tool acting as a heat and chemical barrier. Coated tools can nevertheless have a longer cutting life in high-speed and high-temperature cutting environments due to constant innovation in coating technology. Coatings impart properties to the tool that are optimal for the machining application, such as thermal dissipation and wear resistance. These coatings can be designed in a variety of ways; for example, the outer layer may have an increased wear resistance, while the subsequent layer may focus on thermal dissipation.

Recent milling machining tools are coated cemented carbide tools. These coatings, which are either PVD or CVD deposited, are applied on a base material referred to as the substrate[9]. Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD) can be used to deposit the coatings (PVD). Chemical vapor deposition films can be created in a variety of ways, as seen in figure 1.6. CVD films are deposited by pumping a precursor into a closed reactor and controlling the flux using control valves. The precursor molecules travel through the substrate and deposit themselves on its surface, forming a thin hard covering. This technique operates between 300 and 900°C. Additionally, the film thickness is typically homogeneous throughout the whole surface of the substrate.

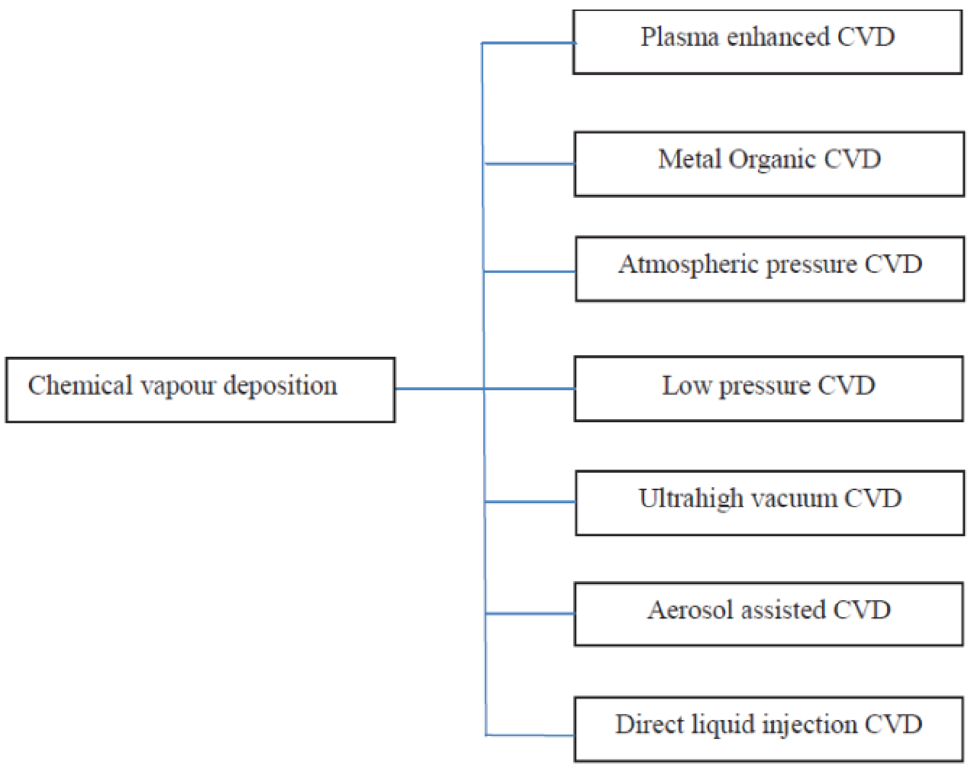

Figure 1.6 CVD Coating deposition methods

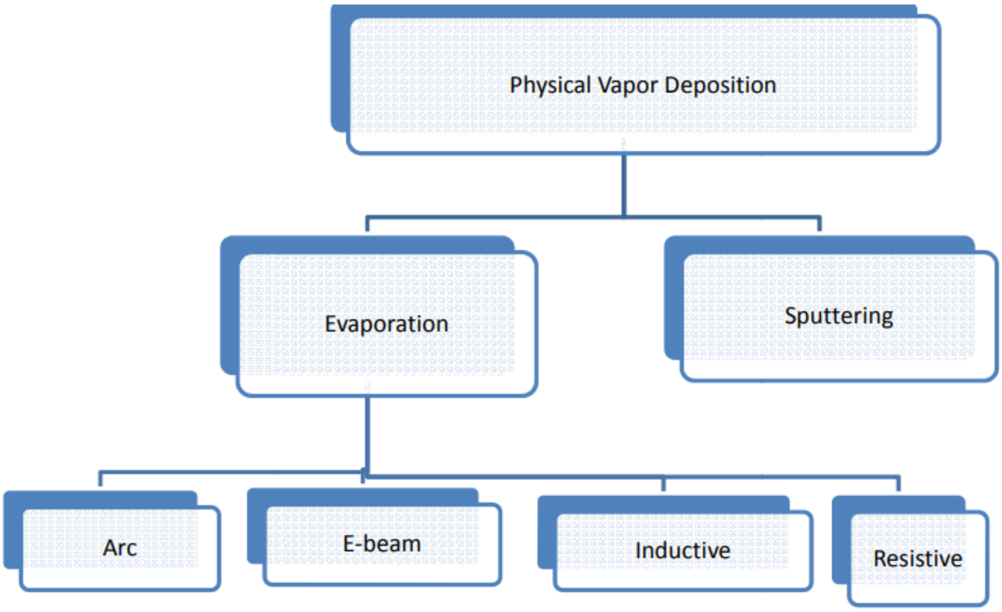

Figure 1.7 PVD Coating deposition methods

PVD coatings can be deposited using a variety of techniques, as seen in figure 1.7, with DC (direct current) magnetron sputtering being the most frequently utilized. PVD operates at a lower temperature (less than 500°C) than CVD and is more environmentally friendly due to the materials used in CVD. Additionally, PVD is a more energy-efficient procedure than CVD. Consideration must be given to the type of coating used on a cutting tool. CVD coatings are typically thicker and more suitable for roughing operations; however, they can be applied only to cemented carbide cutting tools due to their superior behavior at elevated temperatures, whereas PVD coatings can be applied to coated tool steel due to the PVD process's overall low temperature.

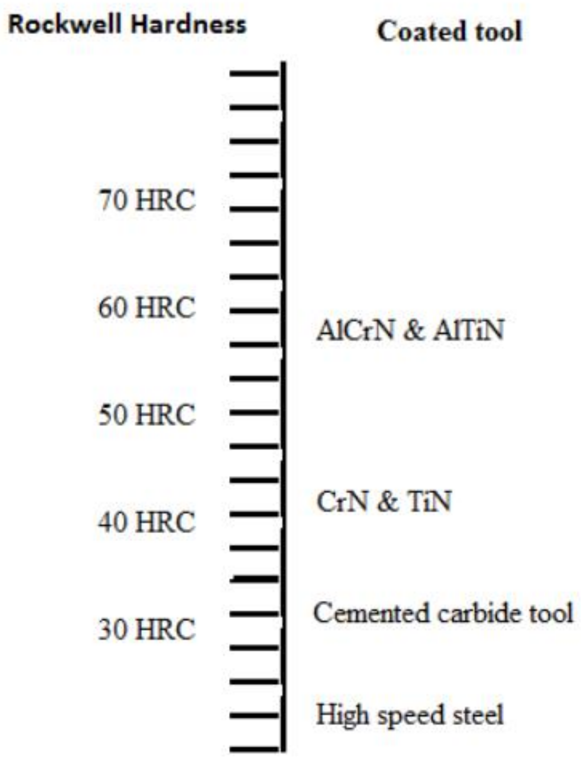

Figure 1.8 Compare hardness values of workpiece and cutting tools

Coatings are applied in accordance with the machining process and its prerequisites. To choose which coating to apply and where to apply it, cutting tool behavior has been evaluated. Numerous elements affect the cutting performance of the cutting tool, including the cutting speed, feed rate, depth of cut, lubrication regimen, tool shape, and even the thickness of the tool coating. Cutting tools are used to machine tool steel should have a hardness value three times greater than the tool steel's Vickers hardness value. Numerous coated tools are suggested for machining based on the workpiece hardness value, as seen in figure 1.8. On hardened workpiece materials, high speed steel (HSS) cannot be used. Cemented carbide cutting tools can be used on materials with a hardness of up to 30 HRC. CrN and TiN coated tools are mostly employed on 40 to 50 HRC materials, while AlCrN coated tools perform exceptionally well on 50-60 HRC workpiece materials.

Table 1.2 Various coated tool with application

TiN	The general-purpose coating for cutting, forming, injection molding as well as tribological applications
TiCN-MP	Universal high-performance coating for cutting such as drilling, milling, reaming and turning
TiAIN	Tough Multi Purpose coating for interrupted cutting, milling, stamping, forming and hobbing

AlTiN	High-performance coating with very high aluminum content and heat resistance. Used for dry high speed machining
TiCN	Conventional carbon nitride coating for interrupted cutting, milling and tapping, stamping, punching and forming
AlCrN	A coating with high wear resistance against abrasive loads, good heat and oxidation resistance. It performs extremely well in milling applications and is outstanding for very dry applications.
CrN	The standard coating for non-cutting application for moulds, dies and machine parts. Especially suited for applications where copper is the material being altered.
ZrN	A monolayer coating that effectively reduces the built-up edges when machining aluminum (

Coated tool providers offer a wide variety of PVD (Physical Vapor Deposition) and CVD (Chemical Vapor Deposition) surface treatments. There are numerous coating materials in the market, including TiN, TiAlN, TiCN, TiC and CrN. To ensure the cutting tool performs optimally, the appropriate cutting tool materials must be chosen with consider of its application. The coating materials and their applications are listed in table 1.2.

1.3.3 Types of end mill cutting tool

According to peripheral cutting edge

End mill tools come in a variety of shapes and sizes. The conventional flute type, as illustrated in figure 1.9 (a), is mostly utilized for side milling and general milling operations, although it is also employed for slotting. Tapered flutes are utilized in milling to create mould drafts and angled faces, as illustrated in figure 1.9 (b). Roughing flutes have a roughing tooth in the shape of a wave as illustrated in figure 1.9 (c), and are ideal for roughing surfaces. As illustrated in figure 1.9 (d), a formed flute is similar to a corner radius cutter tool. It is capable of producing an endless variety of shape cutters.

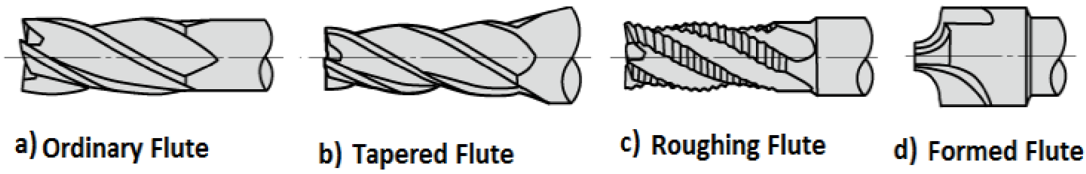

Figure 1.9 Types of peripheral cutting edge in end mill

According to end cutting edge

As illustrated in figure 1.10 (a), square ends (with a center hole) are frequently used for slotting, side milling, and shoulder milling. This sort of end mill grinds from the center. Additionally, slotting, side milling, and shoulder milling are performed with a square end (with center cut). Vertical cutting is possible with this sort of end mill, as illustrated in figure 1.10 (b). As seen in figure 1.10 (c), a ball end mill is appropriate for profile machining and pick feed milling. For corner radius milling and contouring, an end mill cutter with an end radius similar to that shown in figure 1.10 (d) is utilized. Due to the tiny corner radius and large diameter, it is an efficient tool.

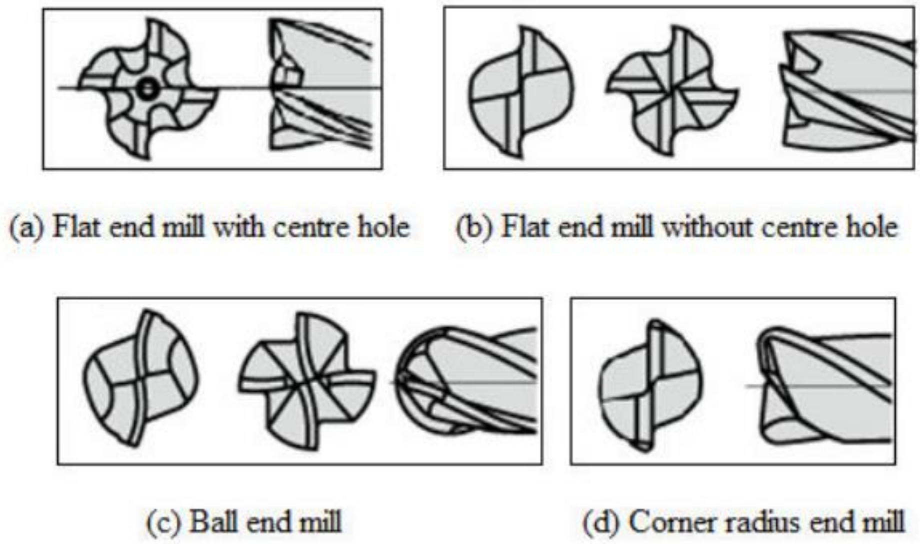

Figure 1.10 Types of End Cutting Edges in end mill

According to shank and neck parts

Various shanks are utilized for milling purpose as illustrated in figure 1.11. Standard shank is utilized for general use as seen in figure 1.11 (a). Straight long shank is utilized for deep slotting, allowing for adjustability of the overhang as illustrated in figure 1.11 (b). As seen in figure 1.11 (c), the long neck type shank tool is suited for boring operations and may also be utilized for deep slotting with a small diameter. Due to the taper shank, the taper neck performs exceptionally well in deep slotting and also on mould draft as illustrated in figure 1.11 (d).

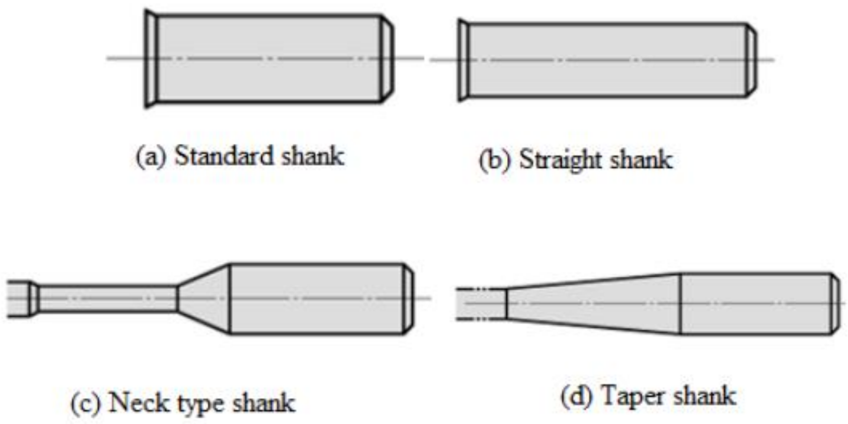

Figure 1.11 Types of shank and neck parts in end mill

1.4 Measurement of Responses

1.4.1 Cutting force

It is a reaction force caused when a cutting tool is pushed into a workpiece. Cutting force changes according to cutting conditions. It is considered as three force components as shown in figure 1.12. Feed force is a horizontal force component in a feed direction. It determines a magnitude of feed power for cutting. Cutting force is a force component acts in a direction vertical to feed force. It affects heating value during cutting. Power requirement during cutting is calculated by a magnitude of cutting force. Thrust force is an axial force component. It becomes force to deform a workpiece and a tool and decreases accuracy when it is large.

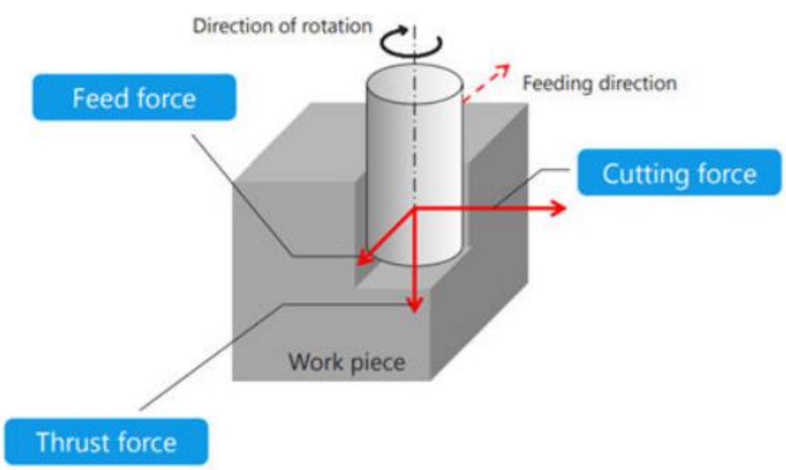

Figure 1.12 Cutting forces in end milling

1.4.2 Surface roughness

Surface roughness is specified as follows; arithmetical mean roughness (Ra), maximum height (Ry) and ten-point mean roughness (Rz). The roughness of the surface is expressed as the arithmetical mean of a randomly sampled area. Numerous techniques are used for determining the surface roughness.

Techniques used for surface roughness measurement

Arithmetical mean roughness (Ra)

A section of standard length of sample is drawn from mean line on the roughness chart as shown in figure 1.13. The mean line is laid on a Cartesian coordinate system. The mean line runs in the direction of the x-axis and magnification is the y-axis. The value obtained with the below formula is expressed in micrometer when y is equal to f(x).

$$R_a = \frac{1}{l}\int_0^l |f(x)|dx$$

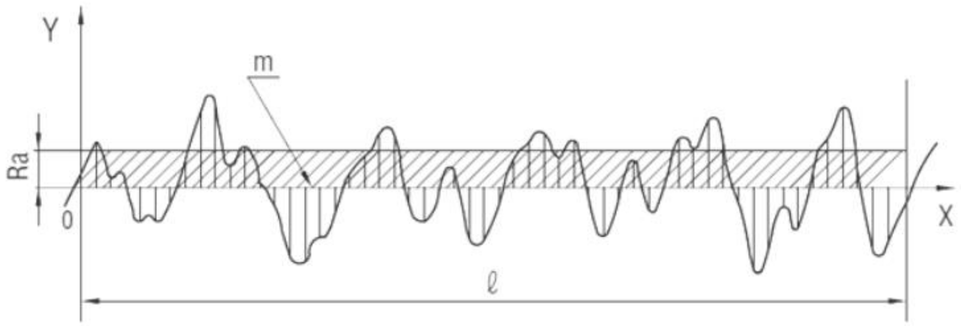

Figure 1.13 Arithmetical mean roughness (Ra)

Maximum peak (Ry)

A section of standard length is sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured as Rp and Rv respectively in the y direction which are seen in figure 1.14. The value is expressed in micrometer (µm).

$$R_y = R_p + R_v$$

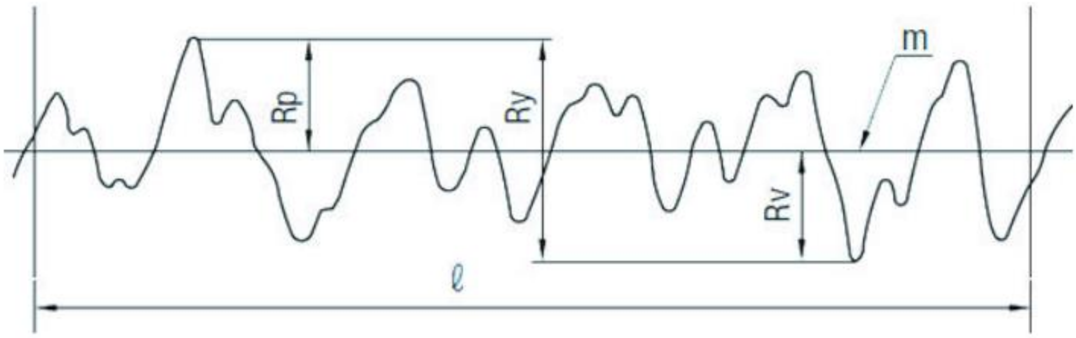

Figure 1.14 Maximum peak

Ten-point mean roughness (Rz)

Rz is calculated by averaging the difference between the heights of the five highest peaks and the five lowest valleys within the sampling length. It provides a measure of the mean roughness of the extreme irregularities on the surface. Rz is particularly useful when evaluating surfaces that may have a few prominent peaks or deep valleys.

• A section of standard length is sampled from the mean line on the roughness chart. The distances between the peaks and valleys of the sampled line in the y-direction are measured, as shown in Figure 1.15. Then, the average peak is obtained by calculating the average value among the five tallest peaks (YP1, YP2, YP3, YP4, YP5). Similarly, the average valley is obtained by calculating the average value among the five lowest valleys (YV1, YV2, YV3, YV4, YV5). The sum of these two values is expressed in micrometers (μm) using the following equation:

$$R_z = \frac{|Y_{P1}+Y_{P2}+Y_{P3}+Y_{P4}+Y_{P5}|+|Y_{V1}+Y_{V2}+Y_{V3}+Y_{V4}+Y_{V5}|}{5}$$

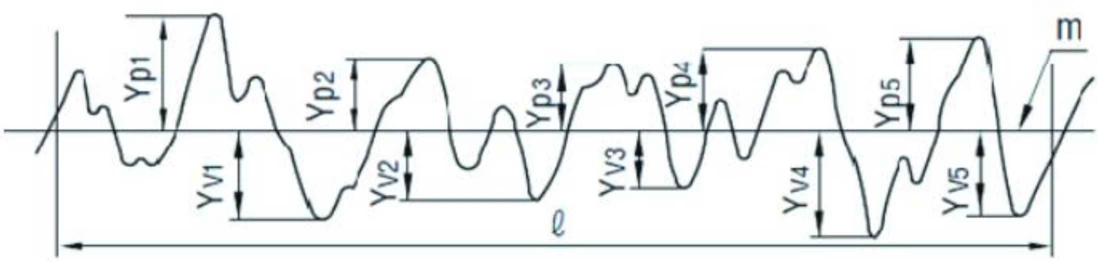

Figure : 1.15 Ten-Point Mean Roughness (Rz)

To determine surface roughness, various techniques and instruments are employed, including:

Profilometer : These instruments use a stylus or a non-contact method to measure the vertical deviations of the surface profile. They provide detailed information on the surface roughness parameters.

• Surface Roughness Comparators: These are visual or tactile reference standards with known roughness values. They are used to visually or manually compare the roughness of a surface.

• Optical Profilometer : This method uses optical interference or focus variation techniques to measure surface roughness non-destructively. It provides highresolution 3D surface topography data

• Atomic Force Microscopy (AFM): AFM utilizes a sharp tip to scan the surface, providing nanoscale resolution and detailed information about surface roughness and topography.

The choice of technique depends on the required accuracy, surface finish characteristics, and the nature of the material being measured.

CHAPTER 2:

LITERATURE REVIEW

2.1 Introduction

Among the various milling methods available, such as end milling and face milling, the majority of research studies on machining. This indicates that end milling has received the most attention. End milling involves the use of a cylindrical cutting tool with multiple cutting edges, while face milling utilizes a milling cutter with cutting edges on its face. The focus of these investigations is to understand the impact of various factors, such as cutting parameters, tool wear, surface quality, and cutting conditions, on the machining using the end milling technique.

While face milling is another milling method that can be used for machining 6063 alumnium alloy, the existing literature places greater emphasis on face milling. Studies specifically dedicated to face milling in the context 6063 alumnium machining are relatively limited compared to end milling

2.2 Coated cutting tool

Milling of hard materials has been gained high interest due to lesser machining time and machining cost associated with production of moulds and dies [11].To keep pace with the times, researchers have been working to improve the coating structure by doping a range of functional alloy elements, resulting in high-hardness, high-wear-resistant, high-performance coatings, self-lubricating and high-temperature oxidation-resistant tool coatings[12]. Tool life is reduced due to machining of hard material. Problems are arisen in machining of hardened steel due to its high hardness and toughness as well as its inhomogeneous microstructure, which contributes to accelerated tool wear and chipping. Finding the ways for enhancement of tool life in the hard milling domain is a major task in manufacturing industries[13] Recently, the development of new cutting tools have enabled to machining of very hard materials like tool steel[14]. Due to higher strength of hardened steel, milling of hard material is a challenging task for die and mould manufacturing industries. Tool wear is a major drawback due to higher thermo-mechanical stress on cutting tool[15]. Milling has evolved as a process with new machines and procedures being used to constantly achieve the greatest results. From the uncoated high speed steel tool to the presently widely used coated tools, milling tools have undergone a significant evolution[16]. Coatings of carbide tools increase the tool working life and reduce tool wear rate in machining processes[17]. When the milling cutter starts cutting of hard material, it will become more difficult for further machining. Higher cutting force and higher temperature are generated due to hardening effect. Coated tools are still hard to bear high load impacts, high temperature and improve wear resistance significantly[18].

Coatings on cutting tools reduce the coefficient of friction between cutting tool and chip. Due to that it gives better performance under similar cutting condition compare than uncoated cutting tool[19].

Coating has to possess high hot hardness and improved oxidation resistance at elevated temperatures for machining of hardened steel, when high load and high temperature control wear behaviour[20].

Coating can effectively improve tool life of cutting tool in hard milling. Coating enhances lubricity of tool and oxidation resistance, reduces the temperature variation in the tool, protects the tool against diffusion wear and rendering it less susceptible to crack[21]. Coated carbide tools are useful especially milling of hardened material due to their high toughness and hot hardness[22].

Experiments have been performed on cold work tool steel using various coated tool and found that the cutting forces are approximately two times higher in the case of uncoated tool[23]

Surface topography gains better yield with coated tool as compared to uncoated tool due to high wear and temperature of hardened steel [24].

There are two well established vapor processing for coating, namely chemical vapor deposition (CVD), which was the first to appear, and physical vapor deposition (PVD). TiC, TiN and Al2O3 were the first materials to be used for coating inserts by CVD and showed excellent results due to their built-up edge resistance, wear resistance and heat resistance respectively. Varying combinations of these coating materials also showed considerable improvements in tool life. PVD process offered unique advantages over CVD due to lower deposition temperatures [25].

PVD coatings are generally used to increase production and tool life of cutting tool. At present, PVD coatings are mostly used in manufacturing industries due to reducing cycle time of components, reduce wear (which are caused by chemical interaction, crater wear and build up edge) and reduce the need of cutting fluid. In last few years, PVD coating is mostly used and replacing the CVD coating technologies because it is possible to achieve good coating properties like high hardness, good adhesion and wear resistance. Close tolerance can be achieved by thin PVD coatings. PVD coating processes are also applied at relatively low coating temperature [26].

PVD coatings and CVD coating have been compared during milling of AISI 4140 alloyed steel at normal milling speed as well as high milling speed [27].

There are various list of coating properties and applications shown in Table-2.2. Coated tools of nitride coatings with high aluminum content (like AlTiN and AlCrN) can be performed better than aluminum-free nitride coated tools (like TiN and CrN) in wear protection at high temperatures due to their oxidation resistance, higher hot hardness and lower thermal conductivity [28].

Addition of Cr creates strong Al–Cr metallic bonds in coating, the hot hardness and oxidation resistance is improved at high temperatures[29].Because of addition of Cr in metastable Al-rich metal matrix, the solubility limit of AlN phase is increased in the complex nitride and the concentration of heavy metal matrix ion vacancies is reduced within crease in nitrogen ion vacancy content[30].

