STUDY ON EFFECT OF END MILLING PARAMETERS ON CUTTING FORCES & SURFACE FINISH USING RESPONSE SURFACE METHOD

A project report submitted in partial fulfillment of the requirements

for the Award of the Degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

By

G.SIVA PADMAJA	314126520063
K.BALA MURALI KRISHNA	314126520010
B.AVINASH NADH	314126520014
G.PRADEEP CHANDU	314126520051

Under the guidance of

Smt. N. INDRAJA

Assistant Professor

ANITS

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Approved by AICTE, Affiliated to Andhra University, Accredited by NBA, NAAC- 'A' grade approved)

SANGIVALASA, VISAKHAPATNAM (District) – 531 162

(2014-2018)

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Affiliated to Andhra University)

Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

PRAGNANAM BRAHMA

ANITS

CERTIFICATE

This is to certify that the Project Report entitled **"STUDY ON EFFECT OF END MILLING PARAMETERS ON CUTTING FORCES & SURFACE FINISH USING RESPONSE SURFACE METHOD"** has been carried out by G.Siva Padmaja, K.Bala Murali Krishna, B.Avinash Nadh and G.Pradeep Chandu, during the year 2017-2018 under the esteemed guidance of **Smt. N.Indraja** in the partial fulfillment of the requirement for the award of the degree of **Bachelor of Mechanical Engineering**, Anil Neerukonda Institute of Technology and Sciences, Visakhapatnam.

APPROVED BY

24.4.18

(Dr. B. Naga Raju)
Head of the Department
Dept. of Mechanical Engineering
ANITS, Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A P

PROJECT GUIDE

Indraja

(Smt. N. Indraja)
Assistant Professor
Dept. of Mechanical Engineering
ANITS, Visakhapatnam.

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER:

Dr. B. Naga Raju
M.Tech,M.E.,Ph.d
Professor & HOD
Dept.of Mechanical Engineering
ANITS, Sangivalasa,
Visakhapatnam-531 162

EXTERNAL EXAMINER

ACKNOWLEDGEMENTS

We express immensely our deep sense of gratitude to **Smt. B. Indiraja**, Assistant Professor, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, Sangivalasa, Bheemunipatnam Mandal, Visakhapatnam district for her valuable guidance and encouragement at every stage of the work made it a successful fulfillment.

We were very thankful to **Prof. T.V. Hanumantha Rao**, Principal and **Dr. B. Naga Raju**, Head of the Department, Mechanical Engineering Department, Anil Neerukonda Institute of Technology & Sciences for their valuable suggestions.

We express our sincere thanks to the members of non-teaching staff of Mechanical Engineering for their kind co-operation and support to carry on work.

Last but not the least, we like to convey our thanks to all who have contributed either directly or indirectly for the completion of our work.

G. Siva Padmaja	(314126200063)
K. Bala Murali Krishna	(314126520010)
B. Avinash Nath	(314126520014)
G. Pradeep Chandu	(314126520051)

ABSTRACT

Now a day's research over improvement of surface roughness on mechanical elements has become quite significant in the operational and aesthetical point of view. To enhance accuracy and precision manufacturing firms are adopting automated systems in order to achieve manufacturing excellence. In the present work the effect of various process parameters like spindle speed, feed and cutting fluid composition on cutting forces and surface finish in End milling process is investigated by using Surface Response Method (RSM). Three factor- Three levels are used and total 15 experiments are performed as per Box Benhken Design Matrix. The coefficients are calculated by using regression analysis and the model is constructed. The adequacy of the developed model is checked using Analysis of Variance (ANOVA) technique. By using the mathematical model the main and interaction effect of various process parameters on cutting forces and surface finish are studied. Contour plots are drawn to find the dominating parameter and surface plots are drawn to identify the optimal combination of input parameters to get the desired output responses. The developed model helps in selection of proper machining parameters for a specific material and also helps in achieving the desired cutting forces and surface finish.

CONTENTS

CHAPTER I – INTRODUCTION **PAGE NO.**

CHAPTER III - DESIGN OF EXPERIMENTS

CHAPTER IV - EXPERIMENTAL SETUP

CHAPTER V - EXPERIMENTAL PROCEDURE AND ANALYSIS

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

LIST OF TABLES

NOMENCLATURE

Serial No.	Keyword	Description
1	DOE	Design of Experiments
2	F-test	Fisher's Test
3	P	Probabaility
4	SS	Sum of squares
5	MS	Mean Squares
6	ANOVA	Analysis of Variance
7	RSM	Response Surface Method
8	DF	Degrees of Freedom
9	ANN	Artificial Neural Network
10	HSS	High Speed Steel
11	MRR	Metal Removal Rate
12	TLBO	Teaching Learning Based Optimization
13	GA	Genetic Algorithm

CHAPTER - I

INTRODUCTION

1.0 The History of Metal Cutting

The history of metal cutting dates from the latter part of the eighteenth century. Before that time machine tools did not exist and the extract from the diary of the English Engineer, Richard Reynolds was attempting to produce a cylinder for fire engineer for drawing the water from a coal pit.

In 1976 James Watt built the first successful steam engine and one of his greatest difficulties in developing this machine was the boring of the cylinder casting. Later Johan Wilkinson has invented the horizontal boring machine. This boring machine was first effective machine tool and it enabled James Watt to produce successful steam engine.

Metal cutting as we know it now started with the introduction of this first machine tool. Today machine tools form the basis of our industry and are used either directly or indirectly in the manufacturing of all products of modern civilization.

1.1 History of Research in Metal Cutting

Research in metal cutting did not start until approximately 70 years after the introduction of the first machine tool. It is not proposed to give a complete history of research in metal cutting but to indicate some of the more important steps that have been made.

According to finenie, who published a historical review of work in metal cutting early research in metal cutting started with Cocqulhat in 1851 and was mainly directed towards measuring the work required to remove a given volume of material in drilling. In 1873 tabulations of the work required in metal cutting were presented by Harting in a bowl that seems to have been the authority the work on the subject several years.

The scrap removed during the cutting of metal are called chips and the first attempt to explain how chips are formed were made by the time in 1870 and the famous French scientist Tresca in 1873, some years later, in 1881, Mallock suggested correctly that the cutting process was basically of shearing the work material to form the chip and emphasised the importance of the effect of friction occurring on the cutting tool face as the chip was removed.

Finenic reports that a step backward in the understanding of the metal – cutting process was taken in 1900 when Reulaux suggested that a crack occurred ahead of the tool and the process could be linked to splitting of wood.

About this time the famous paper by Taylor was published, which reported the results of 26 years of research investigations and experience. Since 1906 when Taylor's paper was published, empirical and fundamental work has been carried out since and the publication of the well known paper by Ernst and Merchant in 1941, dealing with mechanics of the process.

1.2 Introduction to Milling Machine

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work.

The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was first developed by Jacques de Vasucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. Joseph R Brown a member of Brown & Sharpe Company invented the first Universal milling machine in the year 1861.

1.3 Classification of Milling Machines

1.3.1 Column and Knee-Type Milling Machine

Column and Knee-type milling machines are characterized by a vertically adjustable worktable resting on a saddle which is supported by a knee. The knee is a massive casting that rides vertically on the milling machine column and can be clamped rigidly to the column in a position where the milling head and milling machine spindle are properly adjusted vertically for operation. The plain vertical machines are characterized by a spindle located vertically, parallel to the column face, and mounted in a sliding head that can be fed up and down by hand or power. Modern vertical milling machines are designed so the entire head can also swivel to permit working on angular surfaces. The turret and swivel head assembly is designed for making precision cuts and can be swung 360° on its base. Angular cuts to the horizontal plane may be made with precision by setting the head at any required angle within a 180° arc. The plain horizontal milling machine's column contains the drive motor and gearing and a fixed position horizontal milling machine spindle. An adjustable overhead arm containing one or more arbor supports projects forward from the top of the column. The arm and arbor supports are used to stabilize long arbors. Supports can be moved along the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters. The milling machine's knee rides up or down the column on a rigid track. A heavy, vertical positioning screw beneath past the milling cutter. The milling machine is excellent for forming flat surfaces, cutting dovetails and keyways, forming and fluting milling cutters and reamers, cutting gears, and so forth. Many special operations can be performed with the attachments available for milling machine use. The knee is used for raising and lowering. The saddle rests upon the knee and supports the worktable. The saddle moves in and out on a dovetail to control cross feed of the worktable. The worktable traverses to the right or left upon the saddle for feeding the work piece past the milling cutter. The table may be manually controlled or power fed (Figure 1.1).

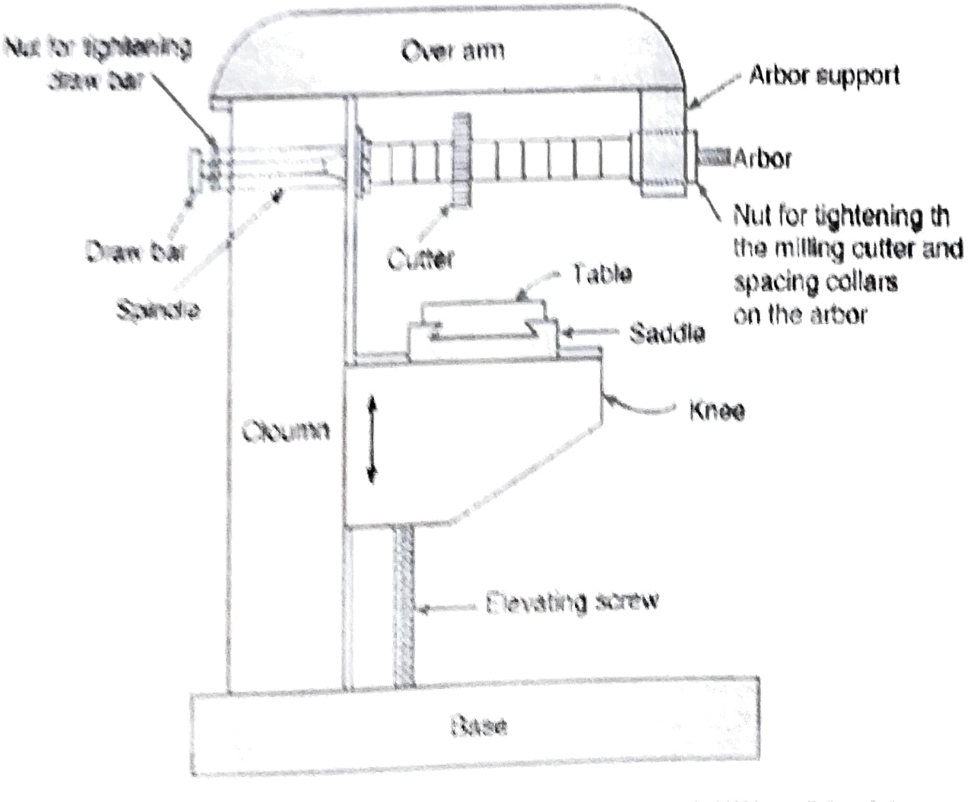


Figure 1.1 Columns and Knee-Type Milling Machine

1.3.2 Vertical Milling Machine

Vertical milling machine is so called, because of the vertical position of the cutter-spindle. The table movements are horizontal, transverse and vertical. In this case, over-arm is small and provides a strong support for the spindle. The spindle can be moved up and down to perform the operations. Generally vertical milling machine is used to perform end milling and face milling operations (Figure 1.2).

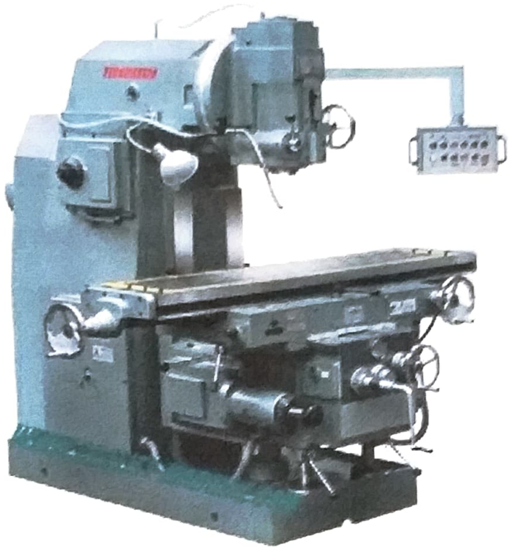


Figure 1.2 Vertical Milling Machine

1.3.3 Ram-Type Universal Milling Machine

The universal ram-type milling machine is characterized by a spindle mounted to a movable housing on the column to permit positioning the milling cutter forward or rearward in a horizontal plane. Two popular ram-type milling machines are the universal milling machine and the swivel cutter head ram-type milling machine (Figure 1.3).

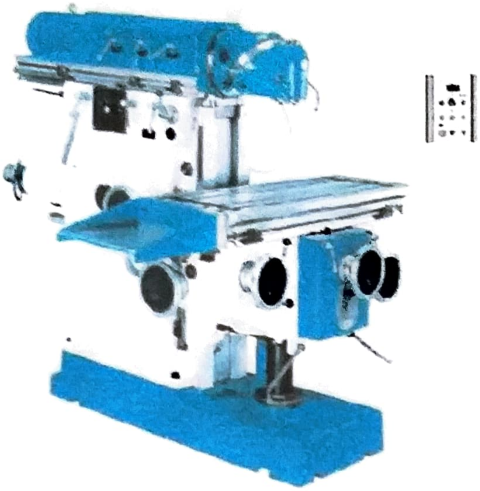


Figure 1.3 Ram-Type Universal Milling Machine

1.3.4 Universal Milling Machine

It is similar to the plain milling machine, with the difference that the table is placed on the swivel is placed on the saddle. Because of the swivel, the table and hence the job can be fixed at a desired angle, so that inclined cuts can be taken and hence the helical gears and drilling flutes are easily cut by machine. This type of machine is essentially a tool-room machine used for very accurate work (Figure1.4).

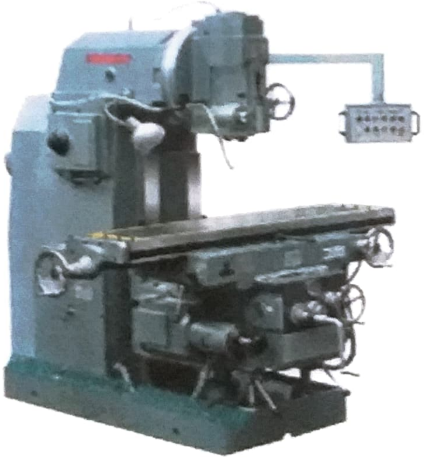


Figure 1.4 Universal Milling Machine

1.3.5 Planar-type Milling Machine

The usual feature of this machine are that of planar. Actually it is a planar adopted for doing milling operations on very big jobs. Table movement is slightly slower than actual planar. In place of tool head, milling heads are mounted on the cross-rails of planar. Rotating cutters of the milling heads do milling operation on the jobs. The variable table feeding movement and the rotating cutter are the principle features that distinguish this machine from the planar (Figure 1.5).

