THESIS ON

ANALYSIS OF SURFACE PROPERTIES IN DRILLING OF DIFFERENT DIE STEELS USED IN MANUFACTURING INDUSTRIES

A thesis report submitted in partial fulfilment of
the requirement for the award of the degree of

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DECLARATION

I hereby declare that the Thesis entitled **"Analysis of surface properties in drilling of different die steels used in manufacturing industries"** is an authentic record of my own work carried out as the requirements for the award of the degree of M.E. **(Production and Industrial Engineering)** at Thapar University, Patiala, under the guidance of **Dr. Vinod Kumar Singla**, Associate Professor, Mechanical Engineering Department. The matter presented in this Thesis has not been submitted for the award of any other degree of this or any other University.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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II

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Abstract

The objective of the work is to analysis of surface properties in drilling of different die steels used in manufacturing industries. A study of the machining sector showed the drilling process is one of the most important due to both number of operations and machine time consumed. The importance of this process is even higher in aerospace industry, heat exchanger, die making and in aircraft manufacturing. As surface roughness is the main problem in drilling of various materials. This is due to various process parameters whether it is due to controllable or uncontrollable factors. The surface roughness will result in about 30% of parts reduction. The roughness will measure from surface roughness tester and average value of surface roughness will find out. The design of experiment approach has been applied for designing the experimentation work. The optimization of process parameters has been done by analysing the results.

ABBREVIATIONS

ANOVA	*Analysis of Variance*
DOF	*Degree of Freedom*
HCHCr	*High-Carbon High-Chromium*
HDS	*Hot Die Steel*
MRR	*Material Removal Rate*
SR	*Surface Roughness*
SEM	*Scanning Electron Microscope*
S/N RATIO	*Signal to Noise Ratio*

NOTATIONS

OA	*Orthogonal array*
A	*Work-piece material*
B	*Feed*
C	*Drill diameter*
D	*Drill material*
E	*Cutting speed*
SS	*Sum of squares*
SS'	*Pure sum of square*
CI	*Confidence Interval*

LIST OF FIGURES

FIGURE NO.	***CAPTION***	***PAGE NO.***

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION TO CONVENTIONAL MACHINING

Conventional machining in which a sharp cutting tool is used to mechanical cut the material to achieve the desired shape, size and geometry. The predominant cutting action in machining involves shear deformation of the work material to form a various kinds of chips; as the chips removed, a new surface is exposed, that is called as machined surface. Machining is a most frequently applied to shape metals. [23]

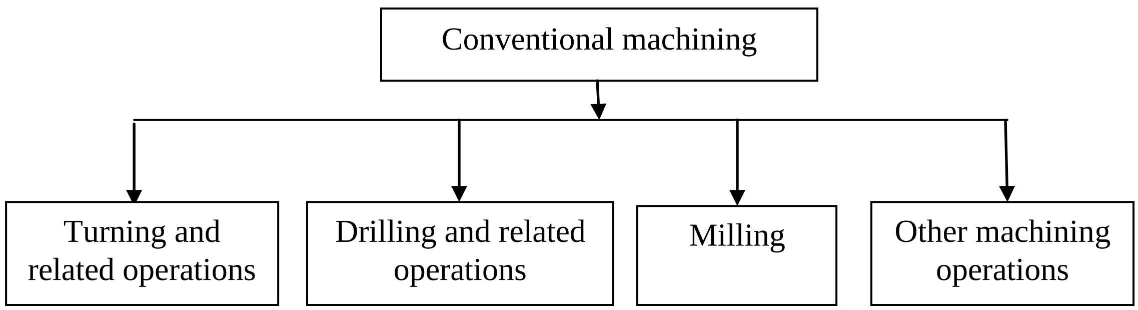

Figure: 1.1 Classification of conventional machining

1.2 DRILLING MACHINE

Drilling is a most common and complex used industrial machining processes of creating and originating a hole in mechanical components and work piece. The tool used, called a drill and the machine tool used is called a drill machine. Drilling can also be define as a rotary end-cutting tool having one or more cutting edges called lips, and having one or more helical or straight flutes for the passage of chips and passing the cutting fluid to the machining zone. The drilling operations performed on a drilling machine, which rotates and feed the drill to the work piece and creates the hole. Drilling usually performed with a rotating cylindrical tool that has two cutting edges on its working end (called a twist drill). Rotating drill fed into the stationary work piece to form a hole whose diameter is determined by the drill diameter. Drilling makes up about 25% of all the machining processes performed. Drilling is really a Complex Process, because

- Only exit for the chips is the hole that filled by the drill.
- Friction results in heat in addition to that due to chip.

- Counter flow of chips makes lubrication and cooling difficult.
- Cutting action takes place inside the work piece.
  Feathers of drilling machines are
- In drilling drill, tips are design to heat up to provide for the plastic flow of metal.
- In drilling chips formed are usually long. [48]

1.3 HISTORY OF DRILLING MACHINE

Drilling machines was first invented and developed by "Arthur James Arnot and William Blanch Brain" The twist drill bit was invented by Steven A. Morse. who received U.S. Patent 38119 for his invention 'Improvements of Drill-Bits" in 1863. The original method of manufacture was to cut two grooves in opposite sides of a round bar, then to twist the bar to produce the helical flutes. This gave the tool its name. Development and improvements of the drilling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide drills. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of drilling machines were, also developed to perform special drilling operations. During this era, computerized machines have been developed to alleviate errors and provide better quality in the finished product. The drilling machine has revolutionized industrial work of every kind and made so such a lot of complex tasks seem easy. Drilling is the cutting process of using a drill bit in a drill to cut or enlarge holes in solid materials, such as wood or metal. Different tools and methods are using in drilling depending on the type of material, the size of the hole, the number of holes, and the time to complete the operation. Drilling is a cutting process in which a hole is originated or enlarged by means of a multi point fluted, end-cutting tool. As, the drill is rotating and advanced into the work piece, material is removed from work in the form of chips that move along the fluted shank of the drill. [48]

1.4 TYPES OF DRILLED HOLES

- Through holes: Drill exits from the opposite side of the work piece called through hole. hole depth is equal to the work piece thickness or height.
- Blind holes: Drill does not exit from the opposite side of the work piece called blind hole, hole Depth is less than work piece thickness or height.[48]

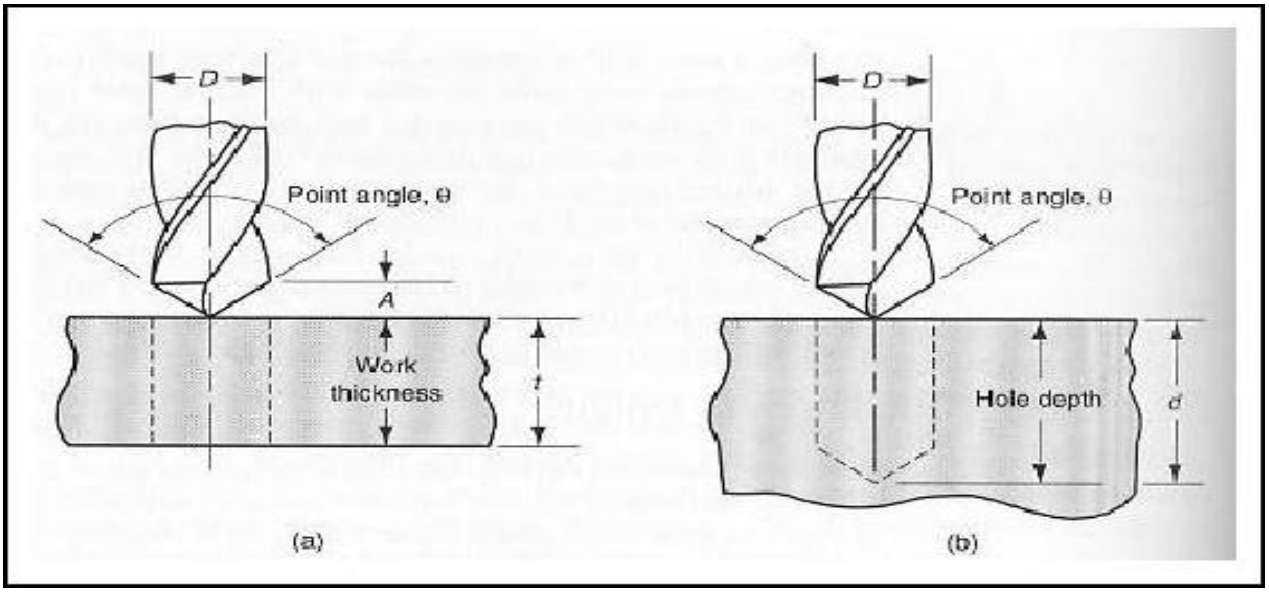

Figure: 1.2 Types of drilled holes [50]

1.5 DRILLING OPERATIONS

- Reaming
- Tapping
- Counter-boring
- Counter-sinking
- Centering or center-drilling
- Spot-facing

1.6 CLASSIFICATION OF DRILLING MACHINES

- Bench type drilling machine

- Upright drilling machine
- Radial drilling machine
- Gang type drilling machine
- Multi spindle type drilling machine
- Deep hole type drilling machine
- Transfer type drilling machine
- General purpose drilling machines of common use
- Pillar drilling machine
- CNC column drilling machine

1.7 RADIAL DRILLING MACHINE

Radial Drilling machine is a machine fitted with a rotating cutting tool called drill bit. This radial drilling machine is use for drilling holes in various materials such as steel, cast iron, composite, plastic and concrete etc. The use of machine is in the metal working industry. A radial drilling machine is a large gear headed drill press in which the head moves along the arm that radiates from the column of the machine. The arm of the machine can swing in relation to the base of the machine. This swing operation helps the drill head to move out of the way so a large crane can place the heavy work piece on the base of the radial drilling machine. In addition, this helps in drilling holes at different locations of the work piece without actually moving the work piece. Power feed of the spindle is a common feature. In addition, coolant system is a common feature of the radial drilling machine. When it comes to mechanical machining, radial drilling machine is used for all functions such as drilling, counter boring, spot facing, lapping, screwing reaming, tapping and boring. Radial drilling machines work well with a variety of material such as cast iron, steel, plastic etc. Drilling machines hold a certain diameter of drill (called a chuck) rotates at a specified rpm (revolutions per minute) allowing the drill to start a hole. A radial drilling machine or radial arm press is a geared drill head that is mounting on an arm assembly that can be move around to the extent of its arm reach. The most important components are the arm, column, and the drill head. The drill head of the radial drilling machine can be move, adjusted in height, and rotated. Aside from its compact design, the radial drill press is capable of positioning its drill head to the work piece through this radial arm mechanism. This is probably one of the reasons, why more machinists prefer using this type of drilling machine. In fact, the radial drilling machine considered the most versatile type of drill press. The tasks that a radial drilling machine can do include boring holes, countersinking, and grinding off small particles in masonry works. Although some drill presses are floor mounted, the most common set-up of radial arm drill presses are those that are mounting on workbenches or tables. With this kind of set-up, it is easier to mount the drill and the work pieces. There is no need to reposition work pieces because the arm can extend as far as its length could allow. Moreover, it is easier to maneuver large work pieces with the radial arm-drilling machine. Large work pieces we can mount on the table by cranes as the arm can be swiveled out of the way. [52]

1.8 COMPONENTS OF RADIAL DRILLING MACHINE

- Column is the part of the radial arm drill press, which holds the radial arm, which can move around according to its length.
- Arm raise adjusts the vertical height of the radial arm along the column.
- Table is the area where the work pieces fed and worked on.
- On/Off button - is the switch that activates and deactivates the drill press.
- Base is the radial arm drill press part that supports the column and the table.
- Arm clamp secures the column and the arm in place.
- Radial arm holds and supports the drill head assembly and can move around on the extent of its length.
- Spindle is the rotated part of the drill press, which holds the drill chuck used in holding the cutting tool
- Drill head is the part of the drill press that penetrates through the material or work piece and drill through the specific hole size.[52]

1.9 KINEMATIC SYSTEM OF GENERAL PURPOSE DRILLING MACHINE AND THEIR PRINCIPLE OF WORKING

Kinematic system in any machine tool is comprised of chain of several mechanisms to enable transform and transmit motion from the power source to the cutting tool and the

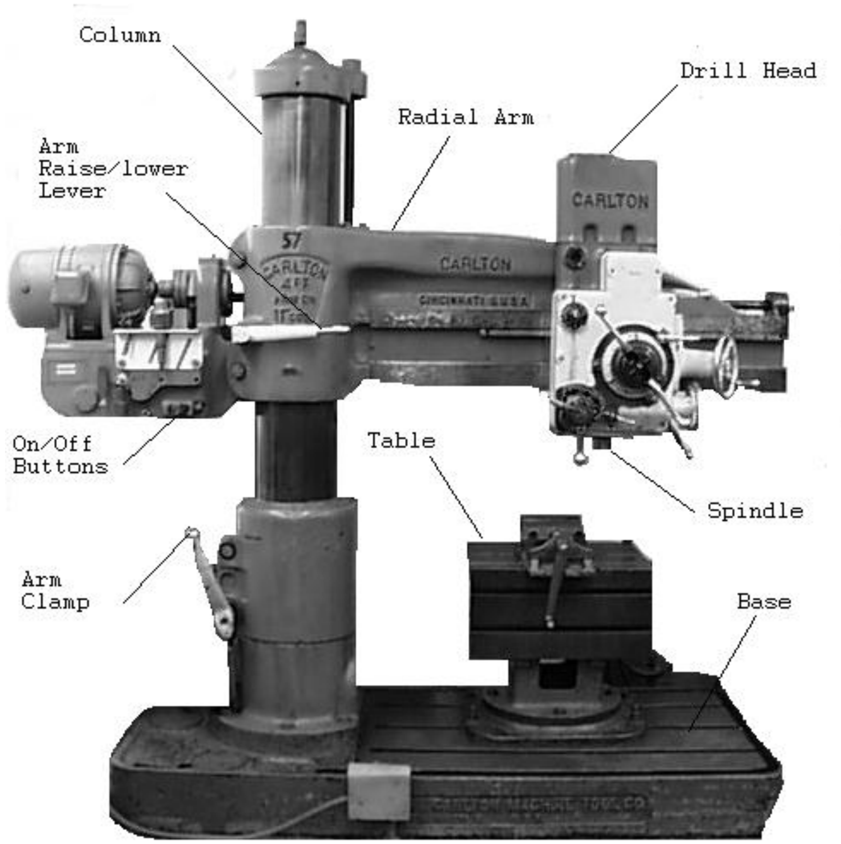

Figure 1.3 Radial drilling machines [48]

work piece for the desired machining action. The kinematic structure varies from machine tool to machine tool requiring different type and number of tool-work motions. Even for the same type of machine tool, say column drilling machine, the designer may take different kinematic structure depending upon productivity, process capability, durability, compactness, overall cost etc targeted. Typical kinematic system of a very general-purpose drilling machine are, a column-drilling machine having 12 spindle speeds and 6 feeds. The kinematic system enables the drilling machine the following essential works as:

1.9.1 Cutting motion

The cutting motion in drilling machines is attain by rotating the drill at different speeds (rpm) Like centre lathes, milling machines etc, drilling machines also need to have a reasonably large number of spindle speeds to cover the useful ranges of work material, tool material, drill diameter, machining and machine tool conditions. It is show that the drill gets its rotary motion from the motor through the speed gearbox (SGB) and a pair of bevel gears. For the same motor speed, the drill speed can be change to any of the 12 speeds by shifting the cluster gears in the SGB. The direction of rotation of the drill can be change, if needed, by operating the clutch in the speed reversal mechanism.

1.9.2 Feed motion

In drilling machines, generally both the cutting motion and feed motion are imparted to the drill. Like cutting velocity or speed, the feed (rate) also needs varying (within a range) depending upon the tool-work materials and other conditions and requirements. The drill receives its feed motion from the output shaft of the SGB through the feed gearbox (FGA), and the clutch. The feed rate can be change to any of the six rates by shifting the gears. In addition, the automatic feed direction can be reverse, when required, by operating the speed reversal mechanism. The slow rotation of the pinion causes the axial motion of the drill by moving the rack provided on the quill. The upper position of the spindle is reduced in diameter and splined to allow its passing through the gear without hampering transmission of its rotation.

1.9.3 Tool work mounting

The taper shank drills are fitted into the taper hole of the spindle either directly or through taper socket. Small straight shank drills are fitted through a drill chuck having taper shank. The work piece is kept rigidly fixed on the bed (of the Table). Small jobs are generally held in vice and large or odd shaped jobs directly mounted on the bed by clamping tools using the T-slots made in the top and side surfaces of the bed. [52]

1.10 GENERAL-PURPOSE DRILLS

Classified as

1.10.1 According to material

- High speed steel – most common
- Cemented carbides
- Without or with coating
- In the form of brazed, clamped or solid

1.10.2 According to size

- Large twist drills of diameter around 40 mm

- Micro drills of diameter 25 to 500 μm
- Medium range (most widely used) diameter ranges between 3 mm to 25 mm

1.10.3 According to number of flutes

- Two fluted – most common
- Single flute – e.g., gun drill (robust)
- Three or four flutes – called slot drill

1.10.4 According to shank

- Straight shank – small size drill being held in drill chuck
- Taper shank – Medium to large size drills, fitted into the spindle nose directly or through taper sockets

1.10.5 According to specific applications

- Centre drills- for small axial hole with 60°
- Taper end to accommodate lathe centre for support [52]

1.11 TWIST DRILLS

Drill bits are cutting tools used to create cylindrical holes. Bits held in a tool called a drill, which rotates them and provides torque and axial force to create the hole. Different point angle drills and different diameter drills and of different length of drills can be used according to the application of work. Drills with no point angle are use in situations where a blind, flat-bottomed hole is required. These drills are very sensitive to changes in lip angle, and even a slight change can result in an inappropriately fast cutting drill bit that will suffer premature wear. Diameters range of twist drill is about 0.15 to 75 mm. Body, Point, and Shank are three basic parts of twist drill twist drill has two spiral or helical grooves called flutes separated by Lands. Angle of spiral flute is call as the helix angle around 30°. Flutes helps for extraction of from the hole. Web is the thickness of the drill between the flutes and it support the drill support over its length. Point of the twist drill has the general shape of a cone having a typical value of 118°. Point can be design in various ways. However, most common design is a chisel edge. The spiral, or rate of twist in the drill, controls the rate of chip removal in a drill. A fast spiral drill is use in high feed rate applications under low spindle speeds, where removal of a large volume of swarf is required.