Table-2.1 List of various coating properties

Coating type	Coating colour	Hardness H [HV]	Friction Coefficient	Max Temp	Use
TiN	Gold	2447-2855	0.4-0.5	500°C	General purpose coating forcutting, forming, injection, moulding applications
AlTiN	Black	3875	0.7	900°C	For dry high-speed machining for hardened materials (> 52 HRC)
CrN	Metal Silver	1835	0.3-0.4	700°C	For deep drawing, extrusion, metal die casting application
ZrN	White Gold	2039	0.4	550°C	For machining of aluminum and titanium alloys
AlCrN	Blue-Grey	3059 - 3263	0.3-0.6	1100°C	For gear cutting tools, die casting; punching, hot forging, moulding and various hardened materials

Performance of AlCrN coated tool and uncoated tool during machining of austenitic stainless steel have been compared and found that Al based coatings provide good chemical inertness, higher hardness and wear résistance due to the formation of $Al2O3$ layer on the tool surface at high temperatures. Also better surface finish has been produced by AlCrN coated tool compare than uncoated tool due to less coefficient of friction and lower thermal conductivity of coating[31].

M. S. Kasim et al [48] have been investigated tool life and wear mechanism during end milling of Inconel 718 using a physical vapor deposition coated ball-type end mill. AlCrN coated tool has exhibited higher wear resistance than TiAlN coated tool in wear mechanism as an abrasion, attrition and delamination. After machining, the wear on the tool center, the rake and flank faces have been examined using a scanning electron microscope as shown in figure 2.2 [32]

. Using a system Bias and cathodic arc evaporation, a heat-treated monolayer coating of AlCrN is produced on a tungsten carbide micro-grain commercial substrate by physical vapour deposition. In a controlled nitrogen atmosphere, Al-Cr alloy is utilised to apply as a coating. To get a layer with a particular thickness, the deposition time can be modified.

2.3 Review on tool wear

Milling of SiCp/Al composites can be carried out using a range of cutting tools, including uncoated cemented carbide inserts, tools with nano TiAlN coatings, and carbide-coated cutting tools. The research conducted by Bian et al. [33] focused on the precise milling of SiCp/Al composites with a higher volume fraction of approximately 65%. These composites were manufactured using the pressure-less infiltration fabrication technology.

The milling process involved the use of a single flute monocrystalline diamond end mill. The researchers investigated the impact of various input parameters such as spindle speed, feed per tooth, and depth of cut on the quality of the machined surface, surface topography, surface roughness, cutting mechanisms of SiC particles, and tool wear characteristics.

They employed scanning electron microscopy (SEM) to analyze the results. During the precision milling, the researchers were able to achieve a highly polished surface finish with a surface roughness of around Ra 0.1 μm. They observed that increasing the depth of cut led to an increase in surface roughness. However, they also noted the presence of some cracks on the machined surface.

These cracks were attributed to the ductile cutting of SiC reinforcements, resulting in partial microfractures. The SEM images revealed that the tool wear predominantly manifested as flank wear on the bottom face of the tool. Additionally, chipping and cleavage were observed on the monocrystalline diamond edge of the tool.

The study conducted by Benjamin et al. [34] examined the side milling of an aluminum alloy matrix reinforced with 10% volume fraction of SiC particles. The composite material was fabricated using a powder metallurgical method. The researchers used a double-edged chemical vapor deposition (CVD) diamond-tipped tool with a diameter of 3mm for the milling tests. The main focus of the research was to investigate the surface characteristics, including roughness and imperfections, as well as residual stress. Additionally, the influence of cutting parameters such as cutting speed and feed rate was analyzed.

To evaluate the surface roughness and imperfections, advanced imaging techniques such as 3D laser scanning microscopy and scanning electron microscopy (SEM) were employed. The results indicate that changes in cutting speed had minimal impact on the depth of surface roughness. However, increasing the cutting speed led to reduced void formation on the machined surface and higher absolute values of compressive residual stresses. study delves into the side milling of an aluminum alloy matrix reinforced with SiC particles. The use of a CVD diamond-tipped tool allows for an investigation of the surface characteristics and residual stress.

The research findings suggest that while cutting speed variations have limited influence on surface roughness, they do affect void formation and residual stress levels. This study enhances our understanding of the machining behavior and surface properties of SiC-reinforced aluminum alloy composites. In the research conducted by Shen et al. [35], it was observed that the uncoated WCCo milling tool experienced the most significant wear on its circumferential cutting edge when milling SiCp/Al composites. In comparison, the diamond-like carbon (DLC)-coated milling tool exhibited slightly lower wear.

However, the milling tool coated with chemical vapor deposition (CVD) diamond demonstrated remarkably superior wear resistance. At the end of the milling tests, the wear on the circumferential cutting edge of the CVD diamond-coated tool was less than 0.07 mm, which was only half of the wear observed in the DLC-coated tool. These findings highlight the importance of tool coating selection for achieving enhanced wear resistance and prolonged tool life in the milling of SiCp/Al composites.

Huang et al. [36] conducted high-speed milling experiments were performed on SiCp/ Al composites with a higher volume fraction (56%) and larger particles. Polycrystalline diamond (PCD) tools were used under both dry and wet machining conditions. The aim of the research was to analyze the effects of cutting speed, feed rate, and depth of cut on the machining process. The results showed that the primary form of tool wear observed during milling was abrasion on the flank face of the tools. Furthermore, it was found that the TiC-based cermet tool was not suitable for machining SiCp/Al composites with higher volume fractions and larger particles due to the intense abrasive nature of the reinforcement material. These findings underscore the importance of carefully selecting appropriate tool materials when machining SiCp/ Al composites with different particle sizes and volume fractions, in order to optimize machining performance and extend tool life.

Shutao et al. [37] conducted a study focusing on the use of polycrystalline diamond (PCD) tools in high-speed milling of SiCp/Al composites with a higher volume fraction (65%) and larger SiC particle sizes. Their research aimed to explore the wear resistance and wear mechanisms of PCD tools with varying diamond particle sizes (5, 10, 25, and 32 μm). The cutting conditions employed were a cutting speed of 352 m/ min and a feed rate of 0.02 mm.

The results revealed an interesting relationship between diamond particle size and tool performance. It was observed that as the diamond particle size increased, the wear resistance of the PCD tools diminished. This was evidenced by increased flank wear and slight deepening of micro-chipping on the cutting edge. Notably, when PCD tools with a 5 μm particle size were used, both the cutting force and surface roughness were reduced. Moreover, throughout the cutting process, the machined surface roughness remained relatively stable, indicating that tool wear had minimal impact on surface roughness.

These findings emphasize the significance of diamond particle size in determining the wear resistance and overall effectiveness of PCD tools during SiCp/Al composite milling. Smaller diamond particles exhibited superior wear resistance and resulted in lower cutting forces and improved surface roughness. Understanding the relationship between tool parameters and machining performance enables the optimization of tool selection and enhances the quality of machined surfaces in SiCp/Al composite milling applications.

Wang et al. [38] investigated the performance of cutting tools in dry high-speed milling of SiCp/Al composites with a volume fraction of 45%. Two types of tools were used: CVD diamond coated tools and PCD tools. The focus of the study was on analyzing the wear patterns exhibited by the tools.

The results indicated that the wear pattern observed in PCD tools was predominantly flank wear, which was caused by the abrasion of SiC particles. This wear phenomenon was more prominent at relatively low cutting speeds. It is worth noting that graphitization, a potential wear mechanism for PCD tools, did not occur due to the low cutting temperatures experienced during the milling process.

Overall, the wear mechanism observed in PCD tools was primarily characterized by abrasive and adhesive wear. These findings provide valuable insights into the tool wear behavior during dry high-speed milling of SiCp/Al composites and can aid in optimizing tool selection, improving tool life, and enhancing the overall machining process.

In their research, Huang and Zhou [39] investigated the suitability of three different cutting tools, namely the TiN-coated tool, cermet tool, and cemented carbide tool, for machining silicon carbide particle reinforced aluminum matrix composites (SiCp/Al) with a volume fraction of 56%. The experiments were conducted at two different milling speeds: a higher speed of 314 m/min and a lower speed.

The main focus of the study was to analyze the wear behavior of these tools during the machining process. It was observed that flank wear, which occurs on the side of the tool, was the predominant mode of wear for all three types of tools. Interestingly, the wear resistance was found to be similar among the TiN-coated tool, cermet tool, and cemented carbide tool, indicating that they performed comparably in terms of wear resistance.

Furthermore, the study revealed that as the milling speed increased, the tool wear also increased. However, the feed rate and depth of cut had a relatively minor impact on the tool wear.

These findings contribute to our understanding of the performance of different cutting tools when machining SiCp/Al composites. They provide valuable insights into the selection of appropriate tools and the optimization of machining parameters to improve the efficiency and effectiveness of the milling process.

Ge et al. [40] investigated the high-speed milling performance of SiCp/2009Al composites using PCD tools at cutting speeds ranging from 600 to 1,200 m/min. They observed that the tool life of PCD tools, defined by a 0.1 mm tool wear criterion, ranged from 25 to 240 minutes. The main causes of tool wear were grain breaking-off, chipping, abrasive wear, micro cracks, and adhesive wear, which resulted from the impact, vibration, and interaction with SiC particles. The cutting force (Fy) varied from 700 to 2,550 N, and the cutting temperature ranged from 240 to 580 degrees Celsius. When the tool flank wear was below 0.09 mm, the achieved surface roughness values were Ra of 0.207-0.542 μm and Rz of 2.02-5.2 μm. The machined surfaces exhibited defects such as pits, voids, grooves, protuberances, and irregularities in the matrix. The depth of the deformation layers was limited to 20-35 μm, and the chip morphology displayed either a semi-flow or saw-toothed pattern.

Ben et al. [40] done the machining of metal matrix composites containing ceramic particles, the wear of cutting tools significantly affects the quality and cost of the produced parts. This research focuses on studying the behavior of tool wear and surface quality during micro milling of 45 vol % SiCp/Al composites under different lubrication conditions : dry and minimum quantity lubrication (MQL). Analysis using scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS) reveals that the wear mechanism of diamond-coated micro mills involves adhesive wear, abrasion, oxidation, chipping, and tipping. This contrasts with previous reports that primarily emphasized abrasion as the dominant wear mechanism for machining similar composites. Comparing the two lubrication methods, it is observed that the environmentally friendly MQL technique improves tool life, surface roughness, and significantly reduces cutting forces under the given cutting parameters. Additionally, finite element simulations are utilized to examine the chip formation process during micro orthogonal cutting, providing insights into the impact of reinforced particles on tool wear and surface quality. The simulations indicate that localized high stress, hard reinforced particles within the metal matrix, as well as deboned and cracked particles, play a crucial role in causing severe tool wear and producing an uneven surface morphology

R. Karthikeyan et al. [41] investigated the face milling characteristics of LM25 A1- SiC particulate composites produced through stir casting. A series of experiments were conducted using an L27 orthogonal array, and mathematical models were developed to analyze the effects of machining on flank wear, specific energy, and surface roughness. The models were evaluated for their accuracy and any insignificant factors were eliminated through a t-test. Additionally, goal programming was applied to optimize the cutting conditions by simultaneously considering multiple objectives such as maximizing metal removal rate and minimizing tool wear, specific energy consumption, and surface roughness.

Ergün et al [42] focused on the milling process of metal matrix composites created through hot pressing, using a CNC milling machine. The objective was to examine how cutting parameters and different coating types affect the resulting surface roughness. The composites were fabricated through hot pressing, combining aluminum as the matrix material and 10% SiC particles as the reinforcement. During the machining of the composite samples, three types of cutting tools (uncoated, multilayered, and Nano TiAlN coated) were employed, along with three different cutting speeds (60, 78, and 101 m/min) and three feed rates (0.04, 0.08, and 0.12 mm/rev). To analyze the effects of these cutting parameters and their interactions. The obtained surface roughness data from the experiments were used to develop mathematical models using the response surface method, allowing for optimization of the cutting parameters. The study also included an evaluation of the wear on the cutting tools, and a comparison was made with previous research to gain insights and discuss the observed wear patterns.

2.4 Review on cutting Force

In the literature review on cutting force in metal matrix composites (MMC), several studies have been conducted to investigate the effects of various factors on the cutting forces experienced during machining operations. The cutting force is a crucial parameter that directly impacts the tool life, surface quality, and overall machining performance of MMCs. Researchers have examined factors such as cutting parameters (cutting speed, feed rate, and depth of cut), tool geometry, tool material, reinforcement type and content, and workpiece material properties to understand their influence on cutting forces.

In different milling investigations, the cutting force and its impact factors are often variable; nonetheless, SiC particles and the machining parameters are crucial.

Jayakumar et al. [43] done research on A356 aluminum alloy powder was reinforced with 10% volume of SiC particles with varying sizes (1 µm, 12.5 µm, and 25 µm). The composites were synthesized using a vacuum hot pressing method, and their mechanical properties and machinability were analyzed. End milling operations were conducted on these composites, and the surface roughness and cutting forces were measured while varying the machining parameters and SiC particle sizes. The results indicated that the composite reinforced with finer particles (1 µm) exhibited lower cutting forces and surface roughness when higher cutting speeds, lower feed rates, and shallower depths of cut were applied. These findings highlight the importance of considering the particle size and machining parameters for optimizing the machinability of composites in milling processes.

Machinability of these composites was investigated using computer numerical control end milling, with cutting speed, feed, and depth of cut as variable parameters. The study measured cutting forces and tool-work interface temperature to analyze the effects of machining parameters and reinforcement on the matrix. The findings provide valuable insights and optimization guidelines for manufacturing industries. Response surface models were developed and compared to experimental results, showing that higher volume percentages of SiCp reinforcement result in increased tool-work interface temperature and require higher cutting forces during the machining process.[44]

Vallavi et al. [45] studied the cutting force characteristics of LM6/SiCp composites using the end milling process. The objective was to develop mathematical models that can accurately predict the cutting force based on key parameters such as spindle speed, axial depth of cut, and weight percentage of SiCp. To achieve this, response surface methodology was employed to create the mathematical models. Experimental tests were conducted on LM6/SiCp composites using a carbide insert, and cutting forces are measured using a milling tool dynamometer. The study examined the individual and combined effects of the machining parameters on the cutting force. Analysis of variance (ANOVA) is utilized to assess the validity and adequacy of the developed models. Ultimately, the research aimed to determine the optimal combination of machining parameters that will result in the most favorable cutting force outcomes.

In the study conducted by Huang et al. [46], it was observed that the milling forces exhibited certain trends in response to variations in the milling parameters. Specifically, an increase in the milling speed was found to correspond to a decrease in the milling forces. Conversely, the milling forces increased as the feed rate and depth of milling were increased. Among the various milling parameters, the milling depth had the most significant influence on the milling forces in the x and y directions, while the feed rate had the greatest impact on the milling forces in the z direction. These findings highlight the importance of carefully selecting and optimizing the milling parameters to achieve desired force levels during the milling process.

Babu et al. [47] observed that the cutting force components were particularly affected by high-speed cutting and full immersion conditions. They found that the cutting force exhibited additional fluctuations due to the unstable chip formation of the composite material and the presence of randomly distributed reinforcement particles. This indicated that the machining process of composites involves complex interactions between the cutting tool, workpiece material, and reinforcement particles, leading to variations in the cutting forces experienced during the operation.

Ge et al. [48] Experimental tests were conducted to study the cutting forces during high-speed milling of SiCp/2009Al composites using PCD tools. The cutting speed ranged from 600 to 1200 m/min. The results showed that the maximum cutting force in the radial direction (Fy) varied between 700 N and 1450 N under the given cutting conditions. Notably, significant vibrations were observed with a maximum amplitude of 700 N in the radial direction of the tool. The cutting forces increased with higher feed rates and radial depths of cut, while they decreased with increasing cutting speeds. It was recommended to use a negative rake angle and a relatively large tool nose radius to minimize cutting forces. Moreover, composites with higher volume fractions or smaller reinforcement particle sizes exhibited higher cutting forces. T6 heat treatment significantly increased the cutting forces, while the use of coolant noticeably reduced them.

Shutao et al [49] conducted experiment on SiCp/Al composites that is subjected to high-speed milling using polycrystalline diamond (PCD) tools with varying diamond grain sizes. The composites had a volume fraction of 45% and SiC particles with a size of 5 µm. The study aimed to assess the tool wear resistance, cutting forces, and surface roughness. The findings revealed that when machining composites with a volume fraction of 45% and smaller SiC particles (5 µm), the PCD tools exhibited significantly higher wear resistance compared to machining composites with a higher volume fraction (56%) and larger SiC particles (60 µm). PCD tools with larger diamond grain sizes demonstrated superior wear resistance, resulting in lower cutting forces and improved surface roughness. The cutting forces exhibited a consistent trend with tool wear as the cutting distance increased. The machined surface roughness generally decreased, albeit with minimal fluctuations. The predominant wear modes observed were flank wear and slight wear groove marks, while chipping and coarse wear groove marks were absent. Adhesion of machined material on the tool face was observed, but no built-up edge formation occurred.. The cutting forces and torque of PCD tools of larger diamond grain sizes are less than those of smaller diamond grain sizes.

2.5 Review on Surface integrity, machining efficiency, and optimization

Huang et al [50] done the experiment on Silicon carbide-reinforced aluminum matrix (SiCp/Al) composites with high volume fractions conducted ultrasonic vibrationassisted scratch (UVAS) tests and conventional scratch (CS) tests using a rotary ultrasonic machine. By analyzing the influence of ultrasonic vibration on the machining process, they were able to evaluate the morphologies of the scratching surfaces, scratching forces, and material removal process in detail. The results, both theoretical and experimental, indicated that ultrasonic vibration altered the interaction between the cutting tool and the workpiece. The vibration enhanced the removal of SiC reinforcements by increasing the occurrence of cracks within them, while simultaneously improving the performance of the aluminum matrix. Consequently, the scratching forces in UVAS were smaller and more stable compared to CS. The coefficient of friction (COF) was also reduced, decreasing the adhesion effect of the aluminum matrix during the scratching process. This study highlights the significance of the removal mode of SiC reinforcements in determining the quality of the machined surface. The findings provide valuable insights for selecting appropriate processing parameters to achieve improved machining outcomes for SiCp/Al composites.

Sheng et al [51] focused on the machinability of SiCp reinforced aluminum metal matrix composites (MMCs) which have gained significant industrial applications. The experimental investigation involves end milling of a composite containing 14 wt.% SiCp using CVD coated carbide tools, with varying cutting parameters. The study examines the relationships between cutting force, surface roughness, cutting speed, and feed. In addition, the study utilizes scanning electron microscopy (SEM) to examine surface defects including ploughed furrows, pits, and matrix tearing. The experimental results provide valuable insights into the machinability of SiCp reinforced aluminum MMCs and shed light on the surface topography defects that may arise during the machining process.

N. Suresh et al [52] investigated the machinability of Al/SiC particulate metal-matrix composites (PMMCs) through end milling. The focus was on surface integrity and comparing the machinability of Al/SiC PMMC with Al alloy. The experimental results show that the presence of reinforcement enhances machinability, resulting in improved surface roughness and reduced tool clogging. The findings contribute to a better understanding of the end milling process and provide insights for better machining of Al/SiC PMMC. This has potential benefits for industrial applications by replacing Al alloys, leading to technological and economic gains.

G.F. Zhang et al [53] aimed to investigate the effect of SiC particle reinforcement on the machining of Aluminum/SiC composite. Experimental milling was conducted on the composite and pure aluminum using a tungsten carbide end mill. Surface observations and roughness measurements revealed that the composite has optimum machining parameters and achieves a smoother surface finish compared to pure aluminum. However, increasing the depth of cut and feed rate beyond certain limits led to the initiation of micro cracks at the SiC-Al interface and periodic formation of macro cracks on the machined surface. The damage mechanism during the machining process is discussed in detail in this paper.

Junwei et al [54] focused on improving the surface quality in micro-milling of SiCp/Al composites. The presence of brittle SiC particles and the size effect of the matrix can cause surface defects during the machining process. To address this, a method was proposed that involves achieving ductile regime machining of the particles and diverting away the defects in both the particles and matrix. Cutting parameters are selected based on this method to improve surface quality. The suitable range of feed per tooth for side milling and end milling is determined and validated through micro-experiments. The results demonstrate that the size effect of the matrix and the removal of SiC particles both affect the machined surface. By using the appropriate feed per tooth, the weak size effect of the matrix can be minimized, and the majority of the particles can be removed in the ductile regime, resulting in the best surface quality. Furthermore, this method has a more pronounced effect in end milling compared to side milling.

M. Chandrasekaran et al [55] focused on the end milling of Al-SiCp metal matrix composite components using a carbide end mill cutter. A fuzzy logic-based surface roughness prediction model is developed, taking into account spindle speed, feed rate, depth of cut, and SiCp percentage as input parameters. The model predicts surface roughness, which is then compared with experimental results. The analysis reveals that feed rate, spindle speed, and SiCp percentage have the most significant influence on surface roughness, while depth of cut has the least influence. This model provides a useful tool for optimizing machining parameters and achieving the desired surface roughness in metal matrix composite machining processes.

K. Shekhar et al [56] done an experimental investigation on the machinability of silicon carbide particulate metal matrix composites during milling, using multilayered coated carbide tools. The study focuses on the influence of machining parameters such as cutting speed, feed rate, and depth of cut on flank wear and surface finish. The microstructure of the machined surfaces, chip formation, and built-up edge (BUE) were examined using scanning electron microscopy (SEM). By analyzing the test results and SEM images, a suitable range of cutting conditions can be determined for effective machining of Al/SiCp MMC. This research provides valuable insights into optimizing the machining process for metal matrix composites.

Tao WANG et al [57] focused on the surface roughness generated during high-speed milling of silicon carbide particle-reinforced aluminum matrix composites (SiCp/Al) with a high-volume fraction (65%). The study examined different surface roughness parameters, including both 2D (Ra and Rz) and 3D (Sa and Sq), to evaluate the impact of milling parameters on surface quality compared to aluminum alloy. Additionally, the 3D topography of the milled surface is analyzed. The results show that the 3D parameters (Sa and Sq) are more effective in describing the influence of milling parameters on surface quality, with Sq being the preferred parameter due to its high sensitivity. Sq decreases with increasing milling speed and increases with higher feed rates. The study also finds that the axial depth of cut has a negligible influence on surface roughness.

R. Ghoreishi et al [58] researched on investigating the influence of high-speed cutting parameters on the surface roughness and cutting forces of machined AL/SiC composite, a type of Metal Matrix Composite (MMC). The cutting parameters include cutting speed up to 2500 m/min and the use of CO2 cryogenic coolant. The AL/SiC MMC used in the study contains 15% silicon carbide. A design of experiment method utilizing a 5-level central composite design was employed. The results indicate that the use of CO2 cryogenic coolant leads to a 3-8% increase in cutting forces, but improves the surface roughness by 19-23%. Optimal surface roughness is achieved when the cutting speed exceeds 1800 m/min, the feed rate is lower than the particle size per tooth, and the depth of cut ranges between 1 to 1.1 mm.

Shutao et al [59] investigated the effects of volume fraction of SiC particles on tool wear, cutting force, and surface roughness during high-speed milling of silicon carbide particle-reinforced aluminum matrix (SiCp/Al) composites. A single-tooth milling cutter with a diamond grain size of 5 μm was used. The volume fractions of SiC particles ranged from 15% to 56%. The results showed that the volume fraction had little effect on tool wear morphology but had a significant impact on wear amount and rate. Lower volume fractions resulted in smaller and slower tool wear, while higher volume fractions led to a significant increase in wear with cutting distance. The measured cutting force varied with the volume fraction, with a more pronounced influence observed as cutting distance increased. The initial cutting stage showed larger and fluctuating surface roughness, which gradually decreased and stabilized as the cutting distance increased. Overall, higher volume fractions of SiC particles resulted in larger surface roughness.

Wang et al. [60] done an experimental investigation on the high-speed milling of particle-reinforced aluminum matrix composites (PRAMCs) using polycrystalline diamond tools (PCD). The focus is on understanding the influence of cutting parameters on surface roughness, surface residual stress, and morphology of the PRAMCs, specifically Al/SiC/65p with a 65% volume fraction. The experiments also compare the surface integrity of the PRAMCs with that of the unreinforced matrix alloy Al 6063. The results reveal that milling speed is the most significant parameter affecting surface roughness, followed by the interaction between feed rate and milling speed, and then the feed rate alone. Axial depth of cut has the highest influence on surface residual stress, followed by milling speed and feed rate. Decreasing the feed rate slightly improves surface roughness, while the effect of milling speed is negligible. Surface residual stress measurements using X-ray diffraction show that the machined Al6063 surface exhibits tensile stress conditions, while the Al/SiC/65p composite surfaces have compressive stress conditions.

Arokiadass et al. [61] This study focused on modeling the machinability evaluation of LM25Al/SiCp metal matrix composites (MMCs) using the response surface methodology. The LM25Al/SiCp MMCs were manufactured through the stir cast route. The study investigates the combined effects of four machining parameters: spindle speed (N), feed rate (f), depth of cut (d), and the weight percentage of SiCp, on the performance characteristic of flank wear . Contour plots were generated to analyze the influence of the process parameters and their interactions on the machinability of the MMCs.

S. Jeyakumar et al [62] analyzed the machinability of aluminum (Al6061) silicon carbide particulate (SiCp) metal matrix composite (MMC) during the end milling process. The material's hardness and wear resistance, attributed to the abrasive nature of the reinforcement element, make it challenging to machine. The influence of spindle speed, feed rate, depth of cut, and nose radius on cutting force is investigated. The study also examines the impact of machining length on tool wear and the relationship between machining parameters and surface finish using a prediction model based on the response surface methodology (RSM). The prediction model was used to determine the combined effect of machining parameters on cutting force, tool wear, and surface roughness. The model's results were compared with experimental data and found to be in good agreement. The prediction model aids in selecting process parameters to minimize cutting force, tool wear, and surface roughness, thereby ensuring high-quality milling processes.

Vamsi et al [63] developed a mathematical models for cutting force (FR), Metal Removal Rate (MRR), and surface roughness (Ra) in order to optimize them. The Response Surface Methodology (RSM) with L31 empirical model was used to conduct trials on Al/SiC composites with different compositions. Various techniques such as XRD, EDS, and optical microscopy were employed to analyze the Al/SiC composites, and the SEM morphology of the machined samples was studied. The developed models for predicting the responses were validated using analysis of variance (ANOVA) to assess their adequacy. The optimal machining configuration was identified, resulting in a MRR reduction of 0.5%, a surface roughness improvement of 14%, and a cutting force reduction of 4% compared to the experimental results.

Rajeshwari et al. [64] focused on determining the optimal combination of geometrical parameters (helix angle, nose radius, rake angle) and machining parameters (cutting speed, feed rate, depth of cut) to minimize surface roughness and tool wear during end milling of Al 356/SiC metal matrix composites (MMCs) using a high-speed steel end mill cutter. The L27 Taguchi orthogonal design and ANOVA analysis are employed to evaluate the influence of each parameter. The grey-fuzzy logic multi-optimization algorithm was used to find the optimal levels for simultaneous reduction of surface roughness and tool wear. The results show the optimal combination and highlight the significance of cutting speed, helix angle, and rake angle. This study contributes to understanding the impact of tool geometry on end milling of MMCs using the Greyfuzzy logic algorithm.

