EFFECT OF COATED HSS TWISTED DRILLS ON RESPONSES IN MACHINING OF SS304 STEEL

A Project report submitted

In partial fulfilment of the requirements for the award of the degree of

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By

GORLE NIKHILESH	**317126520194**
GORAPALLI SATEESH KUMAR	**318126520L41**
GANDHAM DHANA SRIRANGANAYAKULU	**317126520192**
BUSI SIVA SURYA VENKAT	**317126520187**
PUTHI KUSUMA	**317126520216**

Under the esteemed guidance of

Mr. R. CHANDRAMOULI (M.TECH) & Mr. J. MAHESH (M.TECH)

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

Autonomous status accorded by UGC and Andhra University

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and recognised by NBA, accredited by NAAC- ‘A’ Grade)

Sangivalasa, Bheemunipatnam (Mandal)

Visakhapatnam (Dist.) – 531162

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)
(Affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC with A grade)
SANGIVALASA, VISAKHAPATNAM (District) – 531162

CERTIFICATE

This is to certify that the Project Report entitled **"EFFECT OF COATED HSS TWISTED DRILLS ON RESPONSES IN MACHINING OF SS304 STEEL"** being submitted by GORLE NIKHILESH (317126520194), GORAPALLI SATEESHKUMAR (318126520L41), GANDHAM DHANA SRIRANGANAYAKULU (317126520192), BUSI SIVA SURYA VENKAT (317126520187), PUTHI KUSUMA (317126520216) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.J.MAHESH**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

	Approved By
PROJECT GUIDE	**HEAD OF THE DEPARTMENT**
JMahesh	
(MR.J.MAHESH) **Assistant Professor** **Mechanical Engineering Department** **ANITS, Visakhapatnam.**	**(Dr. B. Naga Raju)** **Head of the Department** **Mechanical Engineering Department** **ANITS, Visakhapatnam.**

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

DECLARATION

We, the undersigned, hereby declare that this "**Thesis**" under the title of " **Effect of Coated HSS Twist Drills on Responses in Machining of SS304 Steel**" submitted by me for the award of Degree of "**Bachelor of Technology**" in Mechanical Engineering at ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A), Visakhapatnam, is a record of original research work carried out by us. This work has not been submitted to any University or Institution in India or abroad, for the award of any degree.

TEAM MEMBERS

GORLE NIKHILESH

GORAPALLI SATEESH KUMAR

GANDHAM DHANA SRIRANGANAYAKULU

BUSI SIVA SURYA VENKAT

PUTHI KUSUMA

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER:

EXTERNAL EXAMINER:

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G.Nikhilesh(317126520194)
G.Sateesh Kumar(318126520L41)
G.Dhana Sri Ranganayakulu (317126520192)
B.Siva Surya Venkat (317126520187)
P.Kusuma (317126520216)

ABSTRACT

The present work is aimed to find the effect of drilling process parameters on objectives of material removal rate and surface roughness. Several experiments were performed on SS304 steel with non-coated and coated HSS twisted drills. The optimization was done using Taguchi’s Signal-to-Noise ratios and Response Surface Methodologies. The Optimal Combination of Process Parameters for MRR is obtained at Tool type: HSS, Point Angle:90 degrees, Speed:600Rpm, Feed: 0.06mm/rev**.** The optimal combination of process parameters for Surface Finish are found as: Tool Type: HSS-Cobalt, Point angle:118degree, Speed:600Rpm, Feed: 0.06mm/rev. The RSM and Pareto chart results found that the speed is the most influencing factor for the responses respectively.

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INTRODUCTION

CHAPTER-1

INTRODUCTION

1.1 Introduction

Drilling is one of the most complex machining processes. The chief characteristic that distinguishes it from other machining operations is the combined cutting and extrusion of metal at the chisel edge in the center of the drill. The high-thrust force caused by the feeding motion first extrudes metal under the chisel edge. Then it tends to shear under the action of a negative rake angle tool.

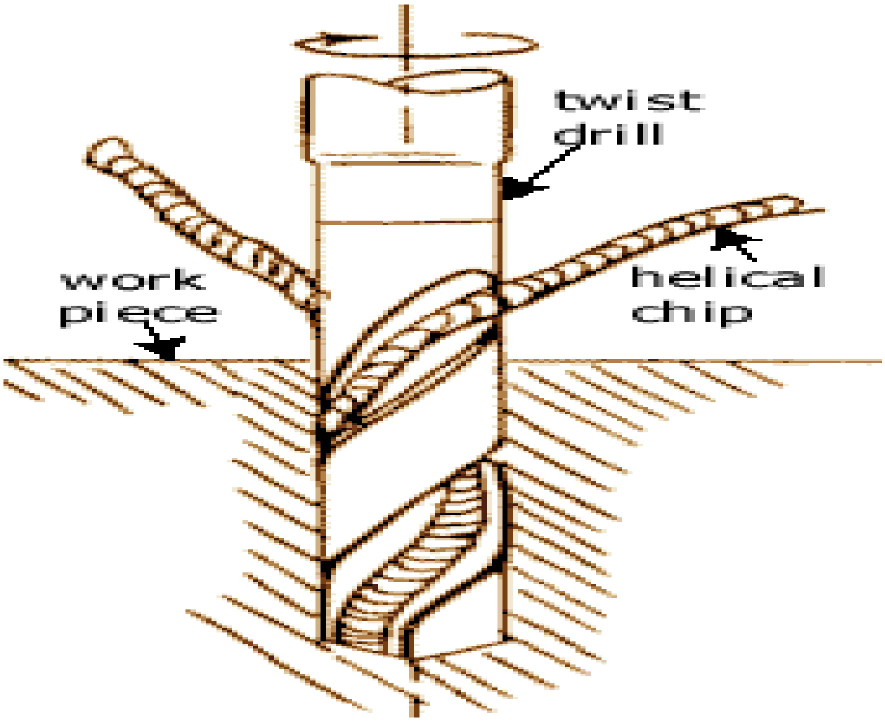

Figure 1.1 Drilling Operation

The cutting action along the lips of the drill is not unlike that in other machining processes. Because of variable rake angle and inclination, however, there are differences in the cutting action at various radii on the cutting edges. This is complicated by the constraint of the whole chip on the chip flow at any single point along the lip. Still, the metal-removing action is true cutting, and the problems of variable geometry and constraint are present. Because it is such a small portion of the total drilling operation, though, it is not a distinguishing characteristic of the process.

The machine settings used in drilling reveal some important features of this hole-producing operation. Depth of cut, a fundamental dimension in other cutting processes, corresponds most closely to the drill radius. The un-deformed chip width is equivalent to the length of the drill lip, which depends on the point angle as well as the drill size. For a given set-up, the un-deformed chip width is constant in drilling. The feed dimension specified for drilling is the feed per revolution of the spindle. A more fundamental quantity is the feed per lip. For the common two-flute drill, it is half the feed per revolution. The un-deformed chip thickness differs from the feed per lip depending on the point angle.

The spindle speed is constant for any one operation, while the cutting speed varies all along the cutting edge. Cutting speed is normally computed for the outside diameter. At the center of the chisel edge the cutting speed is zero; at any point on the lip it is proportional to the radius of that point. This variation in cutting speed along the cutting edges is an important characteristic of drilling. Once the drill engages the work piece, the contact is continuous until the drill breaks through the bottom of the part or is withdrawn from the hole. In this respect, drilling resembles turning and is unlike milling.

1.2 Drill Nomenclature

The most important type of drill is the twist drill. The important nomenclature listed below.

Drill: A drill is an end-cutting tool for producing holes. It has one or more cutting edges, and flutes to allow fluids to enter and chips to be ejected. The drill is composed of a shank, body and point.