- The point angle or angle formed at the tip of the drill determine by the material.

- Harder materials require a larger point angle, and softer materials require a sharper angle.
- The lip angle determines the amount of support provided to the cutting edge.
- Both conditions can cause binding, wear, and eventual catastrophic failure of the tool. The proper amount of lip clearance determine by the point angle.[48]

1.12 DIFFERENT GEOMETRY OF DRILLS

Point angle considered as one of the main factor for quality of hole different materials have different point angle as shown.

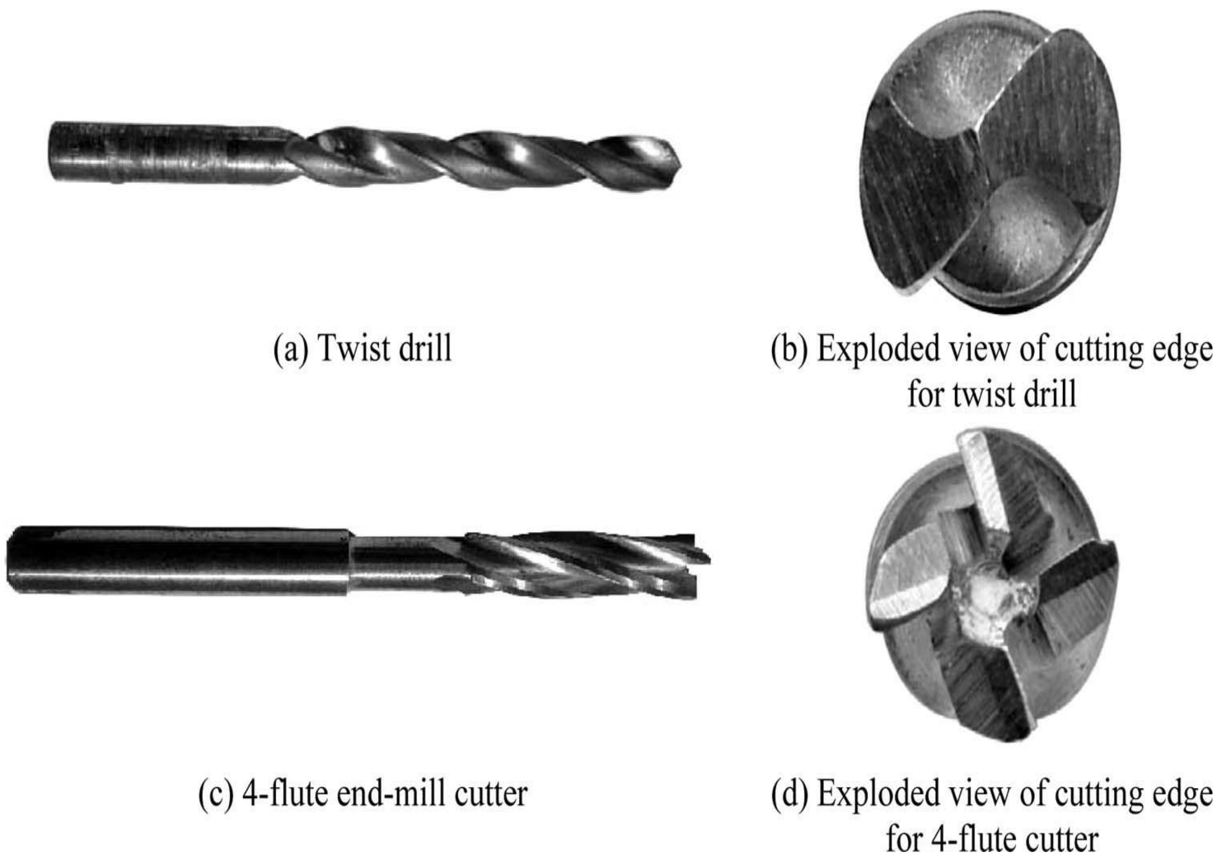

Figure 1.4 Different types of drills [1]

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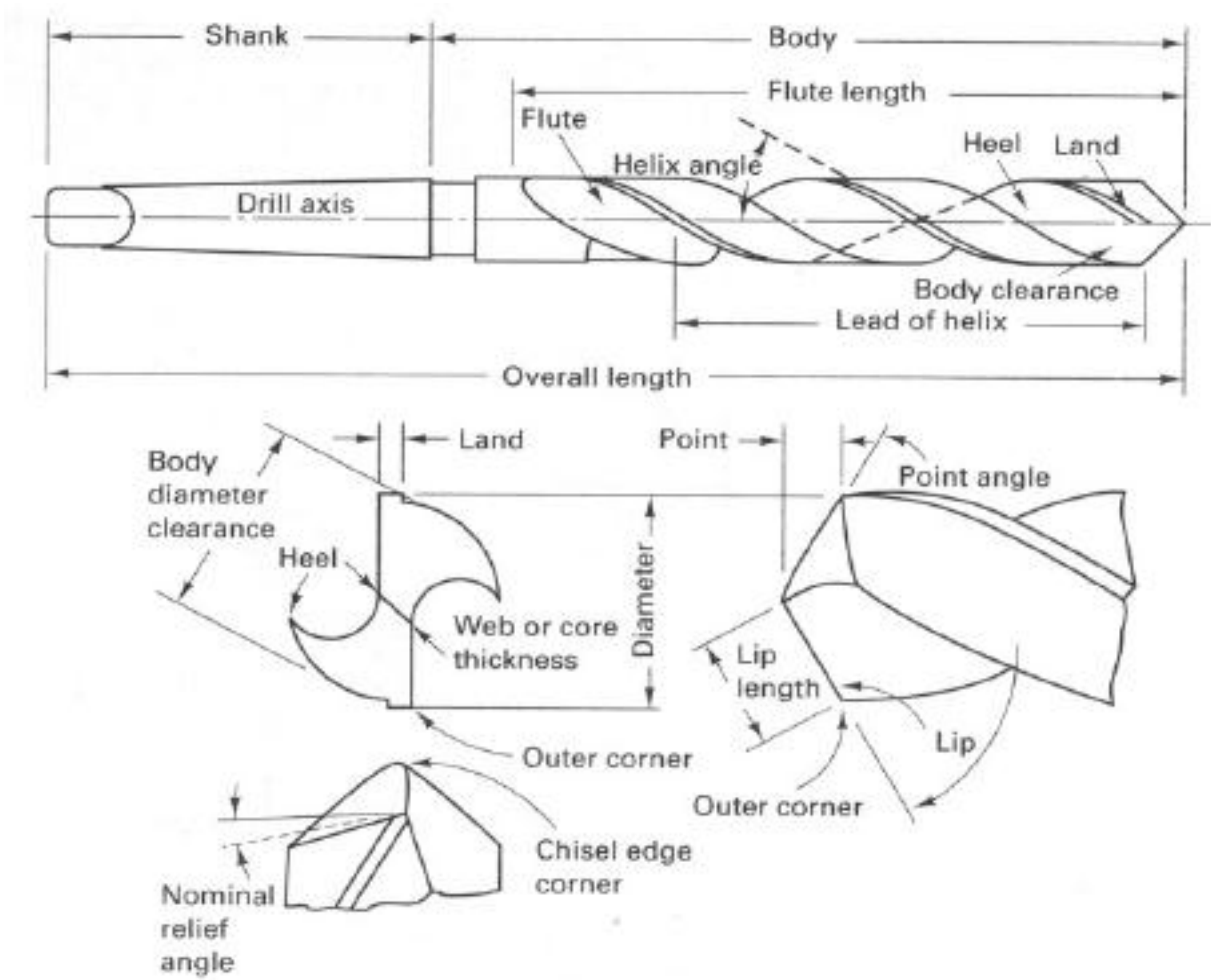


Figure 1.5 Nomenclature and Geometry of twist drill [48]

1.13 THRUST FORCE

Thrust force during drilling defined as "the force acting along the axis of the drill during the cutting process." Cutting forces help to monitor tool wear, since forces increase with tool wear. Thrust force is also use to monitor tool wear and, in turn, monitor tool life. Tool failure can occur if tool wear is not monitor. Other than being an important factor in the monitoring of tool wear, thrust force is consider to be, the major contributor of delamination during drilling. Considerable research has been done to prove that there is a "critical thrust force" that causes delamination, and thrust force below that will constrain or eliminate delamination during drilling. Vibratory drilling has been known as one of the methods to reduce thrust force during drilling of steel and during drilling of composites. If

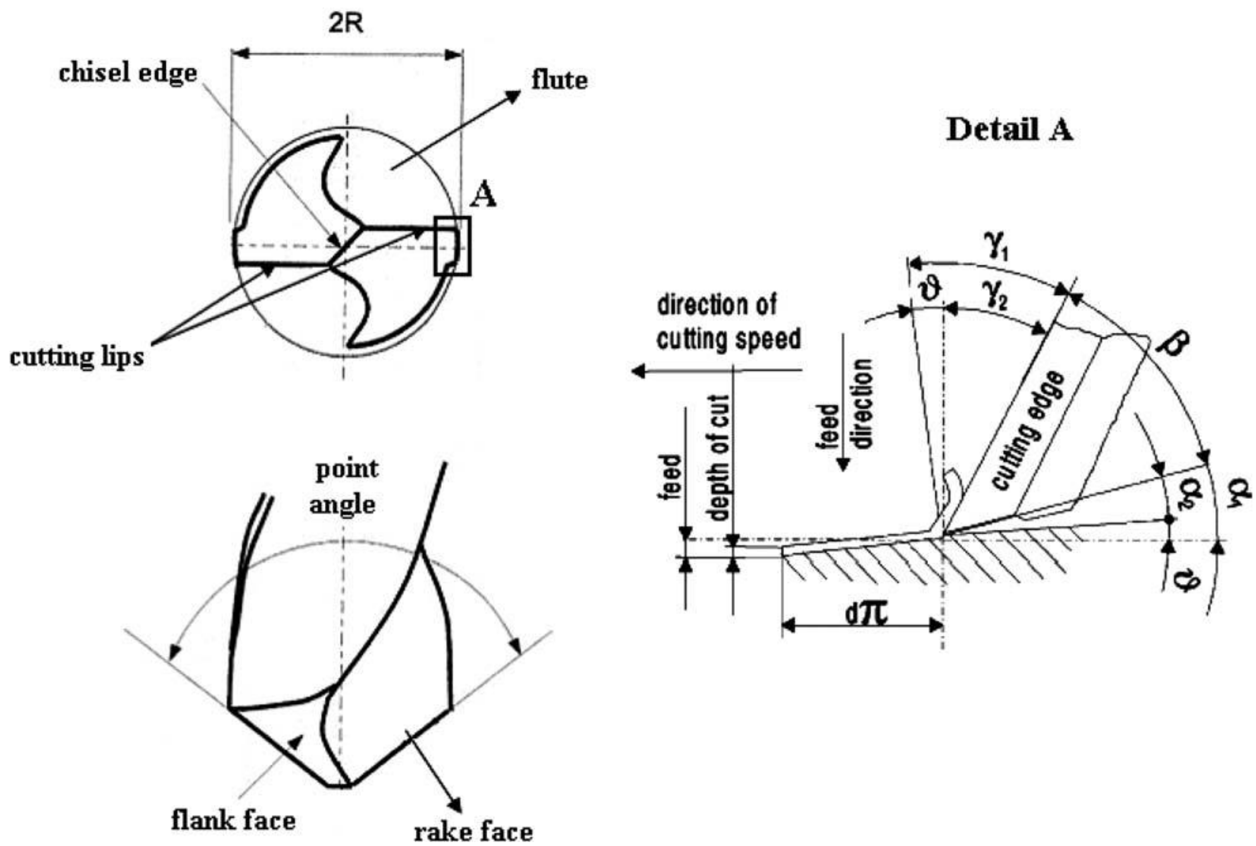


Figure 1.6 Cutting lips at the twist drill where the orthogonal cutting model is applied [35]

the "critical thrust force" is known, then the machining efficiency can be increased and higher quantities can be machined.

Hole making is one of the important machining operations to facilitate the assembly operations. Though a number of approaches have been used for making holes in components conventional drilling till date is the most widely acceptable and frequently practiced machining operation for hole making. Conventional drilling however results in damage in the form of delamination, micro cracks, fiber pull out and matrix burning around the hole and may ultimately cause variation in the residual strength of the component with a drilled hole. However, delamination has been observed as a most critical problem in drilling

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A large work has been done on different aspects of drilling machine. This chapter covers the literature on various input parameter of drilling machine and its effect on surface roughness, hole diameter, tool wear, delamination, burr height and micro hardness of the surface.

2.2 LITERATURE SURVEY

A lot of research has been conducted on the effects of drilling on various materials. Most has been targeted toward the study of delamination.

2.3 ACCORDING TO CUTTING SPEED, FEED AND THEIR EFFECT ON DELAMINATION

Palanikumar, Prakash and Shanmugam [1] (2008) find out the effect of spindle speed, feed rate & two different cutting tool i.e. HSS twist drill and 4-flute cutters on Delamination, when Drilling of GFRP Composites by forming L9 Orthogonal Array, using Taguchi methods and Response Surface Regression methods. Found that feed rate is the dominant parameter, which affects the delamination in drilling of GFRP composites, in both Drills. To reduce delamination feed rates (major parameter) should be lower or preferred.

Gaitonde, Karnik and Davim [2] (2008) carried out study on drilling of LAMIPAN PB (wood coating layer) Medium Density Fibre board panel using cutting conditions i.e. spindle speed & feed rate to minimize the delamination tendency Using Response Surface Methodology and Taguchi Design & by forming L9 Orthogonal Array on 16 mm thickness panel and 5 mm diameter panel. Cemented Carbide drills (K20 grade, 20º helix and 60º point angle) were, employed for the experimentation. Result of Response surface analysis clearly indicates it is necessary to employ low values of feed rate along with the higher values of cutting speed. By Taguchi optimization, found that the feed rate is the dominant factor followed by the cutting speed in minimizing the delamination factor at entry and exit of the holes.

Tsao [3] (2008) consider the effect of diameter ratio, spindle speed, feed rate on thrust force & delamination of core saw drill in drilling (CFRP) carbon fibre reinforced composites laminates dimensions were 60×60×6 mm using Taguchi L18 orthogonal array. Results shows that feed rate, spindle speed are the main factors, small feed rate produce low thrust force in drilling which can reduce delamination also. The core saw drill is more advantage then the core drill.

Palanikumar [4] (2010) develop model and analysis of Delamination factor and surface roughness when drilling of GFRP composites using response surface methodology. Three-factors (spindle speed, feed and drill diameter) five-level central composite design is employed for carrying out this work. Result shows feed rate is the factor, which has greater influence on delamination factor and surface roughness in drilling of GFRP composites. Drill diameter has very good influence on deciding the delamination factor in drilling of GFRP composites. For surface roughness, drill diameter has less influence than feed rate considered. The results of analysis of variance indicated that the developed models are adequate at 95% confidence level within the limits of factors being considered.

Gaitonde, Karnik, Rubio, Correia, Abraoc and Davim [5] (2008) study the effect of process parameters these are cutting speed, feed rate and point angle on delamination during high-speed drilling of carbon fibre reinforced plastic (CFRP) composite are consider using response surface methodology. The drilling experiments using cemented carbide (K20) twist drills based on full factorial design of experiments. The computed values of delamination factor are empirical related to process parameters by developing a second order non-linear regression model based on response surface methodology (RSM). The investigation reveal that the delamination tendency decrease with increase in cutting speed or said that high-speed cutting plays a major role in reducing damage at the entrance of hole. The study also suggests low values of feed rate and point angle combination for reducing the damage.

Tsao and Hocheng [6] (2007) study the comprehensive analysis of delamination caused by the drill wear for twist drill in drilling carbon fibre-reinforced composite materials. Drill wear is a serious concern in hole-making industry, as it is necessary to prevent damage of cutting tools, machine tools and work pieces. The industrial experience shows the worn drill causes more delamination. The critical thrust force at the onset of delamination for worn drill is predict and compared with that of ideal drill. The results shows that though the critical thrust force is higher with increasing wear ratio, the delamination becomes more liable to occur because the actual thrust force increases to larger extent, compared to sharp drill, the worn twist drill allows for lower feed rate below which the delamination damage can be avoid.

Hochenga and Tsao [7] (2006) study the effect of different special drills on drilling-induced delamination due to the different drill geometry, these drills show different levels of the drilling thrust force, which varies with the feed rate. The advantage of these special drill bits lies in their higher threshold feed rate at the onset of delamination. Among the five drills, the core drill offers the highest critical feed rate followed by the candlestick drill, saw drill and step drill, while the traditional twist drill allows for the lowest feed rate. In other words, the core drill, candlestick drill, saw drill and step drill can be operate at larger feed rate or in shorter cycle time without delamination damage compared to the twist drill. The results are compared with the theoretical predictions of critical thrust force at the onset of delamination and illustrate that thrust force exerted by drill that is distributed toward the drill periphery rather than concentrated at hole centre.

Durao, Moura and Marques [8] (2006) analysed, delamination during drilling of carbon/epoxy plates using the finite element method. The composite plate is model by successive layers, allowing the usage of different stacking sequences. The tool is model as a rigid body, and different tool geometries are compare, as well as axial thrust forces and delamination continuously monitored. The model simulations consider non-linear three- dimensional analysis and include the use of previously formulated interface finite elements incorporating a damage model based on fracture. Result shows numerical thrust force results were compare with values from the experimental work. The force–displacement curve generated by the model has a shape that corresponds to the experimental curve result for thrust force. He concluded that the model presented in this paper is capable to simulate quasi-isotropic carbon/epoxy. In finite element model, it was not possible to evaluate the effect of the cutting parameters – feed rate and cutting speed – that have some importance on the measurable forces – thrust and torque.