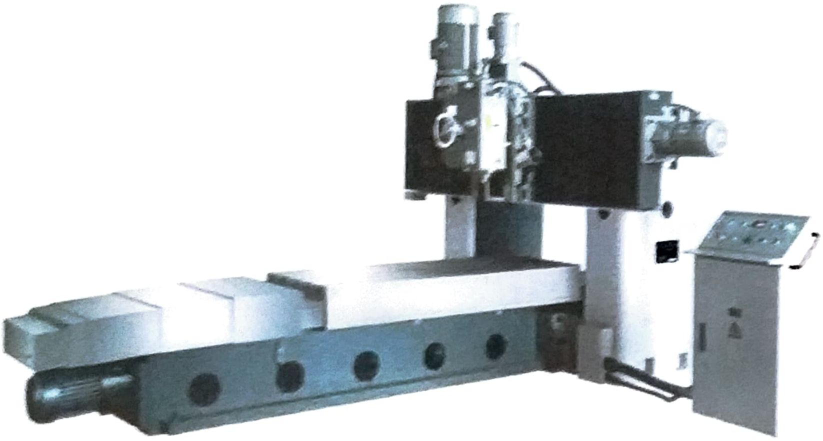


Figure 1.5 Planar-type Milling Machine

1.4 Types of Milling Operations

1.4.1 Peripheral Milling

In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the workpiece surface to be machined (Figure 1.6).

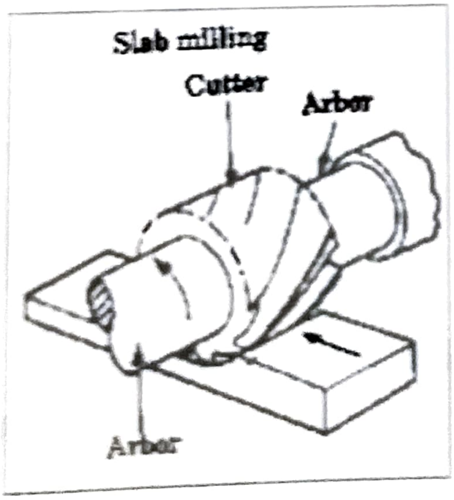


Figure 1.6 Peripheral Milling

1.4.2 Face Milling

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface. The milled surface results from the action of cutting edges located on the periphery and face of the cutter (Figure 1.7).

Figure 1.7 Face milling

1.4.3 End Milling

The cutter in end milling generally rotates on an axis vertical to the workpiece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body (Figure 1.8).

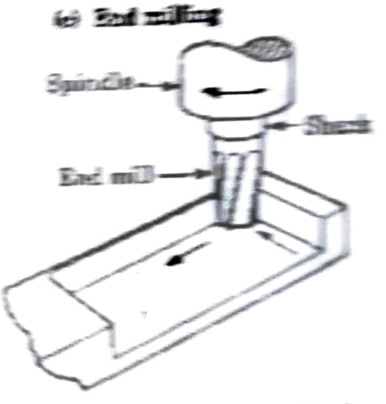


Figure 1.8 End milling

1.5 Methods of Milling

1.5.1 Up Milling

Up milling is also referred to as conventional milling. The direction of the cutter rotation opposes the feed motion. For example, if the cutter rotates clockwise , the workpiece is fed to the right in up milling (Figure 1.9).

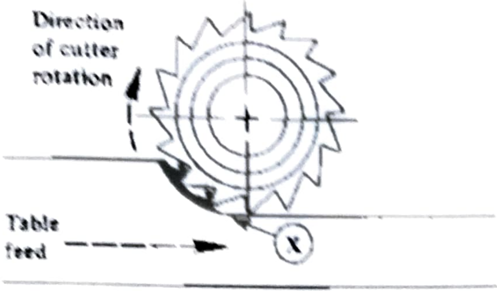


Figure 1.9 **Up milling process**

1.5.2 Down Milling

Down milling is also referred to as climb milling. The direction of cutter rotation is same as the feed motion. For example, if the cutter rotates counterclockwise , the workpiece is fed to the right in down milling (Figure 1.10).

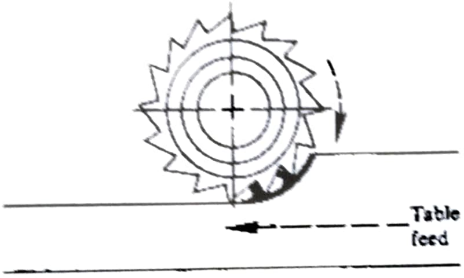


Figure 1.10 Down milling process

The chip formation in down milling is opposite to the chip formation in up milling. The figure for down milling shows that the cutter tooth is almost parallel to the top surface of the workpiece. The cutter tooth begins to mill the full chip thickness. Then the chip thickness gradually decreases.

1.6 Nomenclature of End Milling Cutter

An End Mill cutter with two flutes and its nomenclature is shown in Figure 1.11.

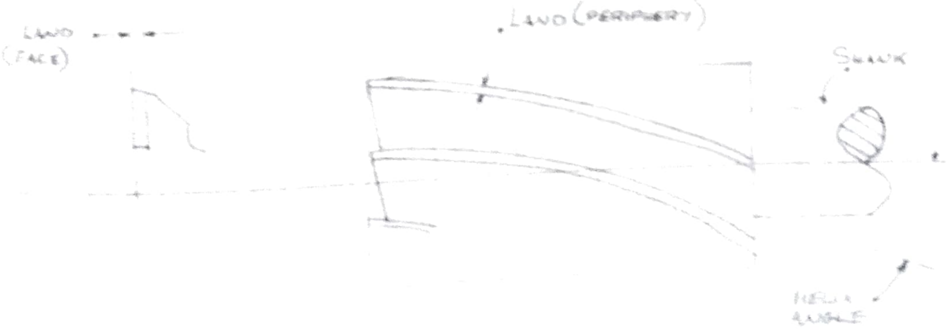


Figure 1.11 **End Milling cutters**

Milling cutters come in several shapes and many sizes. There is also a choice of coatings, as well as rake angle and number of cutting surfaces.

- **Shape**: Several standard shapes of milling cutter are used in industry today, which are explained in more detail below.
- **Flutes / teeth**: The flutes of the milling bit are the deep helical grooves running up the cutter, while the sharp blade along the edge of the flute is known as the tooth. The tooth cuts the material, and chips of this material are pulled up the flute by the rotation of the cutter. There is almost always one tooth per flute, but some cutters have two teeth per flute. Often, the words *flute* and *tooth* are used interchangeably. Milling cutters may have from one to many teeth, with 2, 3 and 4 being most common. Typically, the more teeth a cutter has, the more rapidly it can remove material. So, a 4-tooth cutter can remove material at twice the rate of a 2-tooth cutter.
- **Helix angle**: The flutes of a milling cutter are almost always helical. If the flutes were straight, the whole tooth would impact the material at once, causing vibration and reducing accuracy and surface quality. Setting the flutes at an angle allows the tooth to enter the material gradually, reducing vibration. Typically, finishing cutters have a higher rake angle (tighter helix) to give a better finish.
- **Center cutting**: Some milling cutters can drill straight down (plunge) through the material, while others cannot. This is because the teeth of some cutters do not go all the way to the centre of the end face. However, these cutters can cut downwards at an angle of 45 degrees or so.
- **Roughing or Finishing**: Different types of cutter are available for cutting away large amounts of material, leaving a poor surface finish (roughing), or removing a smaller amount of material, but leaving a good surface finish (finishing). A roughing cutter may have serrated teeth for breaking the chips of material into smaller pieces. These teeth leave a rough surface behind. A finishing cutter may have large number (4 or more) teeth for removing material carefully. However, the large number of flutes leaves little room for efficient swarf removal, so they are less good for removing large amounts of material.

- **Coatings:** Tool coatings can have a great influence on the cutting process. The right coating can increase cutting speed and tool life, and improve the surface finish. Polycrystalline Diamond (PCD) is an exceptionally hard coating used on cutters which must withstand high abrasive wear. A PCD coated tool may last up to 100 times longer than an uncoated tool. However the coating cannot be used at temperatures above 600 degrees C, or on ferrous metals. Tools for machining aluminium are sometimes given a coating of TiAlN. Aluminium is a relatively sticky metal, and can weld itself to the teeth of tools, causing them to appear blunt. However it tends not to stick to TiAlN, allowing the tool to be used for much longer in aluminium.

1.7 Shank

The shank is the cylindrical (non-fluted) part of the tool which is used to hold and locate it in the tool holder. A shank may be perfectly round, and held by friction, or it may have a Weldon Flat, where a grub screw makes contact for increased torque without the tool slipping. The diameter may be different from the diameter of the cutting part of the tool, so that it can be held by a standard tool holder.

1.8 Cutting Fluids

1.8.1 Purpose of cutting fluids

There is a wide variety of cutting fluids available today. Many new coolants have been developed to meet the needs of new materials, new cutting tools, and new coatings on cutting tools. The goal of machining operations must be to improve productivity and reduce costs. This is accomplished by machining at the highest practical speed while maintaining practical tool life, reducing scrap, and producing parts with the desired surface quality. Proper selection and use of cutting fluids can help achieve all of these goals.

In machining almost all of the energy expended in cutting is transformed into heat. The deformation of the metal to create chips and the friction of the chip sliding across the cutting tool produce heat. The primary function of cutting fluids is to cool the tool, work piece, and chip, reduce friction at the sliding contacts, and prevent or reduce the welding or adhesion on the contact edges that causes a built-up edge on the cutting tool or insert. Cutting fluids also help prevent rust and corrosion and flush chips away.

Most shops try to reduce the number of different types of fluids that they keep in stock. They try to stock fluids that have long-life, do not need to be changed constantly, don't smoke in use, and don't cause skin irritation. One large consideration is disposal. It is very costly to dispose of cutting fluids.

Cooling

Machining operations create heat. This heat must be removed from the process. The chip helps carry away heat from the tool and work piece. Coolant takes heat from the chips tool, and work piece. To be effective the fluid must be able to transfer heat very rapidly. The fluid absorbs the heat and carries it away.

Lubrication

In a typical machining operation, two-thirds of the heat is created by the resistance of the work piece atoms to being sheared. The friction of the chip sliding over the cutting tool face creates the other one-third of the heat.

Cutting fluid with good lubrication qualities can reduce the friction of the chip sliding over the tool face. The lubrication actually changes the shear angle, which reduces the shear path and produces a thinner chip. Good lubrication also reduces internal friction and heat through less molecular disturbance.

1.8.2 Types of cutting fluids

Cutting fluids can be broken into four main categories: straight cutting oils, water miscible fluids, gasses, and paste or solid lubricants. Two of the three (chemical-based and emulsions) are primarily water. Water quality has a large effect on the coolant. Water that is very hard (high mineral content) can cause rust, stains, and corrosion of machines and work pieces. Water can be deionized to remove the impurities and minerals.

Water is the best fluid for cooling. It has the best ability to carry heat away. Water, however, is a very poor lubricant and causes rust.

Oil is great for lubrication but very poor for cooling. Oil is also flammable. You

[illegible]

[illegible] Water Miscible cutting fluids

Emulsions

[illegible]

Chemical Fluids

Chemical coolants are also miscible cutting fluids. Chemical cutting fluids are pre-concentrated emulsions that contain very little oil. Chemical fluids mix very easily with water. The chemical components in the fluid are used to enhance the lubrication, bacterial control, rust and corrosion characteristics. There are several types of chemical coolants available including coolants for extreme cutting conditions.

Inactive chemical cutting fluids are usually clear fluids with high rust inhibition, high cooling, and low lubrication qualities. Active chemical fluids include wetting agents. They have excellent rust inhibition and moderate lubrication and cooling properties. Some contain sulfur or chlorine additives for extreme pressure cutting applications.

Semi-chemical Coolants

Semi-chemical fluids are a combination of a chemical fluid and an emulsion. They have a lower oil content but more emulsifier. This makes the oil droplets much smaller. They have moderate lubrication and cooling and high rust inhibition properties. Sulfur, chlorine, and phosphorous are sometimes added to improve the extreme pressure characteristics.

Straight Cutting Oils

Straight cutting oils are not mixed with water. Cutting oils are generally mixtures of mineral oil and animal, vegetable, or marine oils to improve the wetting and lubricating properties. Sulfur, chlorine, and phosphorous compounds are sometimes added to improve the lubrication qualities of the fluid for extreme pressure applications. There are two main types of straight oils: active and inactive.

Inactive Straight Cutting Oils

Inactive oils contain sulfur that is very firmly attached to the oil. Very little sulfur is released in the machining process to react with the work piece. Mineral oils are an example of straight oils. Mineral oils provide excellent lubrication, but are not very good at heat dissipation (removing heat from the cutting tool and work piece). Mineral oils are particularly suited to nonferrous materials, such as aluminum, brass, and magnesium. Blends of mineral oils are also used in grinding operations to produce high surface finishes on ferrous and nonferrous materials.

Active Straight Cutting Oils

Active oils contain sulfur that is not firmly attached to the oil. The sulfur is released during the machining operation to react with the work piece. These oils have good lubrication and cooling properties. Special blends with higher sulfur content are available for heavy duty machining operations. They are recommended for tough low carbon and chrome-alloy steels. They are widely used in thread cutting. They are also good for grinding as they help prevent the grinding wheel from loading up. This increases the life of the grinding wheel.

Gasses

Cutting oils and water miscible types of cutting fluids are the most widely used. Gasses are sometimes use. Compressed air and inert gasses are sometimes used. Carbon dioxide, Freon, and nitrogen are also used sometimes.

Paste and Solid Lubricants

Waxes, pastes, soaps, graphite, and molybdenum disulfide may be used. These are generally applied directly to the work piece or tool, or in some cases, impregnated directly into a tool, such as a grinding wheel. One example would be lard. Many experienced journeymen recommend lard for tapping.

1.8.4 Benefits of cutting fluids in milling

Details about various benefits of using cutting fluids while Milling is presented in Table 1.1.

Table 1.1 Benefits of cutting fluids

Improve Part Quality	The use of cutting fluids reduces friction and heat. The removal of the heat prevents the work piece from expanding during the machining operation, which would cause size variation as well as damage to the material's microstructure.
Reduce tooling costs	Proper use of cutting fluids increases tool life, which reduces the tooling costs. Increased tool life also reduces tool changes and downtime which decreases labor costs.
Increase Cutting Speeds and Feeds	Cutting tools reduce friction and heating a machining operation. This allows high speeds and feeds to be used to achieve optimal cutting conditions.
Improved Surface Finishes	Effective use of cutting fluids helps remove the chips. This prevents the chip from being caught between the tool and work piece where it causes scratches and a poor surface finish
Reduces Bacterial Growth	Bacteria can drastically affect cutting oils. Bacteria growth can turn a cutting fluid rancid. Additives in coolants help reduce the effects of bacteria, but it is important that pure water is used for coolant mixing.

Rust and Corrosion Prevention	Cutting fluids should protect the tooling, machine, and work piece against rust and corrosion. Cutting fluids should leave a small residual film that remains after the water has evaporated.

1.9 Surface Roughness

Surface roughness plays an important role in designing and manufacturing various components used in automobile, aerospace, machine tools etc.