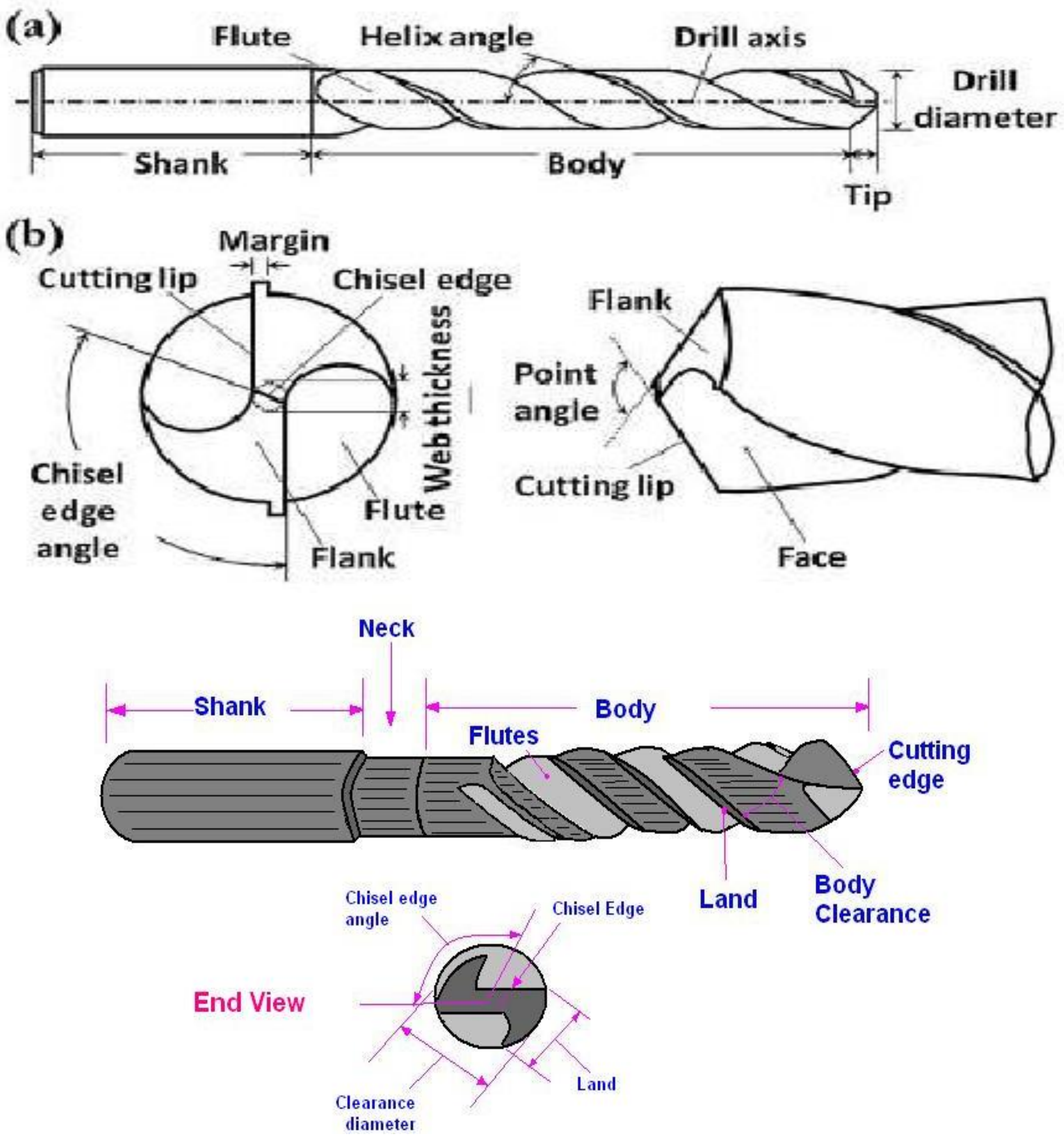

Figure 1.2 Twist Drill and Parts

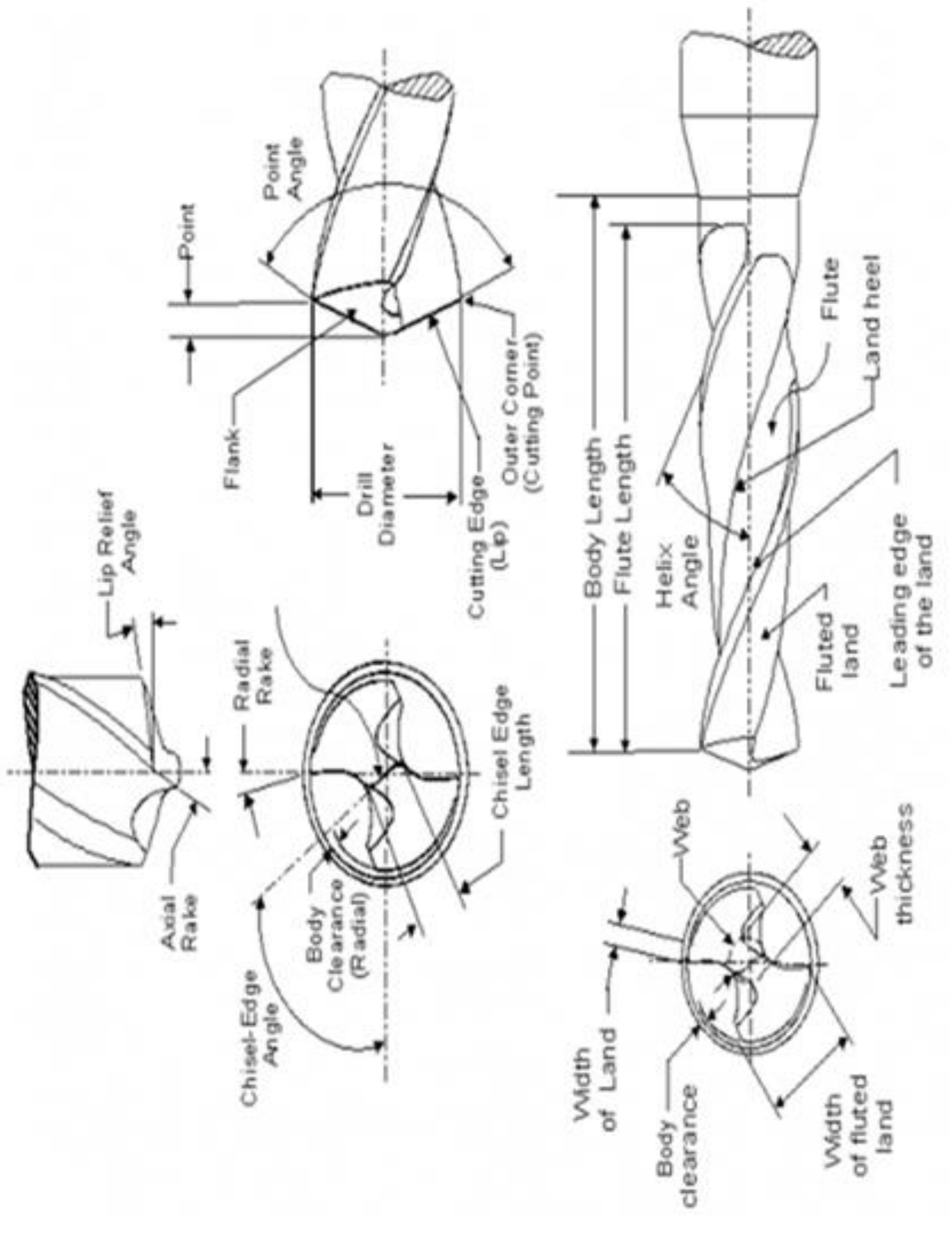

Figure 1.3 Nomenclature of Twist Drill

Shank: The shank is the part of the drill that is held and driven. It may be straight or tapered.

Tang: The tang is a flattened portion at the end of the shank that fits into a driving slot of the drill holder on the spindle of the machine.

Body: The body of the drill extends from the shank to the point, and contains the flutes. During sharpening, it is the body of the drill that is partially ground away.

Point: The point is the cutting end of the drill.

Flutes: Flutes are grooves that are cut or formed in the body of the drill to allow fluids to reach the point and chips to reach the work piece surface. Although straight flutes are used in some cases, they are normally helical.

Land: The land is the remainder of the outside of the drill body after the flutes are cut. The land is cut back somewhat from the outside drill diameter to provide clearance.

Margin: The margin is a short portion of the land not cut away for clearance. It preserves the full drill diameter.

Web: The web is the central portion of the drill body that connects the lands.

Chisel edge: The edge ground on the tool point along the web is called the chisel edge. It connects the cutting lips.

Lips: The lips are the primary cutting edges of the drill. They extend from the chisel point to the periphery of the drill.

Axis: The axis of the drill is the centerline of the tool. It runs through the web and is perpendicular to the diameter.

Neck: Some drills are made with a relieved portion between the body and the shank. This is called the drill neck. In addition to these terms that define the various parts of the drill, there are a number of terms that apply to the dimensions of the drill, including the important drill angles. Among these terms are:

Length: Along with its outside diameter, the axial length of a drill is listed when the drill size is given. In addition, shank length, flute length and neck length are often used.

Body diameter clearance: The height of the step from the margin to the land is called the body diameter clearance.

Web thickness: The web thickness is the smallest dimension across the web. It is measured at the point unless otherwise noted. Web thickness will often increase in going up the body away from the point, and it may have to be ground down during sharpening to reduce the size of the chisel edge. This process is called "web thinning."

Helix angle: The angle that the leading edge of the land makes with the drill axis is called the helix angle. Drills with various helix angles are available for different operational requirements.

Point angle: The included angle between the drill lips is called the point angle. It is varied for different work piece materials.

Lip relief angle: Corresponding to the usual relief angles found on other tools is the lip relief angle. It is measured at the periphery.

Chisel edge angle: The chisel edge angle is the angle between the lip and the chisel edge, as seen from the end of the drill.

1.3 Classes of Drills

There are different classes of drills for different types of operations. Work piece materials may also influence the class of drill used, but it usually determines the point geometry rather than the general type of drill best suited for the job. The twist drill is the most important class. Within the general class of twist drills there are a number of drill types made for different kinds of operations.

Figure 1.4 Types of Drills

Figure 1.5 Drills Based on Helix Angle

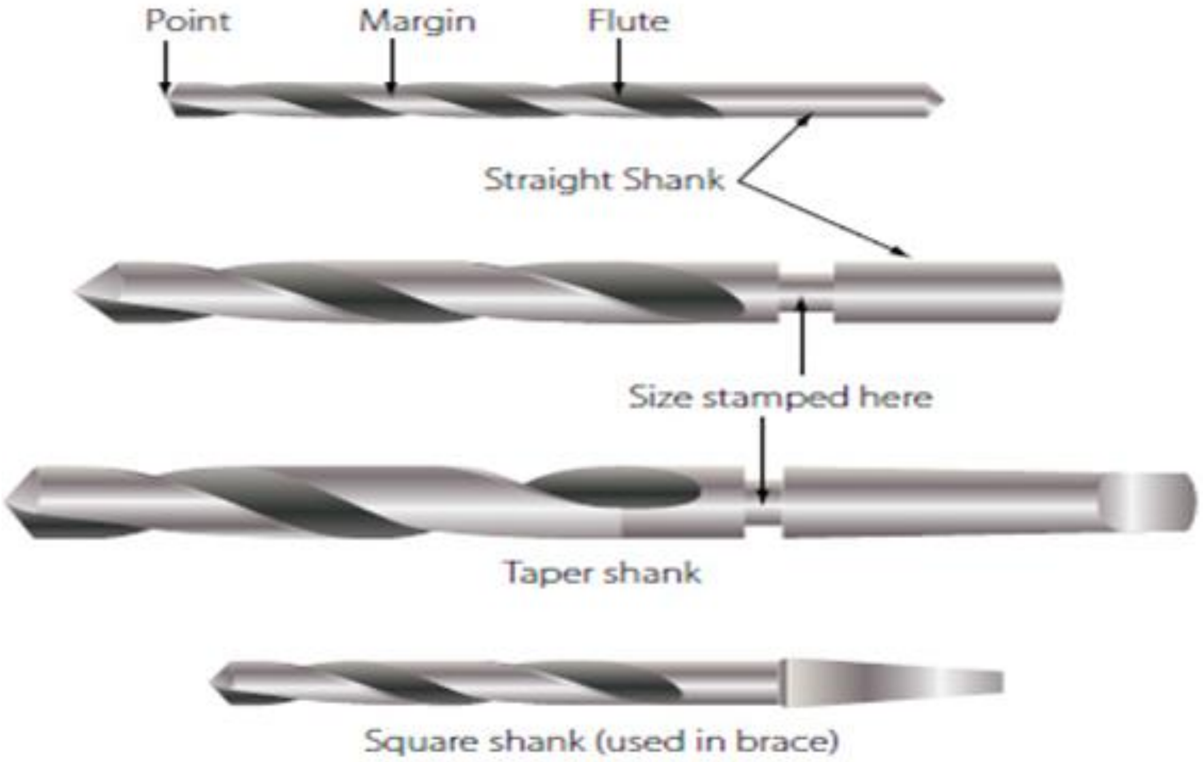

Figure 1.6 Drills Based on Shank Type

High helix drills: This drill has a high helix angle, which improves cutting efficiency but weakens the drill body. It is used for cutting softer metals and other low strength materials.