Yong, Jun and Bing-Tao [9] (2007) study delamination on laminated vibration damping steel sheet using finite element method. An interface cohesive model between the skin sheets was develop by using a contact/interface approach, and the model was applied to simulate T-peel and lap-shear processes of LVDSS. Interface contact stress distribution during the T-peel and lap-shear processes is obtain, and the finite element analysis (FEA) results agree satisfactorily with the corresponding experimental results. Compare the result of simulation with the experimental results, it is proved that the model is an effective model to simulate the cohesive of LVDSS including initiation of interface crack, evolution of the degradation, and complete delamination.

Hocheng and Tsao [10] (2003) consider the effect of various drills on delamination of composite materials in this study. Various drill types, such as saw drill, candlestick drill, core drill and step drill excluding twist drill. In this study, the critical thrust force at the onset of delamination is predict and compared with the twist drill. Result shows for saw drill, the case of s = zero reduces the twist drill, while s approaches to one allows for very high critical thrust force. For candlestick drill, the case of α = zero reduces to the twist drill, while $\alpha=\infty$ approaches to the saw drill. For core drill, the case of s = zero and $\beta = 1$ reduces to the twist drill. For step drill, the case of $i = \xi$ = zero and s = zero reduces to the twist drill case. While $i = \xi = 0$ and $\beta = 1$ approaches to the core drill.

Tsao [11] (2006) identifying the effect of pilot hole between drill diameter (Z) and inner uncut portion (G) for delamination free drilling based on linear elastic fracture mechanics. Experimental results indicate the critical thrust force is reduce with pre-drilled pilot hole, while the drilling thrust largely reduced by removal of chip effect. Controlling the ratio of pre-drilled pilot hole relative to drill diameter, one can conduct medium to large hole of composite laminates drilling at higher feed rate without delamination damage.

Mercado [12] (2003) study multichip package Delamination and die fracture. In the early stage of development, mould Delamination and die cracking observe after assembly. With some mould compound materials, die backside have large Delamination areas, while with other mould compound, delamination stops early but dies cracks. Finite element analysis, incorporated with interface fracture mechanics method, has been conducted to understand these phenomena.

Impact of mould material properties and package geometry on post-assembly delamination has been evaluated. Good agreements have been obtained between experiment data and the simulation results. The phenomenon of crack branching into the die was also studied. Finite element simulation can be used to predict whether and when the crack at the interface will turn and crack the die. With a thorough understanding of the failure mechanism, both mould delamination and die cracks have been eliminated in the final package development.

Sudha, Sampathkumar and Vijaya [13] (2009) Analysis the effect of Delamination in GFRP Composite materials when, drilling through Acoustic Emission. Acoustic emission is an online technique, which can be use to monitor and measure the delamination as it occurs. An online monitoring tool is ideally suited for this purpose. Acoustic emission waveform obtained during drilling of GFRP composites are analysed and presented. The way of classifying the waveforms continuous, mix of continuous and burst. As long as there is continuous emission of signals, it indicates that there is no delamination. Burst emission is an indication of delamination. In addition, damages like delamination at entrance and exit by showing change in slope of cumulative graph of Acoustic emission RMS signal vs. Time.

Kilickap [14] (2010) study the effect of cutting parameter such as tool geometry, spindle speed & feed rate on GFRP composites that have E-glass fibre & epoxy matrix size is 400×400×10 mm by forming L16 Taguchi orthogonal array (diameter of tool is constant). Tool geometry are HSS twist drill with point angle of 118°, HSS-E coating twist drill with point angle of 135º, HSS steel step drill with point angle of 118º, Step angle of 90º, & HSS standard brad point drill. In addition, found that for minimum delamination feed rates & cutting speed should be lower. In addition, the step drill produce less delamination at the entrance & exit then the three drills.

Gaitonde & Karnik [15] (2008) did study during drilling of SUPER PAN DECOR (melamine coating layer) Medium Density Fibre board panels as a work for minimization of delamination at entrance & exit using Taguchi methods and utility concepts. Working conditions are under different conditions of feed rate and cutting speed. Result shows that both the feed rate and the cutting speed are the important drilling process parameters to control the delamination factor.

Employing higher cutting speed & low values of feed rate is necessary to reduce the delamination tendency at entry & exit of the holes.

Latha, Senthil, Kumar & Palanikumar [16] (2011) use multiple regression analysis and optimization of process parameters using Taguchi L27 orthogonal array, when drilling GFRP composites to reduce delamination. The parameters considered were spindle speed, feed rate and diameter of the drill bits. The drill bits used in the investigations were made of carbide (K10) tool having diameter 6 mm, 8mm and 10 mm. The results show that the feed rate & drill diameter are the most influential parameters, which affects the delamination in drilling of GFRP composites. The combination of spindle speed & feed rate also affects the delamination in drilling of GFRP composites. In addition, results reveal that the response surface model and optimization studies used in this work is very much suitable for predicting and optimizing the delamination factor in drilling of composites.

2.4 ACCORDING TO CUTTING SPEED, FEED AND THEIR EFFECT ON STEEL MATERIAL

Deng and Chin [17] (2006) investigate the roundness of holes in BTA deep-hole drilling on AISI 1045 steel by Taguchi methods. The machining parameters include tool diameter, shaft length, feed rate and rotational speed, day of the week (as noise factor). Result shows that strongly influence factors were feed rate, rotational speed and tool diameter, moderate influence of shaft length and no or little influence of noise factor on the roundness of the hole.

Zhang and Chen [18] (2009) study effect of feed rate, spindle speed, peck rate, & tool type also noise factors were shop vibration and the presence or absence of magnetism in the work piece material on surface roughness in a (CNC) drilling of 1018 low carbon steel plates forming L9 orthogonal array & Taguchi method. The effect of tool type and spindle speed on surface quality were greater than the effect of feed rate, also different peck rates had an impact on the surface finish of the drilled holes, work piece magnetism & vibration did not generate significant impacts on drilling hole surface roughness.

Çaydaşş, Hasççalık, Buytoz & Meyveci [19] (2011) study the effects of spindle speed, feed rate, drill point angle, drill type, & the number of holes on surface roughness, tool flank wear, Exit burr height, and the enlargement of the hole size, when dry drilling of AISI 304 austenitic stainless steel material with HSS drill, TiN-coated HSS drill, and K20 carbide twist drill. The point angles were 90º 118º and 130º point angles used. In all TiN-coated HSS twist drills provided the bests results with longer tool life and higher hole quality as well as lower surface roughness, followed by the K20 carbide and the HSS tools.

Kuram, Ozcelik, Demirbas, ŞŞik & Tansel [20] (2011) investigated the effect of spindle speed, feed rate and drilling depth & VBCFs (vegetable-based cutting fluids) on thrust force and surface roughness using Taguchi L9 orthogonal array during drilling of AISI 304 work with HSS-E tool. VBCFs were prepared from crude and refined sunflower oils using various surfactants. VBCFs were prepared with base oil and a surfactant, and a mixture of surfactants in different ratios. The Great influence factor was feed rate for all cutting fluids, increase feed rate increased thrust force and surface roughness. The spindle speed had smaller effect. Depth had no significant effect. Tool wears were not observed with all cutting fluids.

Gaitonde, Karnik, Achyutha & Siddeswarappa [21] (2006) took feed rate, rotational speed, drill point angle and lip clearance angle to minimize the burr height and thickness during drilling of AISI 316L stainless steel using HSS twist drill or L9 orthogonal array using Taguchi methods. Investigation shows that lip clearance angle has strong effect in controlling the burr size as compared to other factors.

Chen *et. al.* [22] [2007] gives the optimal geometrical characteristics and corresponding coating for high performance cutting austenitic stainless steel. Optimized special drills with point angle 138°, helix angle 38° and TiCN coating selected as the best coating. However, optimized taps had different geometry structures for tapping through holes and blind holes. The former adopted the spiral pointed tap with inclination angle 15°. The latter was spiral fluted tap with helix angle 34°. In high-performance cutting austenitic stainless steel, the optimized cutting parameters of special drills are 16 m/min and 0.13 mm/rev.

Kilickap *et. al.* [23] [2010] gives uses of response surface methodology (RSM) and genetic algorithm (GA) for finding the optimum combination values of drilling parameters such as cutting speed and feed rate, and point angle affecting the burr height in drilling of AISI 304 stainless steel. The experiments conducted based on the Box–Behnken design. The effects of drilling parameters on the burr height were evaluate using RSM and optimum drilling conditions for minimizing the burr height were determined using GA.

Ozcelik B.and Bagci E. *et. al.* [24] [2005] study the effect of spindle speed and feed rate on the drill temperature using two different work piece materials, AISI 1040 steel and Al 7075-T651. Drill temperatures were measure by inserting standard thermocouples through the coolant (oil) hole of TiAlN-coated carbide drills. drill bit temperature was predicted using a numerical calculation with Third Wave AdvantEdge Lagrangian based on explicit finite element analysis software. The results obtained from experimental study and finite element analysis FEA ware compared. Good agreement between the measured and analyzed temperature results have been found in dry drilling.

S. Dolinsek [25] (2003) study an experimental investigation of the chip transformation process on the cutting edges using quick-stop of the drilling processes as a basis to establish a real cutting model for the drilling austenitic stainless steels.

Kivak *et. al*. [26] (2012) Optimize the drilling Process parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and thrust force (F_f). The experiments were performed on AISI 316 stainless steel blocks using uncoated and coated M35 HSS twist drills under dry cutting conditions. Analysis of variance (ANOVA) was employ to determine the most significant control factors affecting the surface roughness and thrust force. The cutting tool, cutting speed and feed rate selected and find out that, the cutting tool was the most significant factor on the surface roughness and that the feed rate was the most st significant factor on the thrust force.

Meena *et. al.* [27] (2011) tells the use of dry and minimum quantity lubrication (MQL) to drill austempered ductile iron (ADI), a new class of materials used for light weight automotive components like connecting rods and crankshafts. In this study, ADI is produce by a novel processing technique known as continuous casting heat treatment process. The novel technique developed by the integration of casting (in die-casting) and heat treatment processes in the foundry to save energy and time. This paper deals with an experimental investigation on the role of MQL drilling on the cutting forces, tool wear and surface roughness of newly produced ADI at industrial speed-feed combinations by TiAlN-coated tungsten carbide tool. MQL drilling, performance then compared with the dry and conventional drilling process under the same experimental conditions and environment. The results include significant reduction in tool wear, cutting forces and surface roughness by MQL drilling, mainly through reduction in the cutting zone temperature.

2.5 ACCORDING TO CUTTING SPEED, FEED AND THEIR EFFECT ON TITANIUM ALLOYS

Herbert *et. al.* [28] (2012) study the structure of the white layer from an abusive cutting operation (i.e., drilling) in a nickel-based super alloy at both macro and micro scale levels. This has been achieved by using, (a.) Focus Ion Beam to mill a sample for Transmission Electron Microscopy to analyze the grain size within the white layer, (2) Scanning Electron Microscopy to see shape characteristics of the white layer generated, (3) X-ray diffraction to see any alterations to the crystallinity of the structure, and (4) Nano-indentation within this layer to compare its hardness with that of the bulk material. This analysis indicates that the white layer created from machining a combination of both mechanical and thermal effects and not only thermal.

Kwong *et. al.* [29] (2009) study the influence of the drill's minor cutting edge to work piece surface integrity and residual stress distribution for RR1000,, a newly developed nickel-based superalloy and found The thickness of material drag in the hoop direction has been found to be the highest at the top and the least at the bottom of the hole which is directly related to the contact duration between the minor cutting edge and work piece surfaces; moreover this difference increased at higher levels of wear of the minor cutting. This work suggests that material drag increases with the duration of the minor cutting edge–work piece interaction such that plastic deformation is the greatest near the drill entrance holes and that process monitoring of the degree of material drag in hoop direction can be practicable.

Herbert *et. al.* [30] (2011) studies the structure of the white layer generated from non production abusive drilling parameter in a nickel-based superalloy at macro and micro scales. This was achieved using (1) a Focus Ion Beam (FIB) to mill a sample for Transmission Electron Microscopy (TEM), (2) Scanning Electron Microscopy (SEM) and (3) Nano-indentation to evaluate material within and under this layer. In-depth analysis of this layer from non-standard drilling parameters in alloy RR1000 showed the layer is Face Centre Cubic FCC) in structure and is the first to reveal it is polycrystalline with an average grain size of 50 nm compared to the bulk material of 22-63 μm (ASTM 8-5). Nano indentation testing has shown the white layer has a 45% higher hardness than the bulk material.

2.6 RESIDUAL TENSILE STRENGTH

Kishore, Tiwari, Dvivedi and Singh [31] (2009) study the effect of the cutting speed, the feed rate, & the drill point geometry (8-facet drill, 4-facet drill & Jodrill) on the residual tensile strength of the after drilled unidirectional GFRE composite using the Taguchi method. For minimum drilling induced damage & maximum residual tensile strength better to drill at lower cutting speed & feed rate should be lower.

2.7 ACCORDING TO CUTTING SPEED, FEED AND THEIR EFFECT ON ALUMINIUM ALLOYS

Kurt, Bagci and Kaynak [32] (2009) investigate the effect of cutting speeds, feed rates, depths of drilling and different drilling tools (uncoated HSS, HSS+TiN coated and HSS+ TiAlN coated) with a 118° point angle in dry drilling of Al 2024 alloy as work, to optimize surface finish and hole diameter accuracy. Results are the feed rate, cutting speed, differently coated drills affect surface finish by 35.46%, 6.15%, and 53.84% and depth of drilling, feed rate, cutting speed, and differently coated drills affect the hole diametric error by 8.18%, 74.09%, 6.04%, and 0.10%.

Basavarajappaa, Chandramohan and Davim [33] (2008) study the effect of spindle speed are (1000, 2000, & 3000) rpm and feed rate are (0.05, 0.15, 0.25 mm/rev) on feed force, surface finish and burr height using solid carbide multi faceted drills of 5 mm diameter, by Taguchi Orthogonal Array of L9. When drilling of hybrid metal matrix composite (MMCs) of two material (1) Al 2219/15% SiCp and (2) Al2219/15percentage SiCp/3percentage Gr. The result shows that the feed rate is dominant factor than speed for both composites also ceramic–graphite reinforced composite has better machinability than those reinforced with SiCp composites.

Krishna, Kishore & Satyanarayana [34] (2010) consider the effect of two cone angle tools with an included angle of 45°& 90° on axial thrust and torque, when friction drilling of Aluminium (AA6351) work piece by high speed steel conical tool using Taguchi L8 orthogonal array. Results shows that the cone angle of the tool is a critical parameter & effecting both torque and thrust force. Highly burnished surface obtained for at low and medium speed, discolorations observed at high speed. Stray bending also observed on work piece.

Kim, Cho, Seo & Lee [35] (2008) minimize the thrust forces in the step-feed micro drilling process using Taguchi L27 orthogonal array on SM45C work piece, also 200 μm micro drill used for the experiment. Cutting parameters includes feed rate, step-feed, & cutting speed. Based on the results it is determined that the sequence of factors affecting drilling thrusts corresponds to feed rate, step-feed, and spindle rpm. It can conclude that the feed rate is the most influential factor for micro drilling thrust minimization.

Islam, Rafi, and Charoon [36] (2009) present the effect of input parameters cutting speed, feed rate, and canned cycle on diameter error, circularity, and surface roughness when drilling on aluminium 6061 work with (HSS) tool using Taguchi L27 orthogonal array. Canned cycles are the chip-breaking canned cycle (G73), the spot drilling canned cycle (G81) & the deep hole canned cycle (G83). Results presented show that drilled holes are always oversized, and a bell mouth shape is present in all holes; that is, there is enlargement at the entry of the hole, regardless of the type of canned cycle applied. The wobbling of drills during positioning can cause the enlargement of the hole at entry. The results shows that the canned cycle has a profound effect on drilled hole quality, and, spot drilling canned cycle produces the best results**.**

Zhang *et. al.* [37] [2012] presents a literature review on mechanical drilling processes for Ti, namely, twist drilling, vibration assisted twist drilling, ultrasonic machining, and rotary ultrasonic machining. It discusses cutting force, cutting temperature, tool wear and tool life, hole quality (diameter and cylindricity, surface roughness, and burr), and chip type when drilling of Ti using these processes.

2.8 TOOL WEAR

Wang *et. al.* [38] (2008) studied wear mechanism map of uncoated high-speed steel (HSS) tools was under the conditions of dry-drilling die-cast magnesium alloys. Three wear mechanisms appear in the map based on the microanalysis of drilled HSS tools by SEM, including adhesive wear, abrasive wear and diffusion wear. In the map, there exists a minor wear region which is called “safety zone”. This wear mechanism map will be a good reference for choosing suitable drilling parameters when drilling die-cast magnesium alloys.

Faraz, Biermann and Weinert [39] (2009) gives a new approach in unveiling and introducing the cutting edge rounding (CER) a latent wear characteristic as a measure of sharpness/ bluntness of uncoated cemented carbide tools during drilling of CFRP composite laminates. By considering four different types of drills (conventional and specialized) with different shapes and geometry were tested, all angle measured for primary cutting edge and all Angle measure right at the end corner of the cutting edge. Mechanical loads (drilling thrust and torque) were recorded, and the hole entry and exit delamination were quantified. Very appreciable correlations between the CER and the drilling loads, and the quantitative delamination results are observe. Results reveal that this new wear type develops almost similarly for the selected tools and is practically independent of their respective conventional flank wear patterns. The CER correlations with quantitative delamination results are notice quite comparable to those of the conventional flank wear via statistical linear regression analyses.