Sujay et al. [65] examined the impact of speed, feed, depth of cut, and weight fraction on acceleration amplitude in end milling of Al6061-SiC metal matrix composite. Five specimens with different weight fractions were fabricated using the stir casting method. The milling tests were conducted using Taguchi's L25 orthogonal array, and a parametric investigation was performed. The analysis of variance (ANOVA) results revealed that the feed rate had the most significant influence on acceleration amplitude, followed by weight fraction, depth of cut, and speed.

Yingfei et al. [66] investigated the milling of SiCp/2009Al composites using PCD tools. The results showed a tool life of 150 minutes with various types of tool wear. Cutting forces were high, and severe vibrations were observed. The cutting temperature reached 523.7°C. The machined surface exhibited defects and a deformation layer thickness of 20-35µm. Chip formation mechanisms varied depending on the composite's SiC particle volume fraction. Surface generation mechanisms included material swelling, side flow, tool-workpiece vibration, feed rate, and tool nose radius.

In the study conducted by Wang et al. [67] focused on the performance of polycrystalline diamond (PCD) tools during high-speed milling of aluminum reinforced with high volume fraction (65%) and small size (10 µm) SiC particles. The effects of milling parameters (speed and feed rate) and PCD particle size on tool wear were investigated. The results showed that tool wear increased significantly with higher milling speeds, suggesting that speeds above 300 m/min are not suitable for industrial applications. Increasing the feed rate resulted in a larger volume of material removal before the tool wear reached a critical value of 0.6 mm. The optimal PCD particle size was found to be 10 µm. The main wear modes observed were flank wear and crater wear, and wear mechanisms were analyzed using scanning electron microscopy (SEM), laser scanning microscopy (LSM), and Raman spectroscopy

2.6 Research gap

Although numerous studies have investigated the machining characteristics of aluminum alloys there remains a significant research gap in understanding the cutting forces and surface roughness specifically in the face milling on Al6063 using a carbide tool.

Existing research on face milling of Al alloy and Al6063 primarily focuses on other cutting tools such as carbide inserts. Consequently, there is a lack of comprehensive studies that specifically explore the behavior of carbide tools in face milling operations for these materials. carbide tools are known for their unique characteristics, such as their ability to withstand high temperatures, durability, and cost-effectiveness. Understanding how carbide tools perform in face milling on Al6063 is crucial for practical applications, as it allows for optimized tool selection and improved machining efficiency.

Furthermore, while cutting forces and surface roughness are crucial parameters in evaluating machining performance, there is a lack of research specifically investigating their relationship in the context of face milling on Al6063. Most studies focus on end milling or utilize different machining processes altogether. Given the distinct characteristics of face milling (down milling), such as chip thickness variations and the impact of tool engagement, it is essential to investigate the corresponding effects on cutting forces and surface roughness.

In conclusion, the research gap lies in the limited understanding of cutting forces and surface roughness in the face milling (down milling) operation on Al6063 using carbide tools. By investigating this specific context, the thesis aims to bridge this gap and provide valuable insights that can contribute to advancements in machining practices and enable informed decision-making in the selection of cutting tools and machining parameters.

2.7 Scope and Objectives of Research Work

The scope of the research work for the thesis on the investigation of cutting forces and surface roughness in the face milling (down milling) operation on Al6063 with an carbide tool encompasses the following aspects:

1. Experimental Study: The research will involve conducting a series of experimental investigations to analyze the cutting forces and surface roughness during face milling operations. The experiments will be conducted on Al alloy and Al6063 workpieces using an carbide tool.
2. Machining Parameters: The research will focus on studying the influence of various machining parameters on cutting forces and surface roughness. These parameters may include cutting speed, feed rate, depth of cut, tool geometry, and tool wear.

3. Comparative Analysis: The research will involve a comparative analysis of the cutting forces and surface roughness between Al alloy and Al6063 . By examining the differences in machining behavior, the study aims to provide insights into the unique characteristics of these materials and their impact on the machining process.
4. carbide Tool Performance: The research will specifically investigate the performance of the carbide tool in face milling operations. This includes analyzing the tool wear patterns, tool life, and the correlation between tool wear and cutting forces/surface roughness. 5. Data Analysis and Interpretation: The collected experimental data will be thoroughly analyzed and interpreted to understand the relationship between cutting forces, surface roughness, and the machining parameters. Statistical methods and modeling techniques may be employed to extract meaningful insights from the data.

The objectives of the research work can be summarized as follows:

- To investigate the cutting forces and surface roughness in the face milling (down milling) operation on Al6063 using a carbide tool.

- To examine the influence of various machining parameters on cutting forces and surface roughness in the machining process.

- To compare the cutting forces and surface roughness between Al alloy and Al6063, providing insights into the material-specific machining behavior.

- To evaluate the performance of the carbide tool in face milling operations, including tool wear analysis and its correlation with cutting forces and surface roughness.

- To contribute to the existing body of knowledge on machining processes by providing valuable insights and recommendations for the selection of machining parameters and tools in face milling operations.

By accomplishing these objectives within the defined scope, the research work will advance the understanding of cutting forces and surface roughness in face milling operations, specifically for Al6063 with an carbide tool, and provide practical guidelines for improving the machining performance and product quality in industries working with these materials.

CHAPTER 3:

Methodology and Experimental work

3.1 INTRODUCTION

The aim of this study is to examine how cutting speed, feed rate, depth of cut, and width of cut impact cutting force and surface roughness during the face milling (Down milling) operation on Al6063 with carbide tool. In this chapter, we will outline the experimental techniques employed for the research. This means that each parameter was varied individually while keeping the other parameters constant at their default values. By systematically altering one parameter at a time, we were able to observe the isolated effects of each parameter on the cutting force and surface roughness. This approach helps in understanding the individual contributions of the variables and their influence on the machining process.

To ensure efficient and effective experiments, a scientific approach is necessary for planning and conducting them. The process planning involves utilizing statistical design of experiments, which enables the collection of relevant data and its subsequent analysis using statistical methods. This approach ensures that the results obtained are reliable and objective. The design of the experiments and the statistical analysis of the data are interconnected because the chosen method of analysis relies on the experimental design.

By employing the design of experiments, several advantages can be gained. These include improving the performance of existing processes, reducing experimental time, enhancing reliability, achieving product robustness, and minimizing the number of trials required.

All the experimental work in this study was performed using by a HASS CNC milling machine at Blue Earth lab, Jadavpur University, Kolkata, India. Detailed information about the workpiece materials, cutting tools, machine tools, and measuring equipment is provided below.

3.2. Workpiece and cutting tool details

1. Cutting: Once the AL6063 workpiece has solidified, it is removed from the mold. To achieve the desired dimensions and shape, the cylindrical workpiece with diameter 50 mm is cut using a saw cutter. This cutting process ensures that the workpiece is obtained in the desired width and diameter.

Figure 3.1 : Veekay Cutting machine Fig. 3.2 : Cylindrical cast cut into piece

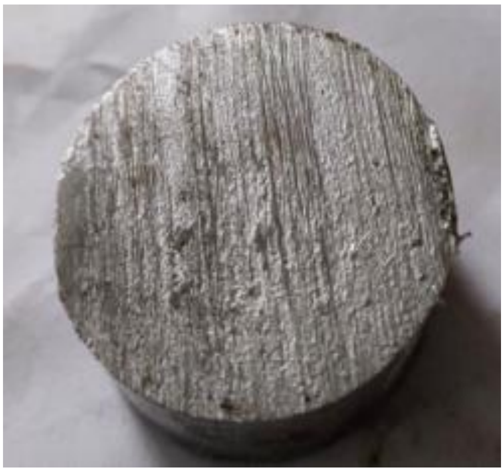

Fig 3.3 : after cutting the cylindrical cast Fig.3.4 : total no. of pieces after cutting

2.Facing: After cutting the workpiece, it may undergo facing operations on a lathe machine. Facing involves removing a thin layer of material from the outer surface of the workpiece to create a smooth and flat surface. This step helps to prepare the workpiece for subsequent machining operations.

Fig.3.5 : lathe machine used for facing

Fig. 3.6 : facing operation

Figure 3.7 : Final workpiece specimen

Fig. 3.8: Total no. of workpiece

Cutting tool

The AlCrN coating is utilized to produce various tools because it has exceptional toughness at high temperatures and wear resistance under intense mechanical stress. This coating is also used to treat materials that are difficult to cut. As shown in figure 3.3, Walter make AlCrN coated tool has been used for experimental work.

Figure 3.9 AlCrN coated end mill tool

The AlCrN coated tool is generally developed through the following process. AlCrN coating is deposited on cemented carbide insert substrates with a mirror-polished surface finish. For AlCr based coating on substrates, the temperature of the substrates is held at 500°C approximately, while the temperature of substrates is held at 600°C for AlTi based coating on substrates. The deposition times are adjusted in order to achieve the thickness of all the coatings. Surface roughness characterization and the material ratio curves for the deposited coatings before and after surface treatment are obtained using a Mahr Perthometer model with surface texture analysis software. Micro-hardness, as well as the Young Modulus of the coatings, has been also measured.

3.3 Milling machine details

The most efficient use of the CNC milling process requires the choice of proper sets of machining process parameters. It can primarily be accomplished by interpreting the interrelationship between various numbers of input machining process parameters and identifying the most favourable machining conditions which directly affect the production time, cost as well as superior quality.

So, in this experimental work, experimental trials have been performed on a particular machine tool. Various process parameters have been comprehended sequentially for two major output response measures as surface roughness and cutting force. In the present work, experiments are executed on HASS CNC machining center.

Figure 3.10 HASS CNC machine

the important specifications of the CNC milling machine are as follows; X, Y, Z travel is 510, 410, 510 mm, respectively; table size is 660 x 360 mm; 20 number of tools; 89 mm is the maximum tool diameter which can be fitted; 250 mm is the maximum tool length; maximum spindle rpm is 10000 and 7.5 KW is the power available.

Controls and Operation: The CNC milling machine incorporates userfriendly controls and interfaces for easy operation. It may feature a control panel with buttons, knobs, and digital displays to set and monitor machining parameters such as spindle speed, feed rate, and tool positioning. Advanced models may include CNC (Computer Numerical Control) capabilities for enhanced automation and precision.

Tooling and Tool Holders: The machine is designed to accommodate a variety of cutting tools and tool holders. Common tooling options include end mills, face mills, and slotting cutters. The tool holders securely hold the cutting tools and allow for quick and efficient tool changes.

Axis Movement: The CNC milling machine typically offers three primary axes of movement: X-axis (longitudinal movement), Y-axis (crosswise movement), and Z-axis (vertical movement). These axes enable precise positioning and machining of the workpiece.

Workpiece Handling: The machine may feature clamping mechanisms or fixtures to securely hold the workpiece in place during machining. This ensures stability and accuracy during milling operations.

Safety Features: CNC milling machines incorporate various safety features to protect operators and prevent accidents. These may include emergency stop buttons, interlocks, and safety guards to shield operators from rotating parts and flying chips.

Applications: The CNC milling machines find applications in a wide range of industries, including automotive, aerospace, tool and die making, and general machining. They are suitable for tasks such as face milling, slotting, contouring, and drilling operations on various materials, including metals, plastics, and composites.

CNC milling machines are known for their reliability, precision, and versatility. They are widely used by manufacturers and machining facilities around the world to produce high-quality components with tight tolerances and superior surface finish.

3.4 Working setup and principle

The HMT horizontal milling machine operates based on the following principles:

1. Setup: The workpiece is securely clamped on the table or held in place with fixtures which is below the dynamometer
2. Tool Selection: The appropriate cutting tool is selected based on the desired operation and material being machined.
3. Tool Setup: The selected tool is mounted on the arbor or tool holder and secured tightly.

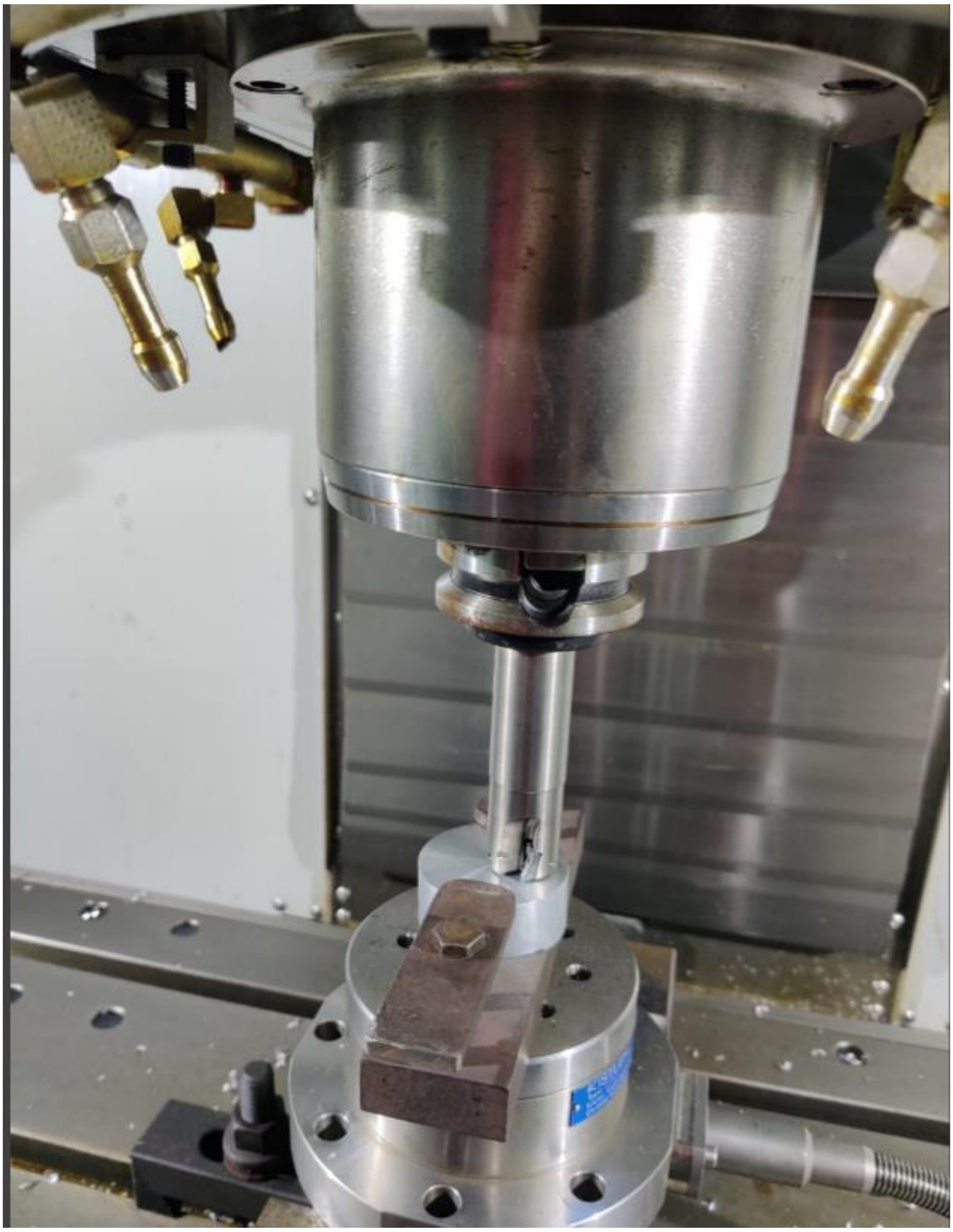

Fig. 3.11 : Experimental setup of machining

4. Machining Parameters: The operator sets CNC Program the required spindle speed, feed rate, and depth of cut.

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N119 G00 G21 G80 G40 G17
N120 G90
N121 G54
N122 G53 Z0.0
N130 T1
N131 M6
N132 S2000 M03
N133 G00 G90 X0.0 Y95.0
N134 G43 Z10.0 H1
N135 M08
N136 G187 P1 E0.005
N137 Z5.0
N138 G01 Z-2 F100.0
N139 Y-95.0 F1000.0
N140 G00 Z10.0
N149 M09
N150 M05
N151 G53 Z0.0
N152 M30
%
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N119 G00 G21 G80 G40 G17
N120 G90
N121 G54
N122 G53 Z0.0
N130 T1
N131 M6
N132 S1500 M03
N133 G00 G90 X13.3333 Y95.0
N134 G43 Z10.0 H1
N135 M08
N136 G187 P1 E0.005
N137 Z5.0
N138 G01 Z-0.8 F120.0
N139 Y-95.0 F1200.0
N140 G00 Z10.0
N141 X-13.3333 Y95.0
N142 Z5.0
N143 G01 Z-0.8 F120.0
N144 Y-95.0 F1200.0
N145 G00 Z10.0
N149 M09
N150 M05
N151 G53 Z0.0
N152 M30
%
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Figure 3.12 : Final CNC Program specimen

5. Operation: The machine is started, and the spindle rotates, driving the cutting tool.
6. 6. Cutting Process: The tool engages with the workpiece, and the table is moved along the desired axes to create the desired shape or size.

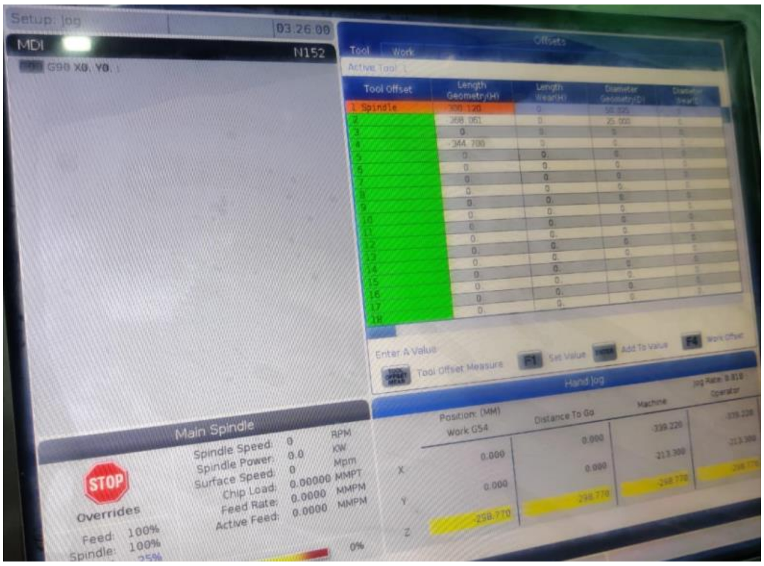


Fig. 3.13 : Experimental setup of machining

DESIGN OF EXPERIMENT AND OPTIMIZATION TECHNIQUES

4.1 Output response measuring equipments

Cutting force and surface roughness measurements have been carried out in this experimental work. Kistler tool dynamometer and Surftest surface roughness measurement have been used to measure cutting force and surface roughness respectively.

4.1.1 Cutting force measurement

Kistler tool dynamometer is widely used to measure cutting forces and torque during end milling as well as drilling process. A four-component dynamometer is used to determine the torque Mz and the three cutting forces. The dynamometer is extremely stiff which results in a high natural frequency. Its higher resolution permits the measurement of the smallest dynamic changes in forces and torques. As illustrated in figure 3.8, the dynamometer comprises a four-component sensor mounted under high preload between a base plate and a top plate. It must be considered that the coupled and eccentric loads may result in a reduction of the measuring ranges. The sensor is grounded. As a result, ground loop issues are virtually avoided.

Figure 4.1 Kistler tool Dynamometer

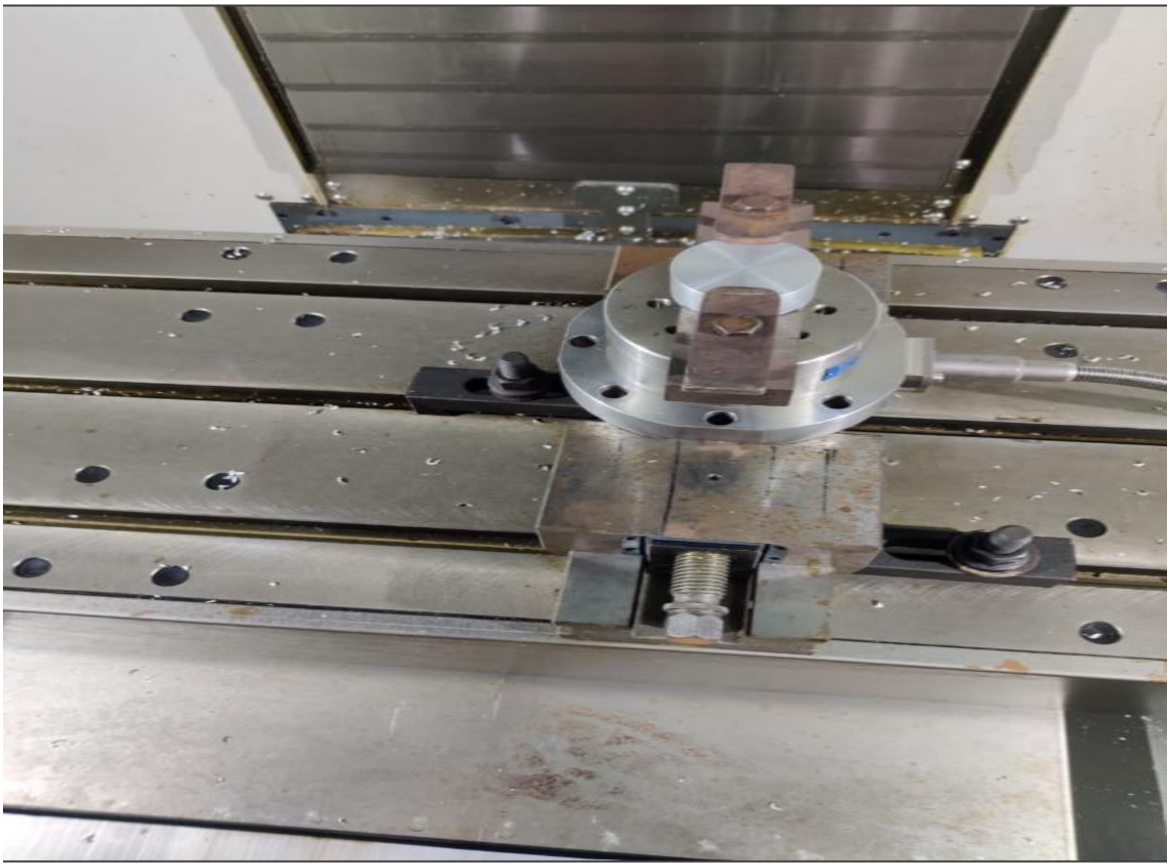


Fig.: 4.2 workpiece setup on dynamometer

Screws may be used to secure the dynamometer to any clean, face-ground supporting surface such as the table of a machine tool. Eight M8 mm threaded holes on the cover plate are provided for mounting the workpiece as shown in figure 3.9. To ensure proper mechanical interaction between the force introducing elements and the cover plate, the supporting surfaces must be face-ground. The tool holder type 9404 is suitable for attaching tools with a shank cross-section of up to 20x20 mm.

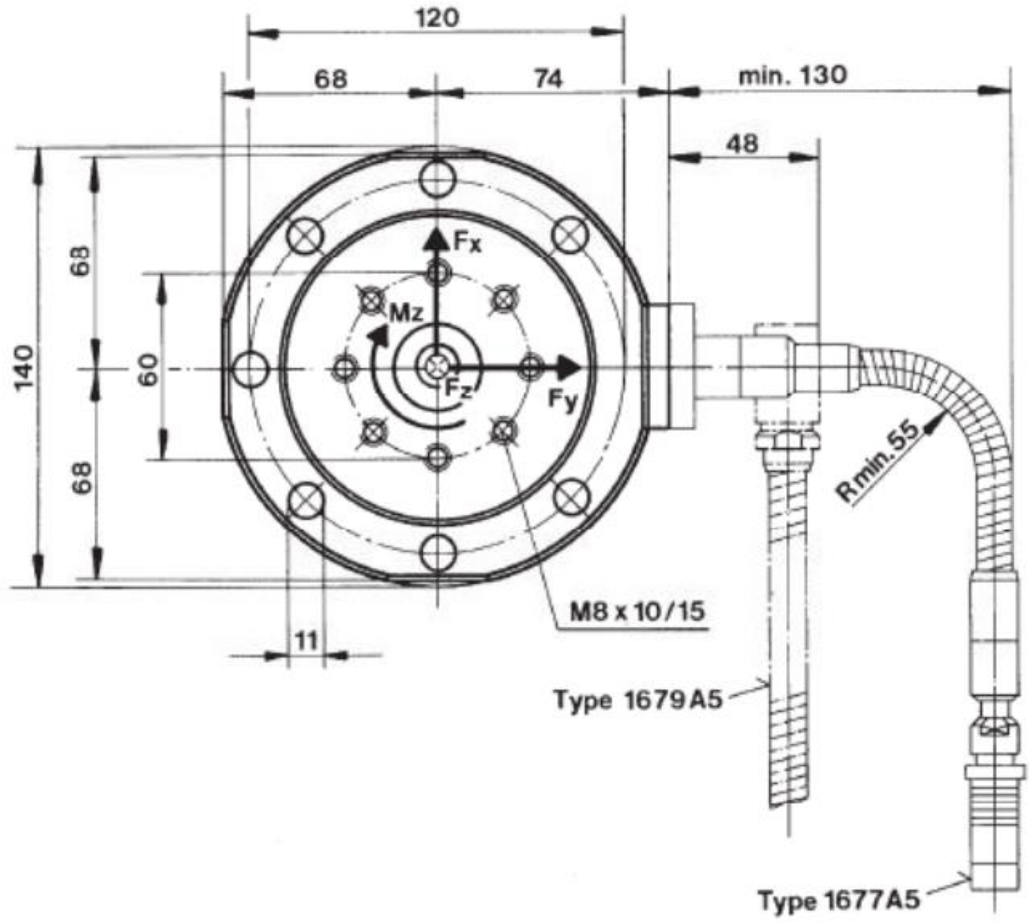


Figure 4.3 Dimensions of Kistler tool dynamometer

A four-component measuring system requires, in addition to the dynamometer, a multicore high-insulation connection cable and four charge amplifier channels. These convert the dynamometer's charge signals to output voltages. The output voltage is proportional to the magnitudes of the forces and moments. The multichannel charge amplifier is utilized for this purpose. Table 3.16 contains technical specifications for the Kistler 9272 tool dynamometer, which has been utilized in this experimental study. Various softwares (such as Lab view, Kistler Dyno Ware etc) have been used for data acquisition during machining.

4.1.2 Surface Roughness Measurement

The surface roughness of the sample surfaces is measured using a stylus-type profilometer called Talysurf (Taylor Hobson, Surtronic 3+). The profilometer is configured with specific settings for accurate measurements. These settings include a cut-off length of 0.8 mm, filter 2CR, traverse speed of 1 mm/s, and a 4 mm traverse length.

By employing these settings, the profilometer scans the sample surfaces, collecting data on the roughness parameters. The measured roughness parameter used in this study is CLA (Center Line Average), which provides an average value of the surface roughness over the specified traverse length.

Fig.4.4: surtronic 3+ device

To ensure consistency in the roughness measurements, the samples are selected based on a criteria of having less than 1% variation in the roughness values. This selection criterion helps to ensure that the samples chosen for further analysis exhibit a relatively uniform and consistent surface roughness.

Overall, the Talysurf profilometer with the specified settings allows for accurate and precise measurement of surface roughness, and the criterion of less than 1% variation in roughness values ensures the selection of suitable samples for subsequent analysis in the investigation.