Low helix drills: A lower than normal helix angle is sometimes useful to prevent the tool from "running ahead" or "grabbing" when drilling brass and similar materials.

Heavy-duty drills: Drills subject to severe stresses can be made stronger by such methods as increasing the web thickness.

Left hand drills: Standard twist drills can be made as left hand tools. These are used in multiple drill heads where the head design is simplified by allowing the spindle to rotate in different directions.

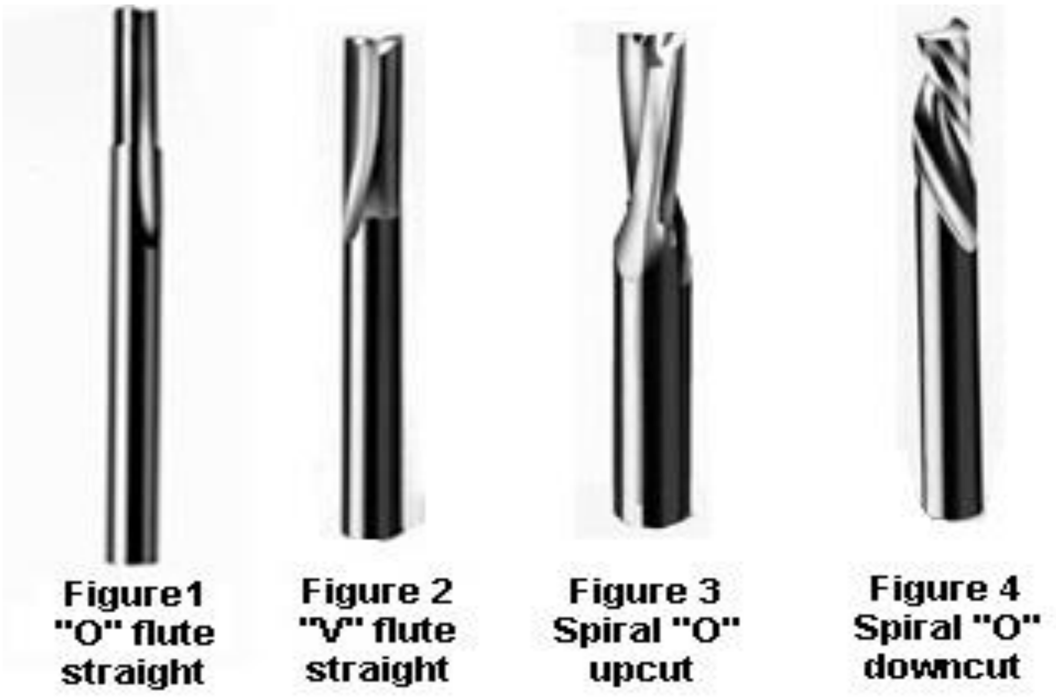

Figure1 "O" flute straight

Figure 2 "V" flute straight

Figure 3 Spiral "O" upcut

Figure 4 Spiral "O" downcut

Figure 1.7 drills Based on Flutes

Straight flute drills: Straight flute drills are an extreme case of low helix drills. They are used for drilling brass and sheet metal.

Crankshaft drills: Drills that are especially designed for crankshaft work have been found to be useful for machining deep holes in tough materials. They have a heavy web and helix angle that is somewhat higher than normal.

Extension drills: The extension drill has a long, tempered shank to allow drilling in surfaces that are normally inaccessible.

Extra-length drills: For deep holes, the standard long drill may not suffice, and a longer bodied drill is required.

Step drill: Two or more diameters may be ground on a twist drill to produce a hole with stepped diameters.

Subland drill: The subland or multi-cut drill does the same job as the step drill. It has separate lands running the full body length for each diameter, whereas the step drill uses one land. A subland drill looks like two drills twisted together.

Solid carbide drills: For drilling small holes in light alloys and nonmetallic materials, solid carbide rods may be ground to standard drill geometry. Light cuts without shock must be taken because carbide is quite brittle.

Carbide-tipped drills: Carbide tips may be used on twist drills to make the edges more wear resistant at higher speeds. Carbide-tipped drills are widely used for hard, abrasive non-metallic materials such as masonry.

Oil hole drills: Small holes through the lands, or small tubes in slots milled in the lands, can be used to force oil under pressure to the tool point. These drills are especially useful for drilling deep holes in tough materials.

Flat drills: Flat bars may be ground with a conventional drill point at the end. This gives very large chip spaces, but no helix. Their major application is for drilling railroad track.

Figure 1.8 Straight, 2 Flute and 3 Flute Drills

Three- and four-fluted drills: There are drills with three or four flutes that resemble standard twist drills except that they have no chisel edge. They are used for enlarging holes that have been previously drilled or punched. These drills are used because they give better productivity, accuracy and surface finish than a standard drill would provide on the same job.

Drill and countersink: A combination drill and countersink is a useful tool for machining "center holes" on bars to be turned or ground between centers. The end of this tool resembles a standard drill. The countersink starts a short distance back on the body.

Figure 1.9 Countersink Drills

1.4 Drilling Operations

Several operations are related to drilling. In the following list, most of the operations follow drilling except for centering and spot facing, which precede drilling. A hole must be made first by drilling and then the hole is modified by one of the other operations. Some of these operations are illustrated below.

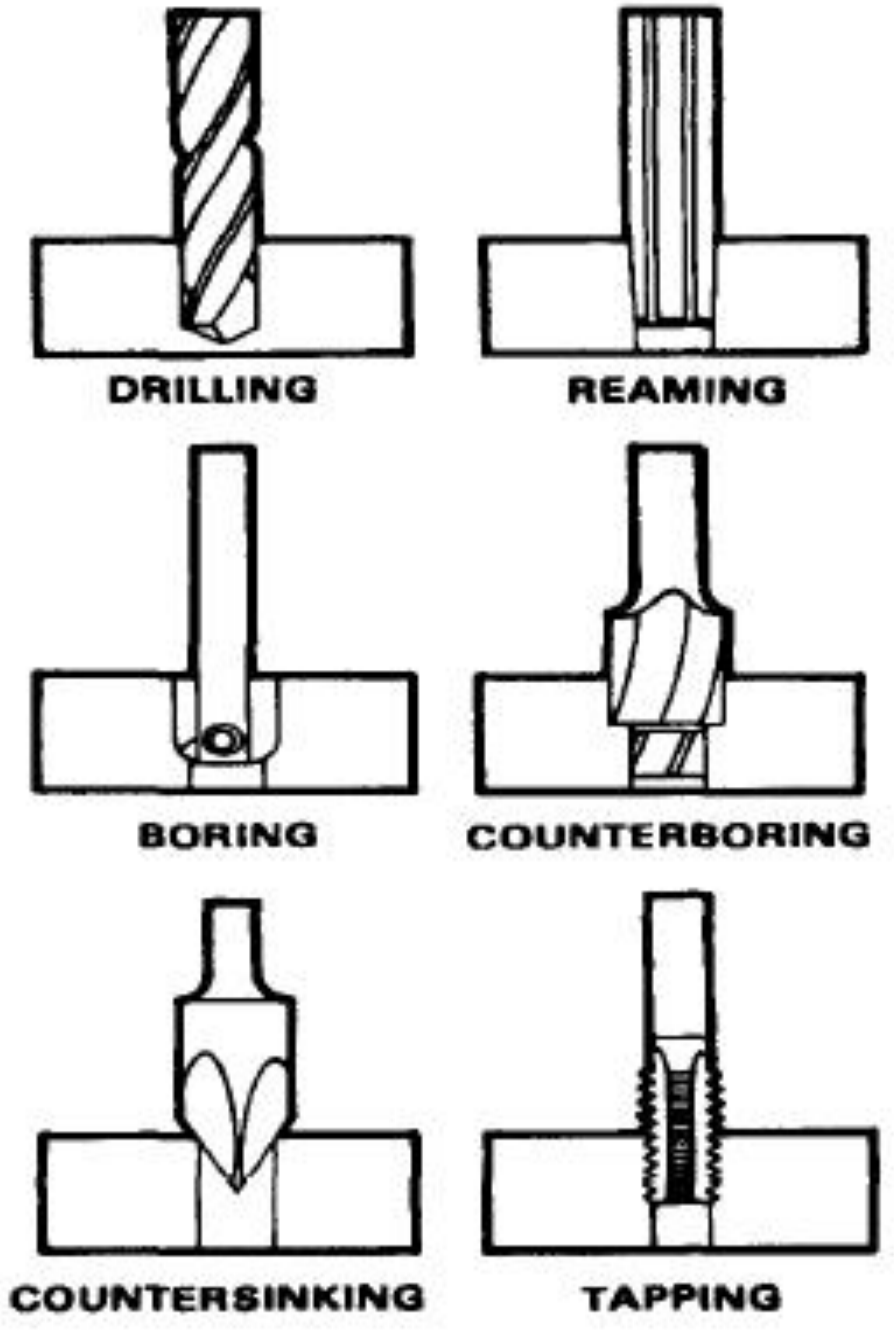

Figure 1.10 Drilling Operations

Reaming: A reamer is used to enlarge a previously drilled hole, to provide a higher tolerance and to improve the surface finish of the hole.

Tapping: A tap is used to provide internal threads on a previously drilled hole.

Counter boring: Counter boring produces a larger step in a hole to allow a bolt head to be seated below the part surface.