Mihoc, Pop, Geaman, Cazangiu and Mitu [40] (2011) make a systematic analysis of the drilling process from the technological system, machine tool, tool, device and material processing on various composites. He considered various process parameters like the mechanism of chip formation, cutting speed, feed rate, cutting force, cutting fluid, drill geometry, drill material and operating environment in response to performance like hole quality, hole accuracy, drill life, capability etc. result shows drill geometry and material have a major role to obtain the desired quality performances at the composite material drilling. The choosing of the drill material has to assure the resistance of the abrasive wear.

Liang and Chiou [41] (2011) use Grey-Taguchi method to minimize tool wear and surface roughness in the micro-drilling operation on PMMA (Poly methyl methacrylate) polymer work pieces with thicknesses of 1.0, 2.0, and 3.0 mm using L9 Orthogonal Array. Three types of HSS twist drills coated with TiN, TiCN and TiAlN were, used to drill through holes. The factors are Coating Layer, Feed Rate, Spindle Speed, and Depth of Cut gives satisfactory result in these sequences as written above.

Tsao [42] (2008) consider drilling parameters (Step angle, stage ratio, feed rate and spindle speed) in step drilling of carbon fibre reinforced plastics (CFRP) laminates were experimentally investigated using Taguchi method and radial basis function network. The experimental results indicate that the step angle, stage ratio, and feed rate are the most significant factors affecting the overall performance. The optimal combinations, such as $A_2B_2C_1D_3$ (i.e., step angle=100° stage ratio=0.4 mm/mm, feed rate=0.01 mm/rev and spindle speed=1,200 rpm), were used under the adopted drilling condition. An experimental approach to the prediction of thrust force produced by step drill using linear regression analysis of experiments and radial basis function network (RBFN) were propose in this study. In the confirmation tests, RBFN (errors within 0.3%) shown to be a better predictive model than multi-variable linear regression analysis (errors within 28%) for quantitative prediction of drilling-induced thrust force in drilling of composite material.

2.9 GAPS IN LITERATURE REVIEW

From the exhaustive literature review, it has been concluded that a lot of work has been done on composite materials AISI 304, mild steel and AISI 316 steels with radial drilling machine. In addition, it is observed that, a little work has been done using different tools on different types of die steels with varying drill diameter. A little work has been reported on EN 31, H11, HCHCr die steels machining with drilling machine. So in the thesis work it is proposed to study the effect of different input parameters such as work piece material, cutting speed, feed, drill diameter and drill type on the MRR, surface roughness, hole diameter and bur height. The effect of various input parameters on output responses have been analyzed using Analysis of Variance (ANOVA).

CHAPTER 3
METHODOLOGY

3.1 OBJECTIVE OF THE PRESENT WORK

The objective of the present work is to find out main effect of cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed on MRR, Surface roughness, Hole diameter error, and burr height. Microstructure analysis of work piece material also did. The formula used for measuring the MRR are given below

MRR is given by:

$$MRR = (W_i - W_f) / \rho t \times 1000 \; mm^3/\text{min} \qquad (3.1)$$

W_i =Initial weight of work piece material in gram

W_f =Final weight of work piece material in gram

t=Time period of machining in minutes

ρ =Density of work piece in gram/cm^3

3.2 DEGREES OF FREEDOM (DOF)

Total degree of freedom required for the entire experimentation determined by the number of factors, their interactions effects and level for factors. The degree of freedom for each factor is given by the number of levels minus one.

DOF for each factor = k-1

Where k is the number of level for each factor

DOF for interactions between factors: $(k_A-1) \times (k_B-1)$

Where k_A and k_B are number of level for factor A and B [50]

3.3 SELECTION OF FACTORS

The determination of factors which needs to be investigated depends on the responses of interest. The factors that affect the responses were identified using several methods such as brainstorming, cause and effect analysis and flowcharting. The lists of factors studied with their levels are given in the Table 3.1 the minimum DOF required in the experiment are the sum of all the degrees of freedom of factors and their interaction. In the present experiment setup, there are 4 three level factors and one is 2-level factor i.e tool material The number of DOF for factors A,B, C, and E are two and for factor D is one. The total DOF for the experiment explained in Table 3.2. As the DOF required for the experiment is nine the orthogonal array (OA) to be used should have more than nine dof. The most suitable orthogonal array which can be used for this experiment is L18, which has 17 DOF assigned to its various columns. The additional four DOF used to measure the random error. [50]

Table 3.1: Factors and their levels of interest

Factors	Factors designation	Level 1	Level 2	Level 3
Work piece material	A	EN 31	H 11 (HDS)	HCHCr
Feed (mm/rev)	B	0.1	0.125	0.15
Dill diameter (mm)	C	4	8	12
Drill material	D	M2 HSS	M35 HSS	
Cutting speed (RPM)	E	80	160	244

Table 3.2 Degrees of freedom

Factors	A	B	C	D	E	A × B	Total
Degree of freedom	2	2	2	1	2	2	11

3.4 ORTHOGONAL ARRAY

OA derived from factorial design of experiment by a series of very sophisticated mathematical algorithms including combinatory, finite fields, geometry and error correcting codes. OA plays a critical part in achieving the high efficiency of the Taguchi method. The OA is constructed in a statistically independent manner. Within each column, number of occurrences of each level is equal and for each level within one column, each level within any other column will occur an equal number of times as well. Then, the columns are called orthogonal to each other. OA is available with a variety of factors and levels in the Taguchi method. Since each column is orthogonal to the others, if the results associated with one level of a specific factor are much different at another level, it is because changing that factor from one level to the next has strong impact on the quality characteristic being measured. Since the levels of the other factors are occurring an equal number of times for each level of the strong factor, any effect by these other factors will be ruled out. The selection of orthogonal array will depend on:

- The number of factors and interactions of interest
- The number of levels for the factors of interest

Taguchi orthogonal arrays are experimental designs that usually require only a fraction of the full factorial combinations. The columns of arrays are balanced and orthogonal. This means that in each pair of columns, all factor combinations occur same number of times. Orthogonal designs allow estimating the effect of each factor on the response independently of all other factors. Once the degrees of freedom are known, the next step is to select the orthogonal array (OA). The number of treatment conditions is equal to the number of rows in the orthogonal array and it must be equal to or greater than the total degrees of freedom. Once the appropriate orthogonal array has been selected, the factor can be assigned to the various columns [49]. L18 Linear graph is shown in figure 3.1 that's used in experiment and experimental design of L18 is shown in Table 3.3

Figure 3.1: L18 Linear Graph [50]

The 18 experimental designs represent the set of values of input process parameters with which particular experiment is to be conducted. Machining time during each experiment was 1 minutes.

The total 18 experiment performed with repetition in order to minimize the effect of uncontrollable factors for each combination of all input parameters. [50]

Table 3.3: L18 Experimental design

Trial no	Tool material	Cutting speed (RPM)	Feed (mm/rev)	Drill diameter (mm)	Work-piece material
1	M2 HSS	80	0.10	4	EN 31
2	M2 HSS	80	0.125	8	H 11
3	M2 HSS	80	0.150	12	HCHCr
4	M2 HSS	160	0.10	4	H 11
5	M2 HSS	160	0.125	8	HCHCr
6	M2 HSS	160	0.150	12	EN 31
7	M2 HSS	244	0.10	8	EN 31
8	M2 HSS	244	0.125	12	H 11
9	M2 HSS	244	0.150	4	HCHCr
10	M35 HSS	80	0.10	12	HCHCr
11	M35 HSS	80	0.125	4	EN 31
12	M35 HSS	80	0.150	8	H 11
13	M35 HSS	160	0.10	8	HCHCr
14	M35 HSS	160	0.125	12	EN 31
15	M35 HSS	160	0.150	4	H 11
16	M35 HSS	244	0.10	12	H 11
17	M35 HSS	244	0.125	4	HCHCr
18	M35 HSS	244	0.150	8	EN 31

3.5 EXPERIMENTAL SET UP

The experiments have been conducted on Radial drilling machine shown in (Figure 3.2) available at Thapar University, Patiala in the Machine Tool lab. Many input parameters like work piece material, cutting speed, feed, drill diameter and drill material has been varied in this experiment. Each factors has its own effect on the output parameters such as Material removal rate (MRR), Surface roughness (SR), hole diameter error and burr height. The input parameters, which kept constant during the experimentation, are given in the Table 3.4 Before start of experiment, the work piece material ground to remove any dust, durt particles or removing any surface defect and tapering effect of work piece.

Table 3.4: Constant input parameters

Sr. No.	Parameters	Value
1	Machining time	60 sec
2	Point angle	118°
3	Helix angle	32°
4	Shank type	Cylindrical
5	No of flutes	2

Figure: 3.2 Radial drilling machine (Source: Machine Tool Lab, TU, Patiala)

3.6 MEASURING AND TESTING EQUIPMENT USED

Surface roughness tests conducted on all the 18 samples produced by the radial drilling machine. MRR was measured using an electric balance (Sartorious, USA) weighing machine which has a resolution of 0.01 mg, whereas Burr height was measured using a digital Calliper which has a resolution of 0.01 mm. The details of important equipment used for the test in the experimental study are given below.

3.6.1: Surface Roughness Tester

Surface roughness test of all the samples measured by contact type stylus (Mitutoyo SJ-400) Model. The accuracy of this device is 0.01 µm. To measure the surface roughness, the blocks were sliced to the holes axes. The surface roughness was measured parallel to each hole axis and the average values of the surface roughness is taken. Surface roughness of a machined product could affect several of the product's functional attributes, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, and resisting fatigue. There are several ways to describe surface roughness. One of them is average roughness which is often quoted as R_a symbol. R_a is defined as the arithmetic value of the departure of the profile from the centerline along sampling length. The Profile of Surface roughness shown in Fig. 3.3 for measuring surface roughness of work piece material sampling length taken is 3 mm and cut off length taken is 0.8 mm.

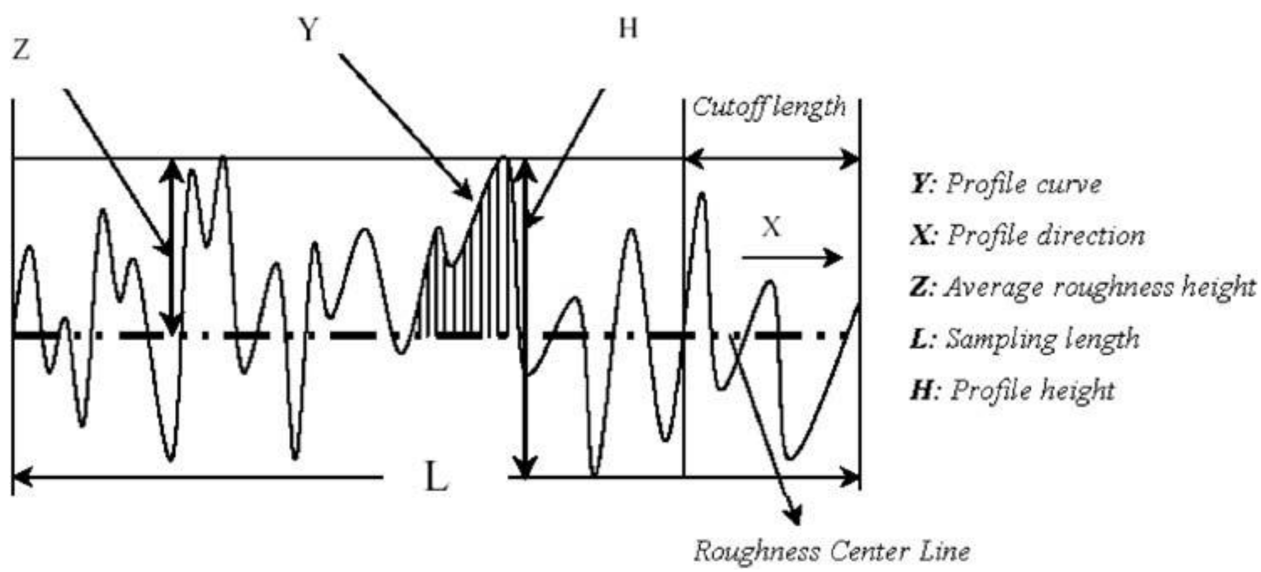


Figure: 3.3 Profile of Surface roughness [47]

Figure: 3.4 Experimental devices for measurement of surface roughness (Source: Mechanical Engineering Department, TU, Patiala)

Surface roughness can be expressed by the following mathematical relationships

$$R_a = \frac{1}{L}\int_0^L |Y(x)|\,dx \qquad (3.2)$$

Where,

R_a arithmetic average deviation from the mean line
Y the ordinate of profile curve

The tools measuring surface roughness with probes, measure, and control in appropriate length and circumference the probe comes in and out holes while traveling on the surface. This movement is turned into electrical current by means of a coil or crystal. After increasing the current by using suitable units, its value is shown with a pointer or digitally. [47]

3.6.2: Profile Projector

Measurement of hole diameter accuracy was investigated on Nikon profile projector (model V-10A) of Japan which is available in Material testing lab of Thapar University, Patiala. The voltage requirement is 220V/230V/240V and current requirement is 0.6 amps.

Figure: 3.5 Device for measurement of hole diameter accuracy (Source: Metrology lab, TU, Patiala

3.6.3 Burr height

The burr height was measured with digital callipers of 0.01 mm resolution. The burr height is taken on four positions on circular parameter and average burr height is taken.

3.7 METHODOLOGY

The Taguchi methodology is one of the optimizing techniques that based on the design of experiments (DOE) approach. The experiments analysis will propose to conduct using the design of experiments technique. Although full factorial designs can be use where in all the possible combinations can be test, we would use fractional factorial analysis methods for the experiment.

The Taguchi Design is a design of experiment (DOE) approach developed by Dr. Genichi Taguchi in order to improve the quality of manufactured goods in Japan. Although similar to factorial design of experiment, the Taguchi design only conducts balanced (orthogonal) experimental combinations, which makes the Taguchi design even more efficient than a fractional factorial design. The Taguchi methodology has been proposed to overcome the limitations of full factorial analysis by simplifying and standardizing the fractional factorial design (Roy, 1990). Taguchi methodology involves identification of controllable and uncontrollable factors and the establishment of series of experiments to find out optimal combinations of the factors that has the greatest influence on the performance and least variation from the target of the design. The main advantage of Taguchi Design is its efficiency in that multiple factors can be consider at once and the optimal parameters can be identified with fewer experimental resources than the traditional (DOE) approach. In addition, Taguchi design allows looking into the variation caused by control factors and noise factors, while the variation caused by noise factors is usually ignore in the traditional DOE approach.

Taguchi methods as an engineered system that comprises four main components as illustrated in Fig. 3.6. It is designed to employ energy transformation in converting input signal into specific, intended function requested by customers by applying the laws of physics. Taguchi methods advocate that when all the applied energy is transformed into creating its intended function without any noise effects, a system reach its ideal function. As shown in Fig. 3.7 at the most common way of expressing the system's ideal function is

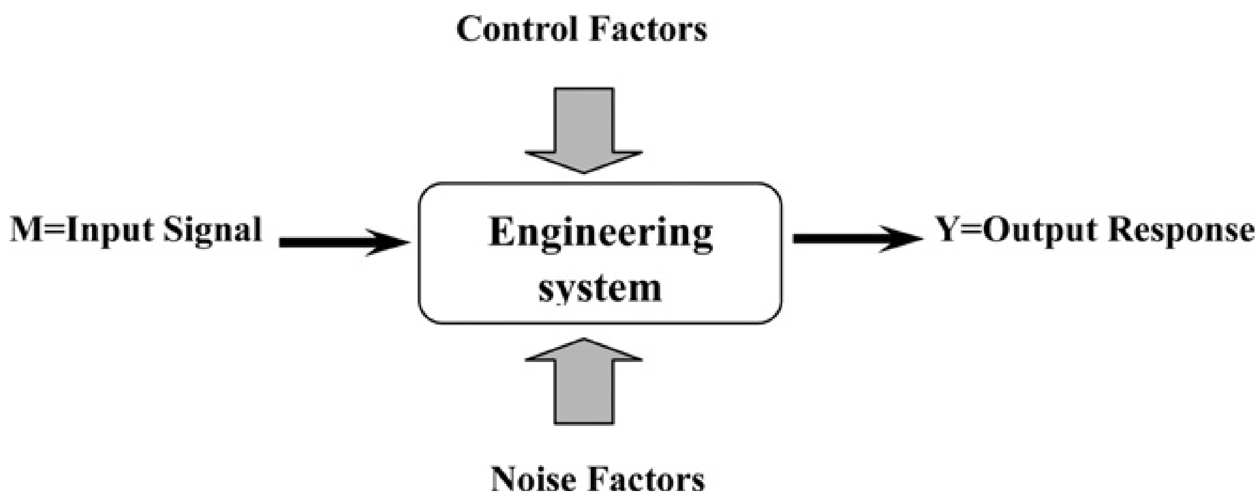


Figure 3.6 Experimental designs [49]

$Y = ßM$

Where a linear relationship exists between Y (= ideal output response) and M (= input signal). However, in reality, energy transformation of any system does not happen as designed or intended due to noise factors disturbing the system. The reality of the system function therefore consists of nonlinear effects between the input/output demonstrated by Fig. 3.7 b the real function Y_r can thus be described as

$Y_r = f\ (M,\ C_1, C_2 \ldots\ldots, C_K,\ N_1,\ N_2, \ldots\ldots N_P\ ) = ßM + F_{error}\ (M,\ C_1, C_2 \ldots\ldots C_K,\ N_1,\ N_2, \ldots\ldots \ldots N_P)$,

Where C_1, $C_2 \ldots\ldots, C_K$ are control factors and N_1, $N_2, \ldots\ldots\ \ldots N_P$ are noise factors. F_{error}
Is the error function between the ideal and the reality. The purpose of Taguchi method is to reach a level where the control factor does not vary much despite the inevitable presence of noise.
The basic functionality of the drilling machine is to create a precise shape as the output requested by customers after receiving the input signal i.e. the tool Therefore, from the standpoint of the transformability the ideal function for this case is designed as electrode dimension (input signal) being proportional to product dimension (output response). [49]