Figure 4.5: setup for surface roughness measurement

4.2 Experimental setup

For the design of experiments in the experimental investigation, the ranges of various parameters have been selected using the one-variable-at-a-time method and data provided by the cutting tool supplier. The following parameter ranges have been chosen:

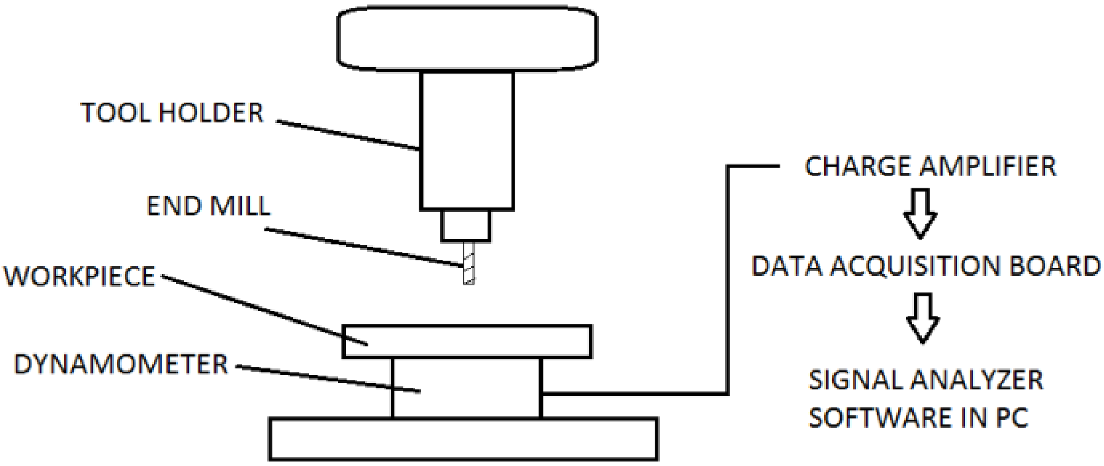


Figure 4.6 Experimental setup

1. Cutting Speed (N): 695-2341 RPM

   • This parameter represents the speed at which the cutting tool moves across the workpiece. It affects the rate of material removal and can impact tool life and surface finish.

2. Feed Rate (F): 196-2000 mm/min

• The feed rate refers to the rate at which the workpiece is fed into the cutting tool. It determines the amount of material removed per unit of time and affects the chip formation and tool wear.

3. Depth of Cut (DOC) (d): 0.659-2.341 mm

• The depth of cut is the distance between the original surface of the workpiece and the final cut surface. It determines the thickness of the material removed in each pass and influences cutting forces and surface finish.

By selecting these ranges, the experimental investigation aims to explore the effects of different cutting speeds, feed rates, depths of cut, and widths of cut on the cutting forces and surface roughness. This approach allows for a systematic analysis of each parameter's individual impact on the machining process and provides valuable insights for optimizing the cutting conditions for improved performance and efficiency

The machining process was performed on a workpiece made of AA 6063 with a diameter of 50 mm. The experiments were conducted using an HASS CNC milling machine. For the experimental work, a carbide tool side and face cutter with a diameter of 20 mm. (as shown in Figure).

To measure the cutting forces during the machining process, a tool dynamometer (9272, Kistler make) was mounted on the table of the machine tool. The tool dynamometer is designed to accurately capture and measure the cutting forces exerted on the tool during the operation. These force signals were then amplified through a charge amplifier to enhance their strength and quality

The amplified force signals were further processed by converting them into analog signals using an A/D (Analog-to-Digital) acquisition card (PCI-6-23E, NI). This acquisition card facilitated the conversion of the analog signals into digital data, which could be easily processed and stored in a computer.

To collect and record the cutting force data, Dynoware software was utilized. Dynoware is a powerful programming environment that enables the acquisition, analysis, and visualization of data in real-time. It provided a user-friendly interface for data acquisition, allowing the researchers to monitor and record the cutting force signals during the machining process accurately.

Figure 4.7 Experimental setup

4.3 Central composite design

A well-designed experiment can significantly reduce the number of experiments required and hence a CCD approach is the most suitable approach to develop first and second-order models. This is the most well-known and often used class of designs for fitting secondorder models.

The star point and center point represent the experimental domain in the CCD method, which aids in determining the response surface plot. By assessing the precision of surface responses, the worth of α can be resolved; where star configuration has been shown as ± α. The α value can be resolved by estimating prospects and obtaining the required precision from surface responses. The location of the α value dictates the nature of the plan. The configuration rate is determined by the position of the points. The accuracy of the estimation is impacted by the number of trials conducted at the focal point. The quality by configuration approach is critical for estimating the variability and reactions of the coefficients. The critical angle means that the forecast error is indistinguishable from all points to the center points at a same distance. Finally, the CCD is categorized into three categories: CCC, CCI and CCF.

CCC (Circumscribed design)

The CCD model is uniformly magnetized with corner points, as indicated by the blue spots . The extract points are compelled from the sides by the red-colored central point. Each factor would have five levels in this CCD model. The star points are establishing new low and high boundaries for all variables. These layouts have circular, spherical or hyper spherical symmetry and each variable requires five levels. The CCC (Circumscribed) is found to be a rotatable design.

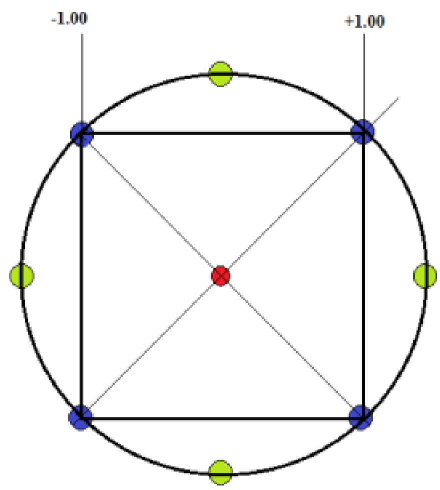


Figure 4.8 CCC mode

CCI (Inscribed design)

CCI (Inscribe design) has been utilized with the variable setting as star point and factorial design has been created within those limits of variable settings. CCI design is nothing new and complicated design but a modified version of CCC design. CCI design is generated by dividing the CCC design with α.

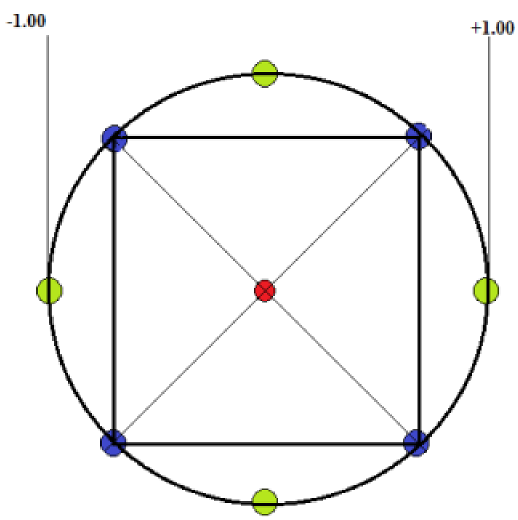


Figure 4.9 CCI Design

CCF (Face Centered design)

CCF design is suitable for 3 levels of each variable. In this CCF design, each face of the factorial space has been shown in figure 4.9 and star points have been shown as the center point, so α = ±1. CCF (Face centered design) is a non-rotatable design.

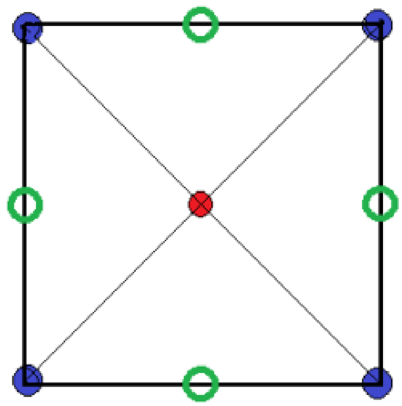


Figure 4.10 CCF (Face centered design)

Calculation of α value

The value of α can be defined as the calculated distance of each individual axial star point from the center in the CCD. If α is less than 1, it indicates the axial point must be inside a cube. If α value is greater than 1, it indicates the axial point is outside the cube. The value of α can be determined by the following equation.

$$\alpha = (\text{Number of factors})1/4$$

Table 4.1 Number of factor and alpha value

Number of factors	α value related to ± 1
2	± 1.414
3	± 1.682
4	± 2
5	± 2.378
6	± 2.828

In the CCD method, the total numbers of experiments are selected based on the number of factors. Also, the design of the four factors factorial has been formulated.

Central composite design matrix for 3 factors

Table 4.2 Central composite design matrix for 3 factors

SL.NO	STD ORDER	RUN ORDER	PT TYPE	BLOCKS	A	B	C
1	8	1	1	1	1	1	1
2	7	2	1	1	-1	1	1
3	2	3	1	1	1	-1	-1
4	4	4	1	1	1	1	-1
5	16	5	0	1	0	0	0
6	14	6	-1	1	0	0	1.68179
7	3	7	1	1	-1	1	-1
8	15	8	0	1	0	0	0
9	10	9	-1	1	1.68179	0	0
10	19	10	0	1	0	0	0
11	6	11	1	1	1	-1	1
12	18	12	0	1	0	0	0
13	11	13	-1	1	0	-1.68179	0
14	20	14	0	1	0	0	0
15	9	15	-1	1	-1.68179	0	0
16	1	16	1	1	-1	-1	-1
17	12	17	-1	1	0	1.68179	0
18	17	18	0	1	0	0	0
19	5	19	1	1	-1	-1	1

20	13	20	-1	1	0	0	-1.68179

Followings are the advantages of the CCD method; It turns out to be the extension of 2 level factorial designs. It gives maximum information in a minimum experimental data and helps to assess the squared terms in the second-order model. It helps to predict curvature in achieved continuous reactions and to estimate nonlinearity of output responses in the given informational set.

Followings are limitations of the CCD method; It is seen that the star points are outside the hypercube, so the quantity of levels that must be adapted to each factor is five rather than three, and some of the time it is difficult to accomplish the value of factors. Depending upon the design, the squared terms in the model won't be symmetrical to one another and inability to estimate individual interaction terms, i.e., linear by quadratic or quadratic by quadratic.

The objective of this research work is to investigate the effect of cutting speed, feed, depth of cut and width of cut on surface roughness and cutting force during milling of AL6063 . The experimental details have been described in this chapter. The details of the workpiece, cutting tool and machine tool have been described. The details of the equipment to measure the output responses have also been discussed here. The initial ranges of input parameters have been chosen based on One Variable at a Time (OVAT). Response surface methodology (RSM) central composite design (CCD) method is employed for the design of experiment. A graphic representation of different points has been shown for the three variables.

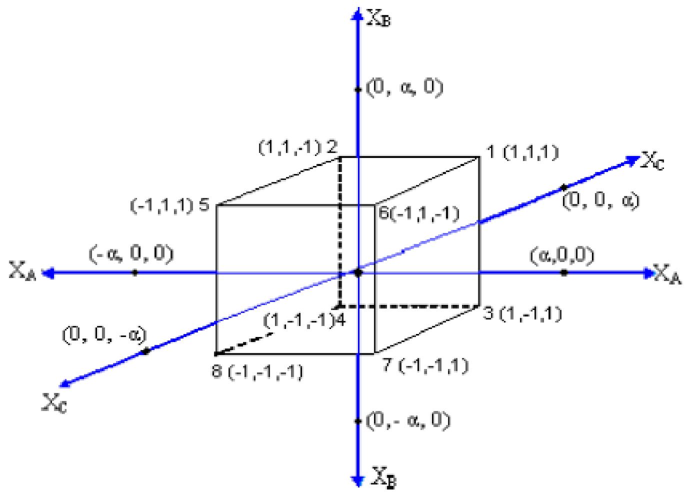


Figure: 4.10 Configuration of CCD for 3 factors

<u>Value of experiment Central composite design matrix for 3 factors</u>

Table 4.2 Value of experiment Central composite design matrix for 3 factors

SL.NO	STD ORDER	RUN ORDER	PT TYPE	BLOCKS	DOC	FEED	SPEED
1	8	1	1	1	2	1000	2000
2	7	2	1	1	1	1000	2000
3	2	3	1	1	2	400	1000
4	4	4	1	1	2	1000	1000
5	16	5	0	1	1.5	700	1500
6	14	6	-1	1	1.5	700	2341
7	3	7	1	1	1	1000	1000
8	15	8	0	1	1.5	700	1500
9	10	9	-1	1	2.341	700	1500
10	19	10	0	1	1.5	700	1500
11	6	11	1	1	2	400	2000
12	18	12	0	1	1.5	700	1500
13	11	13	-1	1	1.5	196	1500
14	20	14	0	1	1.5	700	1500
15	9	15	-1	1	0.659	700	1500
16	1	16	1	1	1	400	1000
17	12	17	-1	1	1.5	1204	1500
18	17	18	0	1	1.5	700	1500

19	5	19	1	1	1	400	2000
20	13	20	-1	1	1.5	700	695

In this experimental work, cutting speed Vc is converted into spindle speed N as a machining parameter For conversion cutting speed into spindle speed following equation is used ;

$$Vc = \pi DN/1000 \text{ (m/min)}$$

Where Vc is cutting speed in m/mm, D is the diameter of the cutting tool in mm and N is spindle speed in revolutions/minute. The diameter of cutting tool is 25 MM. so the following spindle speeds have been converted from cutting speeds which have been taken during experiment work as shown in the table 4.3

Table 4.3 : Convert spindle speed into cutting speed

Sr.No.	Spindle speed (rpm)	Cutting speed (m/min)
1	2000	314
2	1000	157
3	1500	235.5
4	2341	367.5
5	695	109.115

In milling operation, the cutting operation is always intermittent and the risk of thermal cracking is also caused higher by the coolant. So dry machining is, therefore, the primary choice to increase tool life, especially when cutting with mmc, cast iron and some composite materials. In terms of cutting force and chatter stability, the down face milling mode is more suited for face milling than the up end-milling mode. All experiments have been repeated two times and an average value has been considered. Following process or has been done for experimental work.

1. Cutting tool has been fixed in the spindle of the CNC milling machine.

2. Tool dynamometer has been mounted on the machine bed and connected with the amplifier and dynoware system properly.

3. Workpiece has been mounted on tool dynamometer with help of clamping.

4. Experimental readings have been taken using Carbide tool with cutting parameters such as spindle speed 2000, 1000, 1500, 2341 and 695 rpm , feed 314, 157, 235.5, 367.5, 109.115mm/min, depth of cut 1 and 2mm.

5. Total of 20 experiment runs have been done in this way.

6. Cutting forces have been measured during the machining process using a tool dynamometer

7. Surface roughness has been measured using a surface roughness tester after the machining process.

4.4 Summary

This chapter provides a detailed description of the workpiece, including types, designations, and behavior, along with a comprehensive discussion on the cutting tool, including types, designations, and a detailed drawing. The measurement of important responses such as cutting force and surface roughness is explained, supported by illustrations, photographs, and principles of the measuring equipment. The specifications of the tool dynamometer, surface roughness measuring equipment, and horizontal milling machine are tabulated. Initial experiments are analyzed to determine levels of input parameters for the subsequent design of experiments, which are detailed using response surface roughness. The levels of input parameters and measured responses are tabulated, and the significant effects of the input machining parameters on the responses are reported. Overall, this chapter provides a comprehensive foundation for understanding the workpiece, cutting tool, measurement process, and subsequent investigation of input parameters and their effects on the responses.

CHAPTER 5

RESULT AND DISCUSSION

The results and discussion section of this thesis presents a comprehensive analysis of the cutting forces and surface roughness obtained from face milling operations in down milling mode, specifically focusing on Al6063 using a carbide tool. This section highlights the findings and their significance in understanding the effects of various cutting parameters on these machining responses. The discussion explores the relationships between cutting forces, surface roughness, and the selected cutting parameters, shedding light on the optimization of machining conditions for improved performance and surface quality. By examining the experimental data and comparing it with existing literature, this section provides valuable insights into the behavior of Al6063 MMC during face milling operations, offering practical implications for the machining industry.

5.1 RESULT AND DISCUSSION ON CUTTING FORCE AND MRR

The main effect plot of cutting speed, feed, depth of cut and width of cut are plotted for cutting force and surface roughness during end milling of AI6063. The analysis of variance (ANOVA) has been performed to ensure the competence of the fitted model and carry out graphical and regression analysis.

Table 5.1 Experimental Result

SL. NO	DOC (mm)	FEED (mm/ min)	SPEED (rpm)	Fx (N)	Fy (N)	Fz (N)	SR (µm)	AVG SR (µm)	MRR
1	2.000	1000	2000	7.969696	5.648042	7.885649	1.04 1.06 1.08	1.06	3.195
2	1.000	1000	2000	5.66696	6.0008118	7.428851	1.02 1.05 1.07	1.07	2.990
3	2.000	400	1000	6.29029	22.41238	21.26522	0.80 0.90 0.84	0.886	6.290
4	2.000	1000	1000	5.993316	16.44139	18.44322	1.86 1.90 1.88	1.88	6.138
5	1.500	700	1500	8.813389	11.38208	14.67943	1.37 1.38 1.30	1.35	5.060
6	1.500	700	2341	6.035001	8.808919	9.98805	1.50 1.44	1.48	7.956

							1.46		
7	1.000	1000	1000	7.94885	8.797263	12.33096	1.56	1.59	3.102
							1.59		
							1.53		
8	1.500	700	1500	7.986148	11.46004	15.4433	1.4	1.2	5.322
							1.0		
							1.2		
9	2.314	700	1500	4.707932	18.16671	19.48811	0.75	0.743	1.050
							0.740		
							0.71		
10	1.500	700	1500	6.315541	132.5706	15.34767	1.34	1.36	3.004
							1.38		
							1.30		
11	2.000	400	2000	9.468133	16.61843	13.85391	0.950	0.977	6.008
							0.927		
							0.977		
12	1.500	700	1500	14.45434	13.96413	12.47014	1.20	1.28	5.032
							1.30		
							1.26		
13	1.500	196	1500	6.936258	21.11144	18.93174	0.51	0.519	5.491
							0.520		
							0.518		
14	1.500	700	1500	7.343039	10.41746	11.40354	1.0	1.2	5.128
							1.4		
							1.2		
15	0.659	700	1500	6.958832	5.151397	5.248367	0.97	0.979	1.895
							0.988		
							0.95		
16	1.000	400	1000	10.98667	9.883589	11.70525	0.932	0.937	2.452
							0.941		
							0.938		
17	1.500	1204	1500	7.212881	8.507192	11.46935	1.36	1.34	3.462
							1.36		
							1.32		
18	1.500	700	1500	12.20056	10.25214	13.38982	1.45	1.49	4.278

							1.53		
							1.49		
19	1.000	400	2000	6.758712	11.56435	7.984416	0.70	0.71	3.179
							0.73		
							0.72		
20	1.500	700	695	8.588861	17.12253	21.74211	1.40	1.41	4.639
							1.42		
							1.40		

5.2 Regression Equation

The regression equation in the terms of the actual factor for the cutting force as a function of three input process variables has been developed using experimental data and is given underneath. The insignificant coefficients of several terms have been omitted from the quadratic equation.

Regression Equation of Fx

Fx = 10.4 + 2.0 DOC + 0.0047 FEED - 0.0032 SPEED - 4.30 DOC*DOC
- 0.000007 FEED*FEED
- 0.000002 SPEED*SPEED + 0.00195 DOC*FEED + 0.00583 DOC*SPEED
+ 0.000001 FEED*SPEED

5.3Regression Equation of Fy

Fy = -1227602 + 702880 DOC + 913 FEED + 735 SPEED - 234285 DOC*DOC - 0.652 FEED*FEED
- 0.244 SPEED*SPEED - 0 DOC*FEED - 0 DOC*SPEED - 0.000 FEED*SPEED

Regression Equation of Fz

Fz = -9.0 + 29.94 DOC + 0.0100 FEED - 0.00157 SPEED - 3.68 DOC*DOC + 0.000001 FEED*FEED
+ 0.000001 SPEED*SPEED - 0.00738 DOC*FEED - 0.00467 DOC*SPEED
- 0.000004 FEED*SPEED

Regression Equation of SR

SR = -74 + 94.1 DOC - 0.013 FEED + 0.0004 SPEED + 10.5 DOC*DOC + 0.000030 FEED*FEED
+ 0.000011 SPEED*SPEED - 0.0882 DOC*FEED - 0.0530 DOC*SPEED
+ 0.000087 FEED*SPEED

Regression Equation

MRR
R = -11.36 + 19.28 DOC + 0.00775 FEED - 0.00255 SPEED - 4.38 DOC*DOC
- 0.000000 FEED*FEED
+ 0.000003 SPEED*SPEED - 0.00286 DOC*FEED - 0.00192 DOC*SPEED
- 0.000003 FEED*SPEED

Effect of input Parameters on Performance Measure

The effect of various input process variables on performance measures such as surface roughness, cutting force and MRR has been presented in this section. Individually as well as the interaction effects of various input process parameters have been discussed on the considered responses. The effect of different parameters on different performance measures is given in subsequent subsections.

5.3Main Effects Plot

A main effects plot is a plot of the mean response values at each level of a design parameter or process variable. One can use this plot to compare the relative strength of the effects of various factors.

Main Effect plot can be seen that an increase in cutting speed from 109.115 to 367.5 m/min leads to reduction in surface roughness. The surface roughness is reduced due to reduction of the cutting force. From previous research works, surface roughness and cutting force have a strong positive correlation. Surface roughness has been reduced with increase in the cutting speed (from 109.115 to 367.5 m/min) because of thermal softening of work material and related reduction in cutting force. In general, the contact area between the workpiece and cutting tool has been increased by increasing feed rate. more feed rate has resulted in higher thrust force and vibration which has produced poor surface finish. More heat is generated at the contact area between workpiece and cutting tool due to higher thrust force by increasing depth of cut. It has been presented by figure that by increase in depth of cut, surface roughness has been reduced.

As shown in figure

Main Effect plot for Fx

Doc, Feed and Speed increase Fx increase than Decreasing for Fx. Fx force as well as vibration can be reduced resulting in higher surface finish. As shown in figure 5.31

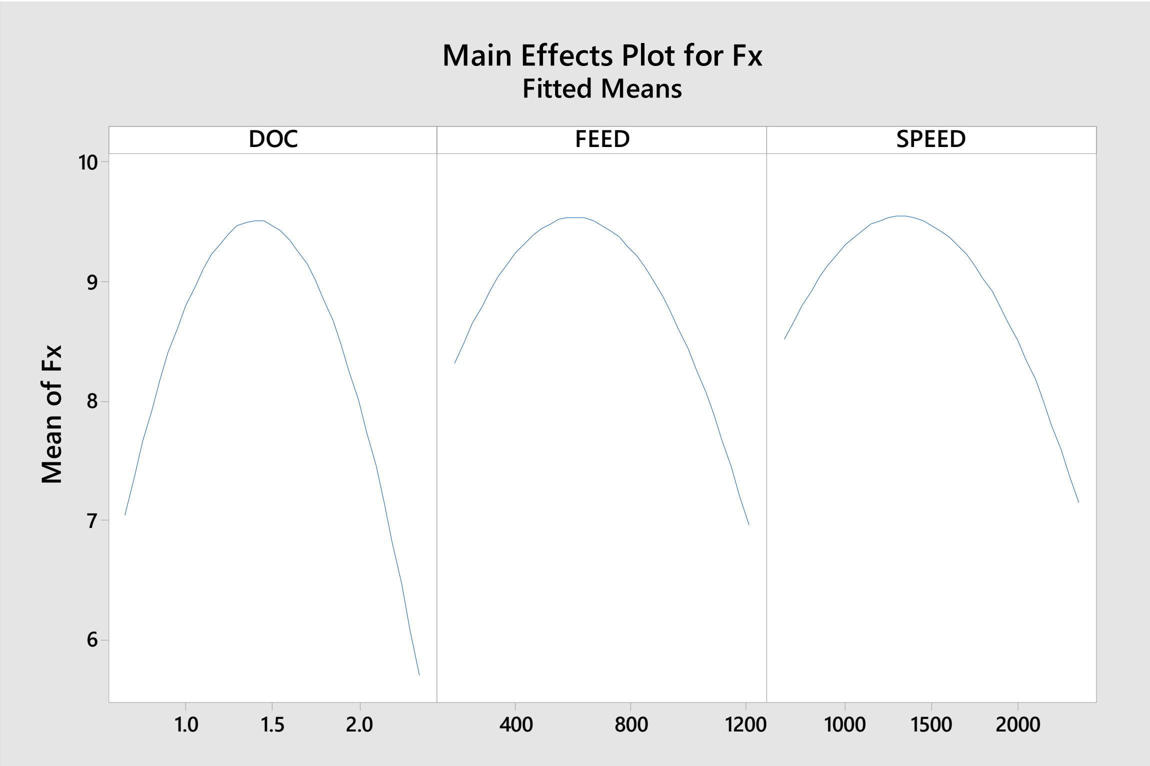


Figure 5.3.1 *plot for Fx*

Main Effects plot for Fy

Doc ,Feed and Speed increase Fy increase than Decreasing for Fy. As shown in figure 5.3.2

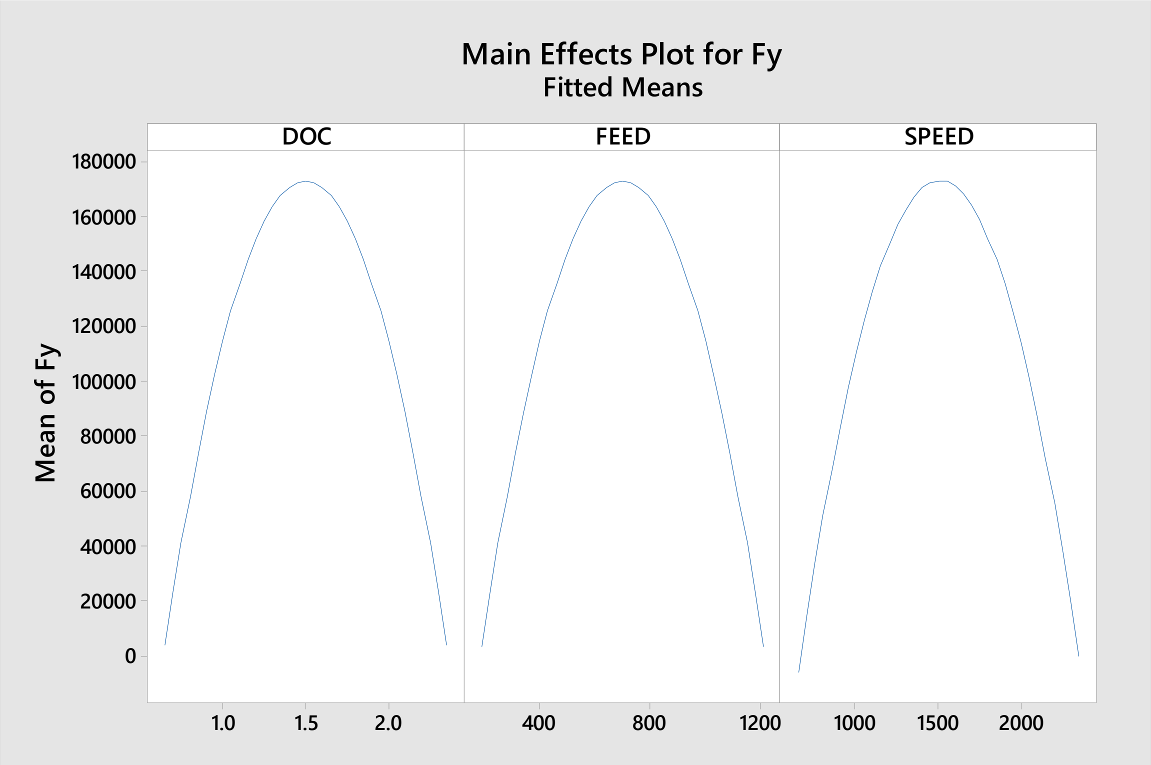


Figure 5.3.2 *plot for Fy*

<u>Main Effects plot for Fz</u>

Doc, Feed and Speed increase Fz increase than Decreasing for Fz. As shown in figure 5.3.3