Counter sinking: Countersinking is similar to counter boring except that the step is angular to allow flat-head screws to be seated below the surface.

Centering: Center drilling is used for accurately locating a hole to be drilled afterwards.

Spot facing: Spot facing is used to provide a flat-machined surface on a part.

1.4.1 Operating Conditions: The varying conditions, under which drills are used, make it difficult to give set rules for speeds and feeds. Drill manufacturers and a variety of reference texts provide recommendations for proper speeds and feeds for drilling a variety of materials.

Drilling speed: Cutting speed may be referred to as the rate that a point on a circumference of a drill will travel in I minute. It is expressed in surface feet per minute (SFPM). Cutting speed is one of the most important factors that determine the life of a drill. If the cutting speed is too slow, the drill might chip or break. A cutting speed that is too fast rapidly dulls the cutting lips. Cutting speeds depend on the following seven variables:

- The type of material being drilled. (The harder the material, the slower the cutting speed.)
- The cutting tool material and diameter. (The harder the cutting tool material, the faster it can machine the material. The larger the drill, the slower the drill must revolve.)
- The types and use of cutting fluids allow an increase in cutting speed.
- The rigidity of the drill press.
- The rigidity of the drill. (The shorter the drill, the better.)
- The rigidity of the work set-up.
- The quality of the hole to be drilled.

Drilling Feed: Once the cutting speed has been selected for a particular workpiece material and condition, the appropriate feed rate must be established. Drilling feedrates are selected to maximize productivity while maintaining chip control. Feed in drilling operations is expressed in inches per revolution, or IPR, which is the distance the drill moves in inches for each revolution of the drill. The feed may also be expressed as the distance traveled by the drill in a single minute, or IPM (inches per minute), which is the product of the RPM and IPR of the drill. It can be calculated as follows: IPM = IPR x RPM.

The selection of drilling speed (SFPM) and drilling feed (IPR) for various materials to be machined often starts with recommendations in the form of application tables from manufacturers or by consulting reference books.

1.5 Cutting Tool Material Selection:

M2 High Speed Steel (HSS) is the standard Rota broach cutting tool material. M2 has the broadest application range and is the most economical tool material. It can be used on ferrous and non-ferrous materials and is generally recommended for cutting materials up to 275 BHN. M2 can be applied to harder materials, but tool life is dramatically decreased. Cobalt High-Speed Steel (HSS) drill bits have added Cobalt which gives the material a higher red hardness than standard HSS. This additional hardness permits these drill bits to be used for drilling materials that have a hardness of Rockwell 38C or greater such as treated stainless steel, cast iron, or titanium. They are also capable of being utilized at higher cutting speeds than conventional HSS and exhibit superior abrasion resistance.

Figure 1.11 HSS Drill Bits

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review

Many researchers have studied the effect of various cutting parameters such as cutting speed, feed rate, drill tool diameter, cutting fluid, point angle, depth cut etc on the surface finish in drilling. Some of the literature related to this has been discussed below:

Yogendra Tyagi, Vedansh Chaturvedi, et al. (2012) [1]studied the effect of cutting parameters such as spindle speed, feed rate and depth of cut for maximizing the material removal rate as well as minimizing the surface roughness in drilling mild steel. Taguchi L9 orthogonal array used in the experiment and the results were analysed using Taguchi DOE software. They have found spindle speeds affects significantly surface roughness and feed rate largely affects material removal rate.

M Sundeep, M Sudhahar, et al. (2014) [2] have investigated the drilling of Austenitic stainless Steel (AISI 316) using Taguchi L9 array. Spindle speed, feed rate, and drill diameter were taken as process parameters. They found that spindle speed plays the most dominating role in the surface finish as well as Material removal rate in drilling.

Kadam Shirish, M. G. Rathi (2013) [3] focused on optimization of drilling parameters by using the Taguchi Method. Taguchi L9 orthogonal array was used to drill on EN-24 steel blocks. Uncoated M32 HSS twist drill has been used under dry condition. Cutting speed, feed rate and depth of hole were taken as the process parameter. They found that cutting speed has the most significant effect on surface roughness and the tool life.

Turgay Kıvak, Gurcan Samtas, et al. (2012) [4] studied the effect of cutting parameters such as cutting tool, cutting speed and feed rate on drilling of AISI 316 stainless steel. Experiments were conducted in CNC vertical machine using Taguchi L16 array. Coated and uncoated M35 HSS twist drill bit were employed under the dry condition for this purpose. Analysis of variance was employed to draw the effects of the control factors. They found that cutting tool and feed rate were the most significant factor on surface roughness and thrust force respectively.

Adem Çiçek, Turgay Kıvak, et al. (2012) [5] studied the effect of deep cryogenic and cutting parameters on surface roughness as well as roundness error in the drilling of AISI 316 austenitic stainless steel. Cutting tools, cutting speeds and feed rate were taken as the control factors. M35 twist drill bit was used in the experiment. Taguchi L8 orthogonal array was employed and multiple regression analysis was performed to find out the predictive equation of surface roughness.

A. Navanth, T. Karthikeya Sharma (2013) [6] concentrated on optimization of drilling parameters for obtaining minimum surface roughness and hole diameter by using Taguchi method. Al 2014 material and HSS twist drill bit have been selected for performing the experiment. Taguchi L18 orthogonal array was used and the results obtained were analyzed with the help of MINITAB 16. Analysis of variance (ANOVA) was employed to find out the optimal parameters from cutting tool, spindle speed and feed rate.

Reddy Sreenivasulu (2014) [7] concentrated on optimization of surface roughness in the drilling of Al 6061 using Taguchi design methodology and artificial neural network method. In their study cutting speed, feed rate, drill diameter, clearance angle and point angle were taken as process parameters and HSS twist drill bit as a tool. Taguchi L27 orthogonal array, S/N ratio, ANOVA were used to study the effects of the process parameters. They found that cutting speed, feed rate, drill diameter and point angle all were significant on surface roughness. The Optimal settings for roughness were found to be speed 800 rpm, feed rate .3 mm/rev, drill diameter 10 mm, clearance angle 40, point angle 1180.

J.Pradeep Kumar, P.Packiaraj (2012) [8] studied the effect of cutting parameters such as cutting speed, drill tool diameter feed and feed on the surface finish of OHNS material using HSS spiral drill bit as cutting tool. Taguchi L18 orthogonal array, S/N ratio, ANOVA and Regression analysis were employed to study the effect of process parameters on surface roughness. Experimental data wereanalysed using MINITAB 13 and they found that both speed and feed plays most important role in surface roughness, material removal rate.

B.Shivapragash, K.Chandrasekaran, et al. (2013) [9] focused on optimization of cutting parameters namely feed rate, spindle speed, depth of cut to study their influence in drilling composite Al-TiBr2. Taguchi methods with Grey Relational analysis were employed to optimize the factors. Taguchi L9 orthogonal array was used and optimal settings found for better surface finish were feed rate (1.5 mm/rev), spindle speed (1000 rpm) and depth of cut 6 mm.

Nalawade P.S. and Shinde S.S. (2015) [10] optimizes the process parameters speed, depth of cut, type of tool and feed to get better Surface Finish and Hole Accuracy in Drilling of EN-31 material. Taguchi L9 orthogonal array, Regression analysis, S/N ratio and ANOVA were employed to find out the optimal settings. Optimal settings for surface roughness were found to be Cutting speed (30 m /min), feed (.2 mm/min), type of tool (HSS uncoated).

Nisha Tamta, R S Jadoun (2015) [11] analyzed the effect of spindle speed, feed rate and drilling depth in drilling Aluminium alloy 6082. They used Taguchi L9 orthogonal array to perform the experiment. Analysis of variance (ANOVA), Signal to noise ratio (S/N) were employed to study the effects drilling parameters on surface roughness. For analysing statistical software MINITAB-15 were used. They found that spindle speed 3000 rpm, feed rate 15 mm/min, drilling depth 9 mm were the optimum value. According to them, drilling depth was the most significant factor for surface roughness followed by spindle speed.

Srinivasa Reddy, S. Suresh, et al. (2014) [12] studied the impact of process parameters such as cutting speed, point angle and feed rate on surface roughness in the drilling of AL 6463 material. HSS drill bit was used as a tool and the experiment was performed in CNC drilling machine using Taguchi L9 orthogonal array. Analysis of variance (ANOVA), signal to noise ratio (S/N) were employed to find out the optimal drilling parameters. They found that Cutting speed, feed rate and point angle plays the most significant role on surface roughness during drilling of AL 6463 material.

Sathish Rao U And Lewlyn .L.R. Rodrigues (2014) [13] have made an attempt to investigate the effect of spindle speed, fibre orientation, feed rate and drill diameter on tool wear during dry drilling of GFRP components. HSS drill bit was used in the experiment. Taguchi L9 orthogonal array was used. S/N ratios, regression analysis, ANOVA were used to find out the optimal settings. They found that speed, feed rate, drill diameter has a significant effect on

tool wear.

Arshad Noor Siddiquee, Zahid A. Khan, et al. (2014) [14] concentrated on optimising drilling parameters such as cutting fluid, speed, feed and hole depth in drilling AISI 312 material. All the experiments were done in CNC lathe machine using solid carbide cutting tool. Taguchi L18 orthogonal array was used for the experiment. Signal to noise ratio (S/N), analysis of variance (ANOVA) were employed to find out the effects of cutting parameters on surface roughness. They found that in the presence of cutting fluid, speed 500 rpm, feed .04 mm/sec, hole depth 25 mm were the optimum value of process parameters. It is seen from the ANOVA analysis that speed was the most significant factor followed by cutting fluid, feed and hole depth for surface roughness.

Vishwajeet N. Rane, Ajinkya P.Edlabadkar, et al. (2015) [15] concentrated on optimizing drilling parameters such as cutting speed, feed and point angle for resharpened HSS twist drill bit on hardened boron steel using Taguchi method. Taguchi L16 orthogonal array was used to perform the experiment in a double spindle drilling machine. Analysis of variance was employed to find out effects of process parameters on surface roughness. They found that point angle was the most significant factor for tool wear and feed rate for surface roughness.