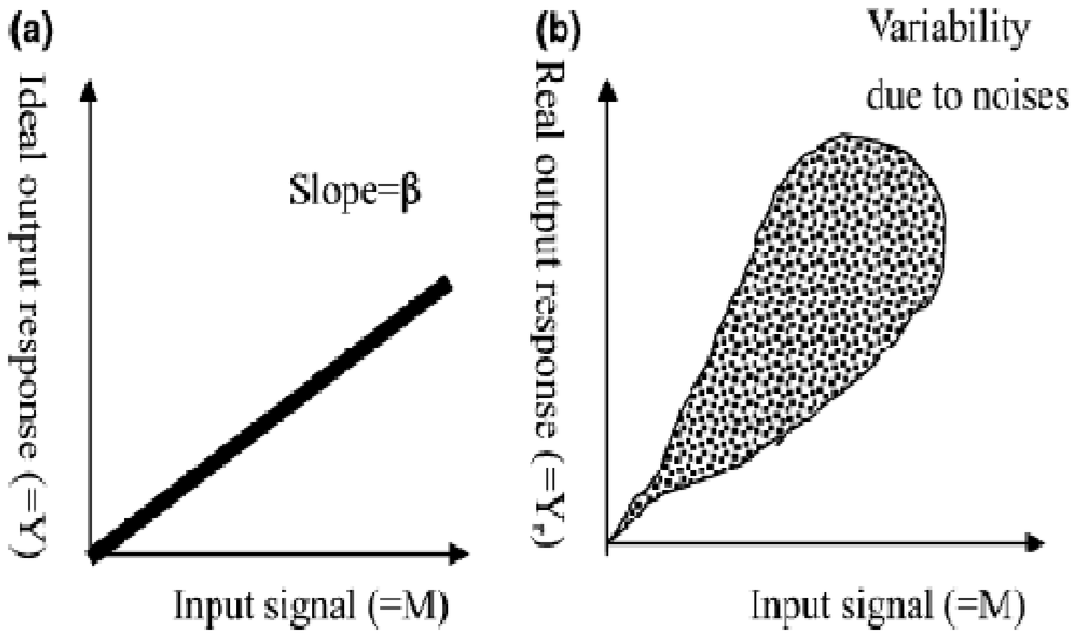


Figure 3.7 the system (a) ideal function (b) the real system [49]

3.8 PROCEDURES OF TAGUCHI METHOD

The brief procedure of Taguchi method is as under

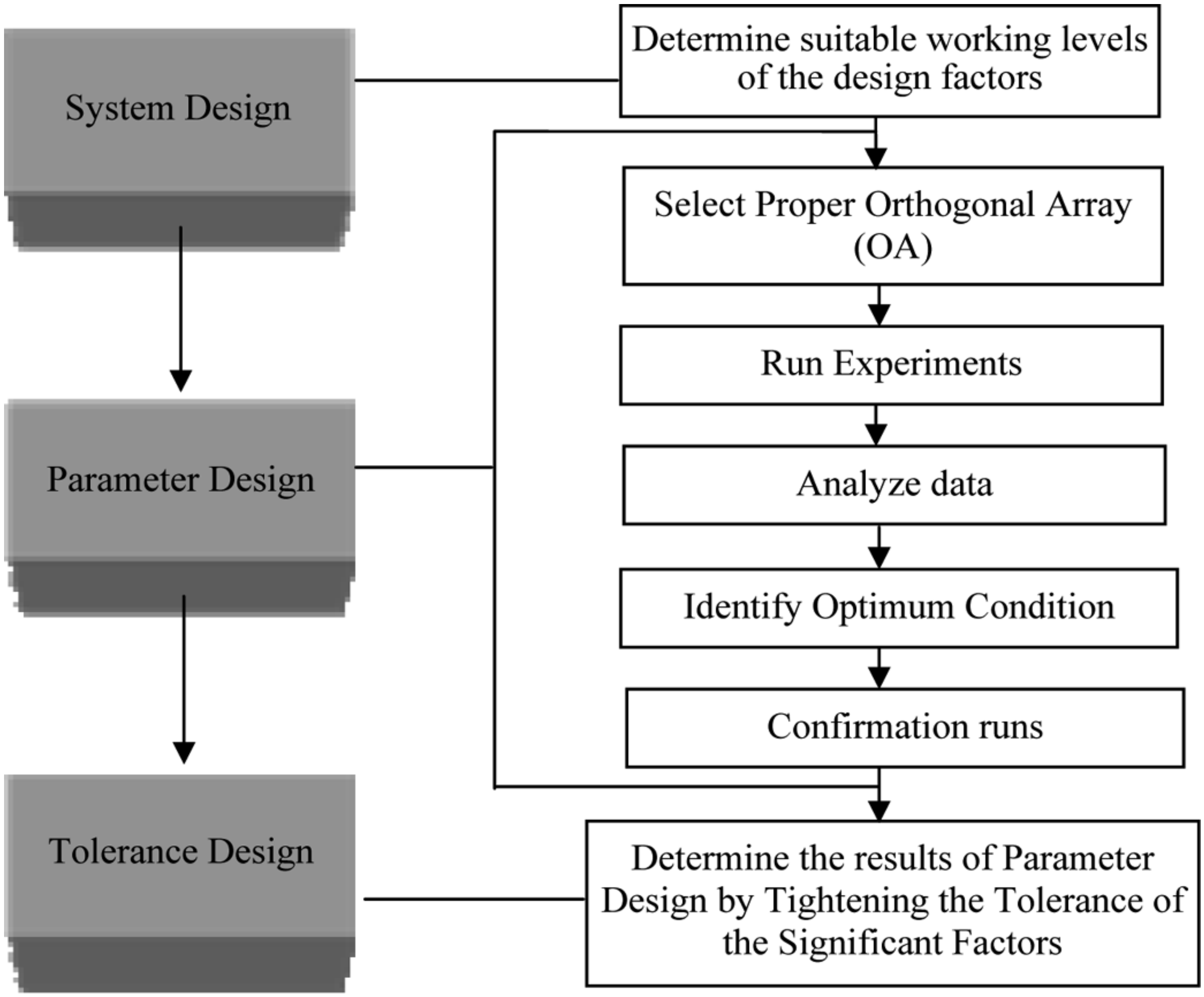


Figure 3.8- Taguchi design procedure [6]

3.9 ANALYSIS OF RESULTS

The parameters that influence the output can be categorized into two classes, namely controllable (or design) factors and uncontrollable (or noise) factors. Controllable factors are those factors whose values can be set and easily adjusted by the designer. Uncontrollable factors are the sources of variation often associated with operational environment. The best settings of control factors as they influence the output parameters are determined through experiments.

Signal-to–noise ratio: signal-to-noise (S/N) ratio used in Taguchi methods as an index of robustness because it measures the quality of energy transformation. The S/N ratio used to measure the quality characteristics and the significant process parameters through (ANOVA). The ratio indicates the degree of predictable performance in the presence of noise factors. These S/N ratios can be used to get closer to a given target value (such as tensile strength or baked tile dimensions), or to reduce variation in the product's quality characteristic. For example, one S/N ratio corresponds to what Taguchi called "nominal is best." Such a ratio selected when a specific target value, such as tensile strength, is the design goal. A high value of S/N ratio implies that the signal is much higher than the random affects of the noise factors or higher the quality (Roy, 1990; Taguchi, 1993; Taguchi et al., 2000). From the analysis point of view, there are three possible categories of the response characteristics explained below.

- Smaller the better
- Larger the better
- Nominal the best

r is the number of tests in a trial (noise of repetitions regardless of noise levels)

$\sum_{i=1}^{r} y^2_i$ Summation of all response values under each trial

MSD = Mean square deviation

Y_j = Observed value of the response characteristic

Y_0 = nominal or target value of the results

1) **Smaller the Better:** The response parameters "smaller the better" which is logarithmic function based on mean square deviation (MSD), given by

$$S/N_{SB=} -10\log (MSD) = -10\log [(1/r \ \sum_i^r y_i{}^2] \quad (3.3)$$

Where MSD_{SB} $[(1/r \sum_{i}^{r} y_i^2]$

2) **Larger the better:** The S/N for higher the better is given by

$S/N_{LB} = -10\log(MSD_{LB})$

Where $MSD_{LB} = \frac{1}{r}\sum_{i=1}^{r} (1/y_i^2)$ (3.4)

3) **Nominal the best:** The S/N for nominal is better is:

$S/N_{NB} = -10\log(MSD_{NB})$

Where $MSD_{NB} = \frac{1}{r}\sum_{i=1}^{r} (y_i - y_0)^2$ (3.5)

Signal to noise ratio for response characteristics

The parameters that influence the output can be categorized in two categories, controllable factors and uncontrollable factors. The control factors that may contribute to reduced variation can be quickly identified by looking at the amount of variation present in response. The uncontrollable factors are the sources of variation often associated with operational environment.

In this experimental work, response characteristics are given in the Table 3.5

Measurement of F-value of Fisher's F ratio

The principle of the *F* test is that the larger the *F* value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. F value is defined as:

$$F = \frac{MS\ for\ the\ term}{MS\ for\ the\ error\ term} \quad (3.6)$$

Depending on F-value, percentage contribution is calculated of each factor.

Table 3.5: Response Characteristics

Response name	Response type	Units
Material Removal Rate (MRR)	Higher the better	mm^3/min
Burr height	Lower the better	mm
Surface Roughness	Lower the better	Microns
Hole roundness	Lower the better	mm

Computation of average performance

Average performance of a factor at certain level is the influence of the factor at this level on the mean response of the experiments. [50]

3.10 ANALYSIS OF VARIANCE

The knowledge of the contribution of individual factors is critically important for the control of the final response. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is a statistically based, objective decision-making tool for detecting any differences in average performance of groups of items tested. It calculates parameters known as sum of squares (*SS*), pure *SS*, degree of freedom (dof), variance, F-ratio and percentage of each factor. Since the procedure of ANOVA is a very complicated and employs a considerable of statistical formula, only a brief description of is given as following.

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data. Let *A* be a factor under investigation

Formula $SS_T = \sum_{i=1}^{n} (Y_i - \bar{T})^2$ (3.6)

Where N = Number of response observations, $\bar{T}$ is the mean of all observations Y_i is the I_{th} response

$$SS_A = \left[\sum_{i=1}^{Ka} (A_i^2/n_{Ai})\right] - \frac{T \times T}{N} \quad (3.7)$$

Where A_i = Average of all observations under A_i level = Ai/n_{Ai}

T = sum of all observations $= \frac{T}{N}$

$\overline{T}$ =Average of all observations

n_{Ai} = Number of observations under A_i level

$$SS_e = \sum_{j=1}^{Ka} \sum_{i=1}^{na} (y_i - \overline{A}_j)^2 \quad (3.8)$$

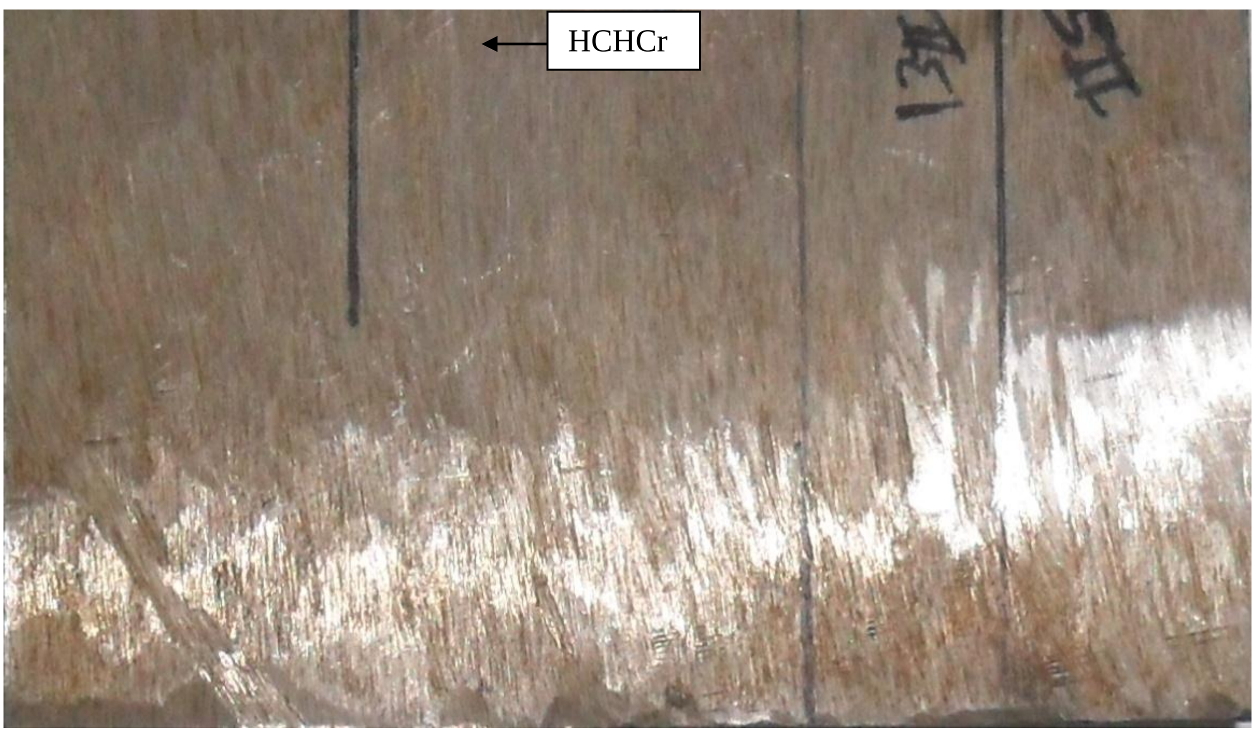
Error Sum of Squares SS_e - Squared deviations of observations from factor (A) average

$$SS_{A\times B} = \sum_{i=1}^{c} \left(\frac{(A\times B)(A\times B)i}{n(A\times B)i}\right) - \frac{T\times T}{N} - SS_A - SS_B \quad (3.9)$$

3.11 TEST RESULTS FOR WORK PIECE & TOOL MATERIAL BEFORE MACHINING

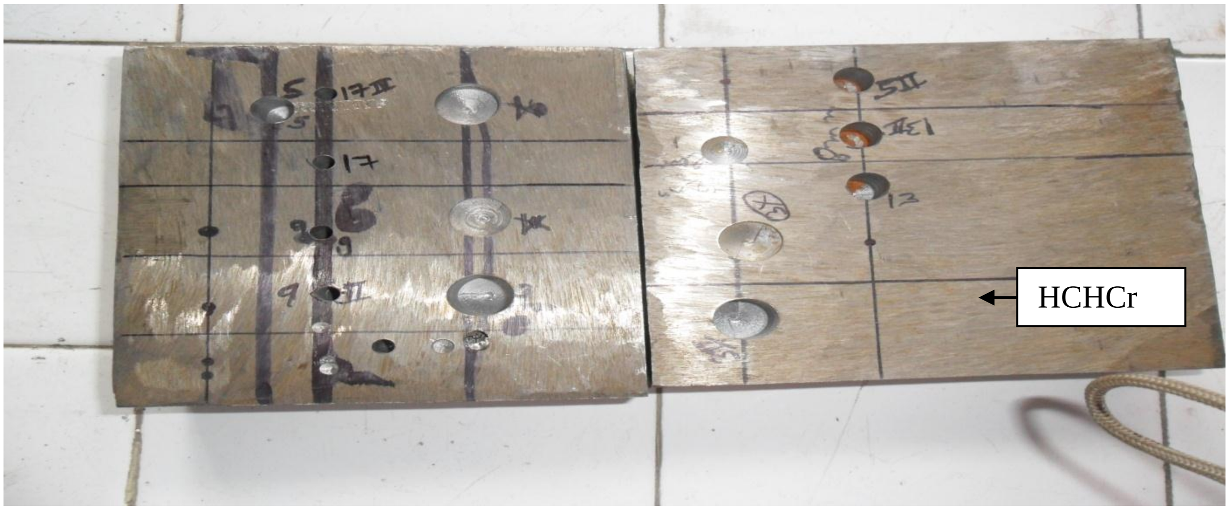
Three work piece materials High-Carbon High-Chromium (HCHCr), Hot Die Steel (H11) and EN 31 die steels and tool materials HSS M2 and HSS M35 drill were tested before start of experimentation the chemical composition of work piece and tool material is shown in tables 3.7 and 3.8. Chemical composition was measured on an Optical Emission Spectrometer DV-6.

(a) H 11

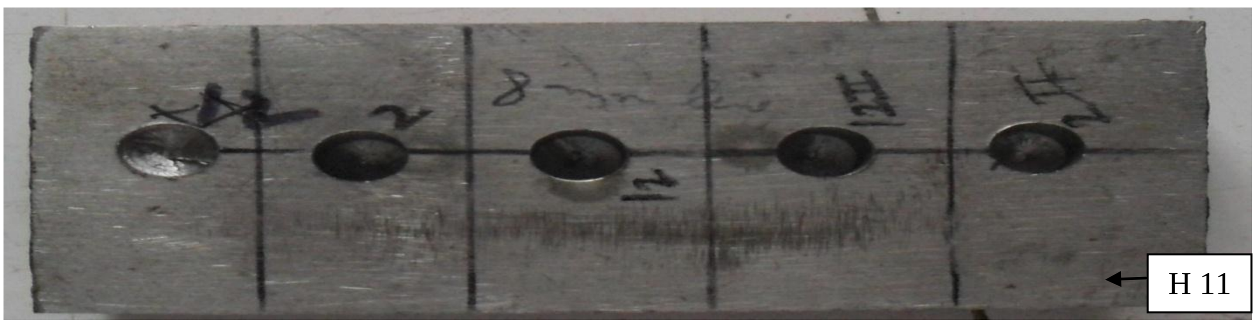


(b) HCHCr

Figure: 3.9 Work piece materials before machining (a) H11 (b) HCHCr



(a) HCHCr



(b) H 11

(c) EN 31

Figure: 3.10 Work piece materials after machining (a) HCHCr (b) H 11 (c)EN 31

The work pieces used before and after machining are shown in the Figure 3.9 and Figure 3.10 respectively. The hardness of work piece material before machining is shown in table 3.6 this hardness is measured on Rockwell hardness testing machine.