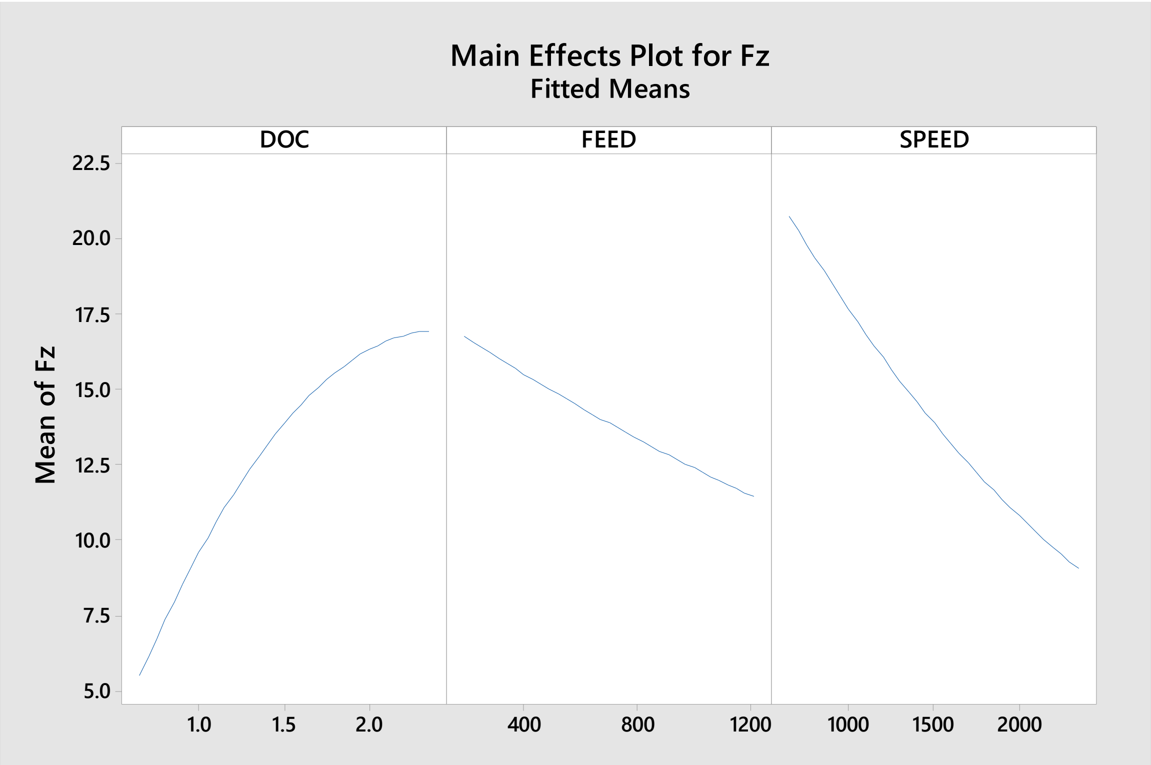


Figure 5.3.3 *plot for Fz*

Main Effects plot for SR

Doc, Feed and Speed increase SR increase than Decreasing for SR. As shown in figure 5.3.4

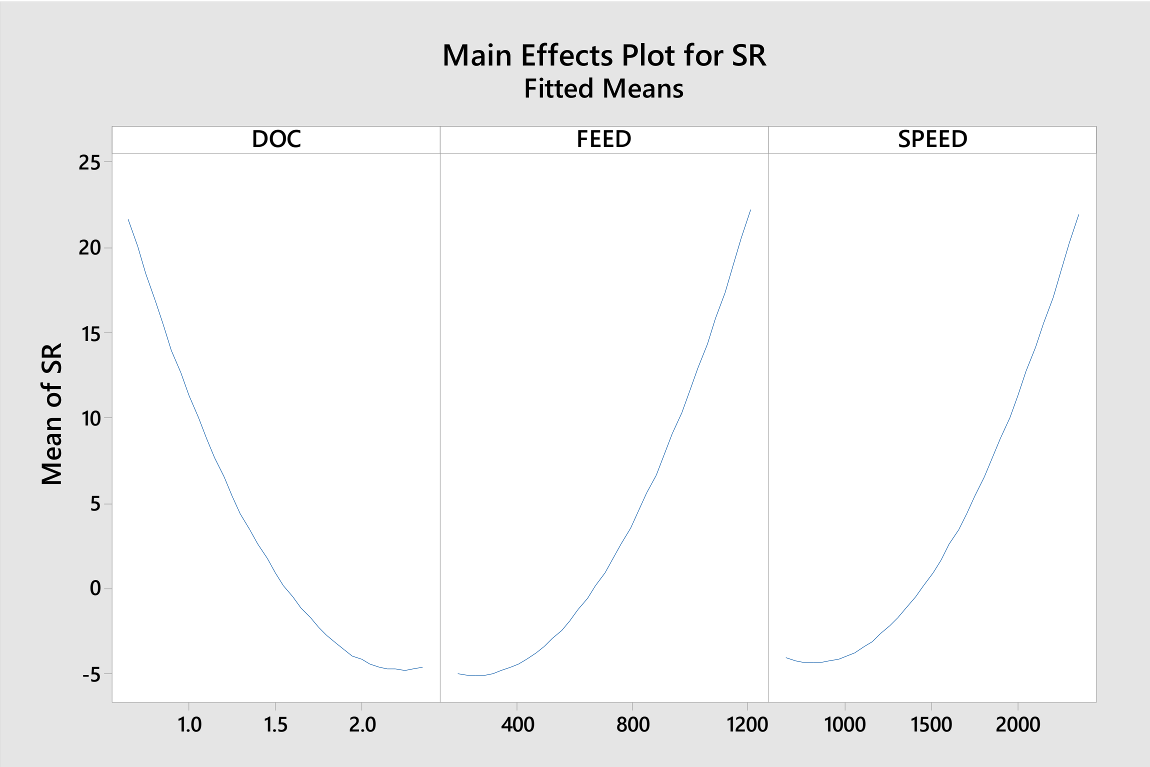


Figure 5.3.4 *plot for SR*

Main Effects plot for MRR

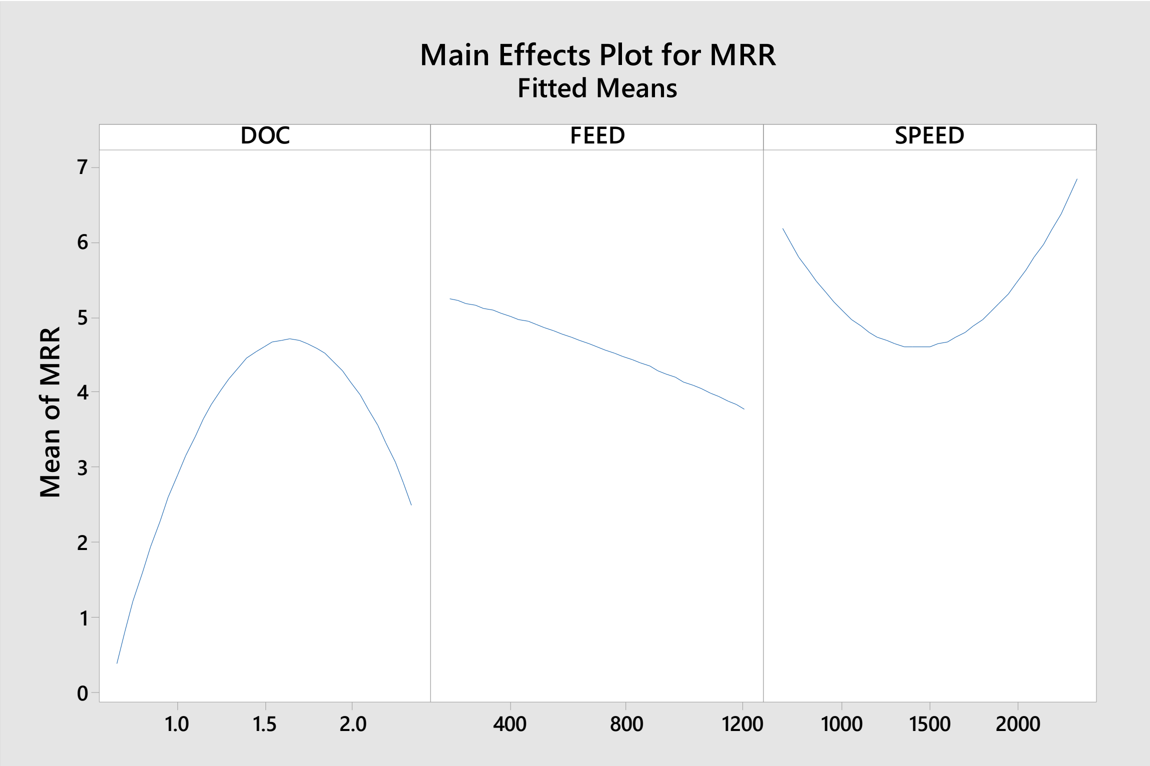


Figure 5.3.5 *plot for MRR*

5.4Contour plot

A contour plot is a graphical technique for representing a 3-dimensional surface by plotting constant z slices, called contours, on a 2-dimensional format. That is, given a value for z, lines are drawn for connecting the (x,y) coordinates where that z value occurs.

Two interactions have been found to be significant (cutting speed- feed and - depth of cut). Cutting force has been obtained by using this plot. As shown in figure