Kadam and Pathak [16], analyzed experimental investigation was conducted to determine the effect of the input machining parameters cutting speed, feed rate, point angle and diameter of drill bit on Hass Tool Room Mill USA made CNC milling machine under dry condition. The change in chip load, torque and machining time are obtained through series of experiments according to central composite rotatable design to develop the equations of responses. The comparative performance of commercially available single layer Titanium Aluminum Nitride (TiAlN) and HSS tool for T105CR1 EN31 steel under dry condition is done. The paper also highlights the result of Analysis of Variance (ANOVA) to confirm the validity and correctness of the established mathematical models for in depth analysis of effect of finish drilling process parameters on the chip load, torque, and machining time.

Ulaş Çaydaş, [17] performed on HSS, K20 solid carbide, and TiN-coated HSS tools in dry drilling of AISI 304 austenitic stainless steel. The roles of spindle speed, feed rate, drill point angle, and number of holes on the surface roughness, tool flank wear, exit burr height, and enlargement of the hole size were experimentally investigated. The structure of this analysis has been determined by means of the technique called the design of experiments (DOE), which allows us to perform a relatively small number of experiments. An L9 orthogonal array was used to collect the experimental data. The experimental results demonstrated that the above-mentioned drilling performances showed a tendency to increase in response to the cutting parameters. TiN coated HSS drill showed the highest performance with longer tool life and higher hole quality, as well as lower surface roughness, followed by the K20 carbide and the HSS tools.

Nouari et al. [18] carried out experiments on Al2024 using uncoated carbide and coated carbide drills with different drill geometries. They concluded that low values of the surface roughness were obtained at high point angle and helix angle. The drill with the highest point angle of 180◦ also contributed well in minimizing the formation of burrs. In addition, minimum deviation from nominal drill size was obtained when there was a decrease in the web thickness and, increase in helix angle and point angle. Furthermore, it was reported that uncoated drills provided lower surface roughness compared to coated drills, where a possible explanation for this might be due to the low feed rate. However, diamond-coated drills were shown to be better at producing a minimum diameter deviation at high cutting velocity. Overall, their study concluded that coated drills did not contribute well to machining quality except for diamond and (TiAlN +WC/C) coated drills which were found to have results close to those of uncoated drills.

Dinesh Kumar, L.P. Singh, Gagandeep Singh, [19] described the Taguchi technique for optimization of surface roughness in drilling process. In their investigation, Taguchi technique was used as one of the methods for minimizing the surface roughness in drilling mild steel. The Taguchi method is a powerful tool to design optimization for quality, was used to find optimal cutting parameters. The methodology is useful for modelling and analysing engineering problems. The purpose of this study is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on surface roughness produced when drilling Mild steel. A plan of experiments, based on detailed L27 Taguchi design method, was performed drilling with cutting parameters in Mild steel. The orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters of Mild steel. From the analysis of means and ANOVA, the optimal combination levels and the significant drilling parameters on surface roughness were obtained. The optimization results showed that the combination of low cutting speed, low feed rate, and medium point angle is necessary to minimize surface roughness. The effect of parameters such as Cutting speed, feed rate and point angle and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Surface roughness.

Jaromír Audy [20], analyzed experimentally the effects of TiN, Ti(Al, N) and Ti(C, N) as well as a M35 HSS tool substrate material on the drill-life of the GP-twist drills by drilling the Bisalloy 360 steel work material. All these experiments have been statistically planned in order to establish the 'empirical' drill-life-cutting speed equations for each of the three coatings as well as to compare statistically the effects of these different coatings on the drill-life. The results demonstrated that although the coated drills performed very well at conditions much higher than applicable for the uncoated drills, none of the three coatings offered any statistically significant advantage over another coating in terms of the drill life.

CHAPTER -3

DESIGN OF EXPERIMENTS

DESIGN OF EXPERIMENTS

3.1.Design of Experiments (DOE) Overview

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product’s manufacturability, reliability, quality, and field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the effects that are important. If there is an interaction between two input variables

They should be included in design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable.

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

3.1.1.Planning

Careful planning help in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Here are some steps need to go through:

- **Define the problem.** Developing a good problem statement helps in studying the right variables.
- **Define the objective.** A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, define the goals of the experiment.

- **Develop an experimental plan that will provide meaningful information.** Review relevant background information, such as theoretical principles, and knowledge gained through observation or previous experimentation.
- **Make sure the process and measurement systems are in control.** Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system. Minitab provides numerous tools to evaluate process control and analyze your measurement system.

3.1.2.Screening

In many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality. This reduction allows focusing process improvement efforts on the really important variables. Screening suggests the “best" optimal settings for these factors.

The following methods are often used for screening:

- Two-level full and fractional factorial designs are used extensively in industry
- Plackett-Burman designs have low resolution, but they are useful in some screening experimentation and robustness testing.
- General full factorial designs (designs with more than two-levels) may also be useful for small screening experiments.

3.1.3.Optimization

After identifying the vital variables by screening, there is need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective.

The optimization methods available in Minitab include general full factorial designs (designs with more than two-levels), response surface designs, mixture designs, and Taguchi designs.

- Factorial Designs Overview describes methods for designing and analyzing general full factorial designs.
- Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.

- Mixture Designs Overview describes methods for designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of the components (factors), rather than their magnitude, are important.

- Response Optimization describes methods for optimizing multiple responses. Minitab provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.
- Taguchi Designs Overview describes methods for analyzing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-outer array designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4.Verification

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

3.1.5.Advantages and Disadvantages of DOE

DOE became a more widely used modelling 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 behaviour. However, when it comes to nonlinear behaviour, DOE does not always give the best results.

3.1.6.Hierarchy

You can determine how Minitab enforces model hierarchy during a stepwise procedure. The Hierarchy button is disabled if you specify a non-hierarchical model in the Model dialog box.

For example, a model that includes the interaction term A*B*C is hierarchical if it includes these terms: A, B, C, A*B, A*C, and B*C.

Models can be non-hierarchical. Generally, you can remove lower order terms if they are insignificant, unless subject area knowledge suggests that you include them. Models that contain too many terms can be relatively imprecise and can reduce the ability to predict the values of new observations.

Consider the following tips:

1. Fit a hierarchical model first. You can remove insignificant terms later.
2. If you standardize your continuous predictors, fit a hierarchical model to produce an equation in uncoded (or natural) units.
3. If your model contains categorical variables, the results are easier to interpret if the categorical terms, at least, are hierarchical.

3.2.Response Surface Methodology

Response surface methodology is a collection of mathematical and statistical techniques, which are useful for the modelling and analysing the engineering problems and developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs, and it is an effective tool for constructing optimization models. RSM consists of the experimental strategy for exploring the space of the process or input factors, empirical statistical modelling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the response outputs. Response surface method designs also help in quantifying the relationships between one or more measured responses and the vital input factors. The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. The cutting speed, feed rate, and cutting environment are the drilling variable, selected for our investigation. In the next step, the planning to accomplish the experiments by means of RSM using a Box-Behnken design. In many engineering fields, there is a relationship between an output variable of interest (y) and a set off controllable variables (x1, x2,…xn). The relationship between the drilling control parameters and the responses is given as:

$$y = f(x_1, x_2, \ldots, x_n) + \varepsilon$$

where, ε represents the noise or error observed in the response (y). If we denote the expected response be $E(y) = f(x_1, x_2, \ldots x_n) = \eta$ and then the surface represented by;

$$\eta = f(x_1, x_2, \ldots x_n)$$

is called a response surface. The variable x1, x2,…xn in Eq. 2 are called natural variables, because they are expressed in natural units of measurement. In most RSM problems, the form of the relationship between the independent variables and the response is unknown, it is approximated. Thus, the first step in RSM is to find an appropriate approximation for the true functional relationship between response and the set of independent variables. Usually, a low-order polynomial in some region of the independent variables is employed. If the response is well modelled by a linear function of the independent variables, then the approximating function is the first order model;

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon$$

If there is curvature in the system, then a polynomial of higher degree must be used, such as the second order model;

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i}^{k-1} \sum_{j}^{k} \beta_{ij} x_i x_j + \varepsilon$$

where, $i = 1, 2, \ldots, k - 1$ and $j = 1,2,\ldots,k$ also $i < j$

3.3.Taguchi Method

Taguchi Method has been developed by a Japanese engineer Dr Genichi Taguchi. It is a statistical tool for standardize the fractional factorial design. He designed orthogonal array (OA) to standardize it and to optimize the levels of process parameters. Taguchi believed in offline quality control. To produce robust design, which are less sensitive to the uncontrollable environmental factors, is the main aim of the Taguchi Method. Taguchi developed the concept of Taguchi loss function and signal to noise (S/N) ratio. S/N ratio is divided into Three groups namely:

1. Smaller the better,
2. Larger the better,
3. Nominal the best type.

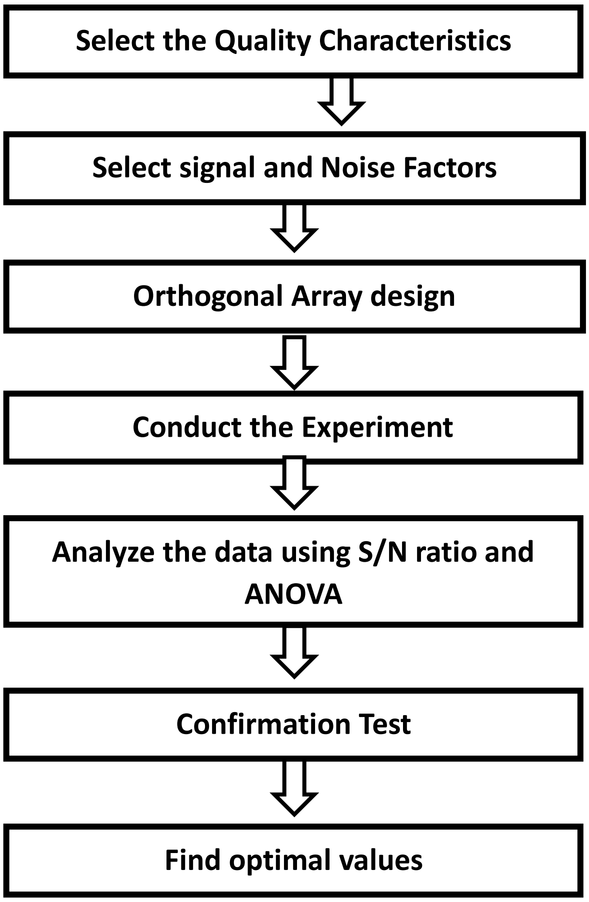

Figure.3.1 Taguchi Method

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for: – designing products/processes so as to be robust to environmental conditions – designing and developing products/processes so as to be robust to component variation; – minimizing variation around a target value. The philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three-step approach, i.e., system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. Basically, classical parameter design, developed by Fisher, is complex and not easy to use. Especially, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio g. Usually, there are three categories of the performance characteristic in the analysis of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio g. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. In this paper, the cutting parameter design by the Taguchi method is adopted to obtain optimal machining performance in turning.