Surface roughness is the measure of the finer surface irregularities in the surface texture. The final surface depends on the rotational speed of the cutter, velocity of traverse, feed rate and mechanical properties of work pieces being machined. Surface roughness also plays a significant role in determining and evaluating the surface quality of a product. Because surface roughness affects the functional characteristic of products such as fatigue, friction, wearing, light reflection, heat transmission, and lubrication, the product quality is required to be at the high level. While surface roughness also decreases, the product quality also increases. Figure 1.5 indicates the surface roughness structure after any cutting process with their terminology. The surface roughness describes the geometry of the surface to be machined and combined with surface texture. The formation of surface roughness mechanism is very complicated and mainly depends on machining process .

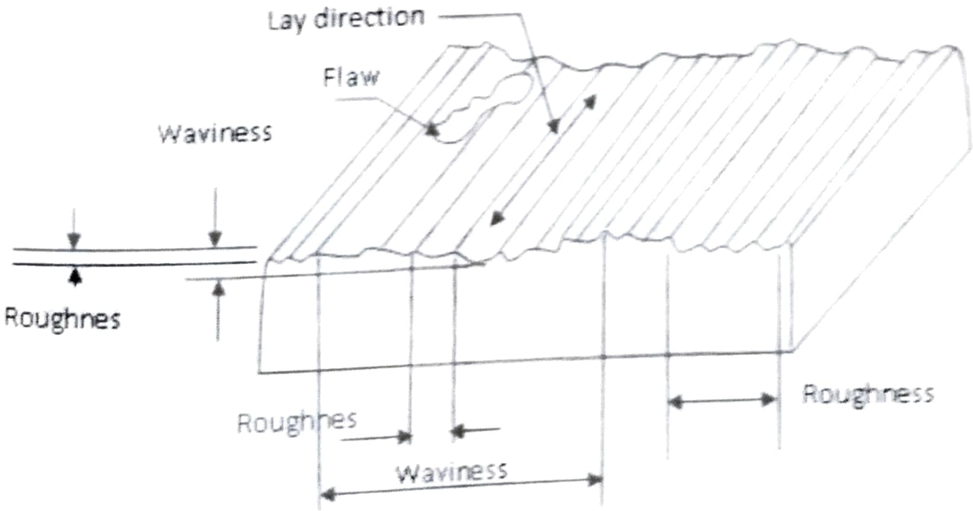


Figure 1.12 Nomenclature of surface roughness

[illegible] Surface Roughness Terminology

Roughness: Roughness consists of surface irregularities which result from the various machining process. These irregularities combine to form surface texture.

Roughness height: It is the height of the irregularities with respect to a reference line. It is measured in millimeters or microns or microinches. It is also known as the height of unevenness.

Roughness width: is the distance parallel to the nominal surface between successive peaks which constitute the predominant pattern of the roughness.

Roughness width cut off: is the greatest spacing of respective surface irregularities to be included in the measurement of the average roughness height. It should always be greater than the roughness width in order to obtain the total roughness height rating.

Lay: the direction of predominant surface pattern produced and it reflects the machining operation used to produce it.

Waviness: The irregularities which are outside the roughness width cut off values. Waviness is the widely spaced component of the surface texture. This may be the result of work piece or tool deflection during machining, vibrations or tool run out.

Waviness width: Waviness height is the peak to valley distance of the surface profile, measured in millimeters.

[illegible] Surface finish in machining

Ideal roughness

It is a function of only feed and geometry. It represents the best possible finish which can be obtained for a given tool shape and feed. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. Natural roughness: In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms a larger proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge. Thus larger the built up edge, the rougher would be the surface produced, and factors tending to reduce chip-tool friction and to eliminate or reduce the built-up edge would give improved surface finish.

CHAPTER-II

LITERATURE REVIEW

This chapter describes the works reported by various researchers on various milling process.

Azlon zain, et al. [1] observed the effect of different parameter like cutting speed, feed and rake angle in surface roughness. They compared the result of regression modeling and genetic algorithm.

V. Tandon et al. [2] presented a new approach to optimizing the cutting conditions in end milling (feed and speed) subject to a near to comprehensive set of constraints. The original set of seventeen constraints was reduced to an equivalent set (of only three equations). Next, a production cost objective function was used to define the parameter to optimize (in this case,minimize). An algorithm for PSO was then developed and used to robustly and efficiently find the optimum cutting conditions. Both feed and speed were considered during optimization. The new technique has several advantages and benefits and is suitable for use with ANN based models.

I.N. Tansela, et al., [3] have taken three parameters namely cutting speed, feed rate and radial depth of cut for milling process and applied ANN. They obtained good agreement between predicted and actual values. Response surface methodology is another technique applied by researchers for developing predictive modeling for surface roughness.

Baskar, et al. [4] showed significant improvement in conventional milling process optimization by using various non conventional optimization techniques. They compared their results with the results obtained from hand books.

J. Balic et al. [5] discussed an approach for the systematic design of condition monitoring system for machine tool and machining operations. The research is based on utilising the genetic optimization method for the on-line optimization of the cutting parameters and to design a program for the signal processing and for the detection of fault conditions for milling processes. Cutting parameters and the measured cutting forces are selected in this work as an application of the proposed approach.

Prakasvudhisarn et al. [6] introduced the new approach consist of two parts first one is machine learning technique called support vector machine to predict the surface roughness and second one is Particle swarm optimization technique for parameter optimization

Zarei et al. [7] proposed a harmony search (HS) algorithm to estimate the optimum cutting parameters for multi-pass face-milling process to minimize total production cost. Mainly four cutting parameters namely cutting speed, feed depth of cut/pass and number of passes are considered in their work. Harmony search algorithm has given significant improvement in result as compare to GA.

Asif Iqbal et al. [8] applied a fuzzy expert system in high speed milling process. The objective is to predict tool life and surface finish by optimize different parameter.

G.H. Qin [9] investigated the procedure that integrates the cutting force module consisting of calculating the instantaneous uncut chip thickness (IUCT), calibrating the instantaneous cutting force coefficients (ICFC) and the cutting process module consisting of calculating the cutting configuration and static form errors. It used to check the process reasonability and to optimize the process parameters for high precision milling. Comparisons of the cutting forces and form errors obtained numerically and experimentally confirm the validity of the proposed simulation procedure.

Onwubolu, et al. [10] however used the Tribes optimization for determination of cutting parameters in multi pass milling process to obtain better results for a particular context. From the review of various papers, the optimization on milling process has started only in recent past. Most of the researchers in were using soft computing based optimization methods and found good results. The literature related to milling optimization is mainly concerned with minimization of surface roughness.

R.V.Savsani, et al. [11] introduced a new optimization method known as Teaching – Learning Based Optimization (TLBO).This algorithm has not only solved many bench mark design problems and given effective and efficient result compared the result with other non-traditional optimization techniques such as PSO, ACO, SA, GA, etc. The results are compared for different performance criteria such as success rate, mean solution, average number of function evaluations required, convergence rate, etc.

Oktem et al. [12] observed closeness in the results between experimental and predicted values in end milling process. They used neural network and genetic algorithm.

Mohammed.T.Hayajneh et al. [13] performed set of experiments to begin the characterization of surface quality for the end-milling process. The objective of this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and builded a multiple regression model .the model which included the effect of spindle speed, cutting feed and depth of cut, and any two variable interactions, predicted the surface roughness values with an accuracy of about 12%.

H.Z.Li et al. [14] presented an experimental study of the tool wear propagation and cutting force variations in the end milling of Inconel 718 with coated carbide inserts. Results showed that significant flank wear was the predominant failure mode affecting the tool life. The tool flank wear propagation in up-milling operations was more rapid than that in down-milling operations. The cutting force variation was also analyzed. While the thermal effects could be a cause for the peak force variation within a single cutting pass, the tool wear propagation was responsible for the gradual increase of mean peak force in successive cutting passes.

Wen-Hsiang Lai et al. [15] introduced the concept of flute engagement. The instantaneous dynamic radii on every cutting position affects the cutting forces directly since the stimulated forces are proportional to chip thickness and chip thickness is a function of dynamic radii and federate. Lengths of the engaged flutes is affected by factors in axial feed and rotational directions. The influence of dynamic radii, cutting feed rate , radial, axial depth of depth are discussed.

Yang Yang et al. [16] discussed the influence of surface roughness on the functional properties of the product. A method based on gene expression programming (GEP) has been proposed to construct the prediction model of surface roughness. It combines the advantages of genetic algorithm (GA) and genetic programming (GP). The experimental results show that proposed approach has achieved satisfactory improvement.

J.W.Sutherland et al. [17] created a dynamic model for the cutting forces system. This model described a) the dynamic transverse response of the end mill via a distributed parameter model. b) The chip load geometry c) dependence of cutting forces on the chip load. The model is verified through comparisons of model predicted cutting force signals with measured cutting forces obtained from machining experiments.

K.A. Abou-El-Hossein et al. [18] reported an experimental study on performance of multi-layered (TiN/TiCN) carbide inserts developed for end-milling of AISI 304 stainless steels. In this study, the possible failure modes of tool wear were discussed and the effect of cutting speed and feed rate variation on tool wear modes was investigated. The most optimum cutting parameter for end milling operation using a single end mill was established in terms of maximum productivity and maximum tool life.

Anna Carla Araujo et al. [19] compared some of the available models for prediction of instantaneous forces in end milling based on this concept the cutting forces on disk like elements that comprised the end mills can be assumed to give the total cutting force models based on empirical constants, orthogonal cutting data and oblique cutting relations are reviewed , proposed and compared.

Muhamad nazumi bin basuki et al. [20] discussed the development of the first and second order models for predicting the cutting force produced in end-milling operation of modified AISI P20 tool steel. The first and second order cutting force equations are developed using the response surface methodology (RSM) to study the effect of four input cutting parameters which is cutting speed, feed rate, radial depth and axial depth of cut on cutting force. The cutting force increased with the slightly reduce of axial depth and cutting speed value. The predictive models in this study are believed to produce values of the longitudinal component of the cutting power close to those readings recorded experimentally with a 95% confident interval.

From the review of various papers, it is understood that the optimization on milling process has started only in recent past. Most of the researchers were using soft computing based optimization methods and found good results. The literature related to milling optimization is mainly concerned with minimization of surface roughness. The objective of the present project work is to study the effect of end milling process parameters on surface finish and MRR.

CHAPTER-III

DESIGN OF EXPERIMENTS

3.0 Introduction to Design of Experiments

Design of Experiment is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modeling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyze the data. A mathematical model has been developed by using analysis techniques such as ANOVA and regression analysis whereby the mathematical model shows the relationship between the input parameters and the output responses. Among the most prominently used DOE techniques are Response Surface Methodology with Central Composite Design, Taguchi's method and Factorial Design. In DOE, synergy between mathematical and statistical techniques such as Regression, Analysis of Variance (ANOVA), Non-Linear Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process. ANOVA helps to identify each factor effect versus the objective function.

Experimental design was first introduced in the 1920s by R. A. Fischer working at the agricultural field station at Rothamsted in England. Fischer concerned with arranging trials of fertilizers on plots to protect against the underlying effect of moisture, gradient, nature of soils, etc. Fischer developed the basic principles of factorial design and the associated data analysis known as ANOVA during research in improving the yield of agricultural crops.

3.1 Advantages & Disadvantages of DOE

DOE became a more widely used modeling technique superseding its predecessor one-factor-at- time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE function in such manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have error occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behavior. However, when it comes to nonlinear behavior, DOE does not always give the best results.

3.2 Factorial Design

Factorial design is used for conducting experiments as it allows study of interactions between factors. Interactions are the driving force in many processes. Vital interface may be unobserved without factorial design of experiments. In a full factorial experiment, responses are measured at all combinations of the experimental factor levels. The combinations of factor levels represent the conditions at which responses are measured. Each experimental condition is called a "run" and the response measurement is called an "observation" while factorial design can be run on two-levels, three-levels and multi-level factorial. The entire set of runs is the "design". According to Myers and Montgomery, Full Factorial Design is a design in which all possible combinations of the factor levels are fulfilled. The result from the full factorial experiments would be more reliable but conducting the full factorial experiments is costly and sometimes prohibitive.

Factorial experiments permits to evaluate the combined effect of two or more experiments variables when evaluated simultaneously. Information obtained from factorial experiments is more complete than those obtained from a series of single factor experiments, in the sense that factorial experiments permit the evaluation of interaction effects. An interaction effect is an effect attributable to the combination of variables above and beyond that which can be predicted from the variables considered separately. For the need of factorial experiments, the information gathered could be used to make decisions, which have a board range of applicability. In addition to information about how the experiments variables operate in relative isolation, it can be predicted, what will happen when two or more variables are used in combination. Apart from the information about interactions, the estimate of the effects of the individual variables is a more practical use. In the case of factorial experiments, the population to which inferences can be made is more inclusive than the corresponding population for a single factor experiments. Factors may be classified as treatment and classification factors.

- Classification factors group the experimental units into classes which are homogeneous with respect to what is being classified.
- Treatment factors define experimental conditions applied to an experimental unit. The administration of the treatment factors is under the direct control of the experimenter, where as classification factors are not, in sense.

The effects of the treatment factors are of primary interest to the experimenter, where as classification methods are included in an experiment to reduce experimental error and clarify interpretation of the effects of the treatment factors.

The design of factorial experiments is concerned with answering the following questions:

- What factors should be included?
- How many levels of each factor should be included?
- How should the levels of the factors be spaced?
- How many experimental units should be selected for each treatment conditions?
- Can the effects of primary interests be estimated adequately from the experimental data that will be obtained?

A factor is a series of related treatments or related classifications. The related treatments making a factor constitute the levels of that factor. The number of levels within a factor is determined largely by the thoroughness with which an experimental desires to investigate the factor.

Alternatively, the levels of a factor determined by the kind of inference the experimental desires to make upon a conclusion of experiment.

The dimensions of a factorial experiment are indicated by the number of levels of each factor.

For the case of p*q factorial experiment, PQ different treatment combinations are possible. As number of factor increases, or as the number of levels within a factor increases, the number of treatment combinations in a factorial experiment increases quite rapidly.

In an experiment, the elements observed under each of the treatment combinations will generally be a random sample from some specified population. This population may contain potentially infinite number of elements. If n elements are to be observed under each of treatment combination in p*q factorial experiment, a random sample of npq elements from population is required. The npq elements are then subdivide at random to the treatment combinations.

The P potential levels may be grouped in to P levels ($p<q$) by either combining adjoining levels or deliberately selecting what are considered to be representative levels.

When $p = P$ then the factor is called the fixed factor. When the selection of the p levels from the potential P levels is determined by some systematic, non-random procedure, then also the factor is considered a fixed factor. In this later case, the selection procedure, reduce the potential P levels to p effective levels .Under this type of selection procedure, the effective, potential number of levels of factor in the population may be designated as $P_{effective}$ and $P_{effective} = p$.

In contrast to this systematic selection procedure, if the p levels of factor A included in the experiment represents a random sample from the potential p levels, then the factor is considered to be random factor. In most practical situations in which random factors are encountered, p is quite small to relative to P, and the ratio p/P is quite close to zero.

The ratio of the number of levels of a factor in an experiment to the potential number of levels in the population is called the sampling fraction for a factor. In term of this sampling fraction, the definition of fixed and random factors may be summarized as mentioned in Table 2.