Contour plot of Fx vs FEED, DOC (Hold value speed 1500) shown in figure 5.4.1

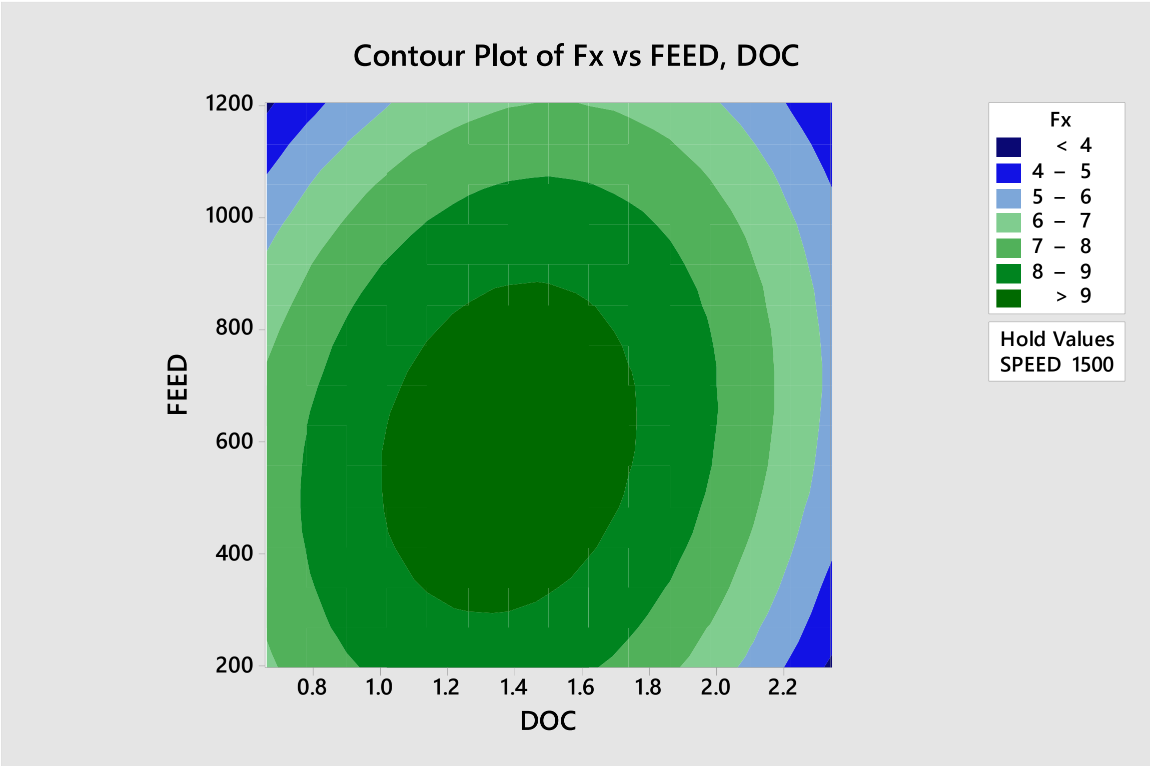


Figure 5.4.1 Contour plot of Fx vs FEED, DOC

Contour plot of Fy vs FEED, DOC (Hold value speed 1500) shown in figure 5.4.2

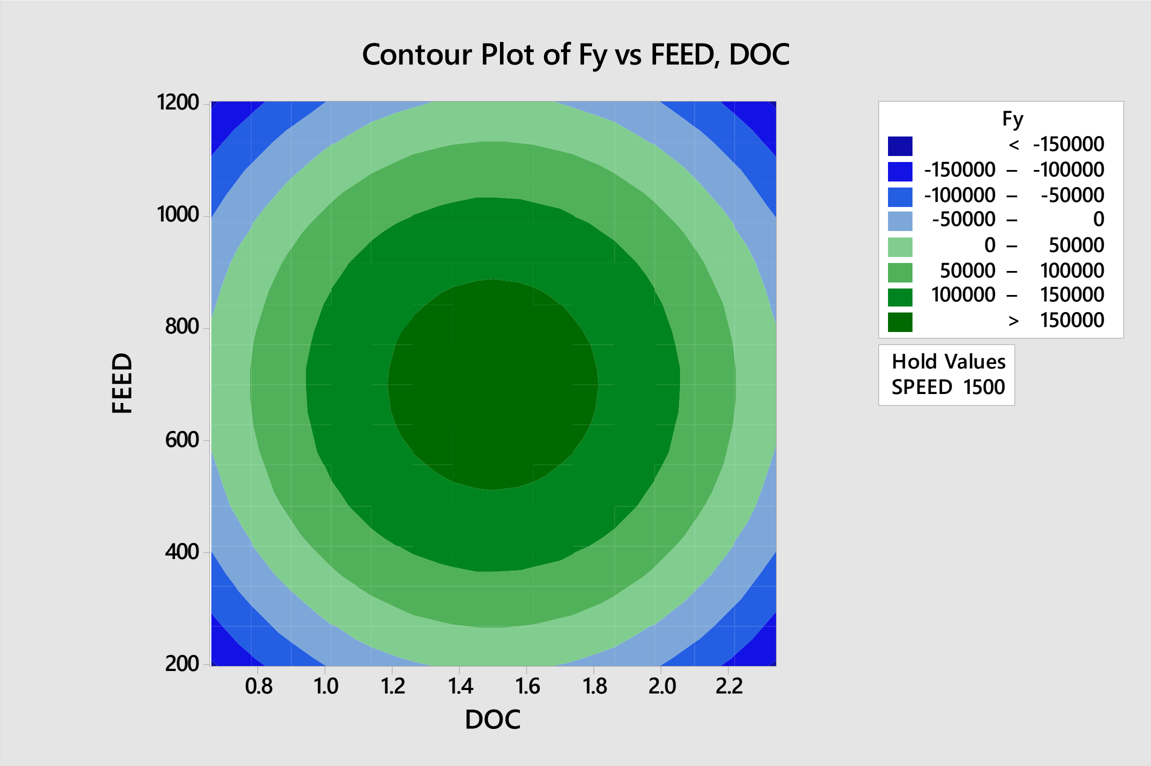


Figure 5.4.2 Contour plot of Fy vs FEED, DOC

Contour plot of Fz vs FEED, DOC (Hold value speed 1500) shown in figure 5.4.3

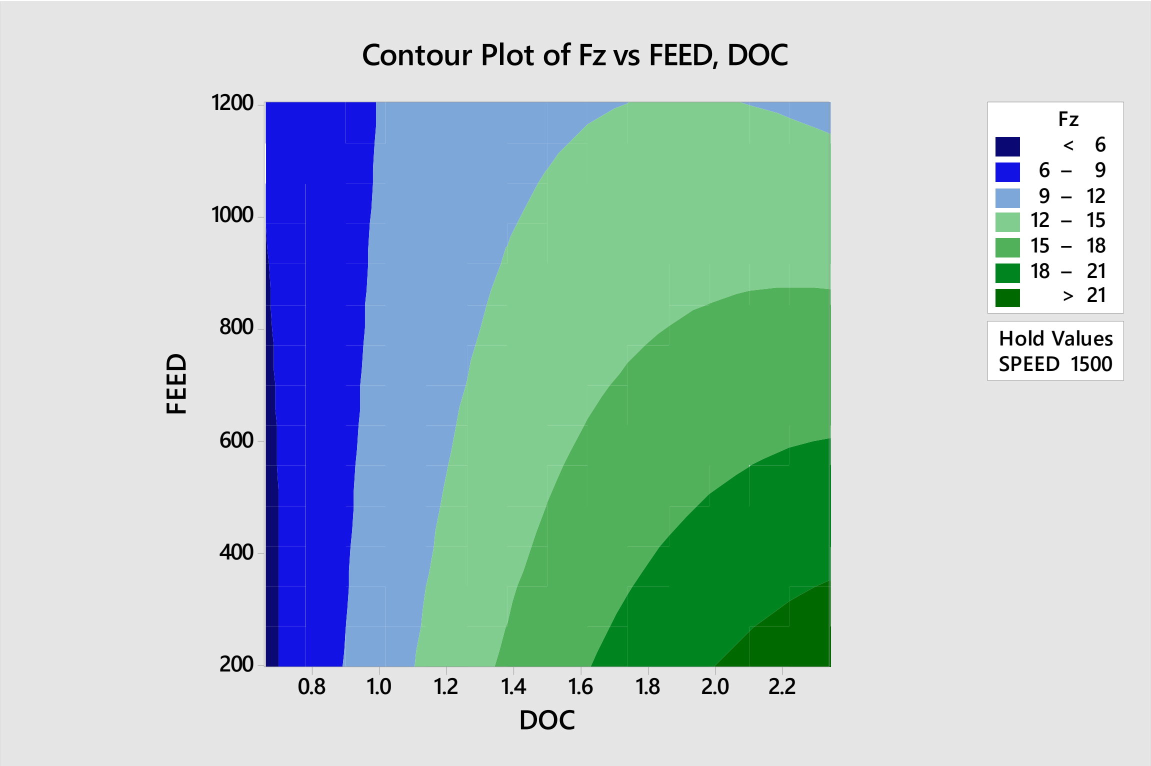


Figure 5.4.3 Contour plot of Fz vs FEED, DOC

Contour plot of SR vs FEED, DOC (Hold value speed 1500) shown in figure 5.4.4

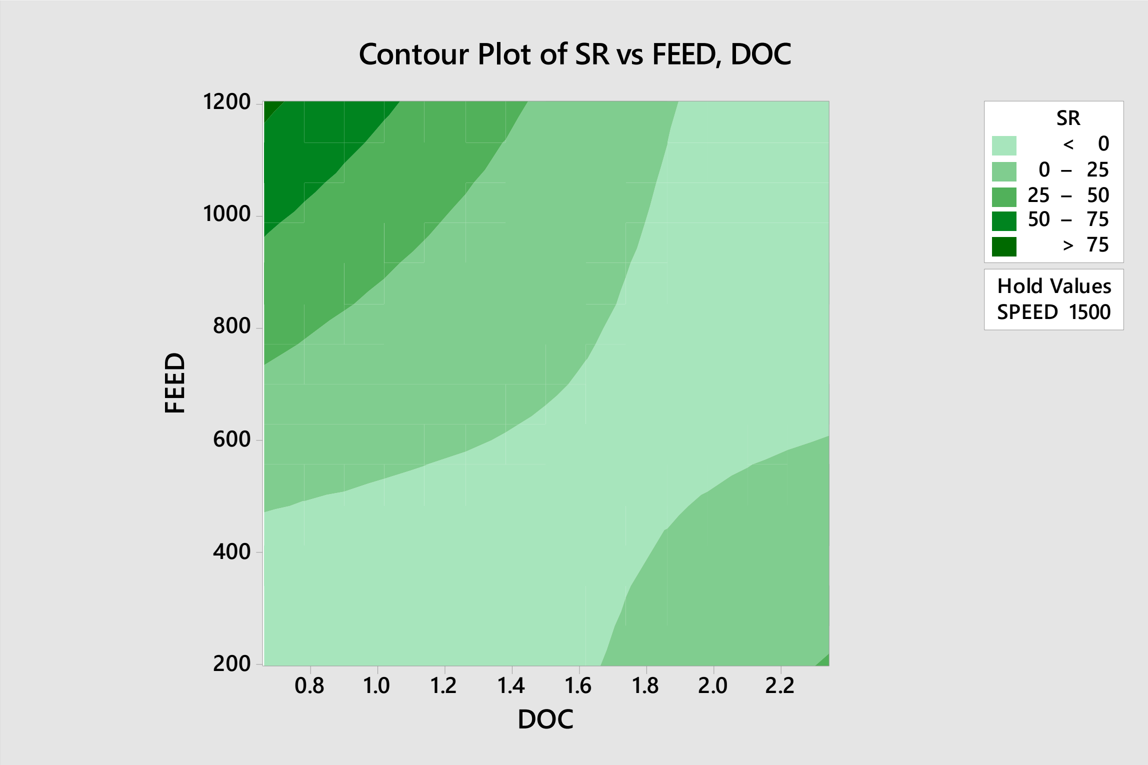


Figure 5.4.4 Contour plot of SR vs FEED,

Contour plot of MRR vs FEED, DOC (Hold value speed 1500) shown in figure 5.4.5

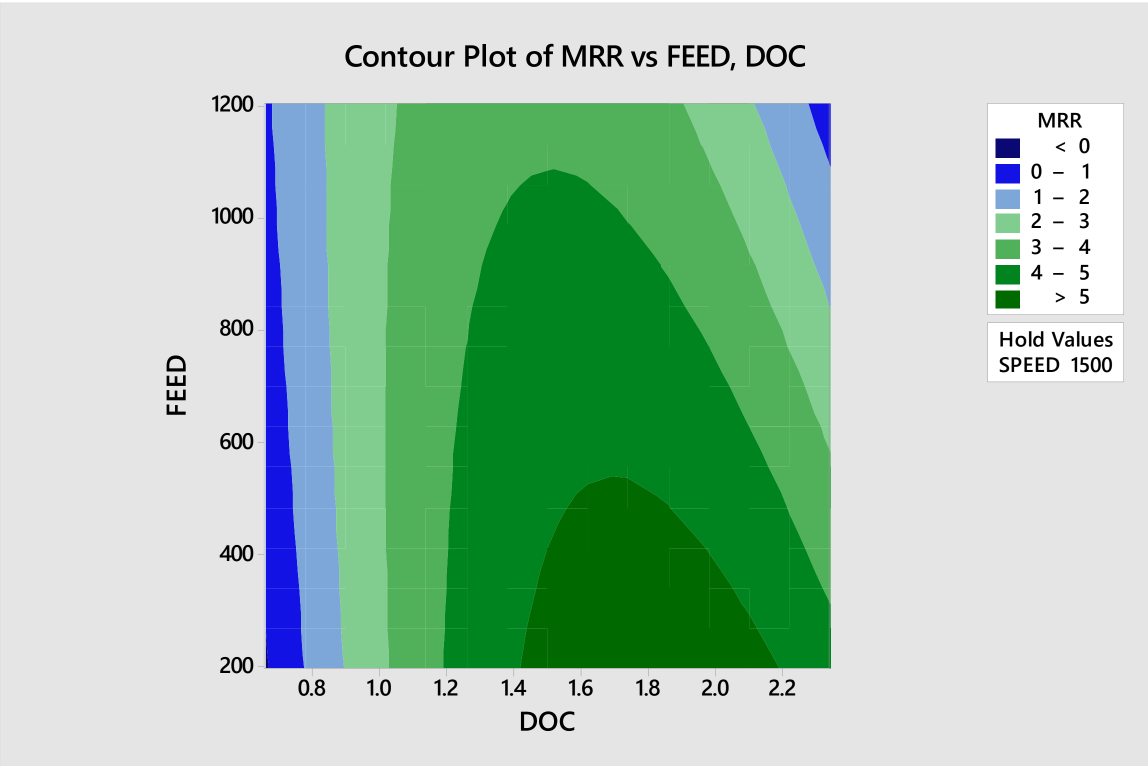


Figure 5.4.5 Contour plot of MRR vs FEED, DOC

Contour plot of Fx vs FEED, SPEED (Hold values DOC 1.5) shown in figure 5.4.6

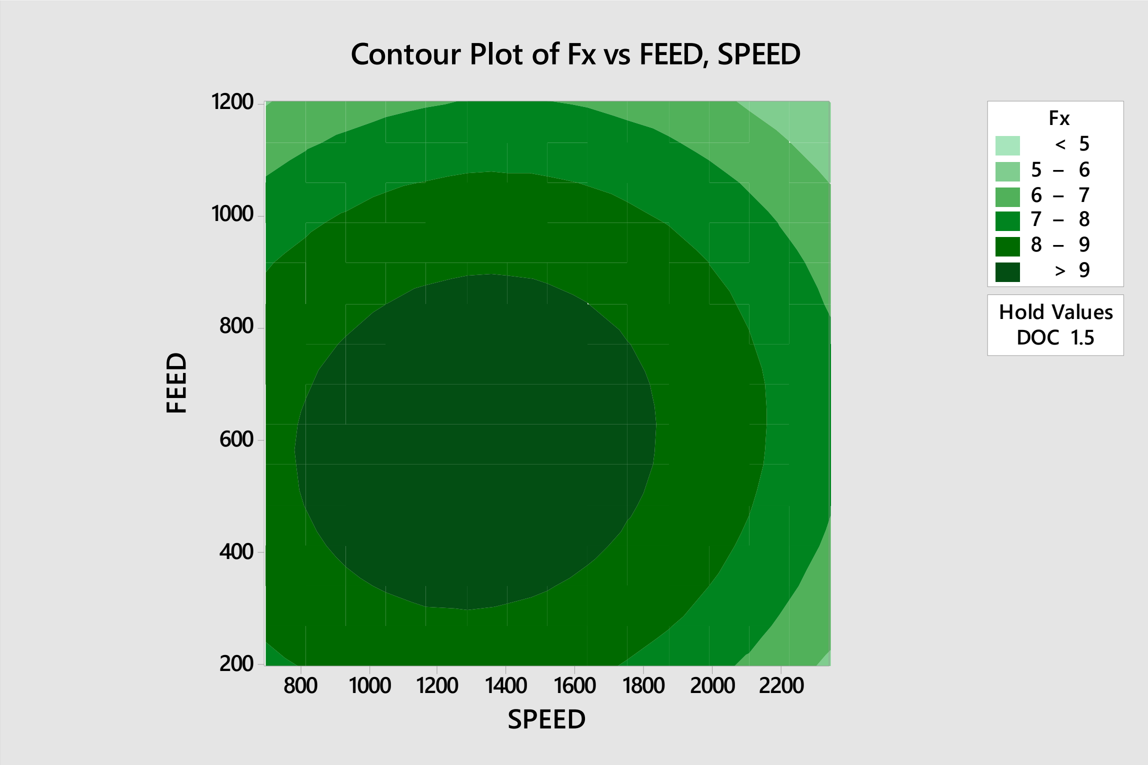


Figure 5.4.6 Contour plot of Fx vs FEED, SPEED

Contour plot of Fy vs FEED, SPEED(Hold values DOC 1.5) shown in figure 5.4.7

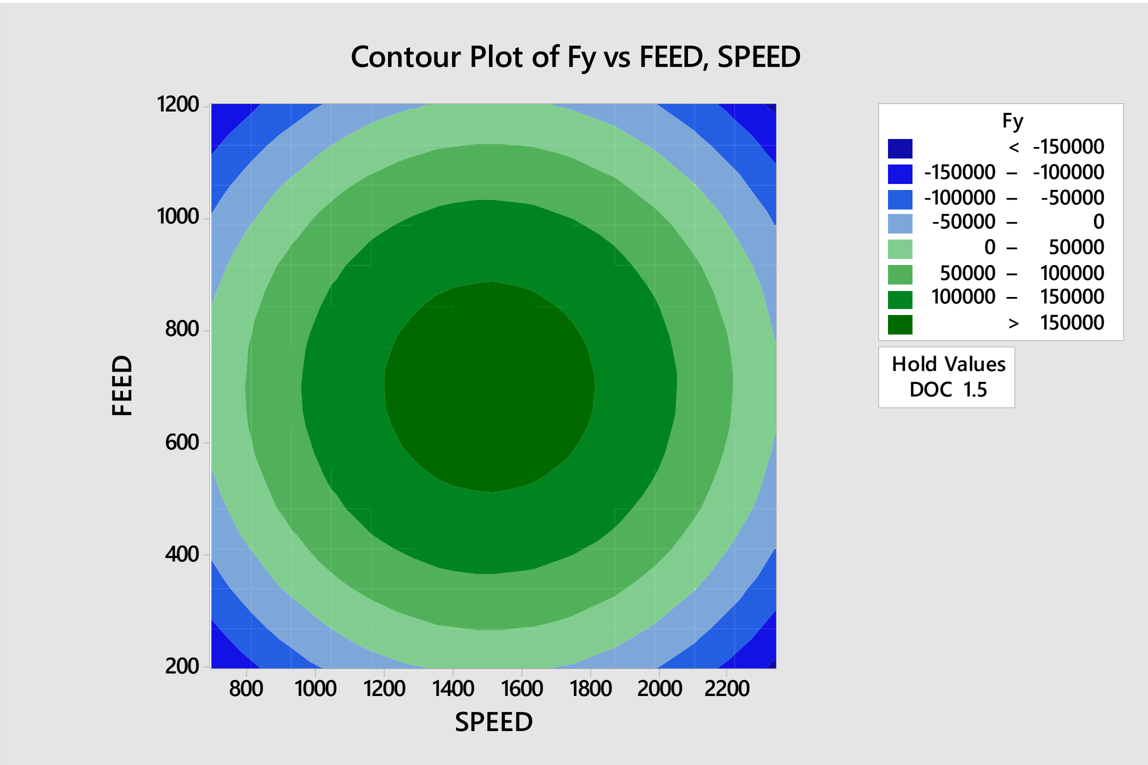


Figure 5.4.7 Contour plot of Fy vs FEED, SPEED

Contour plot of Fz vs FEED, SPEED(Hold values DOC 1.5) shown in figure 5.4.8

Figure 5.4.8 Contour plot of Fz vs FEED, SPEED

Contour plot of SR VS FEED, SPEED(Hold values DOC 1.5) shown in figure 5.4.9

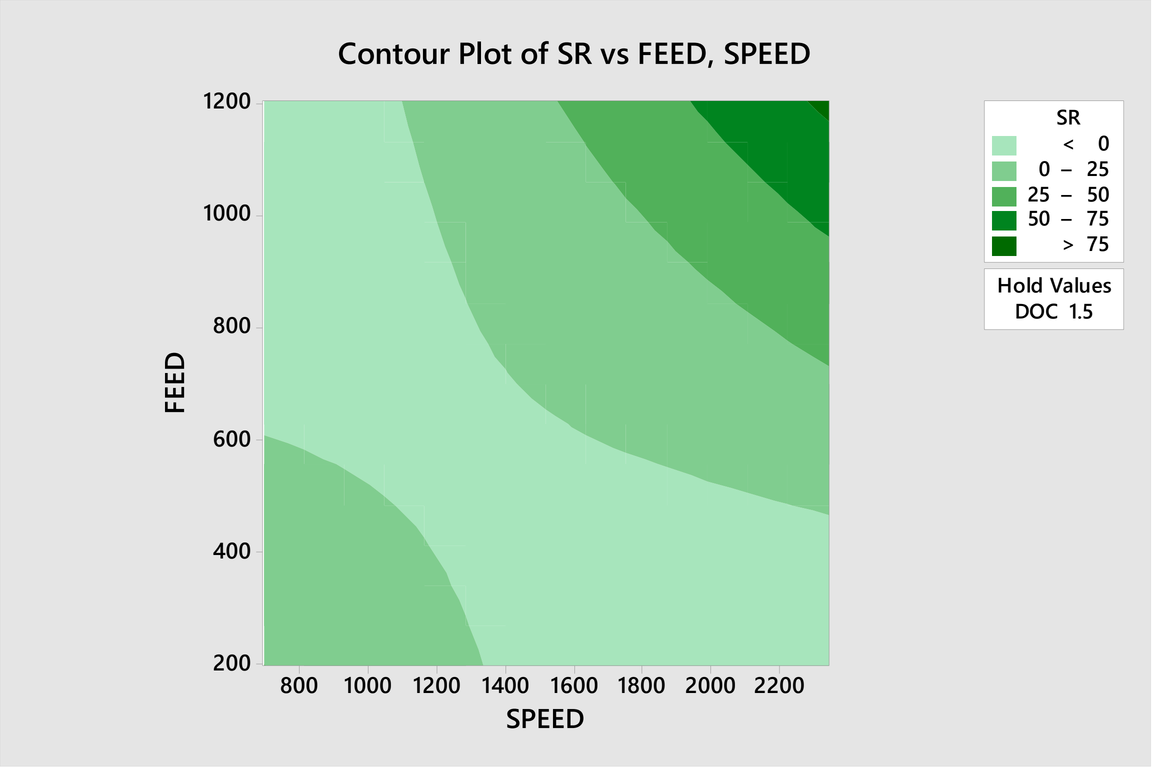


Figure 5.4.9 Contour plot of SR vs FEED, SPEED

Contour plot of MRR vs FEED, SPEED(Hold values DOC 1.5) shown in figure 5.4.10

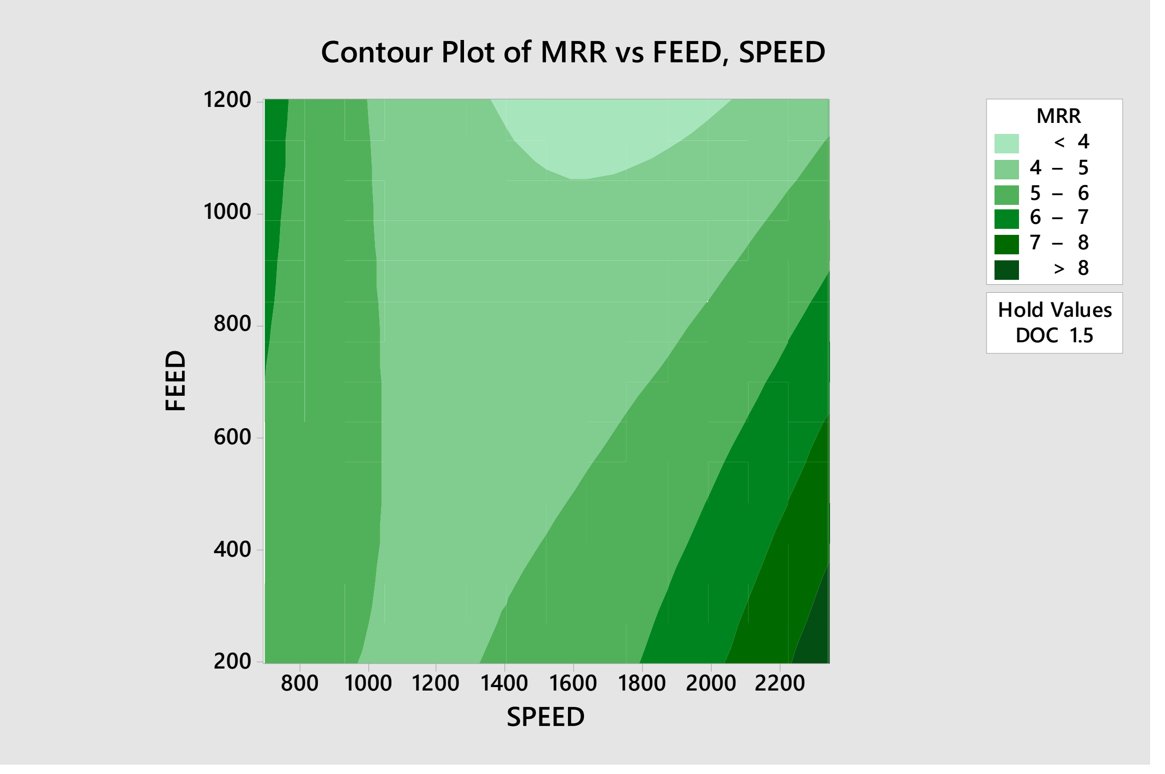


Figure 5.4.10 Contour plot of MRR vs FEED, SPEED

Contour plot of Fx vs DOC, SPEED(Hold values FEED 700) shown in figure 5.4.11

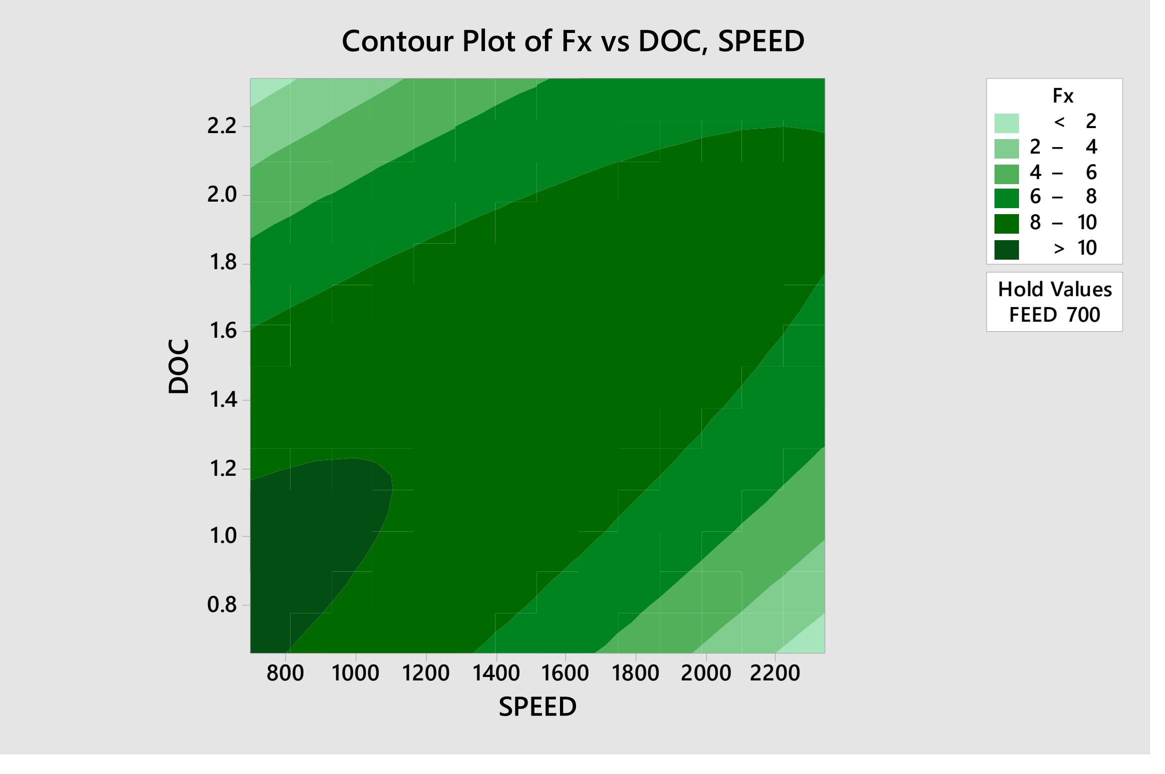


Figure 5.4.11 Contour plot of Fx vs DOC, SPEE

Contour plot of Fy vs DOC, SPEED(Hold values DOC 1.5) shown in figure 5.4.12

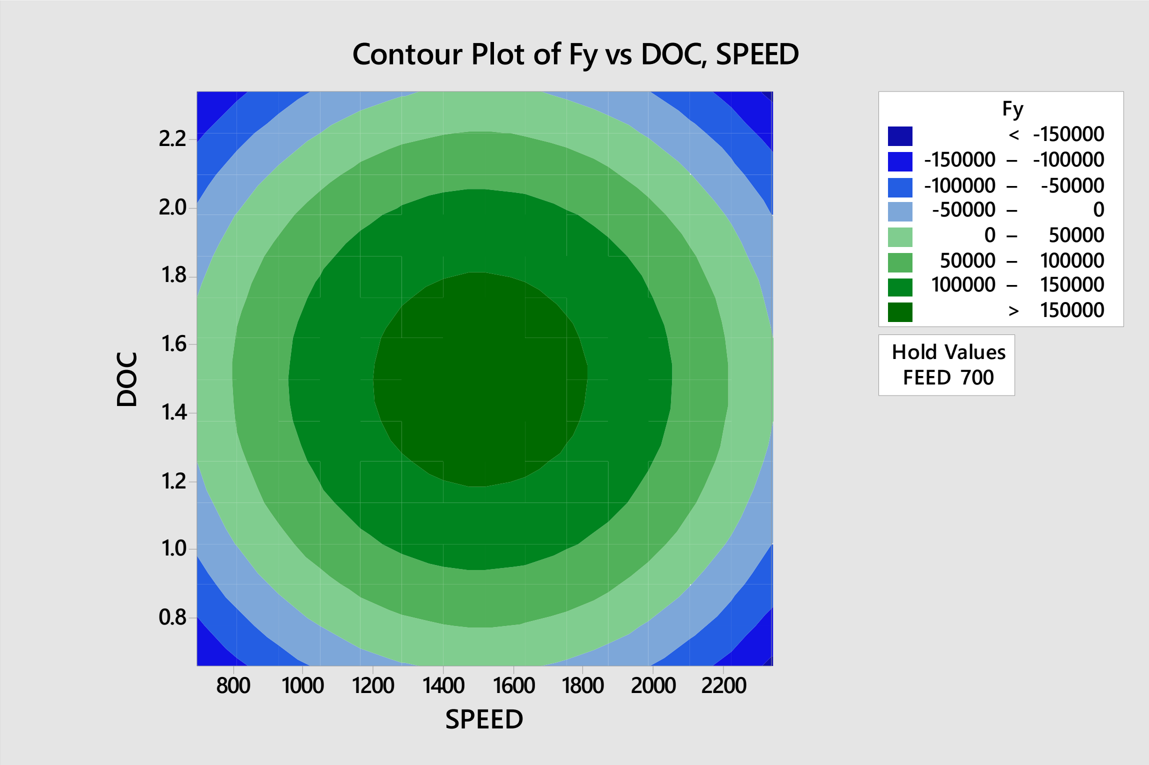


Figure 5.4.12 Contour plot of Fy vs DOC, SPEED

Contour plot of Fz vs DOC, SPEED(Hold values DOC 1.5) shown in figure 5.4.13

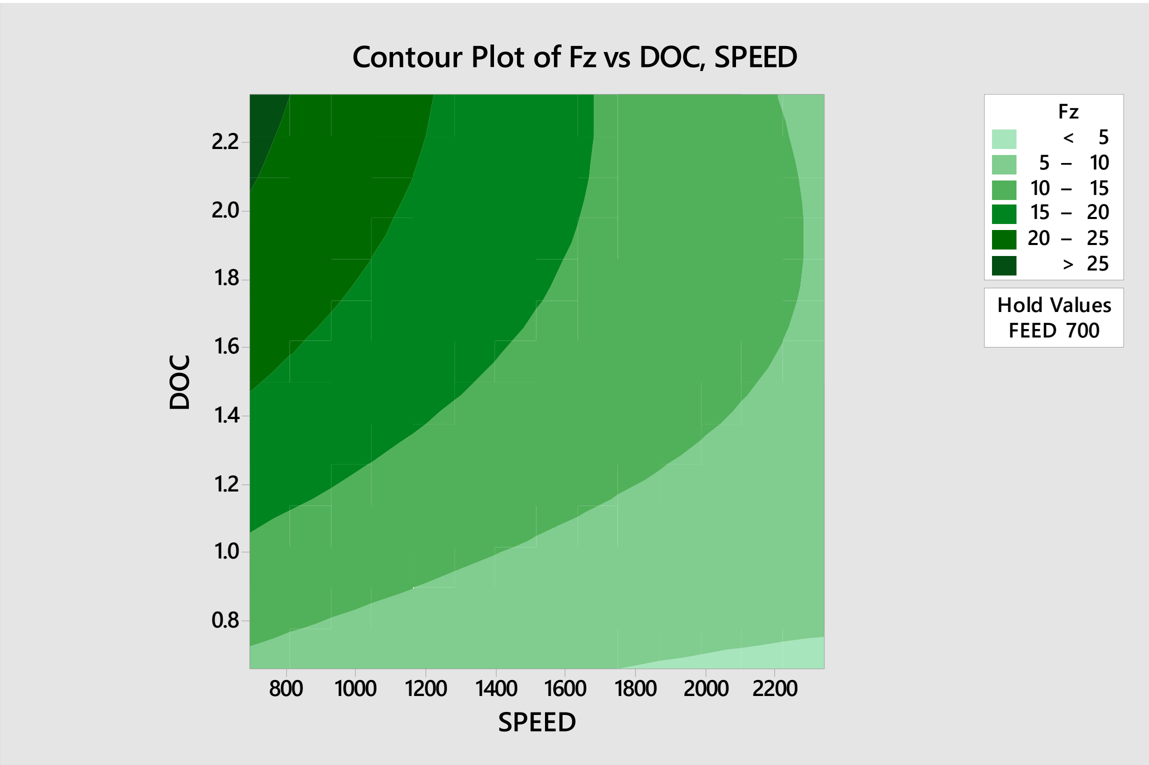


Figure 5.4.13 Contour plot of Fz vs DOC, SPEED

Contour plot of SR vs DOC, SPEED(Hold values DOC 1.5) shown in figure 5.4.14

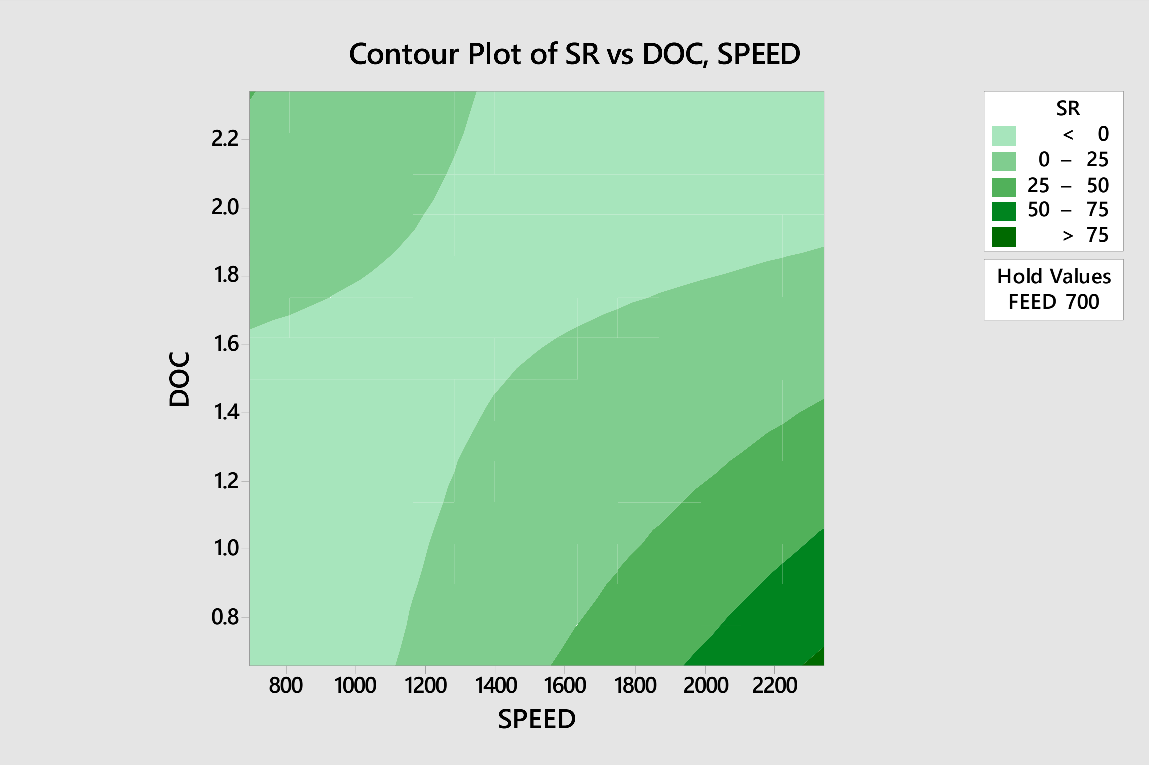


Figure 5.4.14 Contour plot of SR vs DOC, SPEED

Contour plot of MRR vs DOC, SPEED(Hold values DOC 1.5) shown in figure 5.4.15

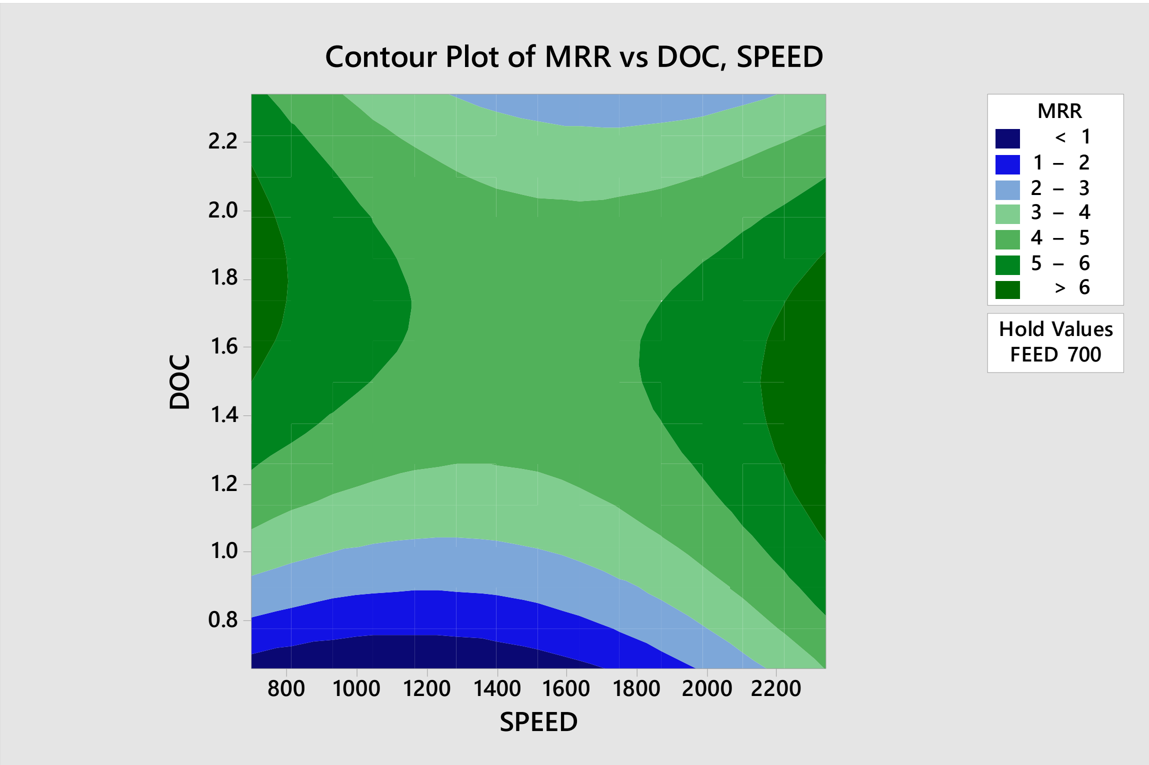


Figure 5.4.15 Contour plot of Fx vs DOC, SPEED

5.5Surface plot

Surface plots are diagrams of three-dimensional data. Rather than showing the individual data points, surface plots show a functional relationship between a designated dependent variable (Y), and two independent variables (X and Z). The plot is a companion plot to the contour plot.