$$\text{Nominal is the best: } S/N_{\mathrm{T}} = 10\log\left(\frac{\bar{y}}{s_y^2}\right) \quad (1)$$

$$\text{Larger-is-the better(maximize): } S/N_{\mathrm{L}} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

$$\text{Smaller-is-the better(minimize): } S/N_{\mathrm{S}} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \quad (3)$$

where y, is the average of observed data, s2 y is the variance of y, n is the number of observations and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale. We would use S/NT if the objective is to reduce variability around a specific target, S/NL if the system is optimized when the response is as large as possible, and S/NS if the system is optimized when the response is as small as possible. Factor levels that maximize the appropriate S/N ratio are optimal. The goal of this research was to produce minimum surface roughness (Ra) in a turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study. The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated. Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Calculate the total loss function and the S/N ratio.
- Analyse the experimental results using the S/N ratio and ANOVA.
- Select the optimal levels of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

3.4.Analysis of Variance (ANOVA) Using MINITAB

ANOVA was developed by the English statistician, R.A. Fisher (1890-1962). Though initially dealing with agricultural data, this methodology has been applied to a vast array of other fields for data analysis. Despite its widespread use, some practitioners fail to recognize the need to check the validity of several key assumptions before applying an ANOVA to their data. It is the hope that this article may provide certain useful guidelines for performing basic analysis using such a software package.

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in comparing (testing) three, or more means (groups or variables) for statistical significance.

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result (when a probability (p-value) is less than a threshold (significance level)) justifies the rejection of the null hypothesis. The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. ANOVA is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is difficult to define concisely or precisely.

3.4.1.Characteristics of ANOVA

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations. In the era of mechanical calculation, it was common to subtract a constant from all observations (when equivalent to dropping leading digits) to simplify data entry. This is an example of data coding.

Classical ANOVA for balanced data does three things at once:

1. As exploratory data analysis, an ANOVA is an organization of additive data decomposition, and its sums of squares indicate the variance of each component of the decomposition (or, equivalently, each set of terms of a linear model).
2. Comparisons of mean squares, along with F-tests ... allow testing of a nested sequence of models.
3. Closely related to the ANOVA is a linear model fit with coefficient estimates and standard errors.

In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

Additionally:

It is computationally elegant and relatively robust against violations to its assumptions.

4. ANOVA provides industrial strength (multiple sample comparison) statistically.
5. It has been adapted to the analysis of variety of experimental designs.

CHAPTER -4

EXPERIMENTATION DETAILS

EXPERIMENTAL DETAILS

This chapter presents the details of work piece (chemical and mechanical properties), drill bits, CNC drilling machine specifications, cutting process parameters and their levels, orthogonal array (L18) design and the setup conditions in measurement of surface roughness values for the machined components etc.

4.1.Work Material and Drills

In the present work the drills are made on a plate of carbon alloy SS304 having 30mm thickness using HSS twisted drills (10mm) shown in the figure 4.2. **SS 304 stainless steel** is the most common stainless steel. The steel contains both chromium (between 18% and 20%) and nickel (between 8% and 10.5%)[1] metals as the main non-iron constituents.. This material is typically used for

- Kitchen sinks, consumer durables
- Chemical containers, including for transport
- Food processing equipment, particularly in beer brewing, milk processing, and wine making
- Fasteners and flange manufacturing
- Architectural applications such as roofing and cladding, doors and windows
- Automotive and aerospace components
- Heat exchangers

Fig 4.1 SS304 steel

Fig 4.2 HSS TWIST DRILL BITS

Fig 4.3 HSS COBALT TWIST DRILL BITS

4.2.Chemical Composition and Mechanical Properties of SS304 steel

SS 304 stainless steel is a T 300 Series Stainless Steel austenitic. It has a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon. It is defined as a Chromium-Nickel austenitic alloy. SS 304 has good processability, weldability, corrosion resistance, heat resistance, low temperature strength and mechanical properties, good hot workability such as stamping and bending, and no heat treatment hardening. SS304 is widely used in the industrial use, furniture decoration, food and medical industry, etc.

Chemical composition of SS304 Material

- Carbon: 0.08%
- Silicon: 0.75%
- Manganese: 2%
- Phosporous: 0.045%
- Chromium: 18%
- Nickel: 8%
- Sulphur : 0.030%
- Nitrogen: 0.10%
- Iron: Remaining of 100%

Mechanical Properties of SS304 material

- Maximum Tensile Strength: 620 Mpa
- Yield Stress : 205 Mpa
- Young’s Modulus: 190
- % Elongation :40
- Rockwell Hardness Number(RHN): 92
- Brinnel Hardness Number(BHN): 201 (Max)
- Density : 8000 Kg/m^3

4.3.CNC Machine Specifications used for Drilling

In the present work the experiments were conducted on CNC drilling machine and the specifications of the machine were tabulated in table

Table 4.1 CNC Machine Specification

Manufacturer	Kitamura
Model	Mycentre 2/585
Type	Vertical Machining Centre with 4 axis
Auto Tool Changer	24 position
X-Axis	585mm
Y-Axis	430mm
Z-Axis	460mm

Fig 4.4 CNC Machine

4.4.Selection of Process Variables

A total of three process variables are selected for the experimental procedure.

The deciding process variables are

1. Tool Type
2. Point Angle
3. Speed
4. Feed

- Speed of the spindle, i.e., the speed at which the spindle rotates the tool.
- Feed is the rate at which the material is removed from the work piece.

4.4.1 Selection of levels

Since it is a three-level design by observing the parameters taken in various projects the levels of the factors are designed as follows.

Table 4.2 Process Parameters and Their Levels

Parameter	**Level1**	**Level2**	**Level3**
Tool Type	HSS	HSS-Cobalt	
Point angle	90	118	136
Speed	600	540	480
Feed	0.02	0.04	0.06

4.4.2 L18 Orthogonal Array:

Table 4.3 L18 Orthogonal Array

Tool Type	Angle	Speed	Feed
HSS	90	600	0.02
HSS	90	540	0.04
HSS	90	480	0.06
HSS	118	600	0.02
HSS	118	540	0.04
HSS	118	480	0.06
HSS	136	600	0.04
HSS	136	540	0.06
HSS	136	480	0.02
HSS_COBALT	90	600	0.06
HSS_COBALT	90	540	0.02
HSS_COBALT	90	480	0.04
HSS_COBALT	118	600	0.04
HSS_COBALT	118	540	0.06
HSS_COBALT	118	480	0.02
HSS_COBALT	136	600	0.06
HSS_COBALT	136	540	0.02
HSS_COBALT	136	480	0.04

4.5.CNC Machine Program

```
O0000
G21
G0 G17 G40 G49 G80 G90
G0 G90 G54
G0 G90 X-30. Y15.
S600 M3
G43 H2 Z50. M8
Z1.
G1Z-4. F40.
G0 Z1.
Z-3.
G1 Z-9.
G0 Z1.
Z-8.
G1 Z-14.
G0 Z1.
Z-13.
G1 Z-19.
G0 Z1.
Z-18.
G1 Z-20.
G0 Z50.
Y-15.
Z1.
G1 Z-4.
G0 Z1.
Z-3.
G1 Z-9.
G0 Z1.
```

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Z-8.
G1 Z-14.
G0 Z1.
Z-13.
G1 Z-19.
G0 Z1.
Z-18.
G1 Z-20
G0 Z50.
Y-15.
Z1.
G1 Z-4.
G0 Z1.
Z-3.
G1 Z-9.
G0 Z1.
Z-8.
G1 Z-14.
G0 Z1.
Z-13.
G1 Z-19.
G0 Z1.
Z-18.
G1 Z-20.
G0 Z50.
X-29.853 Y-.591
Z1.
G1 Z-4.
G0 Z1.
Z-3.
```