Table 3.0: Relationship between Sampling Fraction and Fixed Random Factors

Sampling fraction	Factor
p/P or $p/P_{effective} = 1$	A is a fixed factor
$p/P = 0$	A is a random factor

Cases in which the sampling fraction assumes a value between 0 and 1 do occur in practice.

However, cases in which sampling fraction is either 1 or very close to 0 encountered more frequently. Main effects are defined in terms of parameters. Direct estimates of these parameters will be obtainable for corresponding statistics.

The main effect for the level is the difference between the mean of all potential observations on the dependent variable at the level and grand mean of all potential observations.

The interaction between different levels is a measure of the extent to which the criterion mean for treatment combination cannot be predicted from the sum of the corresponding main effects. From many points of views, the interaction is a measure of the non-additivity of the main effects. To some extent the existence or non-existence of interaction depends upon the scale of measurement. For example, the interaction may not be present in terms of a logarithmic scale of measurement, whereas in terms of some other scale of measurement an interaction may be present. If alternative choices are present, then that scales which leads to the simplest additive model will generally provide the most complete and adequate summary of the experimental data.

3.3 Methodology

For conducting trial runs values or levels of these variables were chosen randomly from an infinite potential level i.e. the sampling fraction for these trials runs was equal to zero however, we got a rough range of these factors from the literature we surveyed. With the help of these trials runs effective representative s levels were developed for each factor (variables).

The numbers of levels for to be included in the experiment were chosen for each factor as per the design. RSM based Box Behnken Design s adopted and for 3 factors and 3 levels, 15 experiments are performed. The levels for each factor were the highest value and the lowest value of the factors in between and at which the outcome was acceptable. These values were outcomes of trials runs. Highest value has been represented by + and the lowest value has been represented by – as mentioned in Table 3.1. As per the design matrix the final runs were conducted and the response

3.4 Development of Mathematical Models

A low-order polynomial is employed for developing the mathematical model for predicting weld pool geometry. If the response is well modeled by a linear function of the independent variables then the approximating function is the first order model as shown in Equation 1.

$$Y = \beta + \beta_1 x_1 + \beta_2 x_2 + \ldots\_\beta_x x_x + \in \qquad \text{Eq-(3.1)}$$

Table 3.1 Typical design matrix

S NO:	Spindle Speed	Feed (mm/min)	Cutting Fluid Proportion (Oil:Water)
1	297	0.43	1
2	520	0.43	1
3	297	1.86	1
4	520	1.86	1
5	297	1.12	0.66
6	520	1.12	0.66
7	297	1.12	1.5
8	520	1.12	1.5
9	357	0.43	0.66
10	357	1.86	0.66
11	357	0.43	1.5
12	357	1.86	1.5
13	357	1.12	1
14	357	1.12	1
15	357	1.12	1

3.5 Estimation of Regression Coefficients

The regression coefficient of the model was computed using the following formula based on the method of least squares.

Bj = xjiyi

N

Where:

j = 0, 1, 2, ……k

N = Number of experimental trails

X = Number of columns of the designed matrix

xji= value of a factor or interaction in coded form.

Yi=Average

A matrix designed to apply the above formula for the calculation of regression co-efficient of the model is given in table. Because of the orthogonal property of the design, the estimated coefficients are un correlate with one another. Since the method of least squares has been used, the estimates also possess the property of minimum variance. All the regression coefficients of the model are expressed by the above equation were estimated for the response parameter i.e. surface and material removal rate.

3.6 Checking the Adequacies of the Models

All the above estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying Analysis of Variance (ANOVA) technique F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider adequate.

In the present case the tabulated value of F-ratio was found out as follows.

$$F_{ratio} = 2 \times (S^2_{ad} / S^2_y)$$

Where.

S^2_{ad} = Variance of adequacy or residual variance

S^2_y = Variance of optimization parameter of variance of reproducibility.

The variance of adequacy was calculated by $S^2_{ad} = 2\,(y_{avg} - y_{pre})^2 /DOF$

Where y_{avg} = Value of response predicted.

DOF = Degree of freedom and is equal to (n-(K+1)

N = No of experimental trials

K = No. of independent variables

S^2_Y = $2\ (y_1 - y_{avg})^2\ /\ DOF$

Y_{avg} = average of response observed

Y_1 = other of the values of response parameter

DOF = Degree of freedom is equal to the number of experimental runs

3.7 Standard Fisher Ratio Table

A ratio has been developed in statistics that is very convenient for testing a hypothesis on the adequacy of the model.

The convenience of using the F-ratio consists in that the testing of hypothesis can be reduced to compare N tabulated value.

The table constructed as follows.

The columns are related to a definite number of degrees of freedom for the number f1 and rows for the denominator f2. The critical values of the F-ratio are found at the intersection of the corresponding rows and columns. As a role, a significance level of 5% (confidence level of 95%) is used in technical problems. (F-table shown in Table 3.2).

3.8 Development of the Final Mathematical Model

The final mathematical model was constructed by using only significant coefficients and is shown in table.

The values predicted by these models were also checked by actually conducting experiments by keeping the value of the process parameter at some values other than those used for developing the models but within the zone and the results obtained were found satisfactory. Then these models were used for drawing graphs and analyzing the results.

Table 3.2 Values of F- Ratio at 5% significance Level

	1	**2**	**3**	**4**	**5**	**6**	**12**	**24**	**00**
1	164.4	199.5	215.7	224.6	230.2	234.0	244.9	249.0	254.3
2	18.5	19.2	19.3	19.3	19.3	19.4	19.4	19.4	19.5
3	10.1	9.6	9.3	9.1	9.0	8.9	8.7	8.7	8.5
4	7.7	6.9	6.6	6.4	6.3	6.2	5.9	5.8	5.6
5	6.6	5.8	5.4	5.2	5.1	5.0	4.7	4.5	4.4
6	6.0	5.1	4.8	4.5	4.4	4.3	4.0	3.8	3.7
7	5.5	4.7	4.4	4.1	4.0	3.9	3.6	3.4	3.2
8	5.3	4.5	4.1	3.8	3.7	3.6	3.3	3.1	2.0
9	5.1	4.3	3.9	3.6	3.5	3.2	2.9	2.7	2.5
10	5.0	4.1	3.7	3.5	3.3	3.2	2.9	2.7	2.5
11	4.8	4.0	3.6	3.4	3.2	3.0	2.9	2.5	2.3
12	4.8	3.9	3.5	3.3	3.1	3.0	2.7	2.5	2.3
13	4.7	3.8	3.4	3.2	3.0	2.9	2.6	2.4	2.2
14	4.6	3.7	3.3	3.1	3.0	2.9	2.5	2.3	2.1
15	4.5	3.7	3.3	3.1	2.0	2.8	2.5	2.3	2.1
16	4.5	3.6	3.2	3.0	2.9	2.7	2.4	2.2	2.0
17	4.5	3.6	3.2	2.9	2.8	2.7	2.4	2.2	2.0
18	4.4	3.6	3.2	2.9	2.8	2.7	2.3	2.1	1.9
19	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.9
20	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.8
22	4.3	3.4	3.1	2.8	2.7	2.6	2.2	2.0	1.8
24	4.3	3.4	3.0	2.8	2.6	2.5	2.2	2.0	1.7
26	4.2	3.4	3.0	2.7	2.6	2.5	2.2	2.0	1.7
28	4.2	3.3	3.0	2.7	2.6	2.4	2.1	1.0	1.7
30	4.2	3.3	2.9	2.7	2.5	2.4	2.1	1.9	1.6
40	4.1	3.2	2.9	2.6	2.5	2.3	2.0	1.8	1.5
60	4.0	3.2	2.8	2.5	2.4	2.3	1.9	1.7	1.4
120	3.9	3.1	2.7	2.5	2.3	2.2	1.8	1.6	1.3
00	3.8	3.0	2.6	2.4	2.2	2.1	1.8	1.5	1.0

CHAPTER – IV

EXPERIMENTAL SETUP

4.1 Description of Universal Milling Machine

A universal milling machine is so named because it may be adapted to a very wide range of milling operations. A universal milling machine can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations, and the table can be swiveled to any angle upto 45° on either side of the normal position. The table can be swiveled about a vertical axis and set at an angle other than right angles to the spindle. Thus in a universal milling machine, in addition to three movements as incorporated in a plain milling machine, the table may have a fourth movement when it is fed at an angle to the milling cutter. This additional feature enables it to perform helical milling operation which cannot be done on a plain milling machine unless a spiral milling attachment is used. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head or index head, vertical milling attachment. Rotary attachment, slotting attachment, etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters, etc. besides doing all conventional milling operations. It may be employed with advantage for any and every type of operations that can be performed on a shaper or on a drill press. A universal machine is, therefore, essentially a tool room machine designed to produce a very accurate work (Figure 4.1).

Universal Milling Machine Specifications

Table Size	300 x 1330mm
Number of Spindles	8
Power	3 HP
Range of speed	63-227 RPM

Figure 4.1 **Universal Milling Machine**

4.2 Surface Finish Indicator

The instrument used for measuring surface finish was surface indicator. This device consists of tracer head and an amplifier. The head housed a diamond stylus, having a point radius of 0.03 mm, which been against the surface of the work and may be moved by hand or it may be another driven. Any movement of the stylus covered by surface irregularities is converted into electric fluctuations by the tracer head. These signals are magnified by the amplifier and registered on the digital display. The reading shown on the display indicator the average height of the surface roughness or the depth of the surface from the reference line. For accurate determination of the surface finish the indicator must first be calibrated by setting it to a precision reference surface on a block calibrated to ASA standards.

4.2.1 Principle of Talysurf

The Talysurf is all electronics instrument working on carrier modulating principle. This instrument gives the information more rapidly and accurately. This instrument records the static displacement of the stylus. The measuring head of this instrument record the static displacement of the stylus. The measuring head of this instrument record consists of a diamond stylus of about 0.002 mm tip radius and which is drawn across the surface by means of motorised driving unit, which provides the motorised speed giving reading. The arm carrying the stylus forms an armature which pivots about the centre piece of e-shaped stamping on two coils with other two resistances's from an oscillator. As the armature is pivoted about the central leg, any movement if the stylus covers the air gap to vary and this the amplitude of the original A.C. current flowing in the coils is modulated. This is further demodulated so that the current flow in directly proportional to the vertical displacement of the stylus only (Figure 4.2).

4.3 Procedure for measuring surface roughness using Talysurf

- Turn the switch on and allow the instrument to warm for approximately 3 minutes.
- Check the machine calibration by moving the stylus over the test block.
- If necessary, adjust the calibration control so that the instrument registers the range as the test book.
- Thoroughly clean the surface to be measured to ensure accurate readings and reduce wear on the rider cap protecting the stylus.
- Now the stylus moves on the work piece smoothly to the specified cutoff length and the value is displayed in micrometers.

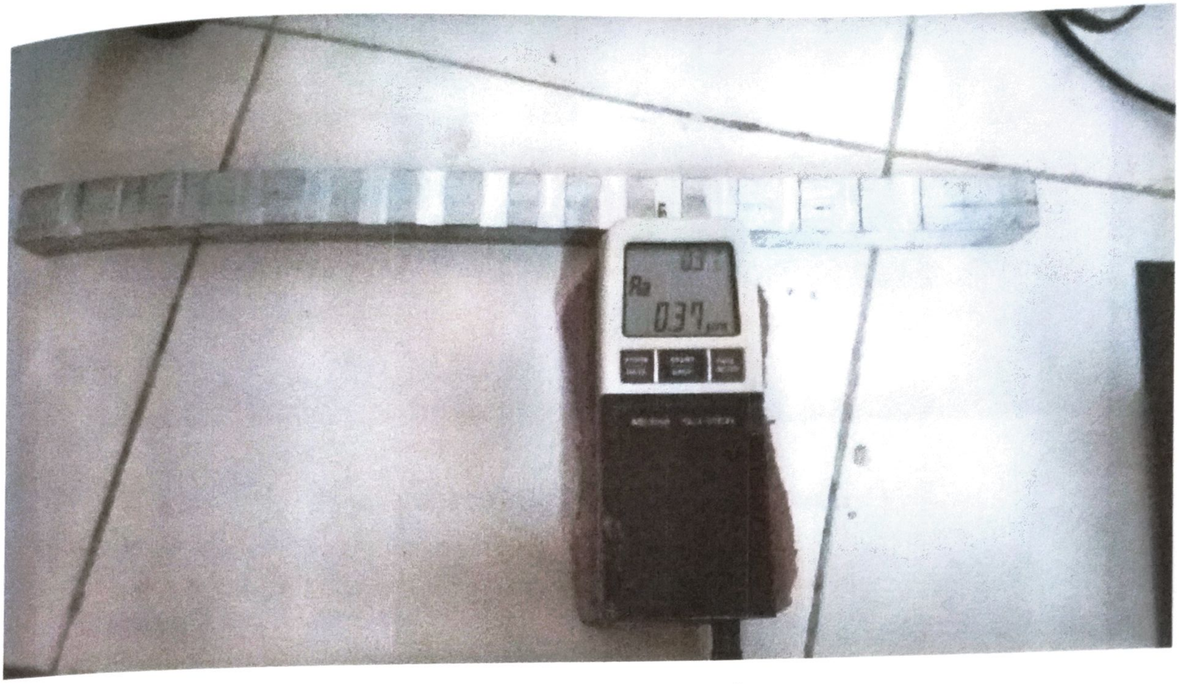


Figure 4.2 Talysurf

4.4 Milling Dynamometer

A milling cutter dynamometer has been designed and developed which enables radial and tangential forces acting on a cutter tooth to be recorded throughout its cutting action.

Digital multicomponent force indicator (three channel)

Instrument comprises of two independent digital display units calibrated to display force directly using three-component milling tool dynamometer. This instrument comprises of independent DC excitation supply for feeding strain gauge bridges, signal processing system to process and compute respective force value for direct independent display in kgf units. Instrument operates on 230v, 50 c/s AC mains. Size – 150x350x270 mm nominal.

Figure 4.3 Milling Tool Dynamometer

4.5 Cutting Tool Material

High Speed Steel tool

High speed steels (HSS) are carbon steels with alloying elements such as Tungsten (W), Chromium (cr), Vandium (V), Molybdenum (Mo) and Cobalt (Co).

These are normally grouped into three classes:

Class – I: 18-4-1 HSS: 18% W, 4% Cr, 1%V.

This type is called Tungsten type HSS and is well known for air and heat resistance.

Class – II: 6-6-4-2: 6%W, 6%Mo, 4%Cr, 2%V. This type is called Molybdenum type HSS and is well known for wear and impact resistance.

Class – III. Super HSS: 2 to 15% Co additionally to increase cutting efficiency for heavier cut imparting higher temperatures.

The HSS is a tough and heat treatable material with high ` red hardness` retaining the cutting edge upto 650^0C. The High speed steels find application s as single point tools, drills, reamers, milling cutters. These can be sharpened by grinding with Aluminum oxide which, economical compared to carbide tools and perform fairly well. The hardness is about 65 to 67 RC. These are used at 20 to 30 surface in / min for most steels.

Figure 4.3 End milling cutters

4.6 Work Piece Material

Aluminium or **aluminum** (in North American English) is a chemical element in the boron group with symbol **Al** and atomic number 13. It is a silvery-white, soft, nonmagnetic, ductile metal. By mass, aluminum makes up about 8% of the Earth's crust; it is the third most abundant element after oxygen and silicon and the most abundant metal in the crust, though it is less common in the mantle below. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals. The chief ore of aluminum is bauxite.