Figure 3.11: Spectroscopy machine (Source: Mechanical Engineering Department, TU, Patiala)

Table 3.6: Hardness of work piece materials before machining

Work piece material	EN 31	H 11 (HDS)	HCHCr
HRC	58	51	62

Table 3.7: Chemical composition of work piece materials before machining

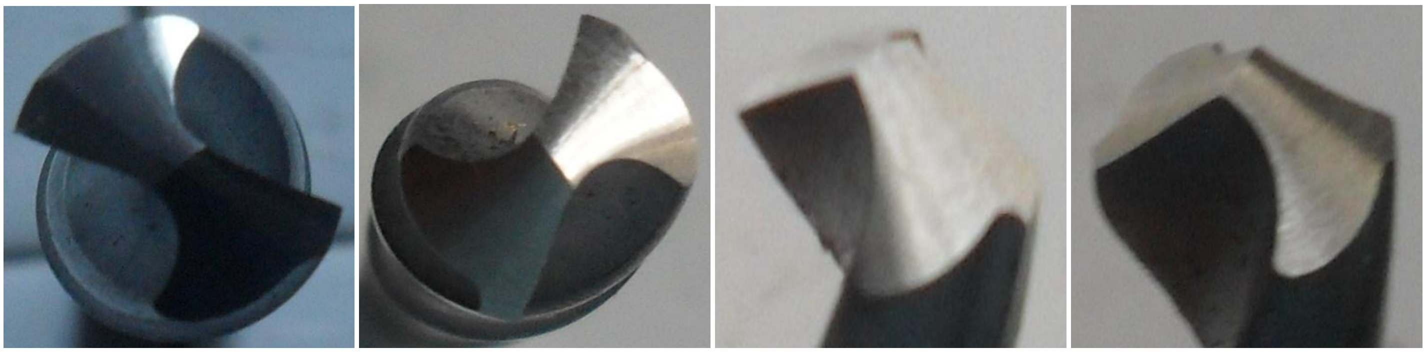
Elements	EN31	H11	HCHCr
Fe%	97.4	90.0	83.1
C%	0.401	0.401	2.11
Si%	0.192	0.713	0.553
Mn%	0.535	0.383	1.02
P%	0.0693	0.0302	0.0251
S%	0.106	0.0337	0.0437
Cr%	1.09	5.56	12.8
Mo%	0.0100	1.24	0.0100
Ni%	0.0909	0.208	0.111
Al%	0.0050	0.0010	0.0197
Co%	0.0100	0.0684	0.0181
Cu%	0.0562	0.101	0.0250
Nb%	0.0050	0.0176	0.0050
Ti%	0.0010	0.0042	0.0197
V%	0.0180	0.708	0.0166
W%	0.0250	0.4233	0.0250
Pb%	0.0500		0.0500

Table 3.8 Chemical composition of tool materials before machining

Elements	M 35	M 2
Fe%	79.1	79.9
C%	0.273	0.851
Si%	0.0200	0.221
Mn%	0.255	0.294
S%	0.0050	0.0201
Cr%	4.00	3.84
Mo%	5.72	5.75
Ni%	0.157	0.198
Al%	0.0050	0.0050
Co%	4.96	0.822
Cu%	0.176	0.110
Nb%	0.0030	0.0030
Ti%	0.0077	0.0107
V%	1.80	1.89
W%	3.44	6.01

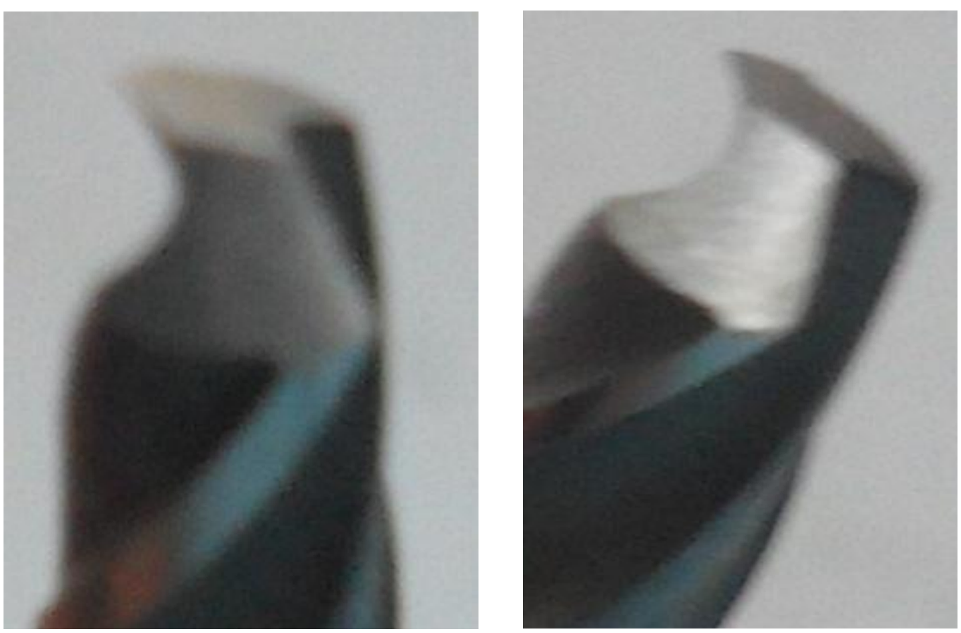
Table 3.9 Geometry of M2 HSS and M35 HSS drills

DRILL TYPE	M2 HSS Drill geometry			M35 HSS Drill geometry		
Tool diameter (mm)	4	8	12	4	8	12
Total length (mm)	75.96	116.15	149.90	75.69	118.09	151.27
Flute length (mm)	47.33	75.63	103.22	46.09	78.93	104.27
Point angle (degree)	118°	118°	118°	118°	118°	118°
Helix angle	32°	32°	32°	32°	32°	32°
Shank type	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical
No of flutes	2	2	2	2	2	2



(a) 12 mm drill

(b) 4 mm M2 drill



(c) 8 mm M2 drill

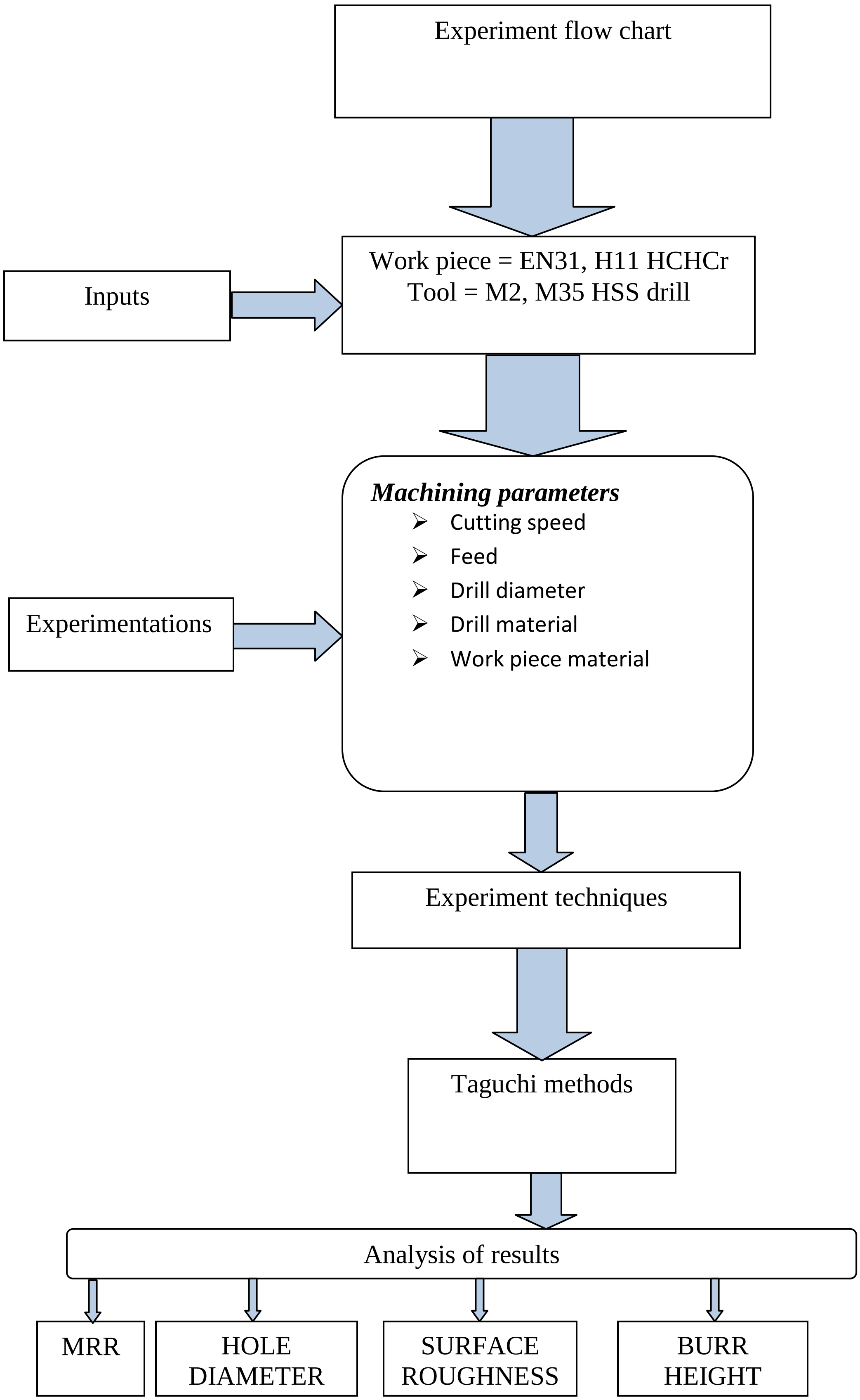
Figure: 3.12 M2 drills before machining

(a) 8 mm drill

(b) 12 mm drill

(c) 4 mm drill

Figure: 3.13 M35 drills before machining


Experiment flow chart
Inputs
Work piece = EN31, H11 HCHCr
Tool = M2, M35 HSS drill
Experimentations
Machining parameters
Cutting speed
Feed
Drill diameter
Drill material
Work piece material
Experiment techniques
Taguchi methods
Analysis of results
MRR
HOLE DIAMETER
SURFACE ROUGHNESS
BURR HEIGHT

CHAPTER 4

EXPERIMENTAL RESULTS AND ANALYSIS OF MRR

4.1 INTRODUCTION

The effect of various parameters such as cutting speed, work piece, feed, drill material, drill diameter and interaction between drill material and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. 18 trials were conducted in the experiment using L18 experimental design. One repetition for each of 18 trials was completed to measure Signal to Noise ratio (S/N ratio).

4.2 RESULTS FOR MRR

The results of MRR for each of the 18 trials with repetition are given in Table 4.1. Weight of work piece before and after each of the trial was calculated to evaluate the MRR of each sample. The MRR is given by

$$MRR = (W_i - W_f)/\rho t \times 1000\ mm^3/\text{min} \qquad (4.1)$$

W_i =Initial weight of work piece material in gram

W_f =Final weight of work piece material in gram

t=Time period of machining in minutes

ρ =Density of work piece in gram/cm^3

Table 4.1: Results for MRR

Trial no	Tool material	Speed (RPM)	Feed (mm/(rev)	Drill diameter (mm)	Work-piece	MRR (mm^3/min)		Mean MRR (mm^3/min)	S/N Ratio
						I	II		
1	M2	80	0.10	4	EN 31	211.69	249.25	230.47	47.25229
2	M2	80	0.125	8	H 11	179.93	155.55	167.74	44.49273
3	M2	80	0.150	12	HCHCr	410.32	462.4	436.36	52.7969
4	M2	160	0.10	4	H 11	247.65	268.47	258.06	48.23441
5	M2	160	0.125	8	HCHCr	657.02	620.9	638.96	56.10947
6	M2	160	0.150	12	EN 31	1079.59	1045.89	1062.74	60.52854
7	M2	244	0.10	8	EN 31	945.63	1000.59	973.11	59.76324
8	M2	244	0.125	12	H 11	1402.59	1461.93	1432.26	63.12044
9	M2	244	0.150	4	HCHCr	379.77	430.77	405.19	52.15317
10	M35	80	0.10	12	HCHCr	515.93	469.89	492.91	53.85535
11	M35	80	0.125	4	EN 31	218.81	231.89	225.35	47.05715
12	M35	80	0.150	8	H 11	355.79	400.33	378.06	51.55121
13	M35	160	0.10	8	HCHCr	578.41	593.01	585.71	55.35365
14	M35	160	0.125	12	EN 31	1269.36	1463.04	1366.2	62.71029
15	M35	160	0.150	4	H 11	279.15	275.69	277.42	48.86276
16	M35	244	0.10	12	H 11	2689.56	2729.8	2709.68	68.65836
17	M35	244	0.125	4	HCHCr	220.98	207.6	214.29	46.62004
18	M35	244	0.150	8	EN 31	1160.96	1143.78	1152.37	61.23184

4.3 ANALYSIS OF VARIANCE – MRR

The results were analysed using ANOVA for identifying the significant factors affecting the performance measures. The (ANOVA) for the mean MRR at 95% confidence interval is given in Table 4.2. The variation data for each factor were F-tested to find significance of each. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that drill diameter with F value of 9.13 and cutting speed with F value of 6.38 are the factors that significantly affect the MRR. All others factors, namely, work piece material, feed, drill material ×cutting speed and drill material were found to be insignificant. Table 4.3 shows the ranks of various factors in the terms of their relative significance. Drill diameter has the highest rank, signifying highest contribution to MRR and drill material has the lowest rank and was observed to be insignificant in affecting MRR. Main effect plot for the mean MRR is shown in the Figure 4.1, which shows the variation of MRR with the input parameters. As it can be seen MRR increases with increase in drill diameter from 4 mm to 12 mm. MRR is decreased with increase in work piece material from EN 31 to HCHCr. Interaction of Drill material ×cutting speed is insignificant for the MRR. The interaction plots for mean MRR shown in the Figure 4.2

Table 4.2: ANOVA for MRR

Sources	SS	V	V	F	p	SS'	%contribution	Status
Work piece (A)	613902	2	306951	1.91	0.228			insignificant
Feed (B)	218214	2	109107	0.68	0.543			insignificant
Dill diameter (C)	2938719	2	1469359	9.13	0.015	2617470.2	36.97	significant
Drill material (D)	179420	1	179420	1.12	0.332			insignificant
Cutting speed(E)	2052205	2	1026102	6.38	0.033	1730956.2	24.45	significant
Drill material ×cutting speed(F)	111143	2	55571	0.35	0.721			insignificant
Residual Error	965438	6	160906					
Total	7079041	17				7079041	100	
E pooled	2088117	13	160624.38			2730614.5	38.58	

Table 4.3: Response table for Means of MRR

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed(E)
1	835	875	268.5	622.8	321.8
2	870.5	674.1	649.3	822.4	698.2
3	462.2	618.7	1250		1147.8
Delta	408.3	256.3	981.6	199.7	826
Rank	3	4	1	5	2