```
G1 Z-9.
G0 Z1.
Z-8.
G1 Z-14.
G0 Z1.
Z-13.
G1 Z-19.
G0 Z1.
Z-18.
G1 Z-20.
G0 Z50.
M5
G91 G28 Z0. M9.
G28 Y0.
```

Fig 4.5 Material after drilling

Fig 4.6 Drilling Operation

Fig 4.7 Surface Roughness Tester (Profilometer)

Fig 4.8 Surface Roughness Tester measuring

CHAPTER -5

Results And Discussions

RESULTS AND DISCUSSIONS

The experimental results and the optimization of those using Taguchi Method and Response Surface Methodology were explained in this chapter. The results of Material Removal Rate and Surface Roughness measured were depicted in table …The observed results were analysed using MINITAB-17 software.

Table 5.1 Experimental Results

Tool type	**Point angle**	**Speed**	**Feed**	**MRR**	**Ra**
Non Coated	90	600	0.02	2.4689	2.740
Non Coated	90	540	0.04	1.8042	3.042
Non Coated	90	480	0.06	1.3987	3.864
Non Coated	118	600	0.02	2.4054	2.564
Non Coated	118	540	0.04	1.8396	2.964
Non Coated	118	480	0.06	1.3987	4.012
Non Coated	136	600	0.04	2.4054	4.313
Non Coated	136	540	0.06	1.8042	4.837
Non Coated	136	480	0.02	1.4431	7.427
Coated	90	600	0.06	2.5356	3.177
Coated	90	540	0.02	1.7706	3.626
Coated	90	480	0.04	1.4214	4.447
Coated	118	600	0.04	2.5356	2.984
Coated	118	540	0.06	1.7372	2.815
Coated	118	480	0.02	1.3794	4.069
Coated	136	600	0.06	2.6058	2.557
Coated	136	540	0.02	1.6752	3.553
Coated	136	480	0.04	1.3596	3.626

5.1.Taguchi Analysis

Taguchi results of MRR and Ra were discusses here, response tables for MRR and Ra were given in table….and ….. respectively. Based on signal-to-noise ratio values, the main effect plots for both the responses were drawn and shown in figures ..and …. Respectively. From the plots, the optimal combinations of process parameters for the responses were found.

MRR versus Tool Type, PA, S, f

Table 5.2 Response Table for Signal to Noise Ratios of MRR

Level	Tool Type	PA	S	f
1	5.249	5.331	2.922	5.150
2	5.295	5.251	4.964	5.308
3		5.234	7.930	5.359
Delta	0.047	0.097	5.008	0.209
Rank	4	3	1	2

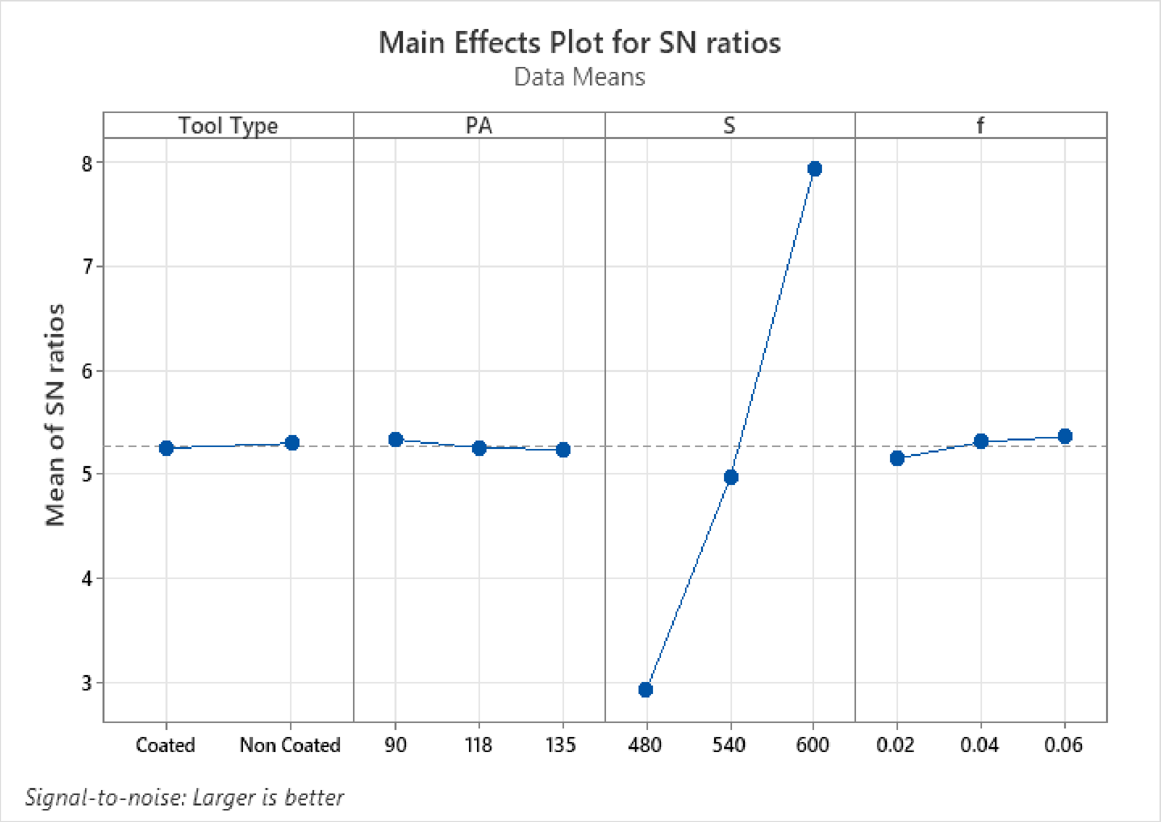

Figure.5.1 Main Effects Plot for SN Ratio For MRR

Ra versus Tool Type, PA, S, f

Table 5.3 Response Table for Signal to Noise Ratios

Level	Tool Type	PA	S	f
1	-10.580	-10.725	-12.927	-11.457
2	-11.516	-10.060	-10.664	-10.907
3		-12.360	-9.553	-10.781
Delta	0.936	2.300	3.374	0.676
Rank	3	2	1	4

Figure 5.2 Main Effects Plot For SN Ratio for Ra

5.2.Response Surface Methodology

RSM was used to analyze the effect of process parameters on the responses. The results obtained in MINITAB for MRR and Ra were depicted in table ….and……. The pareto charts shown in figures ….and…. showing that the parameters effect and interaction effects of between the parameters over the responses. From the results it is found that tool type and speed are the main effecting parameters for the responses respectively. The residual analysis has been done and from the plots ……and ……it is found that the errors are following the normality and constant variance and hence the models prepared for the responses were best fit and they can be use for the prediction of responses.