Aluminum is remarkable for the metal's low density and its ability to resist corrosion through the phenomenon of passivation. Aluminum and its alloys are vital to the aerospace industry and important in transportation and structures, such as building facades and window frames the oxides and sulfates are the most useful compounds of aluminum.

Despite its prevalence in the environment, no known form of life uses aluminum salts metabolically, but aluminum is well tolerated by plants and animals.[8] Because of these salts' abundance, the potential for a biological role for them is of continuing interest, and studies continue.

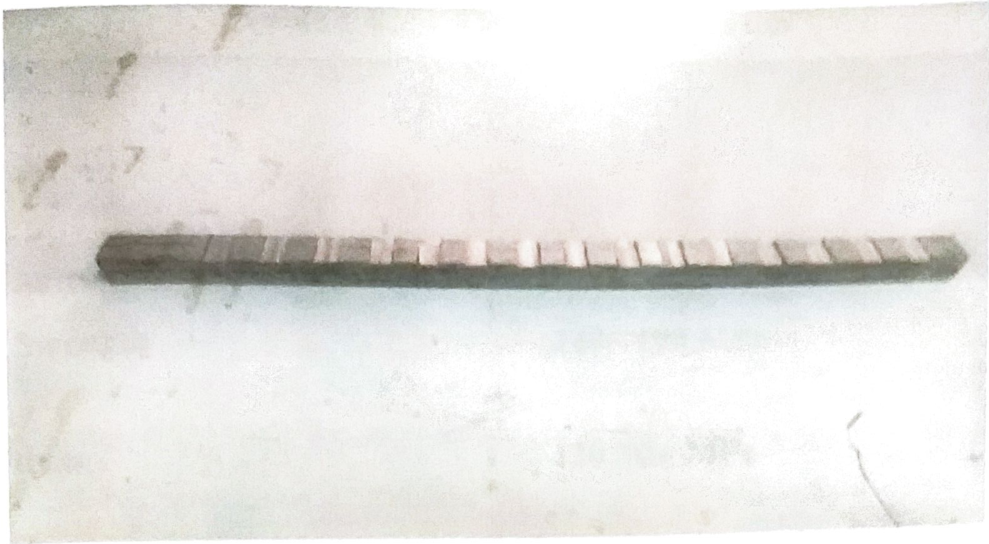


Figure 4.4 Work piece materials (After machining)

Table 4.1 Chemical composition (wt. %)

Element	COMPOSITION (%)
Manganese (Mn)	0.90 - 1.50
Iron (Fe)	0.0 - 0.70
Copper (Cu)	0.0 - 0.10
Magnesium (Mg)	0.0 - 0.30
Silicon (Si)	0.0 - 0.50
Zinc (Zn)	0.0 - 0.20
Other (Each)	0.0 - 0.05
Others (Total)	0.0 - 0.15
Chromium (Cr)	0.0 - 0.10
Titanium + Zirconium (Ti+Zr)	0.0 - 0.10
Aluminum (Al)	Balance

Table 4.2 Physical properties

PHYSICAL PROPERTIES	METRIC
Density	2.73gm/cc

Table 4.3 Thermal properties

THERMAL PROPERTIES	METRIC
Thermal Conductivity	115 W/m-K
Melting Point	655°C

Table 4.4 Mechanical properties

Mechanical Property	Value
Tensile Strength	140 - 180 MPa
Proof Stress	120 Min MPa
Hardness Brinell	45 HB

CHAPTER-V

EXPERIMENTAL PROCEDURE AND ANALYSIS

5.1 Experimentation

Commercial Aluminium plate is taken and grinded in order to remove any surface irregularity. White chalk is applied on one side of the bras plate. By using steel rule and scriber the aluminium plate is divided into 15 subdivisions to facilitate milling process. Four input parameters are chosen, namely spindle speed, feed, depth of cut, cutter diameter and machining condition. The levels and values of chosen parameters are presented in Table 5.1

Table 5.1 Range of input values

	Range		
	(-) Minimum	**(0) Mean**	**(+) Maximum**
Spindle speed (rpm)	297	357	520
Feed (mm/min)	0.43	1.12	1.86
Cutting fluid (oil & water %)	0.66	1	1.5

For three factors and three levels, as per **Box Benhken Design** of Response Surface Method, 15 combinations are performed as per the design matrix shown in Table 5.2

Table 5.2 Experimental results

Exp.No	Spindle Speed (rpm)	Feed (mm/min)	Cutting Fluid Proportion	Cutting Forces		Surface Finish (Microns)
				Fy (Kgf)	Fz(Kgf)	
1	297	0.43	1	1.92	1.42	0.62
2	520	0.43	1	1.82	1.28	0.30
3	297	1.86	1	1.76	1.12	0.72
4	520	1.86	1	1.82	1.02	0.38
5	297	1.12	0.66	1.86	1.18	0.72
6	520	1.12	0.66	1.95	1.32	0.32
7	297	1.12	1.5	2.12	1.42	0.43
8	520	1.12	1.5	1.68	1.08	0.63
9	357	0.43	0.66	2.18	1.52	0.32
10	357	1.86	0.66	1.86	1.24	0.65
11	357	0.43	1.5	1.87	1.12	0.51
12	357	1.86	1.5	1.52	1.04	0.34
13	357	1.12	1	1.84	1.18	0.38
14	357	1.12	1	1.64	1.08	0.48
15	357	1.12	1	1.92	1.16	0.54

5.2 Development of mathematical model

Using MINITAB 14 statistical software package, the significant coefficients were determined and final model is developed using coefficients to estimate cutting forces and surface finish of the end milling slots.

$$Fy = 3.34319-0.00431X_1-0.34214X_2-0.40528X_3$$

$$Fz= 3.03338-0.00473X_1-0.45260X_2-0.76646X_3$$

$$\text{Surface Finish} = 3.25828-0.01278X_1+0.58033X_2-0.86889X_3-0.01X_1X_3-0.026X_2X_3$$

where X_1, X2, X_3 are the coded values of spindle speed, feed and cutting fluid proportion.

5.3 Checking the adequacy of the developed model

The adequacy of the developed model was tested using the Analysis of Variance technique (ANOVA). As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (from F-table) value at a desired level of confidence (say 95%), then the model is said to be adequate within the confidence limit.

Table 5.3 Analysis of Variance for Fy (Kgf)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.23718	0.23718	0.026353	0.84	0.615
Linear	3	0.14576	0.01482	0.004941	0.16	0.920
Square	3	0.03416	0.03488	0.011628	0.37	0.778
Interaction	3	0.05726	0.05726	0.019087	0.61	0.638
Residual Error	5	0.15691	0.15691	0.031383		
Lack-of-Fit	3	0.11531	0.11531	0.038438	1.85	0.370
Pure Error	2	0.04160	0.04160	0.020800		
Total	14	0.39409				

Table 5.4 Analysis of Variance for Fz (Kgf)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.233404	0.233404	0.025934	1.47	0.349
Linear	3	0.159472	0.025342	0.008447	0.48	0.710
Square	3	0.038168	0.037817	0.012606	0.72	0.584
Interaction	3	0.035764	0.035764	0.011921	0.68	0.603
Residual Error	5	0.088036	0.088036	0.017607		
Lack-of-Fit	3	0.082436	0.082436	0.027479	9.81	0.094
Pure Error	2	0.005600	0.005600	0.002800		
Total	14	0.321440				

Table 5.5 Analysis of Variance for Surface Finish (Microns)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.28373	0.28373	0.031526	5.03	0.045
Linear	3	0.08200	0.11609	0.038698	6.17	0.039
Square	3	0.03848	0.03714	0.012381	1.97	0.236
Interaction	3	0.16326	0.16326	0.054419	8.68	0.020
Residual Error	5	0.03136	0.03136	0.006272		
Lack-of-Fit	3	0.01829	0.01829	0.006097	0.93	0.554
Pure Error	2	0.01307	0.01307	0.006533		
Total	14	0.31509				

Figure 5.1, 5.2 and 5.3 indicate the scatter plot for Fy, Fz and Surface finish of the end milling slots and reveals that the experimental and predicted values are close to each other with in the specified limits.

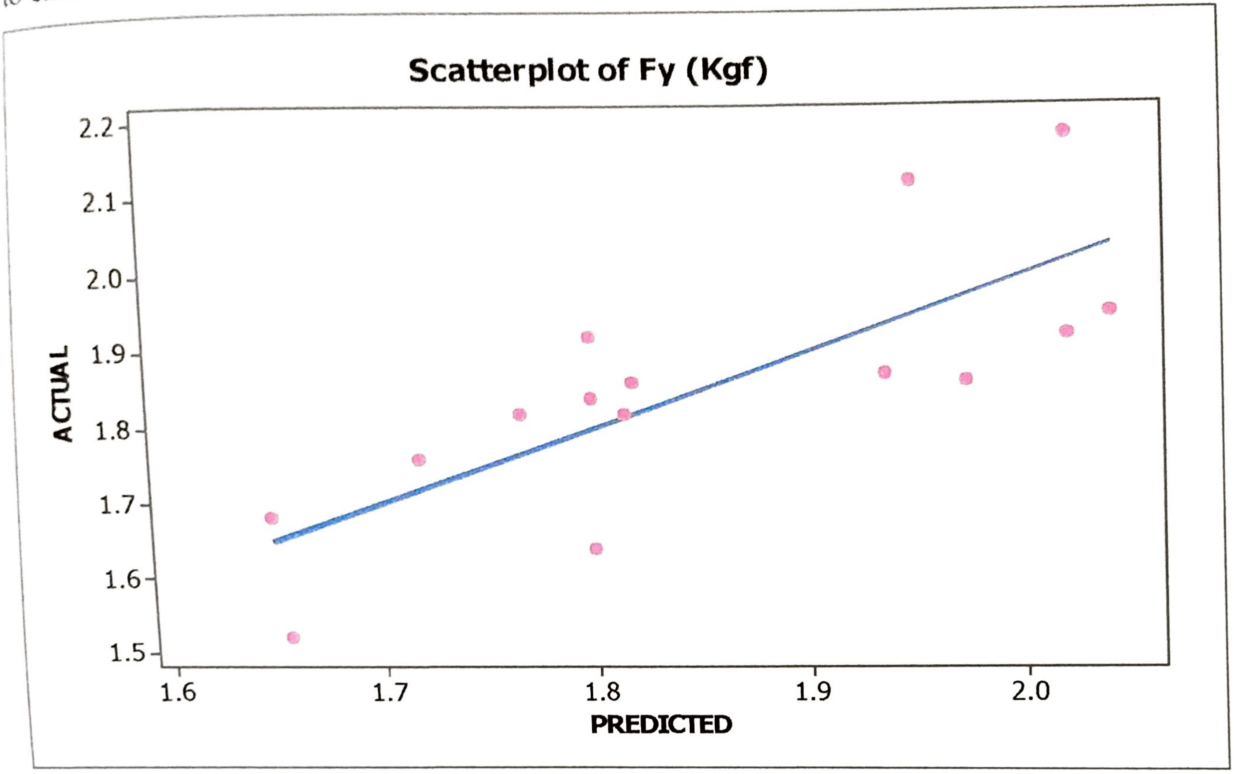


Figure 5.1 Scatter plot for F_Y

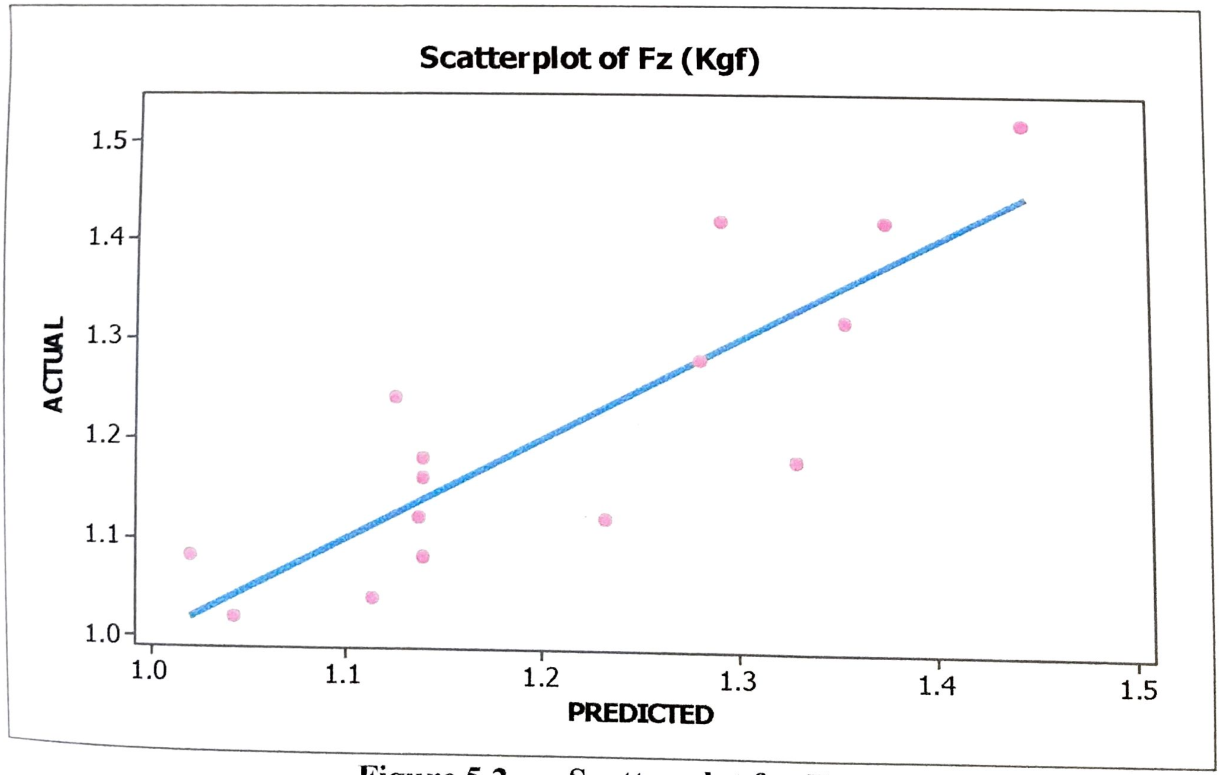


Figure 5.2 Scatter plot for F_Z

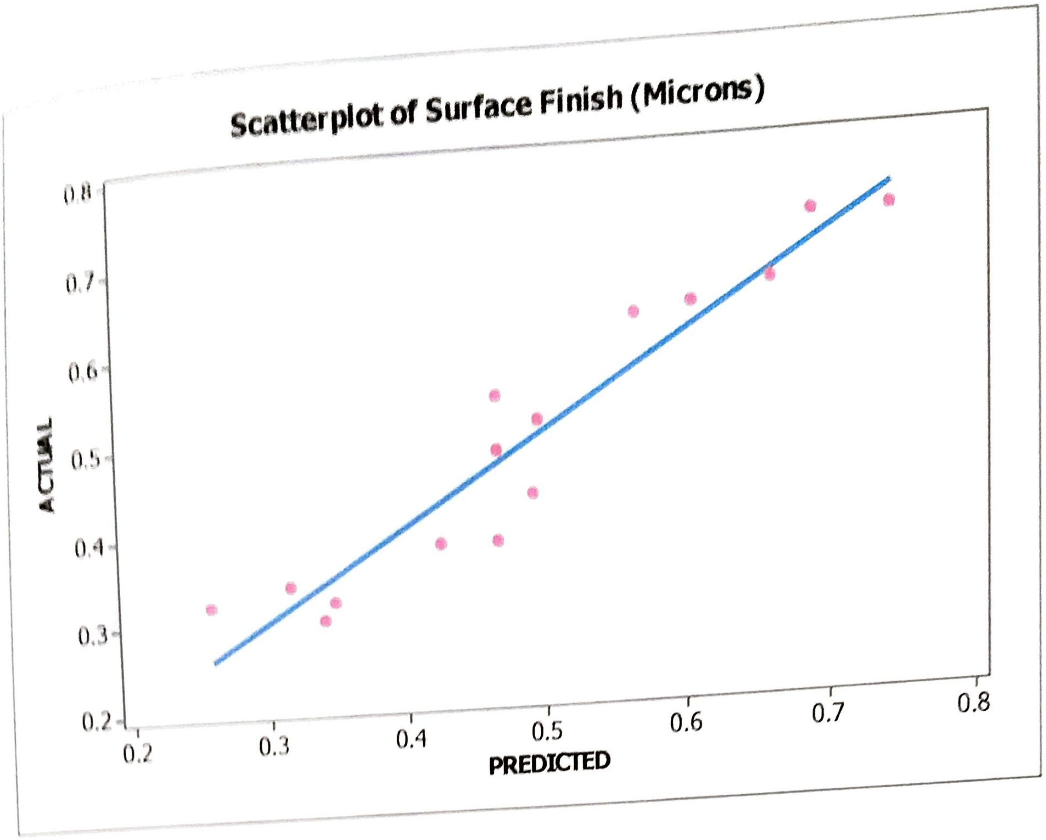


Figure 5.3 Scatter plot for Surface Finish

5.4 Effect of milling parameters on output responses

5.4.1 *Main Effect plots*

Graphs are drawn for each milling parameters separately (Figure 5.4, 5.5, 5.6) and the following observations are made:

The objective of the present project work is to minimise cutting forces and maximise the Surface finish. From Fig 5.4 and 5.5 it is understood that cutting forces are minimum at spindle speed of 540 rpm, feed rate of 1.86mm/min and cutting fluid composition of 1.5.

As the spindle speed increases, cutting speed increases reducing the contact area between the tool and work piece leading to improve in surface finish. As the feed rate increases the rubbing action between the tool and work piece decreases, resulting in better surface finish. Cutting fluid composition improves the lubricating properties and reduces the friction between tool and work piece leading to better surface finish.

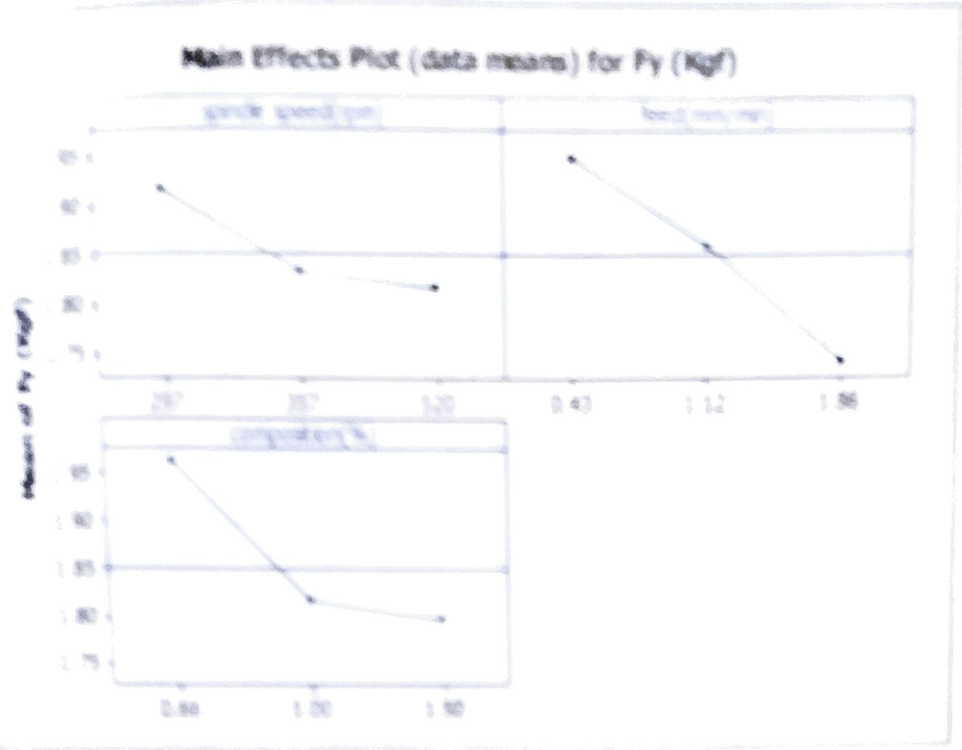


Figure 5.4 Main effects for F_y

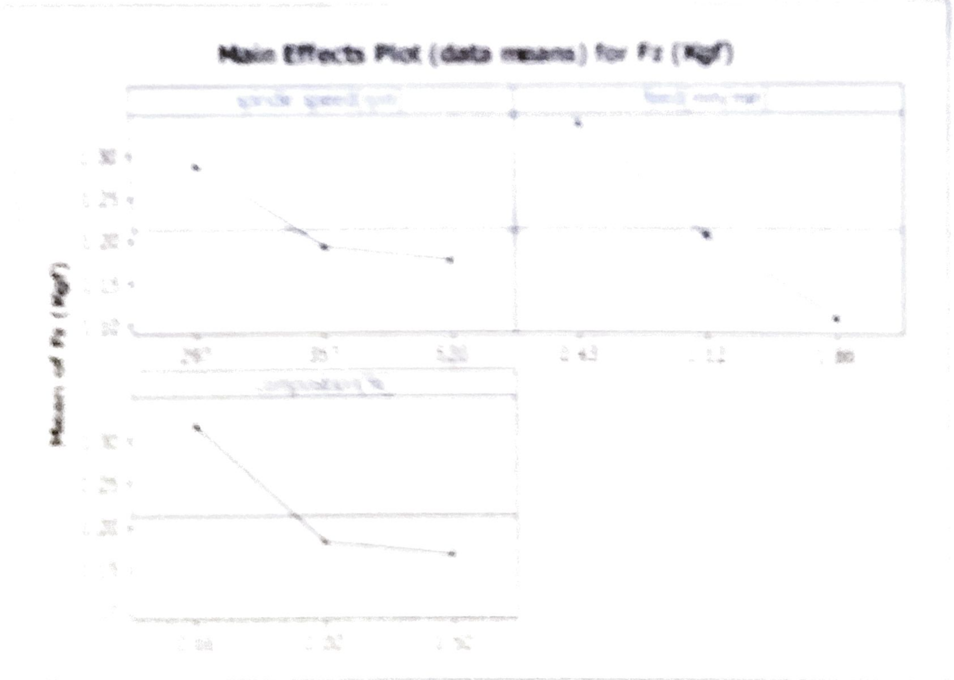


Figure 5.5 Main effects for F_z

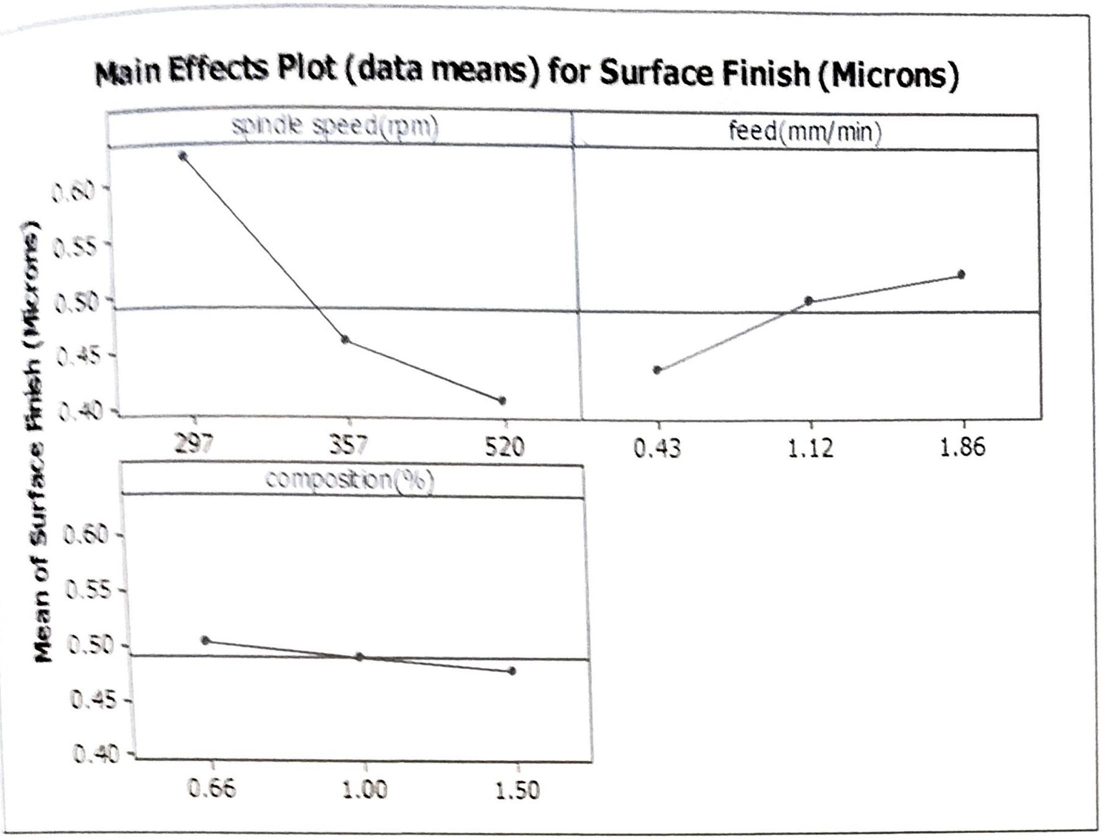
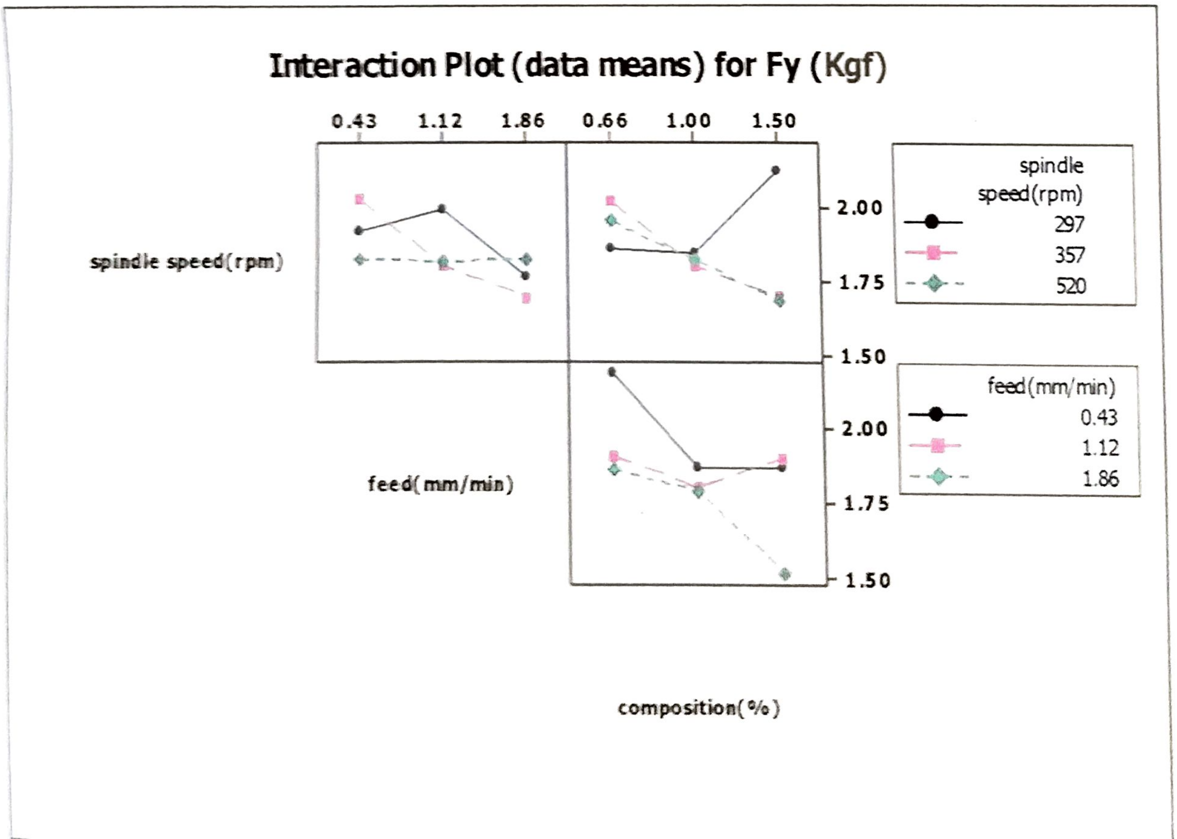


Figure 5.6 Main Effects for surface finish

5.4.2 *Interaction effects*

Interaction plots are drawn in order to the study the effect of all end milling parameters at a time on the Fy, Fz, Surface Finish (Figure 5.7, 5.8 and 5.9).