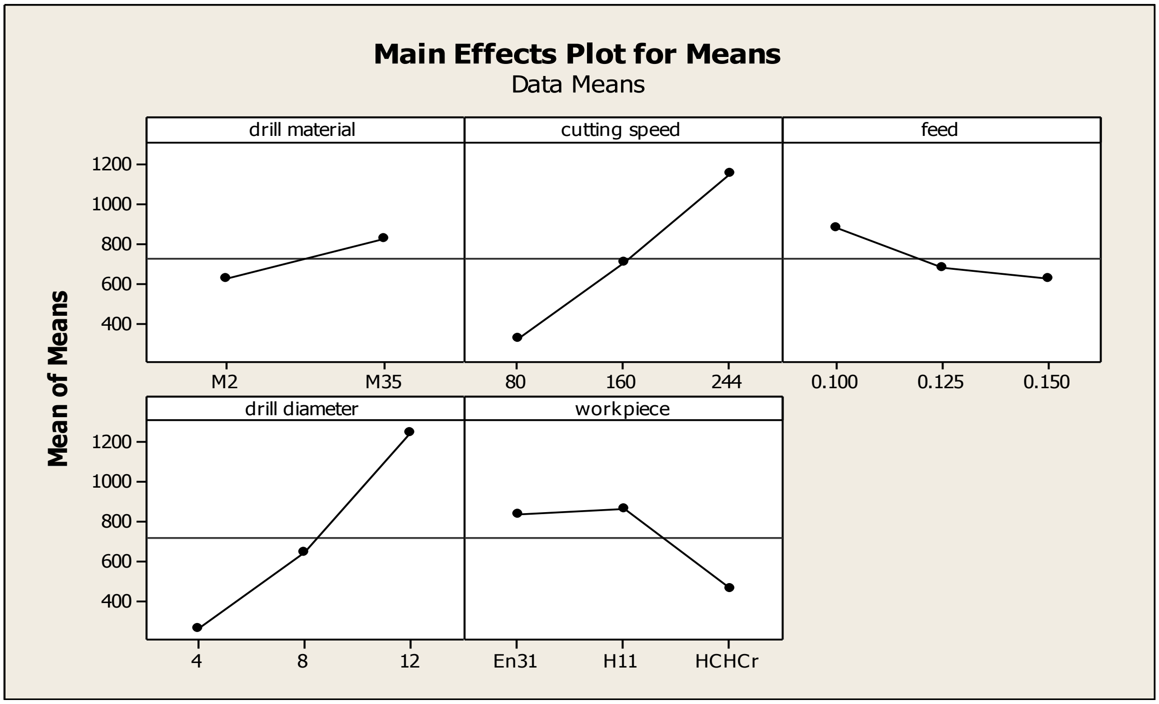


Figure 4.1: Main effect plot for Mean MRR

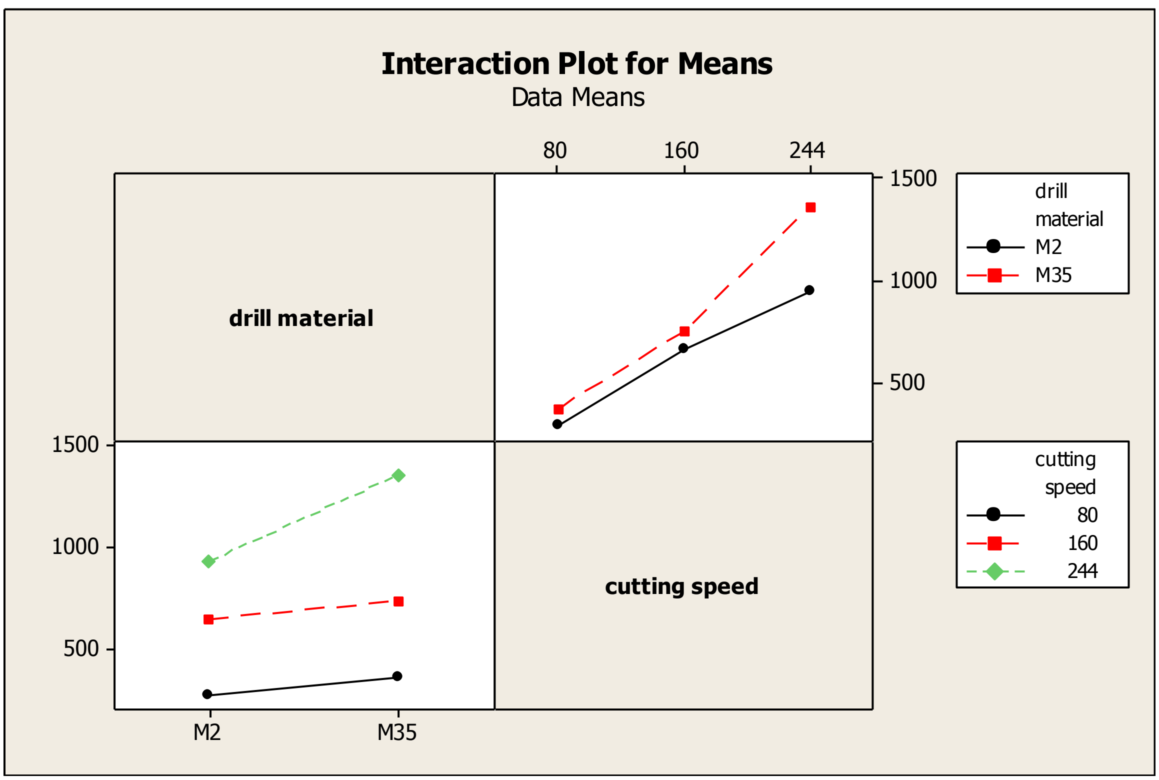


Figure 4.2: Interaction plot for Mean MRR

4.4 RESULTS FOR S/N RATIO – MRR

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in MRR. MRR is a "Higher the better" type response and it is given by a logarithmic function based on the mean square deviation:

$(S/N)_{HB} = -10 \log (MSD_{HB})$ (4.2)

Where $MSD_{HB} = \frac{1}{r}\sum_{i=1}^{r} (1/y_i^2)$ (4.3)

MSD_{HB}= Mean Square Deviation for higher-the-better response.

Table 4.4 shows the ANOVA results for S/N ratio of MRR at 95% confidence interval. Drill diameter and cutting speed are the factors, which are found to be significant for variation. According to F-test drill diameter was found to be the most significant factor affecting the MRR, followed by cutting speed. Main effect plot of S/N ratio for MRR are shown in the Figure 4.3. Table 4.5 shows the ranks of various factors in the terms of their relative significance. Drill diameter has the highest rank, which signifies that it provides highest contribution to MRR and drill material has the lowest rank and was found to be insignificant in affecting MRR. The interaction plots for S/N ratio of MRR shown in the Figure 4.4, which shows interaction of Drill material × cutting speed, is insignificant for the MRR

Table 4.4: ANOVA for S/N ratio of MRR

Sources	SS	v	V	F	p	SS’	%contribution	Status
Work piece (A)	39.946	2	19.973	1.79	0.246			insignificant
Feed (B)	14.128	2	7.064	0.63	0.564			insignificant
Dill diameter(C)	426.640	2	213.320	19.07	0.003	406.22	49.94	significant
Drill material(D)	7.283	1	7.283	0.65	0.451			insignificant
Cutting speed(E)	254.185	2	127.093	11.36	0.009	233.765	28.73	significant
Drill material ×Cutting speed(F)	4.242	2	2.121	0.19	0.832			insignificant
Residual Error	67.134	6	11.189					
Total	813.558	17				813.558	100	
E Pooled	132.732	13	10.21			173.573	21.33	

Table 4.5: Response table for S/N ratio of MRR

Level	Work piece(A)	Feed (B)	Dill diameter(C)	Drill material(D)	Speed(E)
1	56.42	55.52	48.36	53.83	49.50
2	54.15	53.35	54.75	55.10	55.30
3	52.81	54.52	60.28		58.59
Delta	3.61	2.17	11.92	1.27	9.09
Rank	3	4	1	5	2

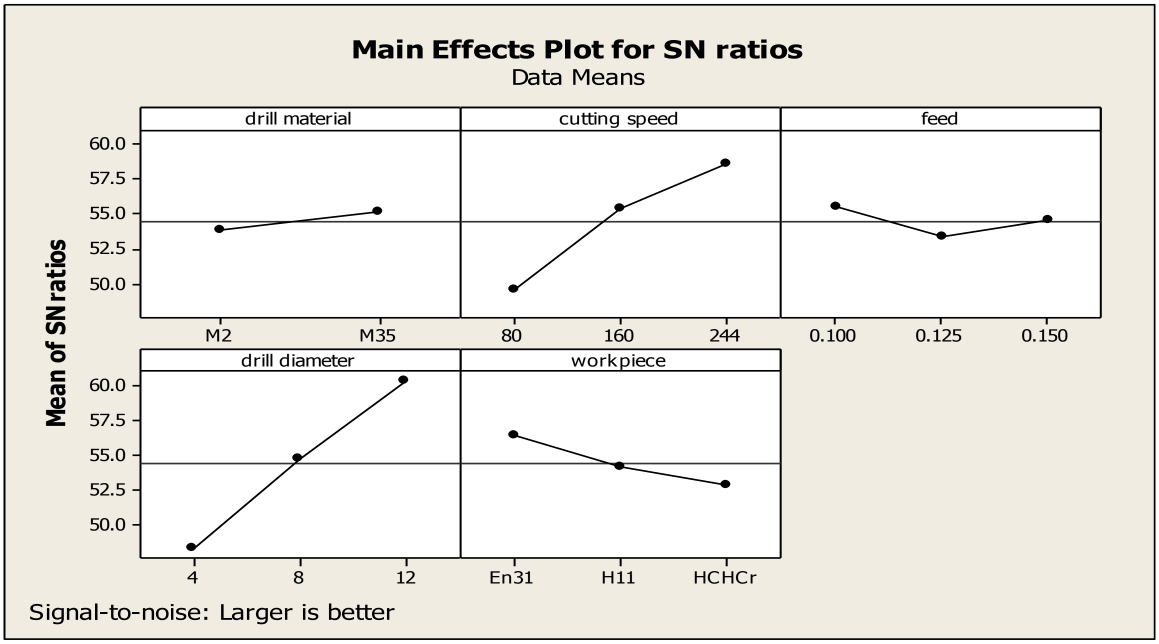


Figure 4.3: Main effects plot for S/N ratio of MRR

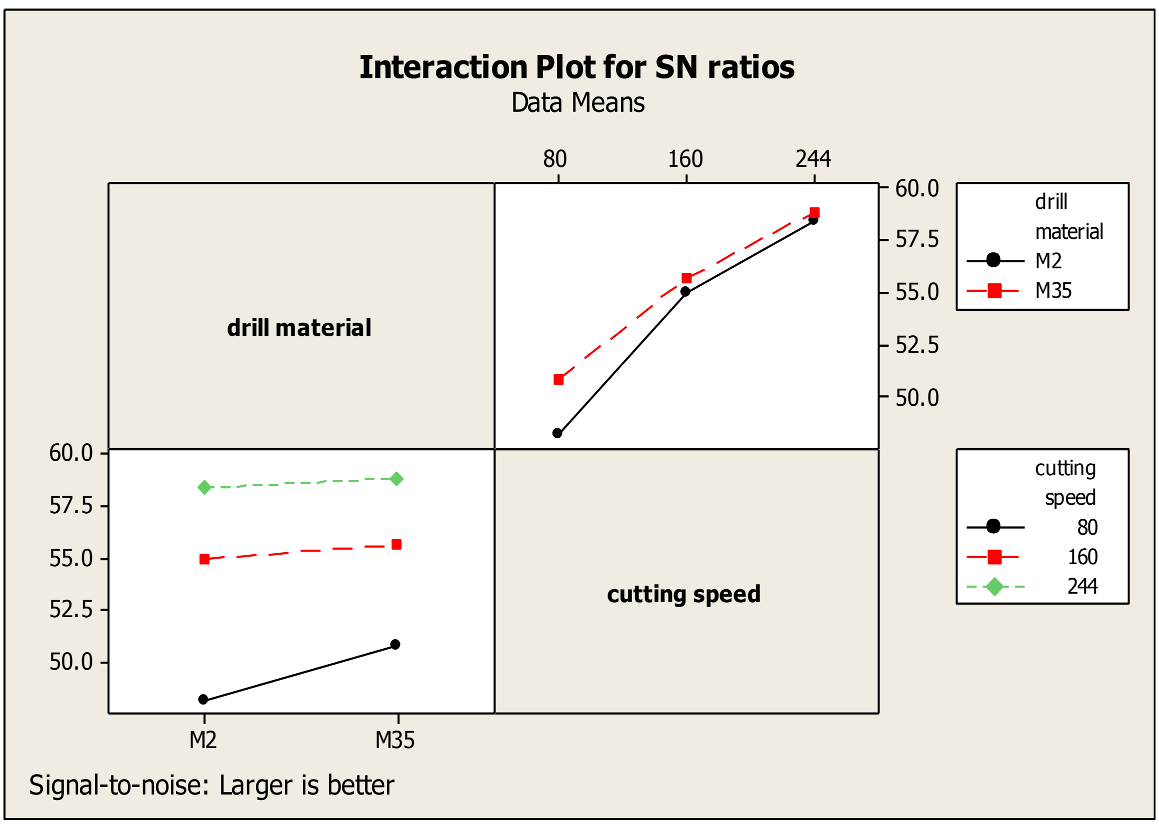


Figure 4.4: Interaction plot for S/N ratio of MRR

4.5 OPTIMAL DESIGN

In this experimental analysis, the main effect plot in Figure 4.1 is used to estimate the mean MRR with optimal design conditions. In Table 4.6 it is concluded that highest MRR was achieve when work piece material machined with 12 mm diameter drill with cutting speed of 244 rpm, In S/N ratio highest MRR was achieve when work piece material machined with 12 mm diameter drill with cutting speed of 244 rpm. In some case, the same levels of the significant factors provide the higher average and reduced variability; hence, nothing has to be compromised. In some case, the levels of factors, which improve the average and improve the uniformity may conflict which means compromise may have to be reached. Moreover, a compromise may have to occur when multiple responses are considered and the same level factor may cause one response to improve and another to reduce.

Estimating the mean

MRR is a "Higher the better" type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of MRR given by:

$$\mu_{C3\ E3} = \bar{C}_3 + E_3 - T = 1250 + 1147.8 - 722.60 = 1675.2 \text{ mm}^3/\text{min} \qquad (4.4)$$

Where T = Total mean value of MRR

Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically it specifies that there is 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

Confidence Interval around the estimated MRR

$$CI = \sqrt{(F_{\alpha}, v_1, v_2\ V_e/\eta_{eff})} \qquad (4.5)$$

Where $F_{\alpha, v1, v2}$ = F Ratio

Table 4.6: Significant factors and interaction for MRR

Factors	Affecting mean		Affecting variation (S/N ratio)	
	Contribution	Best level	Contribution	Best level
Work piece material (A)	insignificant	-	insignificant	-
Feed (B)	insignificant	-	insignificant	-
Dill diameter (C)	significant	Level 3 (12)	significant	Level 3 (12)
Drill material (D)	insignificant	-	insignificant	-
Cutting speed(E)	significant	Level 3 (244)	significant	Level 3 (244)
Drill material ×Cutting speed(F)	insignificant	-	insignificant	-

α = risk (0.05) Confidence = $1-\alpha$

ν_1 = dof for mean which is always =1

ν_2 = dof for error = ν_e

V_e = variance of e pooled

n_{eff} =Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+dof\ C\ E} = \frac{36}{1+2+2} = 7.2$$

Where N = number of trials in the experiment

$$CI = \sqrt{(F_{\alpha}, \nu_1, \nu_2\ V_e/\eta_{eff})} = \sqrt{(4.67 \times 160624.38/7.2)} = 322.77$$

Thus, the confidence interval around the estimated mean of MRR given by 1675.2 ±322.77 mm^3/min

CHAPTER 5

EXPERIMENTAL RESULTS AND ANALYSIS OF SURFACE ROUGHNESS

5.1 INTRODUCTION

The effect of various parameters such as cutting speed, work piece, feed, drill material, drill diameter and interaction between drill material and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. 18 trials were conducted in the experiment using L18 experimental design. One repetition for each of 18 trials was completed to measure Signal to Noise ratio (S/N ratio).

5.2 RESULTS FOR SURFACE ROUGHNESS (R_A)

In this study surface roughness of 18 experimental trials with repetition has measured for each sample. For measuring surface roughness, the sampling length is taken as 3 mm and cut off length is taken as 0.8 mm. The results for surface roughness for each of the 18 experimental trials with repetition are given in Table 5.1.

Table: 5.1 Result for Surface roughness

Trial no	Tool material	Speed (RPM)	Feed (mm/rev)	Drill diameter (mm)	Work-piece	Surface roughness (µm)		Mean Surface roughness (µm)	S/N Ratio
						I	II		
1	M2	80	0.10	4	EN 31	0.65	0.73	0.69	3.223018
2	M2	80	0.125	8	H 11	0.77	0.65	0.71	2.974833
3	M2	80	0.150	12	HCHCr	0.99	1.13	1.06	-0.50612
4	M2	160	0.10	4	H 11	0.98	0.60	0.79	2.047458
5	M2	160	0.125	8	HCHCr	0.89	0.99	0.94	0.537443
6	M2	160	0.150	12	EN 31	1.10	1.06	1.08	-0.66848
7	M2	244	0.10	8	EN 31	0.78	0.70	0.74	2.615366
8	M2	244	0.125	12	H 11	0.88	1.08	0.98	0.175478
9	M2	244	0.150	4	HCHCr	1.15	0.81	0.98	0.175478
10	M35	80	0.10	12	HCHCr	1.02	1.02	1.02	-0.172
11	M35	80	0.125	4	EN 31	0.56	0.82	0.69	3.223018
12	M35	80	0.150	8	H 11	0.79	0.61	0.70	3.098039
13	M35	160	0.10	8	HCHCr	0.89	0.83	0.86	1.310031
14	M35	160	0.125	12	EN 31	0.93	0.75	0.84	1.514414
15	M35	160	0.150	4	H 11	0.75	0.77	0.76	2.383728
16	M35	244	0.10	12	H 11	0.84	0.96	0.90	0.91515
17	M35	244	0.125	4	HCHCr	0.99	1.05	1.02	-0.172
18	M35	244	0.150	8	EN 31	0.86	0.88	0.87	1.209615

Figure 5.1 Profile of surface roughness for experiment no 5, 10 and 16 respectively.

5.3 ANALYSIS OF VARIANCE - SURFACE ROUGHNESS

The results were analysed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean surface roughness at 95% confidence interval is given in Table 5.2. The variation data for each factor were F-tested to find significance of each. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that work piece material with F value of 26.47, drill diameter with F value of 26.61 and cutting speed with F value of 7.74 are the factors that significantly affect the surface roughness. All others factors, namely, feed, drill material ×cutting speed and drill material were found to be insignificant. Table 5.3 shows the ranks of various factors in the terms of their relative significance. Drill diameter has the highest rank, signifying highest contribution to surface roughness and drill material has the lowest rank and observed to be insignificant in affecting surface roughness. Main effect plot for the mean surface roughness is shown in the Figure 5.1, which shows the variation of surface roughness with the input parameters. As it can be, seen surface roughness decrease with increase in drill diameter from 4 mm to 12 mm. Surface roughness increased with increase in feed from 0.1 to 0.15. The interaction plots shown in the Figure 5.2 shows interaction of Drill material ×Cutting speed is insignificant for surface roughness.