Table 5.4

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	13	3.75035	0.28849	163.44	0.000
Linear	4	2.07639	0.51910	294.09	0.000
PA	1	0.00474	0.00474	2.69	0.177
S	1	2.00644	2.00644	1136.72	0.000
f	1	0.00002	0.00002	0.01	0.914
Tool Type	1	0.00246	0.00246	1.39	0.303
Square	3	0.11260	0.03753	21.26	0.006
PA*PA	1	0.00036	0.00036	0.20	0.675
S*S	1	0.11076	0.11076	62.75	0.001
f*f	1	0.00281	0.00281	1.59	0.276
2-Way Interaction	6	0.03562	0.00594	3.36	0.130
PA*S	1	0.00015	0.00015	0.08	0.787
PA*f	1	0.01167	0.01167	6.61	0.062
PA*Tool Type	1	0.00039	0.00039	0.22	0.664
S*f	1	0.00923	0.00923	5.23	0.084
S*Tool Type	1	0.01162	0.01162	6.59	0.062
f*Tool Type	1	0.00068	0.00068	0.38	0.569
Error	4	0.00706	0.00177		

Total	17	3.75741			

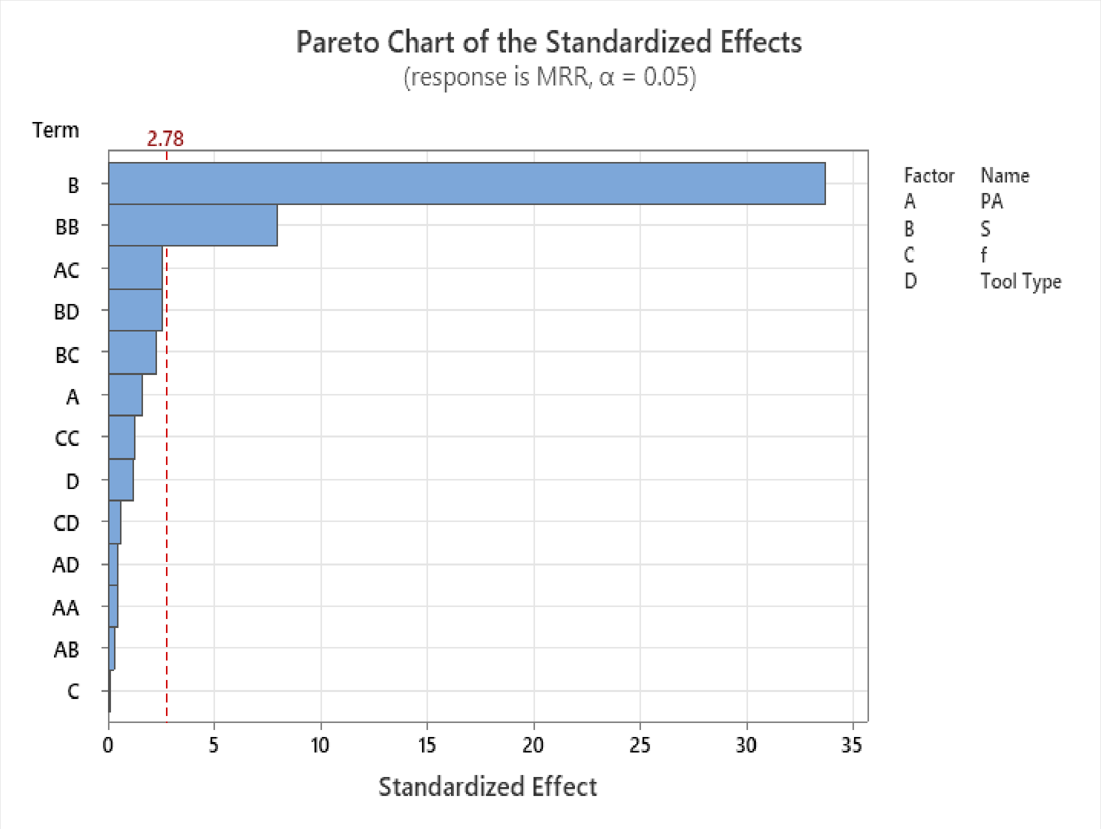

Figure 5.3 Pareto Chart For MRR

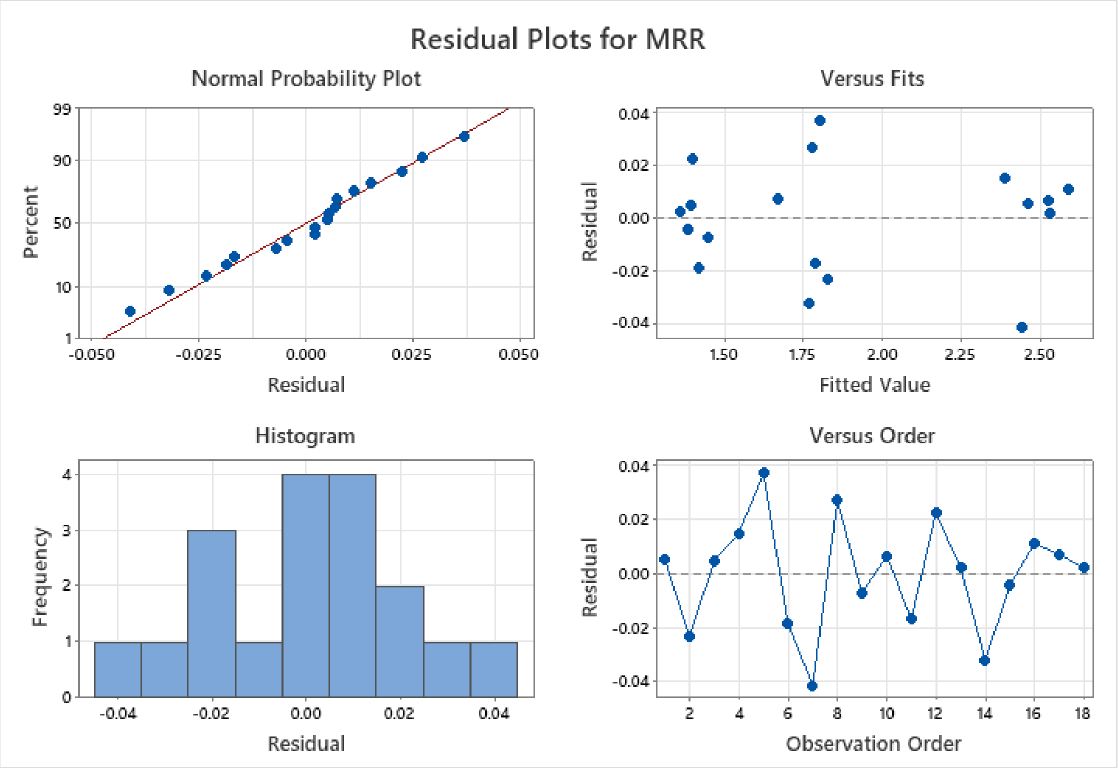

Figure 5.4 Residual Plots For MRR

Response Surface Regression: Ra versus PA, S, f, Tool Type

Table 5.5

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	13	20.7247	1.59421	3.65	0.111
Linear	4	8.5858	2.14645	4.91	0.076
PA	1	1.5472	1.54717	3.54	0.133
S	1	4.5459	4.54591	10.40	0.032
f	1	1.0987	1.09873	2.51	0.188
Tool Type	1	0.9383	0.93835	2.15	0.217
Square	3	2.3001	0.76671	1.75	0.294
PA*PA	1	1.9414	1.94141	4.44	0.103
S*S	1	0.2721	0.27213	0.62	0.474
f*f	1	0.0051	0.00513	0.01	0.919
2-Way Interaction	6	6.8122	1.13537	2.60	0.187

PA*S	1	0.0000	0.00001	0.00	0.997
PA*f	1	0.0052	0.00518	0.01	0.919
PA*Tool Type	1	3.7414	3.74136	8.56	0.043
S*f	1	0.1558	0.15575	0.36	0.583
S*Tool Type	1	0.7048	0.70480	1.61	0.273
f*Tool Type	1	0.0530	0.05298	0.12	0.745
Error	4	1.7480	0.43699		
Total	17	22.4726			

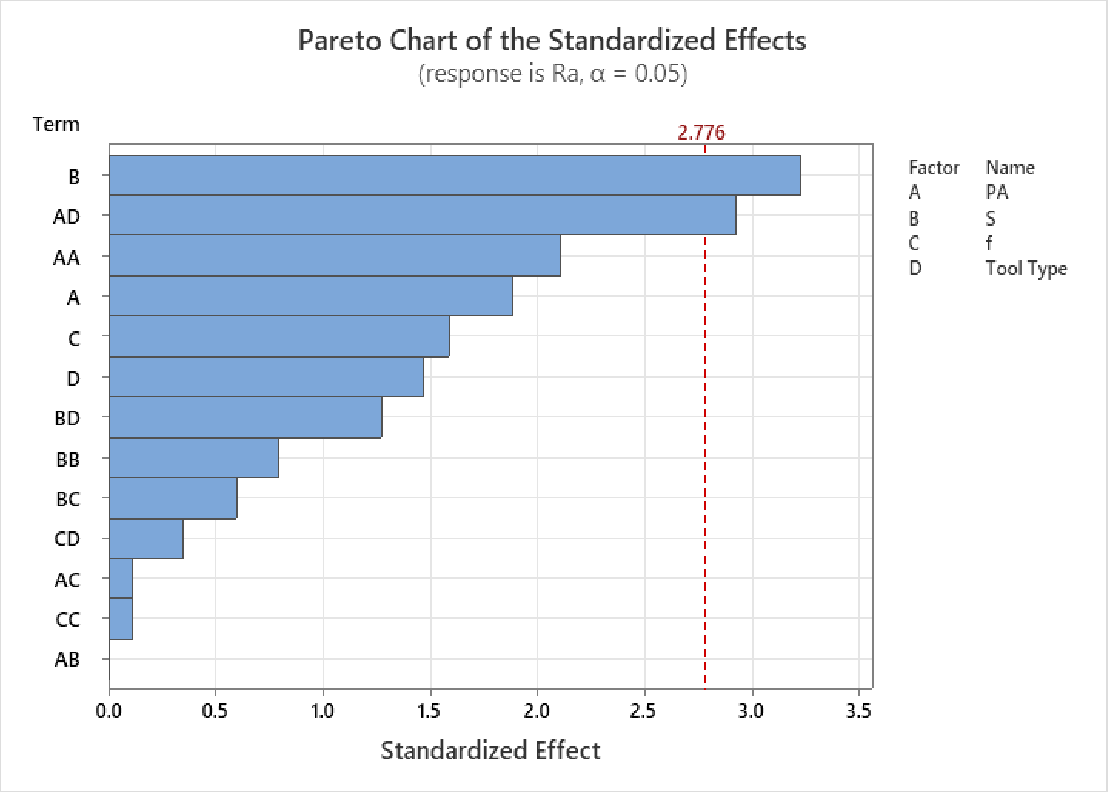

Figure 5.5 Pareto Chart for Ra

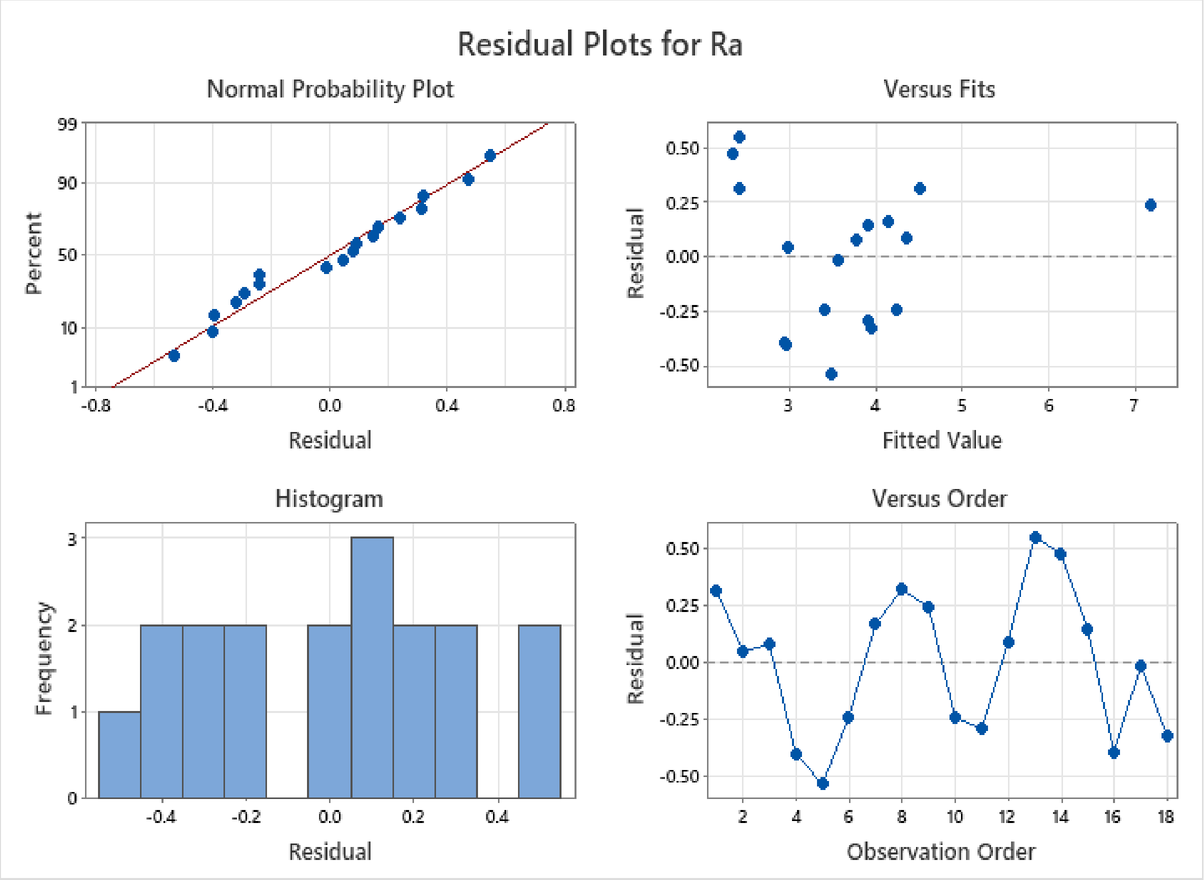

Figure 5.6 Residual Charts for Ra

CHAPTER -6

CONCLUSION

6.1 CONCLUSIONS

The following conclusions are obtained from the experimental analysis,

- From the Main Effect Plots for S/N ratios;

  for MRR the optimal condition is obtained at:

  Tool type: Non Coated

  Point Angle: 90°

  Speed:600 Rpm

  Feed: 0.06 mm/rev.

- From the Main Effect Plot for S/N ratios;

  for Ra the optimal condition is obtained at:

  Tool type: Coated

  Point Angle: 118°

  Speed: 600 Rpm

  Feed:0.06 mm/rev.

- From the Response Surface Methodology, speed is found as the most significant factor for both the responses.
- The residual plots for the responses showed that the errors are normally distributed and they are not following any particular pattern hense the models prepared were best fit and accurate.

CHAPTER-7

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