Surface plot of Fx vs FEED, DOC(Hold values SPEED 1500) shown in figure 5.5.1

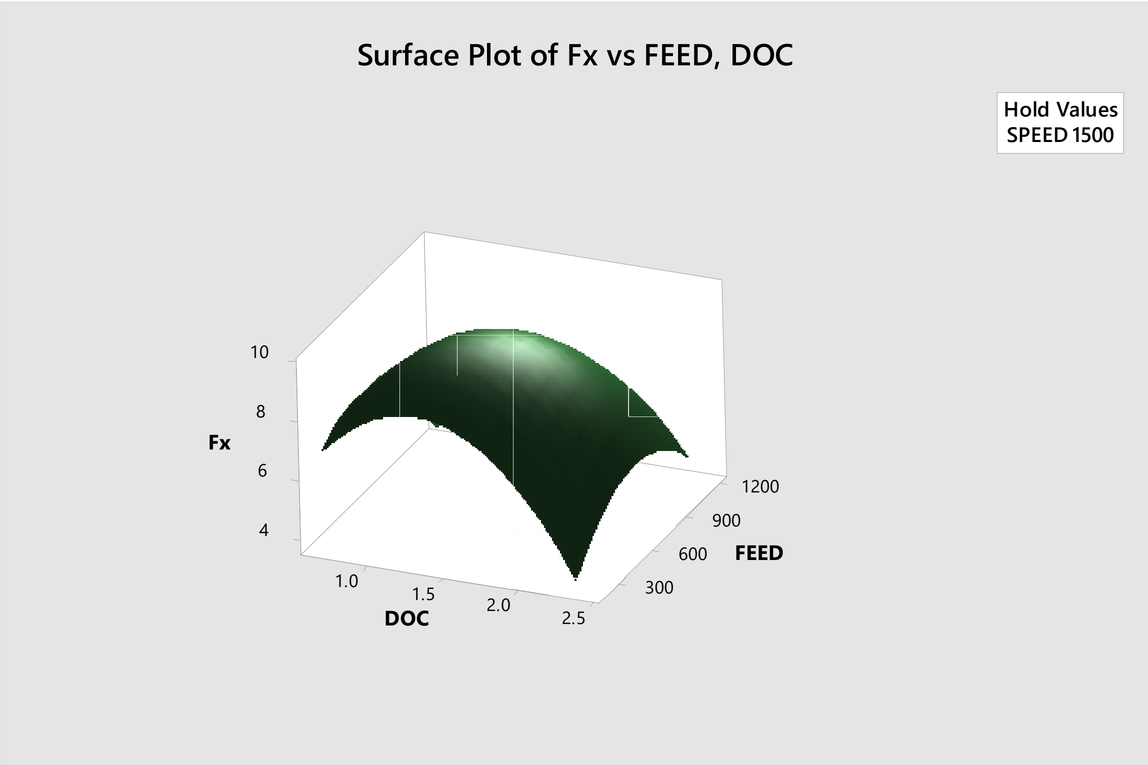


Figure 5.5.1 Surface plot of Fx vs FEED, DOC

Surface plot of Fy vs FEED, DOC (Hold values SPEED 1500) shown in figure 5.5.2

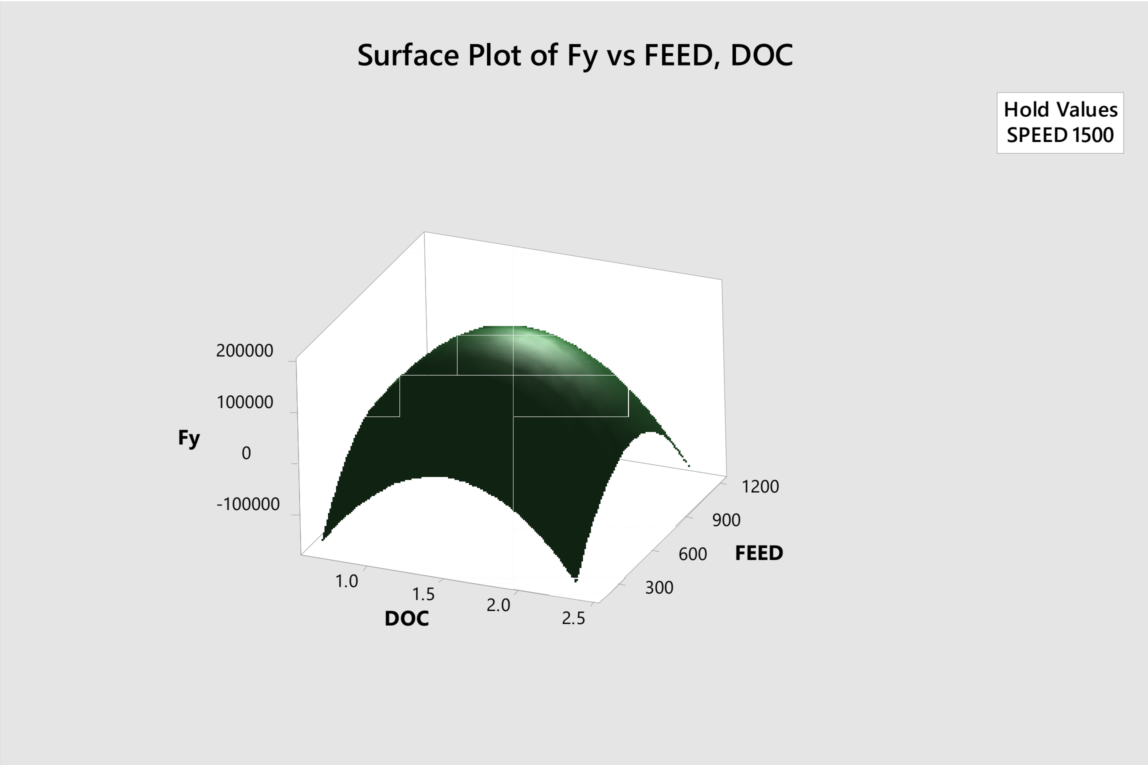


Figure 5.5.2 Surface plot of Fy vs FEED, DOC

Surface plot of Fz vs FEED, DOC (Hold values SPEED 1500) shown in figure 5.5.3

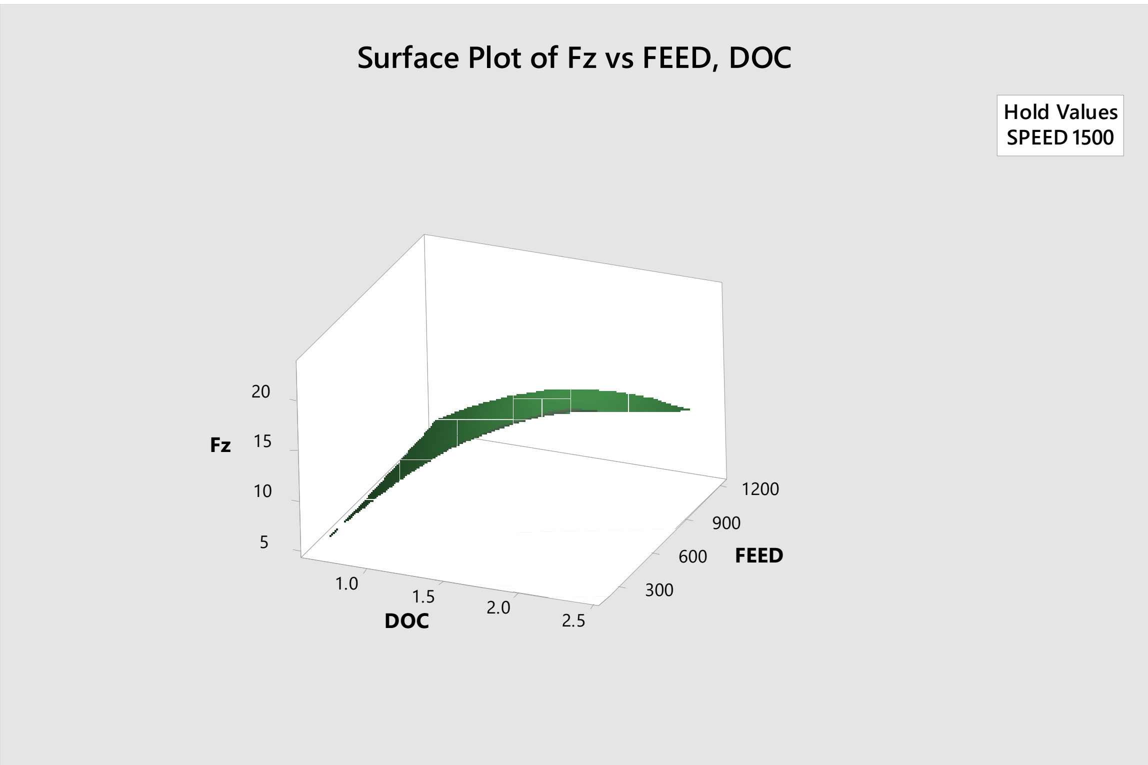


Figure 5.5.3 Surface plot of Fz vs FEED, DOC

Surface plot of SR vs FEED, DOC (Hold values SPEED 1500) shown in figure 5.5.4

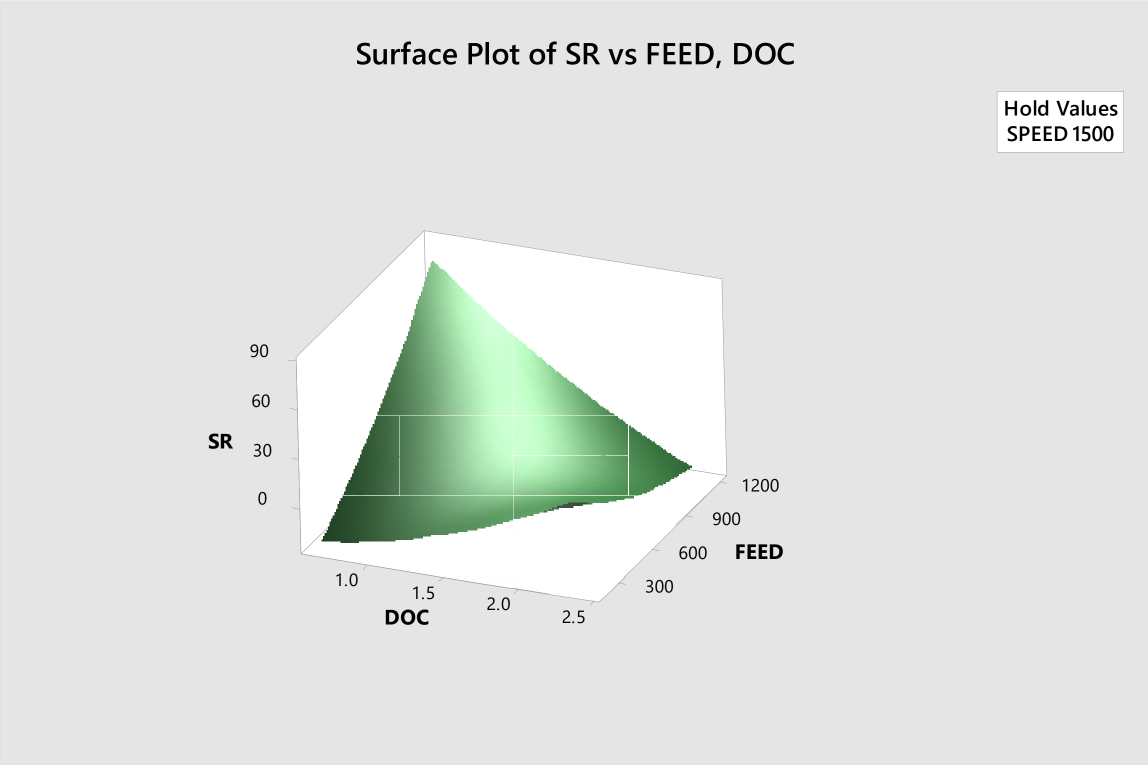


Figure 5.5.4 Surface plot of SR vs FEED, DOC

Surface plot of MRR vs FEED, DOC(Hold values SPEED 1500) shown in figure 5.5.6

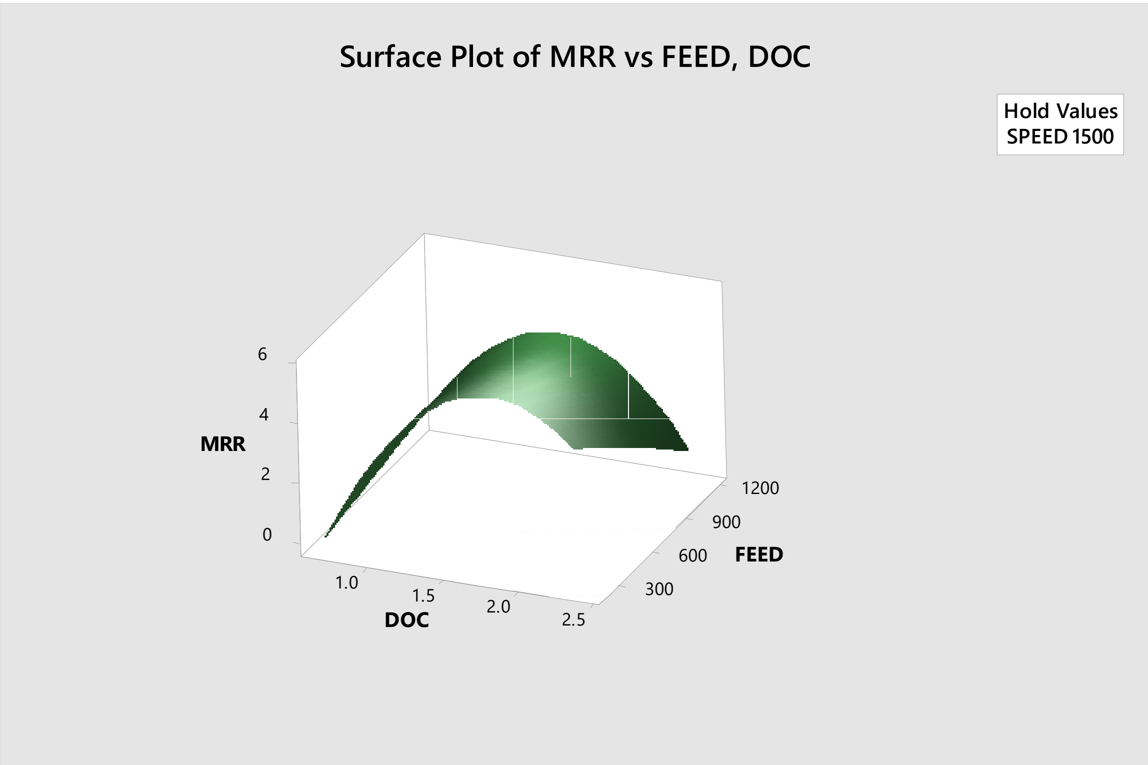


Figure 5.5.6 Surface plot of MRR vs FEED, DOC

Surface plot of Fx vs FEED, SPEED(Hold values DOC 1.5) shown in figure 5.5.7

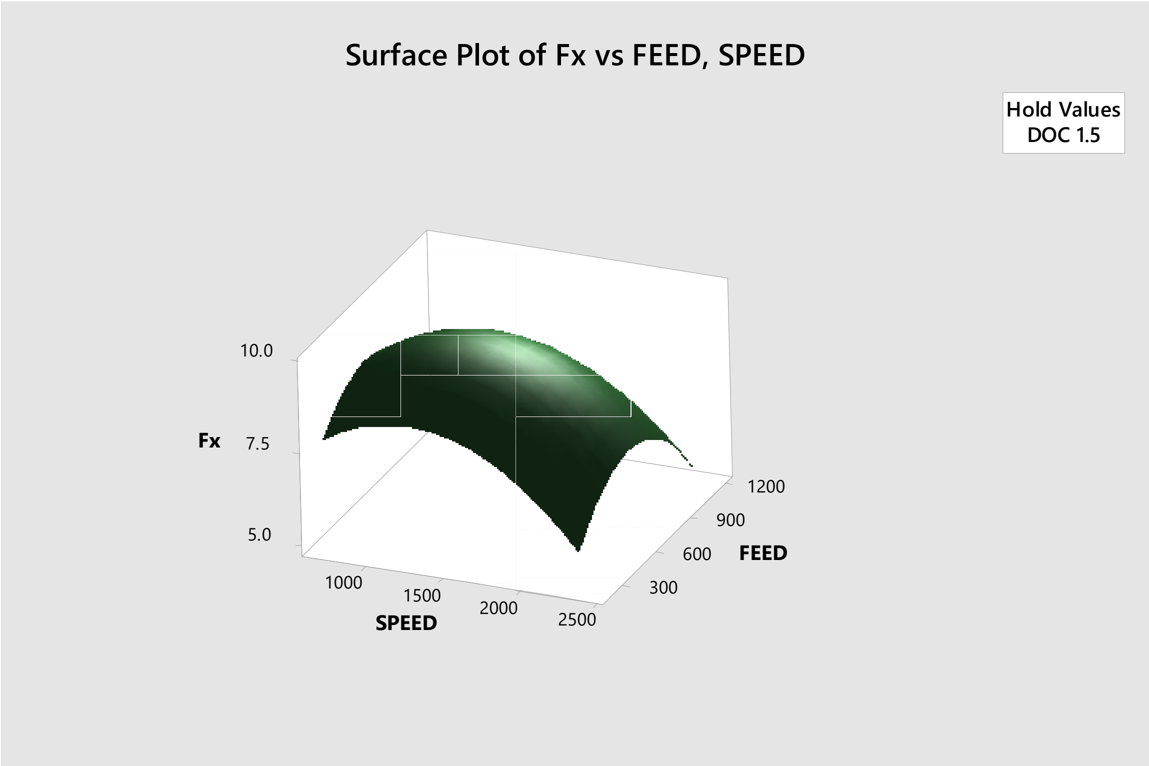


Figure 5.5.7 Surface plot of Fx vs FEED, SPEED

Surface plot of Fy vs FEED, SPEED (Hold values DOC 1.5) shown in figure 5.5.8

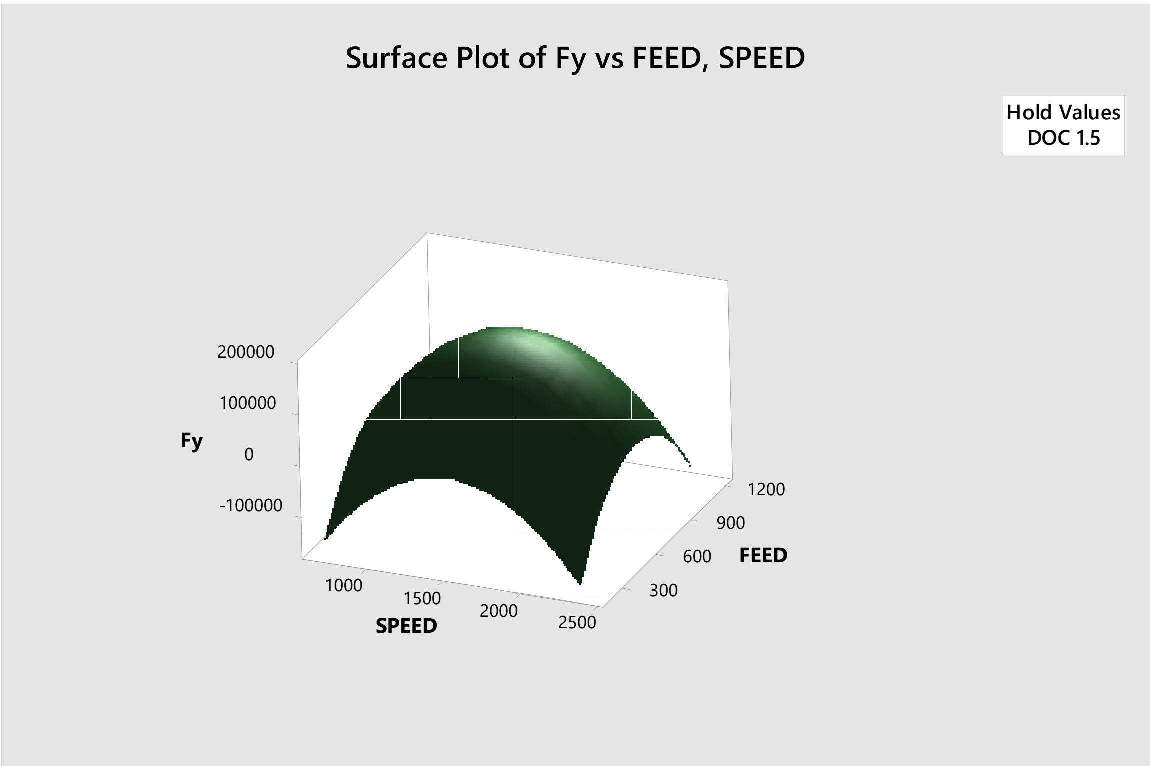


Figure 5.5.8 Surface plot of Fy vs FEED, SPEED

Surface plot of Fz vs FEED, SPEED (Hold values DOC 1.5) shown in figure 5.5.9

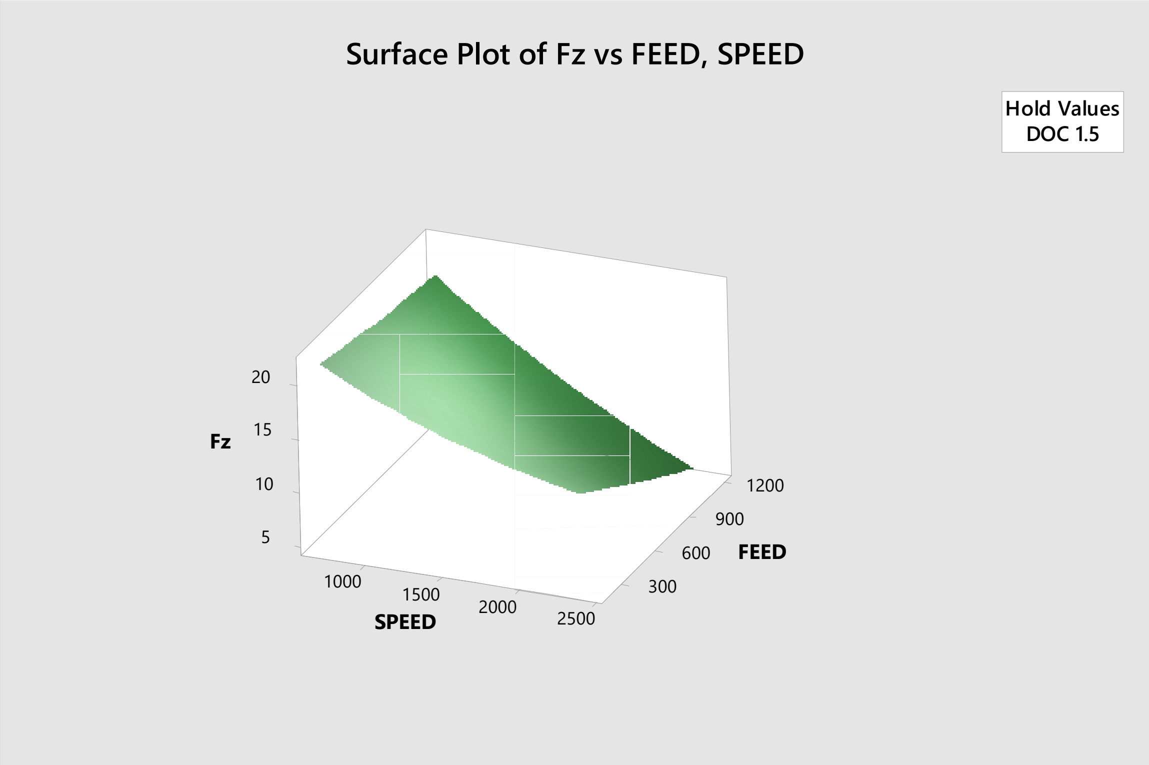


Figure 5.5.9 Surface plot of Fz vs FEED, SPEED

Surface plot of SR vs FEED, SPEED (Hold values DOC 1.5) shown in figure 5.5.10

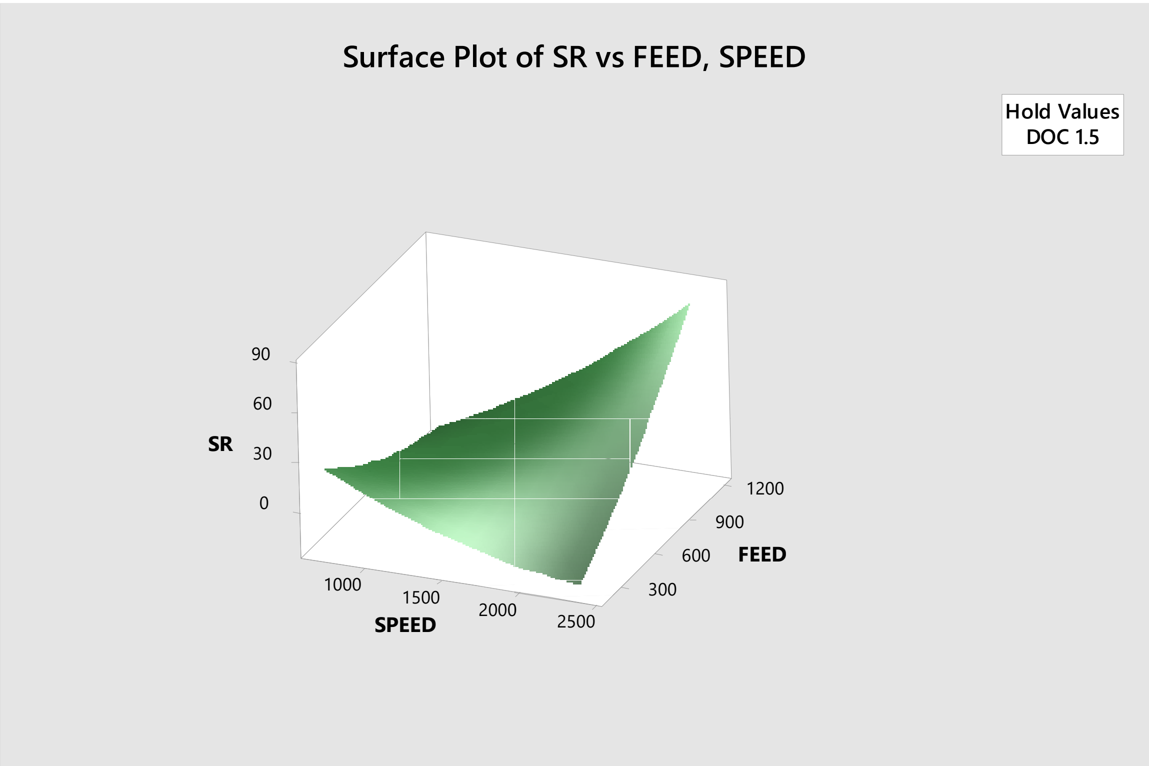


Figure 5.5.10 Surface plot of SR vs FEED, SPEED

Surface plot of MRR vs FEED, SPEED (Hold values DOC 1.5) shown in figure 5.5.11

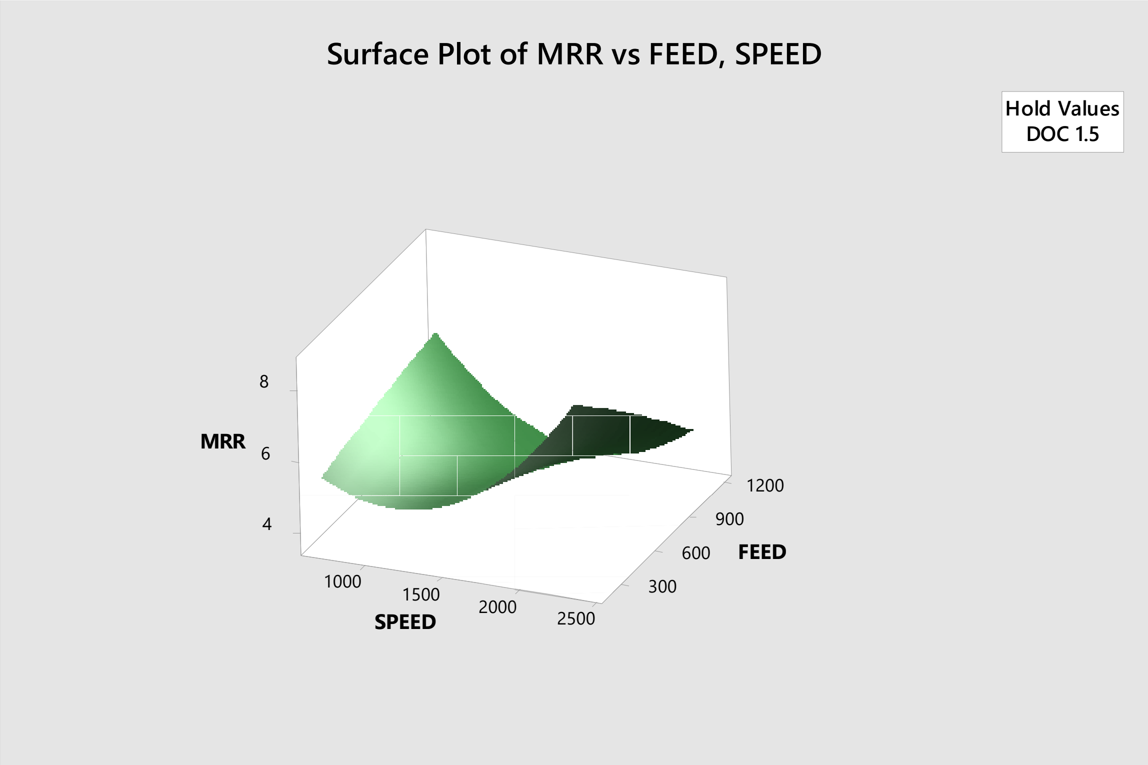


Figure 5.5.11 Surface plot of MRR vs FEED, SPEED

Surface plot of Fx vs DOC, SPEED (Hold values FEED 700) shown in figure 5.5.12

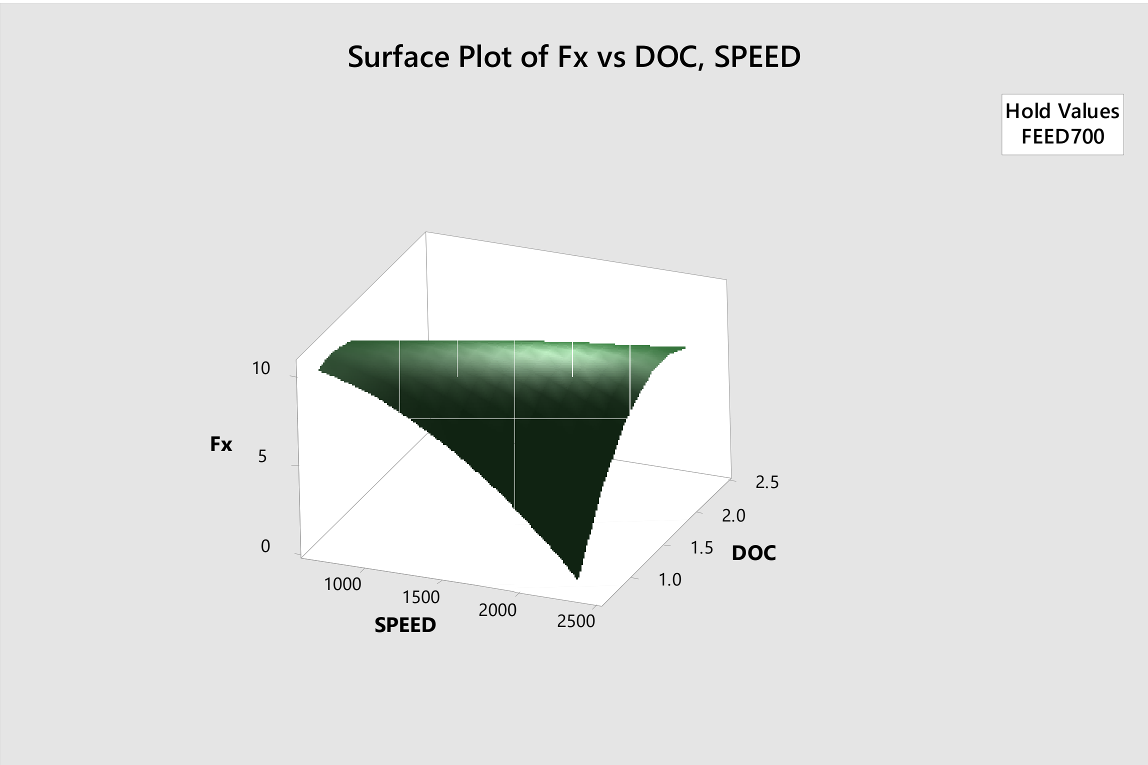


Figure 5.5.12 Surface plot of Fx vs DOC, SPEED

Surface plot of Fy vs DOC, SPEED (Hold values FEED 700) shown in figure 5.5.13

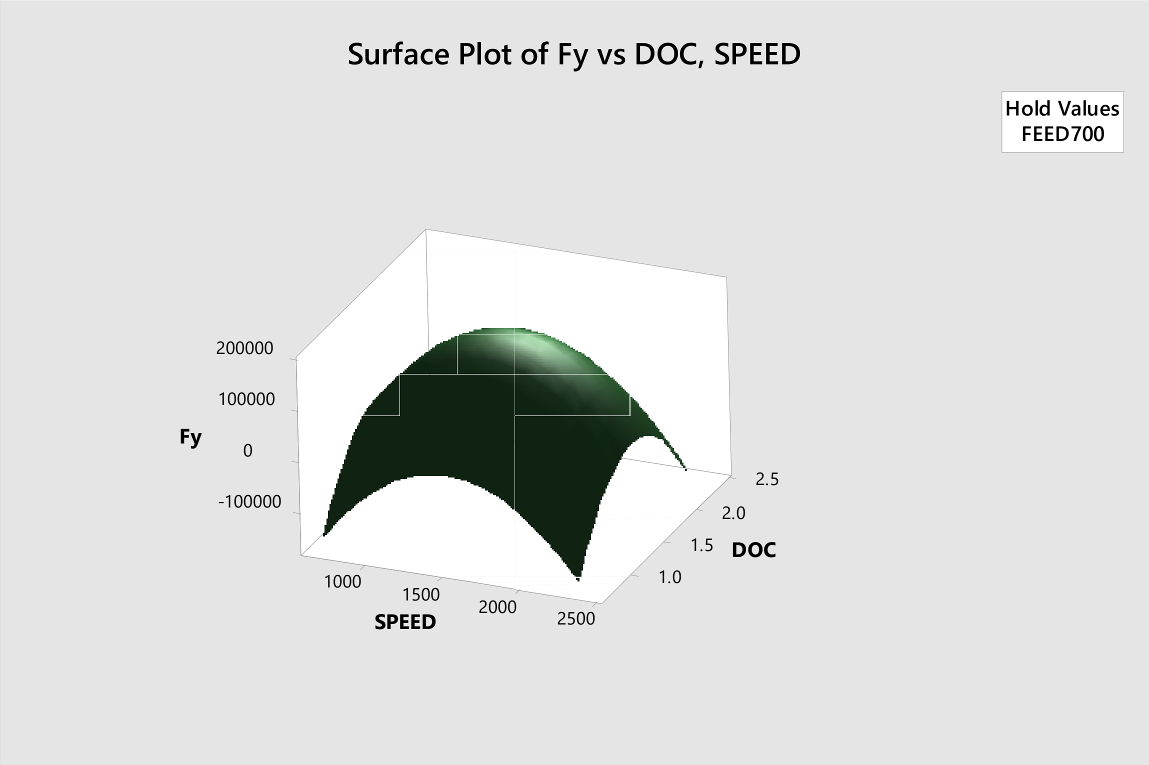


Figure 5.5.13 Surface plot of Fy vs DOC, SPEED

Surface plot of Fz vs DOC, SPEED (Hold values FEED 700) shown in figure 5.5.14

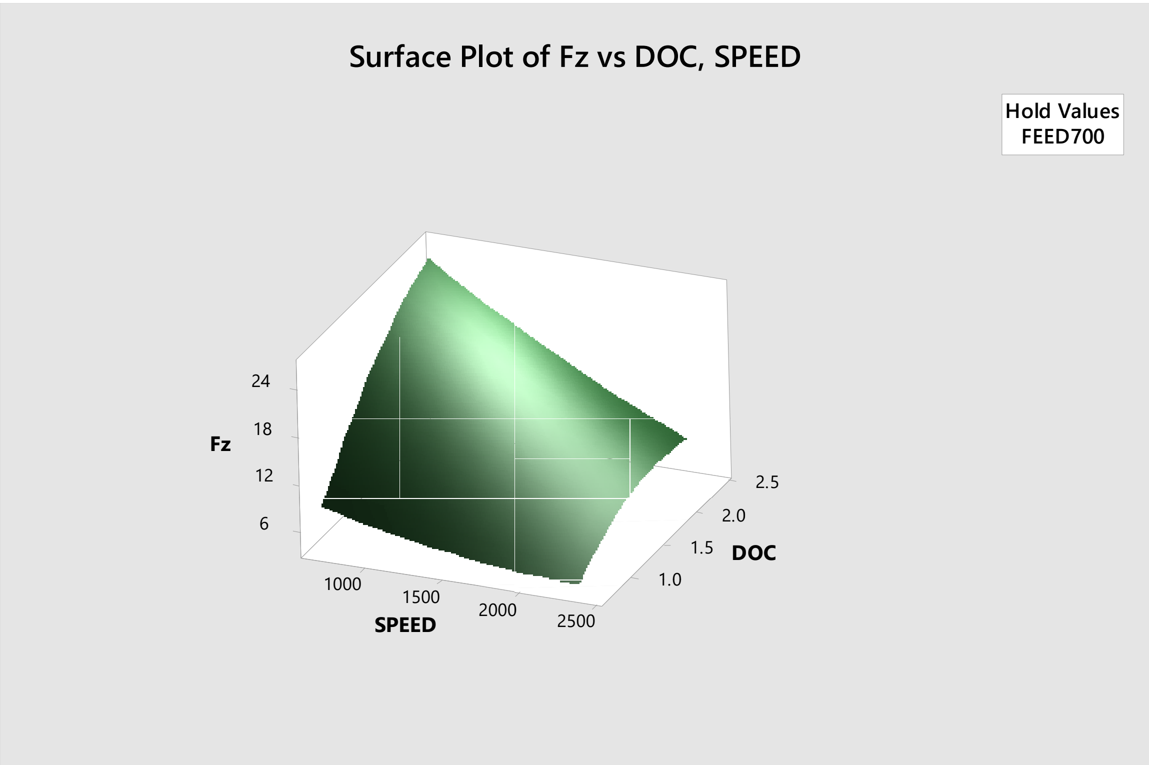


Figure 5.5.14 Surface plot of Fz vs DOC, SPEED

Surface plot of SR vs DOC, SPEED (Hold values FEED 700) shown in figure 5.5.15

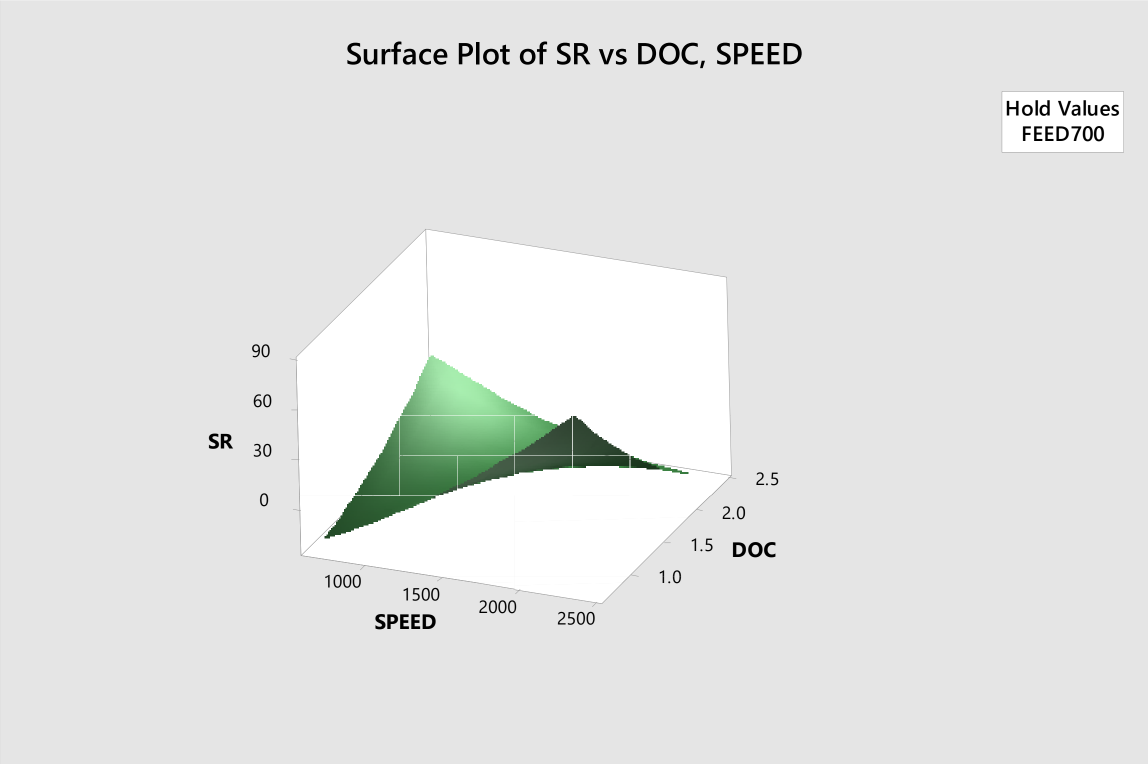


Figure 5.5.15 Surface plot of SR vs DOC, SPEED

Surface plot of MRR vs DOC, SPEED (Hold values FEED 700) shown in figure 5.5.16

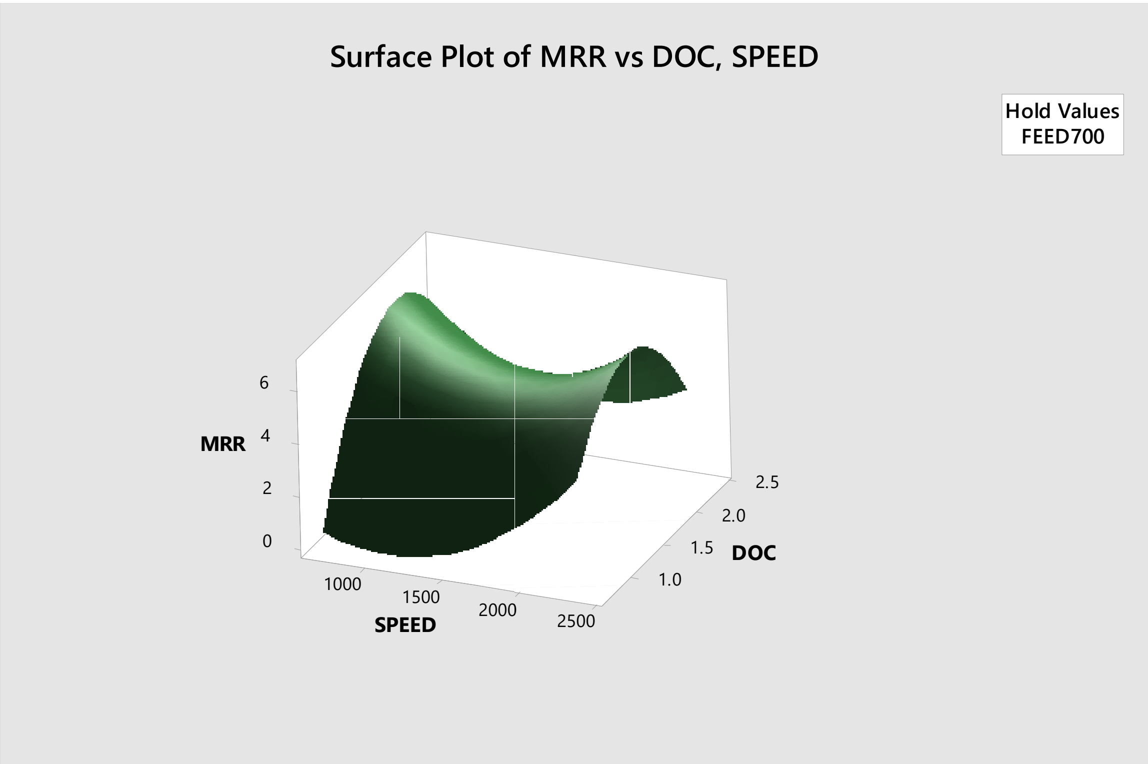


Figure 5.5.16 Surface plot of MRR vs DOC, SPEED

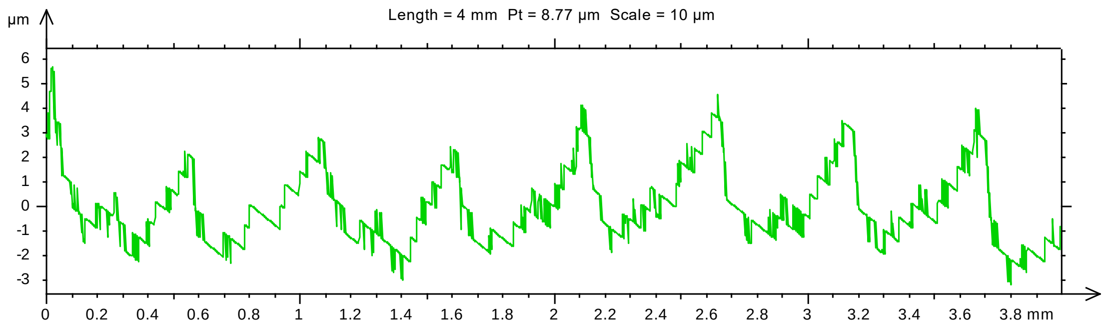
5.2 RESULT AND DISCUSSION ON SURFACE ROUGHNESS

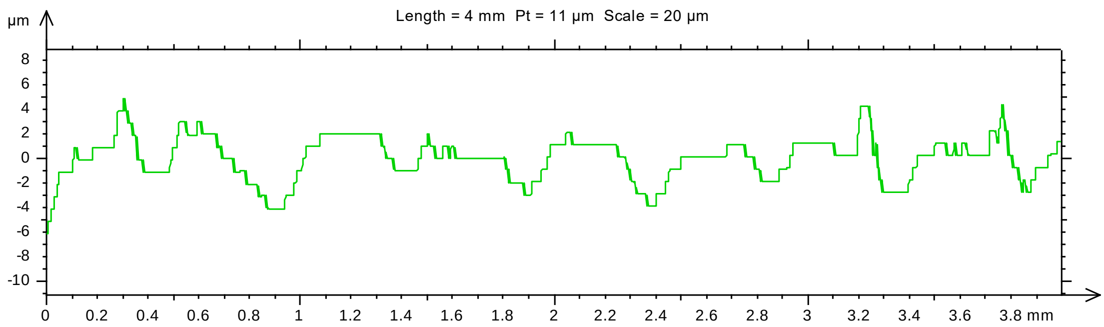
In this experiment, the focus was on investigating the surface roughness of the machined components using two key parameters: Ra (average roughness) and Rrms (root mean square roughness). The experiment involved varying cutting parameters, including cutting speed, feed rate, and depth of cut, while machining was performed on a horizontal milling machine using a side and face cutter

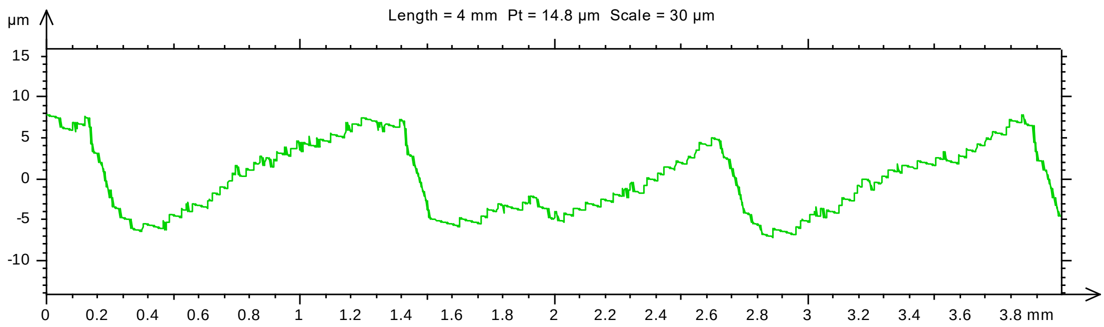
The cutting speed was varied within the range of 1000 to 2000 rpm, allowing for a comprehensive evaluation of its impact on surface roughness. Similarly, the feed rate was varied between 400 to 700 mm/min, while the depth of cut was set at two different levels: 1 mm and 2 mm.

To conduct the experiments, the horizontal milling machine was set up with the appropriate tooling, including the side and face cutter. Machining operations were performed on the workpiece, and surface roughness measurements were taken by surtronic 3 + device . The obtained surface roughness data, specifically the Ra and Rrms values, provided valuable insights into the quality and characteristics of the machined surfaces. By analyzing the data in graphical form are as follow.

<u>SURFACE ROUGHNESS GRAPH</u>







Overall, the experimental findings demonstrate that variations in feed rate and depth of cut can affect surface roughness, leading to an increase in Rrms values. However, the influence of cutting speed on Rrms is consistent with its impact on Ra, with higher cutting speeds generally resulting in a decrease in surface roughness. Understanding these relationships and optimizing the cutting parameters can help achieve the desired surface quality and improve the overall performance of the machining process.

Some important reason behind above surface roughness trends

When face milling operations are performed using a side and face milling cutter in a horizontal milling machine, several possible causes can explain why surface roughness decreases with an increase in cutting speed and a decrease in feed rate and depth of cut:

1. Decreased Tool-Workpiece Contact Time: Increasing the cutting speed reduces the contact time between the cutting tool and the workpiece. This shorter interaction time minimizes the chances of tool vibrations, leading to a smoother surface finish.

2. Enhanced Chip Evacuation: Higher cutting speeds facilitate better chip formation and evacuation. The side and face milling cutter effectively removes chips generated during the cutting process. Proper chip evacuation reduces the chances of chip recutting, tool rubbing, and surface irregularities, resulting in a smoother surface finish.

3. Improved Cutting-Edge Penetration: Increasing the cutting speed allows the cutting tool to penetrate the workpiece more efficiently. The side and face milling cutter engages the material more effectively, reducing tool rubbing and resulting in a cleaner and smoother cutting action.

4. 4. Efficient Heat Dissipation: Higher cutting speeds enable better heat dissipation due to increased chip flow and contact with the workpiece. This helps minimize thermal damage such as work hardening and residual stresses, which can contribute to surface roughness.

5. Reduced Built-Up Edge (BUE) Formation: Increasing the cutting speed hinders the formation of built-up edge (BUE) on the cutting tool. BUE can cause erratic cutting forces and result in poor surface finish. By minimizing BUE formation, the surface roughness is improved.

6. Optimized Chip Thickness: Decreasing the feed rate and depth of cut allows for smaller chip thickness. Smaller chips are easier to evacuate and are less likely to cause surface irregularities, resulting in a smoother surface finish.

7. Improved Lubrication and Cooling: Lower feed rates and shallower depths of cut allow for better application and distribution of cutting fluids. Adequate lubrication and cooling help

reduce friction and heat generation, leading to improved surface finish and reduced surface roughness.

8. Minimized Cutting Forces: Decreasing the feed rate and depth of cut reduces the cutting forces acting on the tool and workpiece. Lower cutting forces result in reduced tool deflection and improved surface finish By carefully optimizing the cutting speed, feed rate, and depth of cut in face milling operations with a side and face milling cutter in a horizontal milling machine, these factors collectively contribute to decreasing surface roughness and achieving the desired surface finish.