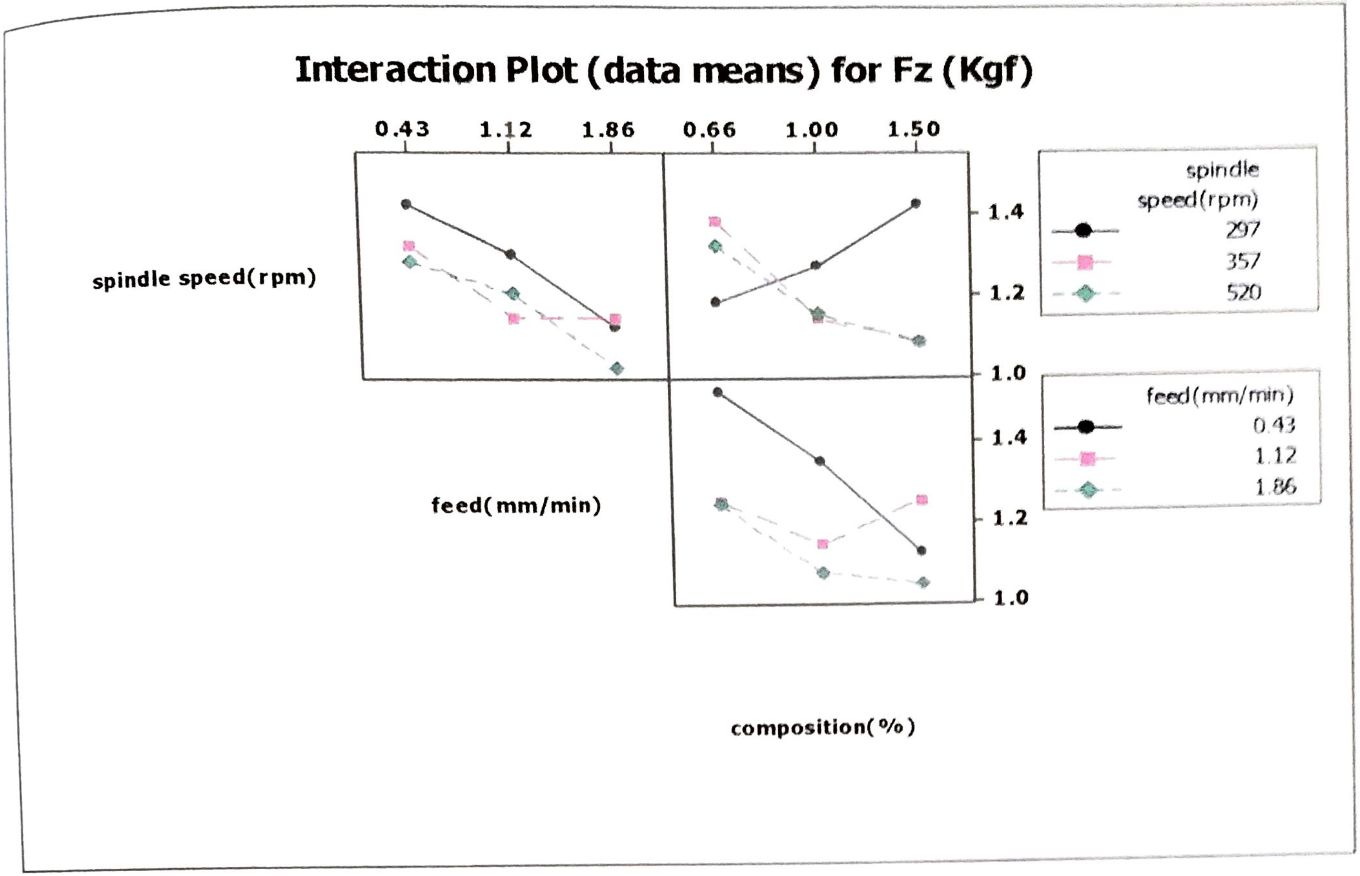
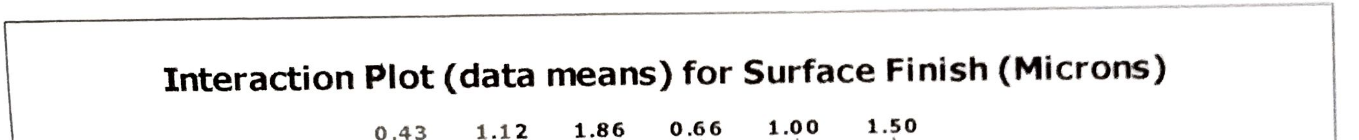


Figure 5.8 Interaction plot for F_z



5.5 Comparison of experimental and predicted values of Fy and Fz

From the developed model, the values of cutting forces Fy and Fz ,surface finish are predicted by substituting the coded values of the drilling parameters in the developed empirical mathematical model. Table 5.3 indicates the experimental and predicted values of cutting forces Fy and Fz ,surface finish for all the 15 combination of experiments performed.

Table 5.6 Comparison table of output responses

	ACTUAL			PREDICTED		
Exp. No	**Fy**	**Fz**	**Composition (%)**	**Fy**	**Fz**	**Composition (%)**
1	1.92	1.42	0.62	2.02	1.38	0.57
2	1.82	1.28	0.30	1.82	1.28	0.34
3	1.76	1.12	0.72	1.72	1.14	0.69
4	1.82	1.02	0.38	1.77	1.04	0.43
5	1.86	1.18	0.72	1.97	1.33	0.74
6	1.95	1.32	0.32	2.04	1.36	0.26
7	2.12	1.42	0.43	1.95	1.29	0.49
8	1.68	1.08	0.63	1.65	1.02	0.61
9	2.18	1.52	0.32	2.02	1.45	0.35
10	1.86	1.24	0.65	1.82	1.13	0.66
11	1.87	1.12	0.51	1.94	1.23	0.50
12	1.52	1.04	0.34	1.66	1.11	0.32
13	1.84	1.18	0.38	1.80	1.14	0.47
14	1.64	1.08	0.48	1.80	1.14	0.47
15	1.92	1.16	0.54	1.80	1.14	0.47

From Table 5.3, it is understood that the error % between actual and predicted values is around 9%.

5.6 Contour plots

The simultaneous effect of two parameters at a time on the output response is generally studied using contour plots. By generating contour plots using statistical software (MINITAB14) for response surface analysis, the most influencing parameter can be identified based on the orientation of contour lines. If the counter patterning of circular shaped counters occurs, it suggests the equal influence of both the factors; while elliptical contours indicate the interaction of the factors.

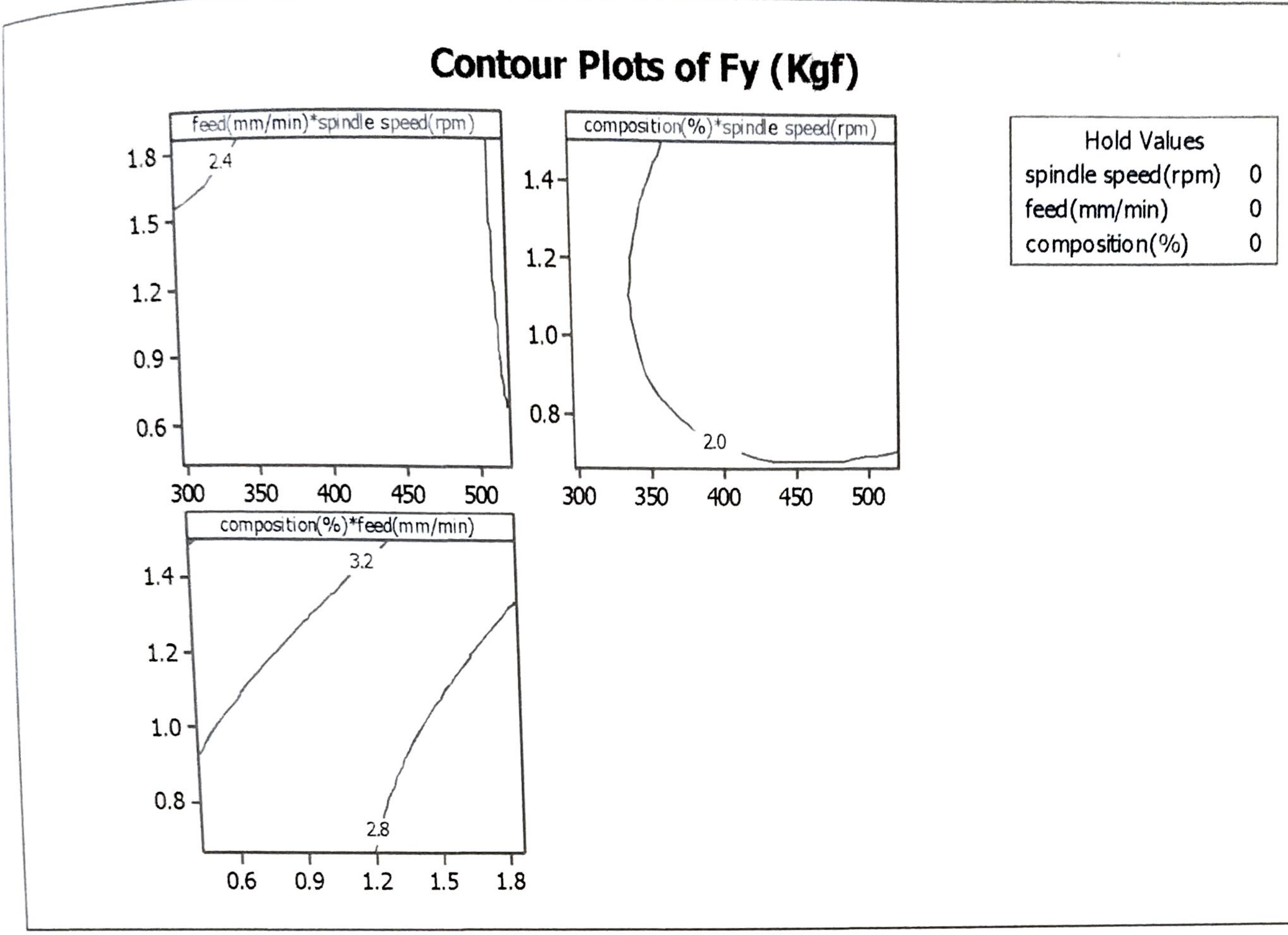
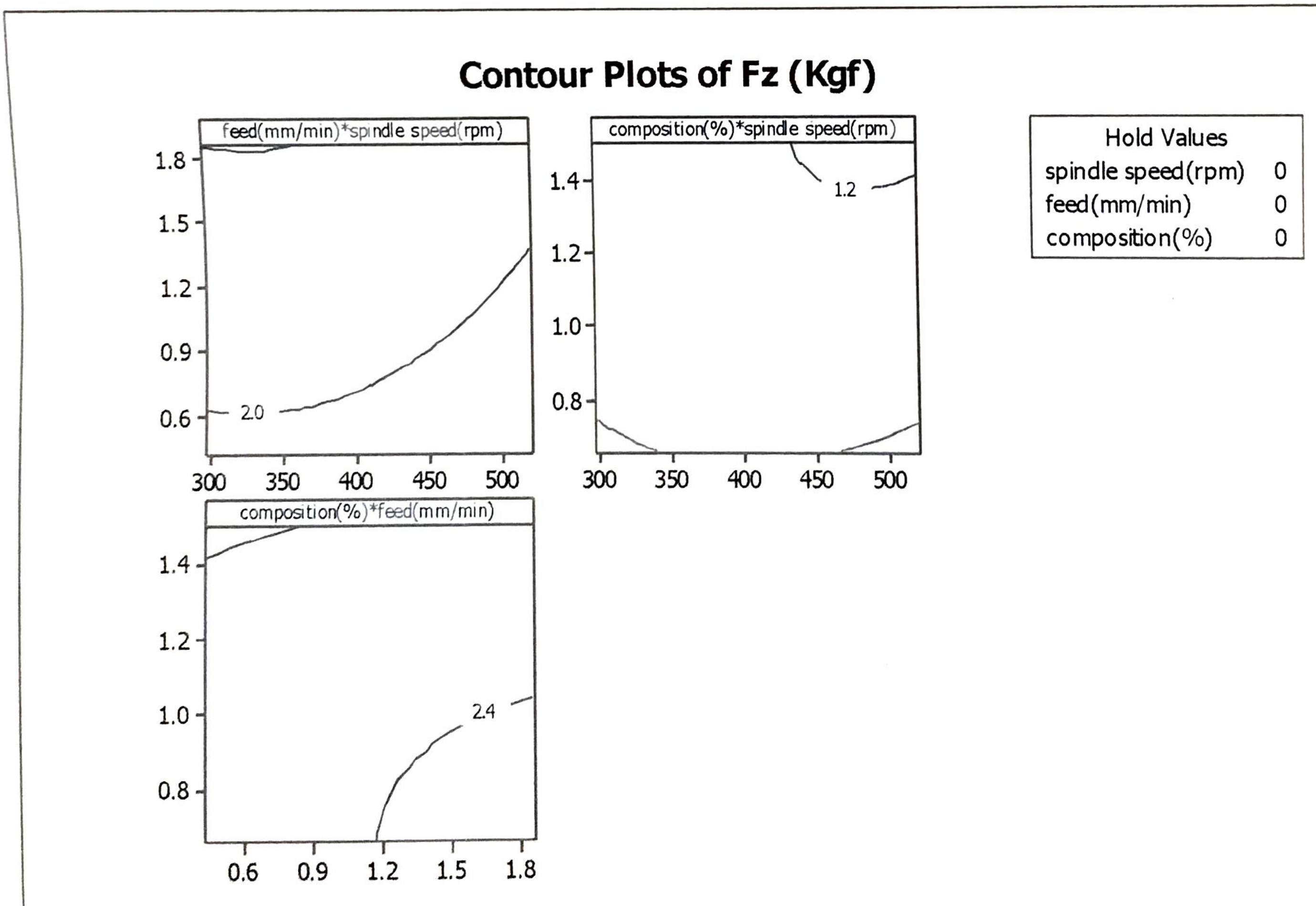


Figure 5.10 Counter plots of Fy



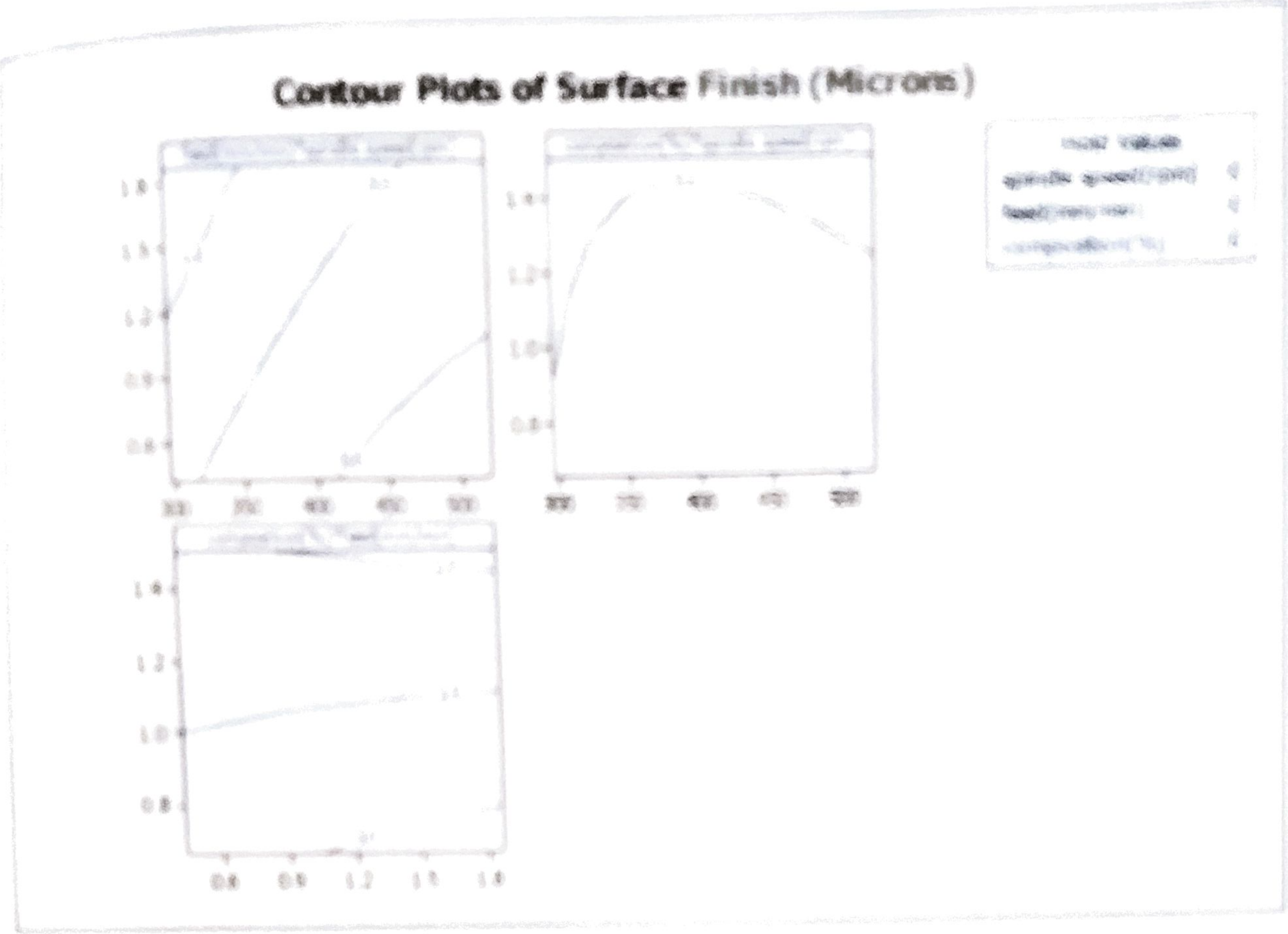


Figure 5.12 Counter Plots of Surface Finish

From the contour plots 5.10 to 5.12, it is understood that cutting speed (spindle speed) is the most dominant parameters affecting the cutting forces and surface finish, followed by feed rate and cutting fluid composition.