5.3 Summary

In this chapter, results from experimental analysis have been discussed. ANOVA is a statistical tool for obtaining the contribution of variable input machining parameters like cutting speed, feed, depth of cut and width of cut towards cutting force and surface roughness. a. The normal probability plots of residuals for cutting force and surface roughness have been generated. The effects of various input process parameters (individually as well as the interaction effects) on output responses such as surface roughness and cutting force have been discussed in this chapter.

CHAPTER 6:

CONCLUSION & FUTURE SCOPE

The objectives of this research work have been focused on cutting force and surface roughness during end milling of AI6063. The effects of cutting speed, feed, depth of cut and width of cut have been investigated on output responses. The following points have been concluded from the experimental study.

6.1 CONCLUSION

The results of the investigation on cutting forces and surface roughness in the face milling (down milling) operation on Al6063 with a carbide tool provide valuable insights into the machining process. The study focused on analyzing the variations in cutting forces with respect to cutting speed, feed rate, and depth of cut.

The findings revealed that as the cutting speed increased, there was a corresponding increase in the cutting forces. This can be attributed to the higher material removal rate at higher cutting speeds, which requires more force to achieve the desired machining outcome. However, beyond a certain point, an interesting phenomenon was observed. The cutting forces started to decrease. This can be attributed to the decreased tool interaction with the workpiece surface at higher cutting speeds. The tool may experience reduced engagement with the workpiece, resulting in lower cutting forces.

Another significant factor influencing cutting forces is the feed rate. The results indicated that as the feed rate increased, the cutting forces also increased. This can be explained by the higher material removal per unit time at higher feed rates, necessitating more force to overcome the resistance of the workpiece.

Furthermore, the depth of cut was found to impact the cutting forces. As the depth of cut increased, the cutting forces also increased. This is due to the larger volume of material being removed during each pass, requiring greater force to accomplish the machining operation

In addition to tool interaction and feed rate, the increase in temperature within the workpiece also influenced the cutting forces. As the cutting speed increased, the temperature within the workpiece rose. This rise in temperature can cause the workpiece material to soften, leading to reduced cutting forces. The softened material offers less resistance to the cutting tool, resulting in decreased cutting forces.

In summary, the investigation demonstrated that cutting forces in the face milling operation on Al6063 with a carbide tool are influenced by cutting speed, feed rate, and depth of cut. Cutting forces initially increase with increasing cutting speed and feed rate, but beyond certain thresholds, they start to decrease. The increase in temperature within the workpiece due to higher cutting speeds also affects the cutting forces. Additionally, the depth of cut has a direct impact on cutting forces, with higher depths of cut resulting in increased forces. These findings provide valuable insights for optimizing cutting parameters and improving the machining process for Al6063.

6.2 FUTURE SCOPE

The investigation on cutting forces and surface roughness in the face milling operation on Al6063 with a carbide tool has provided valuable insights into the machining process. However, there are several potential areas for future exploration that can further enhance our understanding and optimize the machining performance of Al6063.

One promising direction for future research is the optimization of cutting parameters. While the current study analyzed the effects of cutting speed, feed rate, and depth of cut, there is room for conducting a comprehensive parametric study using advanced optimization techniques. By determining the optimal combination of cutting parameters, researchers can minimize cutting forces and achieve superior surface finish in the machining of Al6063.

Another area of interest is the investigation of different tool materials and geometries. Comparing the performance of carbide tools with other materials, such as carbide or ceramic, can help identify the most suitable tool for machining Al6063. Additionally, studying the effects of various tool geometries, such as rake angle and cutting-edge geometry, can provide insights into their impact on cutting forces and surface roughness.

The implementation of effective cooling and lubrication techniques is also worth exploring. Advanced cooling and lubrication methods, such as minimum quantity lubrication (MQL) or cryogenic cooling, can significantly influence cutting forces and surface roughness. Investigating the use of these techniques can help reduce tool wear, temperature rise, and cutting forces, ultimately improving surface quality in Al6063 machining.

Further research can also focus on the influence of material properties and reinforcements. Exploring different reinforcement materials, varying reinforcement content, and distribution within the matrix can provide insights into the machinability of Al6063. Understanding the effects of these factors on cutting forces and surface roughness can aid in optimizing the material composition for improved machining performance.

Advanced machining techniques offer another avenue for future exploration. Highspeed machining, vibration-assisted machining, and adaptive control strategies can be investigated to optimize the machining process. These techniques aim to minimize vibrations, control heat generation, and enhance chip evacuation, resulting in improved surface quality in the machining of Al6063.

Lastly, conducting a comprehensive analysis of the machined surfaces through advanced characterization techniques can provide a deeper understanding of the effects of cutting forces on surface integrity. Analyzing surface morphology, tool-chip interaction, and potential defects or anomalies can help identify areas for improvement and guide future machining strategies.

By addressing these areas, researchers can contribute to the development of optimized machining strategies, improved tool designs, and enhanced surface quality in the face milling operation on Al6063 with a carbide tool. This will ultimately advance the field of machining composite materials and pave the way for their wider application in various industries.

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