5.7 Surface Plots

Surface plots are drawn to identify the optimal combination of input parameters, in order to maximize or minimize the output responses. In the present project, the objective is to maximize surface finish and minimize cutting forces.

From surface plots Fig 5.13 to 5.14, for cutting forces are minimum for optimal combination of input parameters are spindle speed 540 rpm, feed rate 1.86 mm/min and cutting fluid composition of 1:8.

From surface plot 5.15, surface finish is maximum for optimal combination of

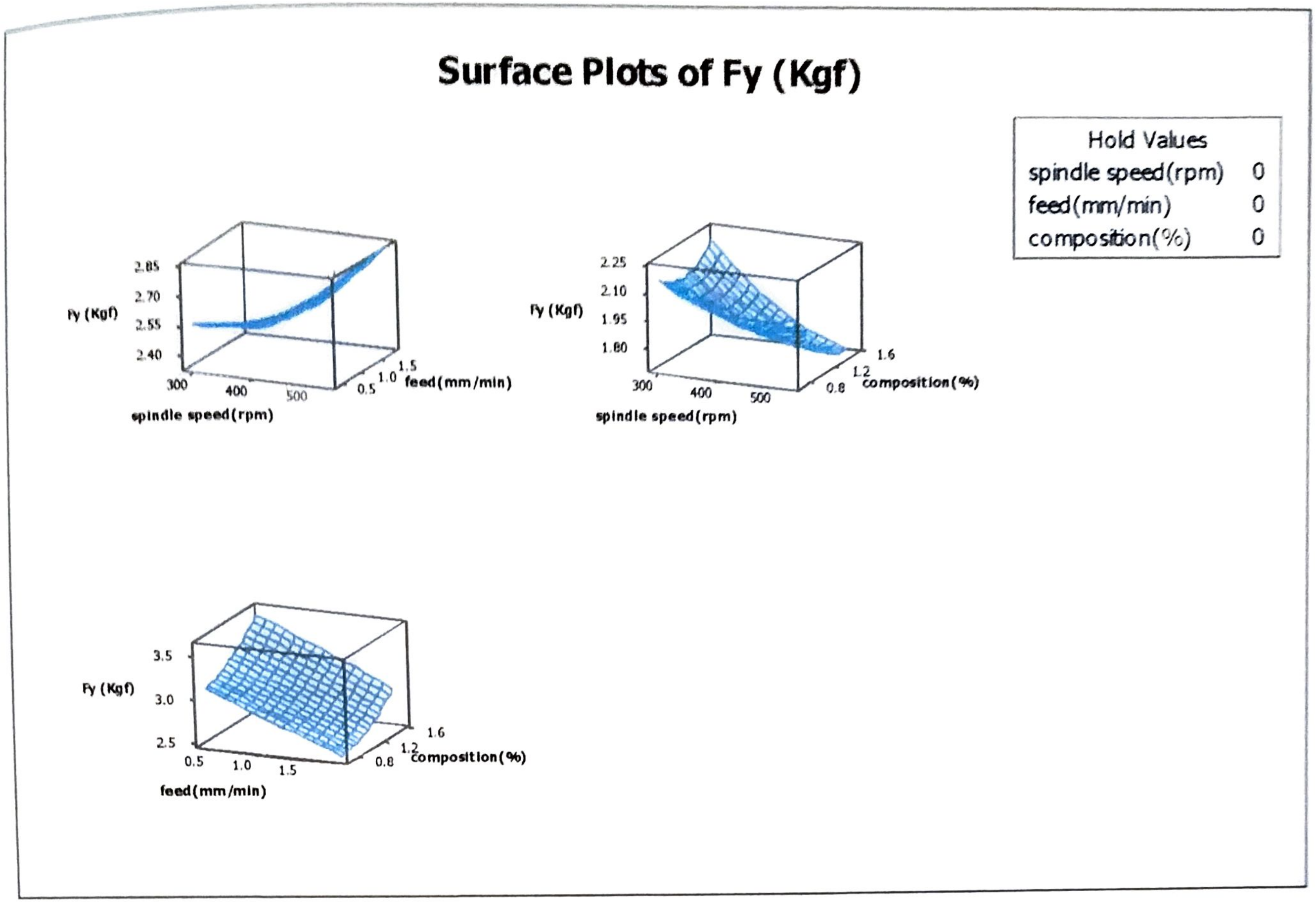


Figure 5.13 Surface plot of Fy

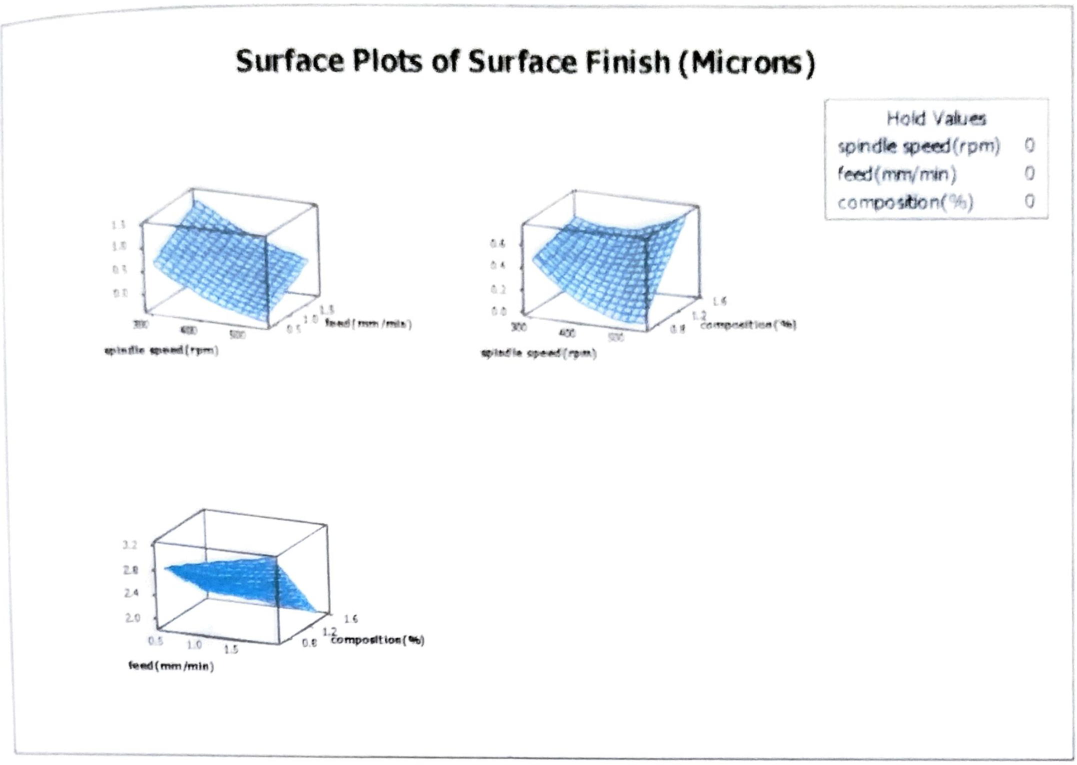


Figure 5.15 Surface plot of Surface Finish

CHAPTER –VI

RESULTS AND DISCUSSION

From the experiments performed the following results are drawn.

- Empirical mathematical models are developed for cutting forces and surface finish in end milling of aluminium in order to predicted their values with in the range of the end milling parameters selected.
- The experimental and predicted values are very close to each other and the error rate is around 9%, which indicate the accuracy of the developed model.
- The adequacy of the developed model is checked using ANOVA at 95% confidence level and found to be adequate.
- From the scatter plot it is understood that experimental and predicted values are close to each other.
- As the spindle speed increases, cutting speed increases reducing the contact area between the tool and work piece leading to improve in surface finish. As the feed rate increases the rubbing action between the tool and work piece decreases, resulting in better surface finish. Cutting fluid composition improves the lubricating properties and reduces the friction between tool and work piece leading to better surface finish.
- From the contour plots , it is understood that cutting speed (spindle speed) is the most dominant parameters effecting the cutting forces and surface finish, followed by feed rate and cutting fluid composition.

- From surface plots for cutting forces are minimum for optimal combination of input parameters are spindle speed 540 rpm, feed rate 1.86 mm/min and cutting fluid composition of 0.8.

- From surface plot for surface finish is maximum for optimal combination of input parameters are spindle speed 540 rpm, feed rate 1.86 mm/min and cutting fluid composition of 1.6.

- The developed empirical models are valid within the selected range of the process parameters and for the specified material (Aluminium).

- The accuracy of the empirical models can be improved by considering more number of input process parameters and higher levels.

CHAPTER –VII

CONCLUSIONS

The following conclusions are drawn based on the experimental results.

- Empirical mathematical models are developed for predicting surface finish and cutting forces of the end milling process by using Surface Response Method.
- The effect of milling parameters on output responses are studied and understood that better surface finish can be achieved at higher cutting speeds, higher feed rate and better composition of cutting fluids.
- From the contour plots , it is understood that cutting speed (spindle speed) is the most dominant parameters effecting the cutting forces and surface finish, followed by feed rate and cutting fluid composition.
- From surface plots for cutting forces are minimum for optimal combination of input parameters are spindle speed 540 rpm, feed rate 1.86 mm/min and cutting fluid composition of 0.8. Surface finish is maximum for optimal combination of input parameters are spindle speed 540 rpm, feed rate 1.86 mm/min and cutting fluid composition of 1.6.

REFERNECES

[1] Azlon zain, Haron and Shariff, (2010) “Application of GA to optimize cutting condition for minimizing surface roughness in end milling machining process”, Vol 37,pp 4650-4659.

[2] Mr. John L. Yang, Dr. Joseph C. Chen,(2001) A Systematic Approach for Identifying Optimum Surface Roughness Performance in End-Milling Operations Journal of Industrial Technology • Volume 17.

[3] I.N. Tansela,W.Y. Baoa, N.S. Reena, C.V. Kropas-Hughesb,(2004), Genetic tool monitor (GTM) for micro-end-milling operations. International Journal of machine tools & manufacture, volume 45, issue 3.

[4] Baskar.N., Asokan.P. Saravanan.R and Prabhaharan.G. (2004), “Optimization of machining parameters for milling operations using Non-conventional methods”, Int J Adv manufac.technol .vol-25, pp: 1078-1088.

[5] J. Balic, M. Milfelner, F. Cus,An, (2005) overview of data acquisition system for cutting force measuring and optimization in milling, Faculty of Mechanical Engineering, Production Engineering Institute, University of Maribor, Smetanova 17, Journal of Materials Processing Technology 164–165 pp:1281–1288

[6] Prakasvudhisarn & Siwaporn Kunnapapdeelert & Pisal Yenradee,(2008) Optimal cutting condition determination for desired surface roughness in end milling.

[7] Zarei, O., Fesangharyb, M., Farshia, B., JaliliSaffarb, R., Razfarb, M.R., (2008), “Optimization of multi-pass face-milling via harmony search algorithm” J. Mater. Process. Tech, Vol 5, pp: 1-7.

[8] Asif Iqbal ,Ning He ,Liang Li,Naeem Ullah Dar,(2007) A fuzzy expert system for optimizing parameters and predicting performance measures in hard milling process Journal Expert Systems with Application.

[9] M.Wan, W.H.Zhang, G.H.Qin,(2008), systematic simulation procedure of peripheral milling process of thin walled workpiece, school of mechatronic engineering, northwestern polytechnical university, shaanxi, china, journal of materials processing technology.

[10] Onwubolu, G.C., (2006), "Performance-based optimization of multi-pass faces milling operations using Tribes" Int. J. Mach. Tools and Manuf., vol-46, pp:717-727.

[11] Rao. R. V., Savsani, V. J., and Vakharia, D. P., (2011), "Teacher – learning – based optimization: A novel method for constrained mechanical design optimization problems", Computer –Aided Design, vol-43,. Pg: 303-315.

[12]Oktem and Erzurumlu,(2006) "Prediction of minimum surface roughness in end milling mold parts using neural network and genetic algorithm", vol-27, pp 735-744.

[13] Mohammed T. Hayajneh , Montasser S. Tahat , Joachim Bluhm (2007), "A Study of the Effects of Machining Parameters on the Surface Roughness in the End-Milling Process", Jordan Journal of Mechanical and Industrial Engineering , Volume 1, Number 1, pages 1-5.

[14] H.Z. Li* , H. Zeng, and X.Q. Chen, "An Experimental Study of Tool Wear and Cutting Force Variation in the End Milling of Inconel 718 with Coated Carbide Inserts", Singapore Institute of Manufacturing Technology, pages 1-22.

[15] Wen-Hsiang Lai(2000), "Modeling of Cutting Forces in End Milling Operations", Department of Mechanical Engineering, University of Kansas, Vol. 3, No. 1, pp. 15-22

[16] Yang Yang, Xinyu Li, Ping Jiang, Liping Zhang, "Prediction of surface roughness in end milling with gene expression programming", State Key Lab of Digital Manufacturing Equipment & Technology, Huazhong University of Science & Technology, pp. 1-6.

[17] J.W. Sutherland. "A dynamic model of the cutting force system in the end milling process". Dept. of mechanical and industrial engineering, university of Illinois. pages 1-16.

[18] E. A. Abou-El-Hossein, Z. Yahya (2005), "High speed end milling of AISI 304 stainless steel using new geometrically developed carbide inserts", 13th international scientific conference on achievements in mechanical and materials engineering, pages 1-4.

[19] Anna Carla Araujo, Jose Luis Silveira. "Models for the prediction of instantaneous cutting forces in end milling", 17th brazilian congress of mechanical engineering, pages 1-11.

[20] Muhamad nazumi bin hasnan. "Prediction of cutting force in end milling operation of modified AISI P20 tool steel". Faculty of Mechanical Engineering, University Malaysia Pahang, pages 1-26.