Table: 5.2 ANOVA for Surface Roughness

Sources	SS	v	V	F	p	SS’	%contribution	Status
Work piece (A)	0.112633	2	0.056317	26.47	0.001	0.103173	33.19	significant
Feed (B)	0.017100	2	0.008550	4.02	0.078			insignificant
Dill diameter (C)	0.113233	2	0.056617	26.61	0.001	0.103773	33.38	significant
Drill material (D)	0.005339	1	0.005339	2.51	0.164			insignificant
Cutting speed(E)	0.032933	2	0.016467	7.74	0.022	0.023473	7.55	significant
Drill material ×Cutting speed (F)	0.016844	2	0.008422	3.96	0.080			insignificant
Residual Error	0.012767	6	0.002128					
Total	0.310850	17				0.310850	100	
E pooled	0.05205	11	.00473			0.230419	25.88	

Table: 5.3 Response table for Means of Surface roughness

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	0.8183	0.8333	0.8217	0.8856	0.8117
2	0.8067	0.8633	0.8033	0.8511	0.8783
3	0.9800	0.9083	0.9800	0.0344	0.9150
Delta	0.1733	0.0750	0.1767		0.1033
Rank	2	4	1	5	3

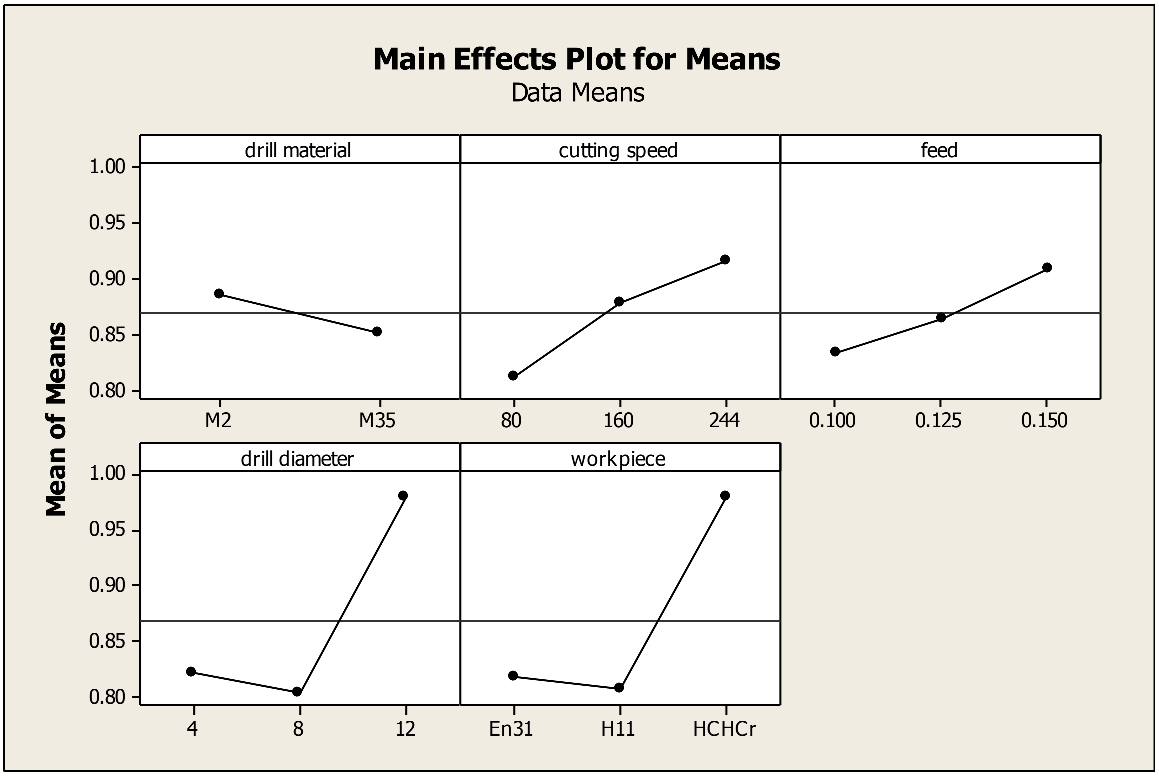


Figure 5.2: Main effect plot for Mean Surface roughness

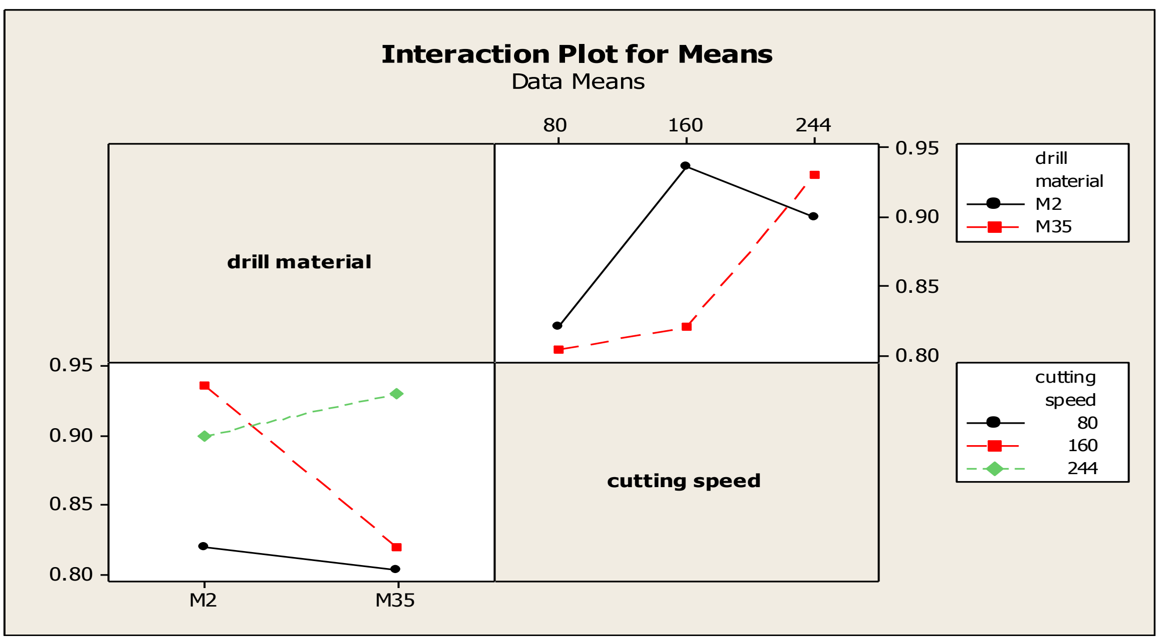


Figure 5.3: Interaction plot for Mean Surface Roughness

5.4 Results for S/N ratio – SURFACE ROUGHNESS

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in surface roughness. Surface roughness is a "lower the better" type response and it is given by a logarithmic function based on the mean square deviation:

$$(S/N)_{LB} = -10 \log (MSD_{LB}) \quad (5.1)$$

Where $MSD_{LB} = \frac{1}{r}\sum_{i=1}^{r} (1/y_i^2)$ (5.2)

MSD_{LB}= Mean Square Deviation for lower -the-better response.

Table 5.4 shows the ANOVA results for S/N ratio of Surface roughness at 95% confidence interval. Drill diameter, work piece and cutting speed are the factors, which are found to be significant. According to F-test drill diameter found to be the most significant factor affecting the Surface roughness, followed by work piece material and cutting speed. Main effect plot for S/N ratio of Surface roughness are shown in the Figure 5.3. Table 5.5 shows the ranks of various factors in the terms of their relative significance. Drill diameter has the highest rank, which signifies that it provides highest contribution to Surface roughness and drill material has the lowest rank and found to be insignificant in affecting Surface roughness. Interaction plot for S/N ratio of Surface roughness are shown in the Figure 5.4, which shows interaction is insignificant for variation.

Table: 5.4 ANOVA for S/N ratio of Surface Roughness

Sources	SS	v	V	F	p	SS’	%contribution	Status
Work piece (A)	11.5405	2	5.7703	30.68	0.001	10.6925	33.76	significant
Feed (B)	1.5242	2	0.7621	4.05	0.077			insignificant
Dill diameter (C)	11.2950	2	5.6475	30.03	0.001	10.447	32.99	significant
Drill material (D)	0.4157	1	0.4157	2.21	0.188			insignificant
Cutting speed (E)	4.1676	2	2.0838	11.08	0.010	3.3196	10.48	significant
Drill material ×Cutting speed (F)	1.5963	2	0.7981	4.24	0.071			insignificant
Residual Error	1.1285	6	0.1881					
Total	31.6678	17				31.6678	100	
E pooled	4.6647	11	0.4240			24.4591	22.77	

Table: 5.5 Response table for Signal to Noise Ratios of Surface roughness

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	1.8528	1.6565	1.8134	1.1749	1.9735
2	1.9324	1.3755	1.9576	1.4789	1.1874
3	0.1955	0.9487	0.2097		0.8198
Delta	1.7370	0.7078	1.7478	0.3039	1.1536
Rank	2	4	1	5	3

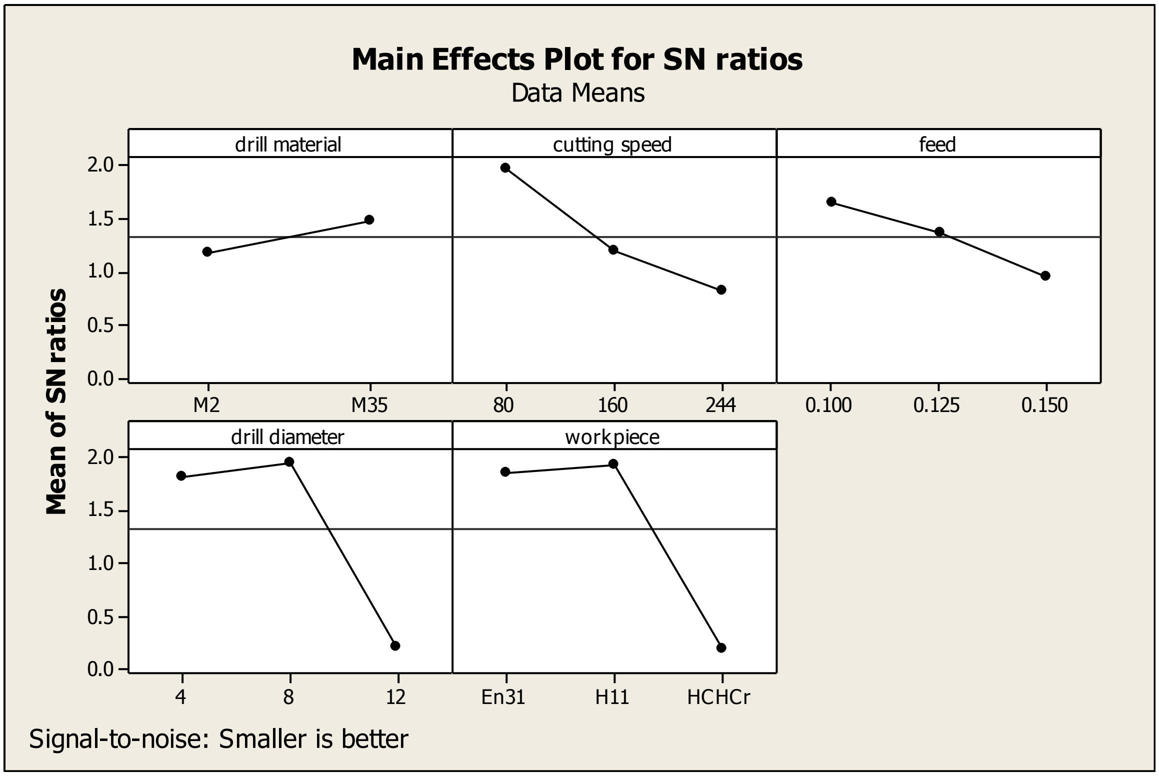


Figure 5.4: Main effect plot for S/N ratio of Surface roughness

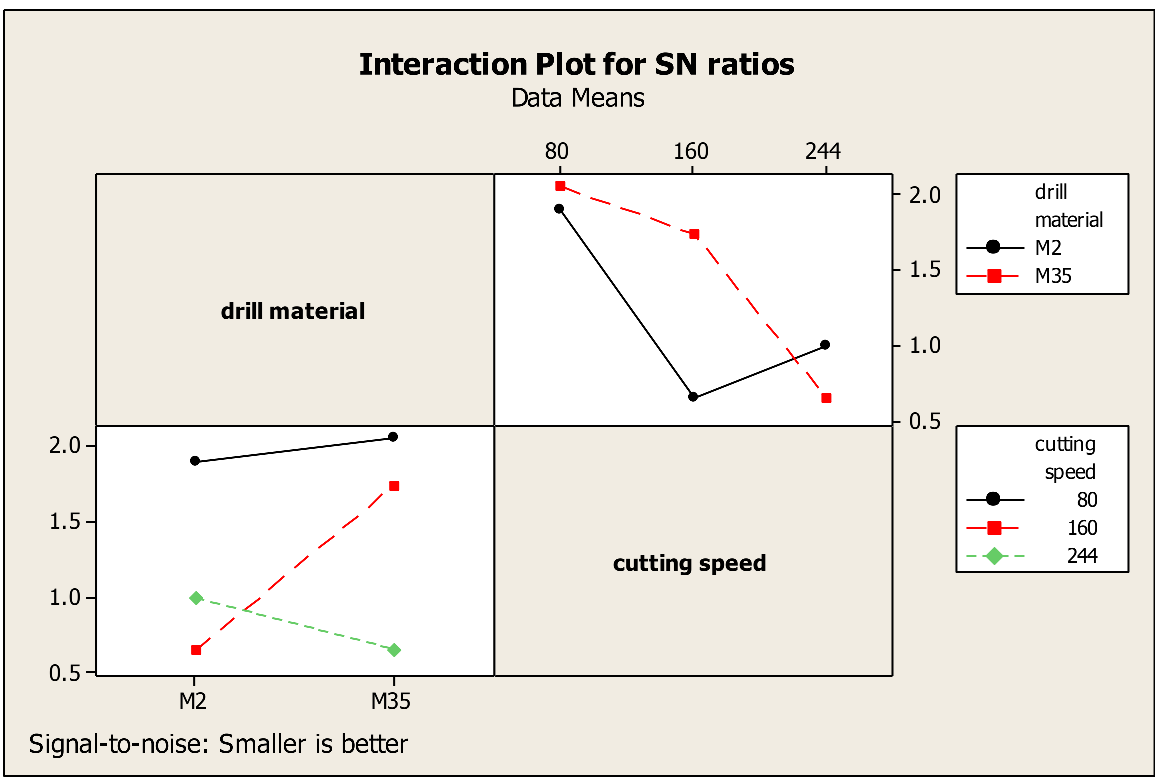


Figure 5.5: Interaction plot for S/N ratio of Surface roughness

5.5 Optimal Design

In this experimental analysis, the main effect plot in Figure 5.1 is used to estimate the mean surface roughness with optimal design conditions. In Table 5.6 it is concluded that minimum surface roughness was achieved when HCHCr work piece, 12 mm drill diameter and cutting speed of 244 rpm was selected in the experiment trial. In S/N ratio minimum surface roughness was achieved when HCHCr work piece, 12 mm drill, diameter and cutting speed of 244 rpm was selected in experiment trial. In this case, the same levels of the significant factors provide the higher average and reduced variability; hence, nothing has to be compromised. In some case, the levels of factors, which improve the average and improve the uniformity may conflict which means compromise may have to be reached. Moreover, a compromise may have to occur when multiple responses are considered and the same level factor may cause one response to improve and another to reduce.

Estimating the mean

Surface roughness is a "lower the better" type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of surface roughness is given by:

$$\mu = A_2 + C_2 + E_1 - 2T = 0.8067+0.8033+0.8117 -2(0.81) = 0.8017 \ \mu m \qquad (5.3)$$

Where T = total mean value of surface roughness

Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically it specifies that there is 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

Confidence Interval around the estimated surface roughness

$$CI=\sqrt{(F_{\alpha}, v_1, v_2\ V_e/\eta_{eff})} \qquad (5.4)$$

Table 5.6: Significant factors and interaction for Surface roughness

Factors	Affecting mean		Affecting variation (S/N ratio)	
	Contribution	Best level	Contribution	Best level
Work piece (A)	significant	Level 2 (HCHCr)	significant	Level 3 (HCHCr)
Feed (B)	insignificant	-	insignificant	-
Dill diameter (C)	significant	Level 2 (12mm)	significant	Level 3 (12 mm)
Drill material (D)	insignificant	-	insignificant	-
Cutting speed (E)	significant	Level 1 (244)	significant	Level 3 (244)
Drill material ×Cutting speed (F)	insignificant		insignificant	

α = risk (0.05) Confidence = $1-\alpha$

ν_1 = dof for mean which is always =1

ν_2 = dof for error = ν_e

V_e = variance of e pooled

n_{eff} =Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+dof A\ C\ E} = \frac{36}{1+2+2+2} = 5.14$$

Where N = number of trials in the experiment

$$CI = \sqrt{(F_{\alpha}, \nu_1, \nu_2\ V_e/\eta_{eff})} = \sqrt{(4.84 \times 0.00473)/5.14} = 0.0667$$

Thus, the confidence interval around the estimated mean of surface roughness given by 0.8017 ± 0.0667 µm

CHAPTER 6

EXPERIMENTAL RESULTS AND ANALYSIS OF HOLE DIAMETER ERROR

6.1 INTRODUCTION

The effect of various parameters such as cutting speed, work piece, feed, drill material, drill diameter and interaction between drill material and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. 18 trials were conducted in the experiment using L18 experimental design. One repetition for each of 18 trials was completed to measure Signal to Noise ratio (S/N ratio).

6.2 RESULT FOR HOLE DIAMETER ERROR

The results of hole diameter error for each of the 18 trials with repetition are measured on each sample given in Table 6.1. hole diameter error were measured from profile projector on all the samples.

Table: 6.1 Result for Hole diameter error

Trial no	Tool material	Cutting speed (RPM)	Feed (mm/rev)	Drill diameter (mm)	Work-piece	Hole diameter error (mm)		Mean Hole diameter error (mm)	S/N Ratio
						I	II		
1	M2	80	0.10	4	EN 31	0.069	0.075	0.072	22.85335
2	M2	80	0.125	8	H 11	0.064	0.068	0.066	23.60912
3	M2	80	0.150	12	HCHCr	0.085	0.099	0.092	20.72424
4	M2	160	0.10	4	H 11	0.078	0.072	0.075	22.49877
5	M2	160	0.125	8	HCHCr	0.075	0.111	0.093	20.63034
6	M2	160	0.150	12	EN 31	0.115	0.095	0.105	19.57621
7	M2	244	0.10	8	EN 31	0.101	0.123	0.112	19.01564
8	M2	244	0.125	12	H 11	0.094	0.108	0.101	19.91357
9	M2	244	0.150	4	HCHCr	0.130	0.11	0.12	18.41638
10	M35	80	0.10	12	HCHCr	0.058	0.040	0.049	26.19608
11	M35	80	0.125	4	EN 31	0.045	0.055	0.05	26.0206
12	M35	80	0.150	8	H 11	0.060	0.048	0.054	25.35212
13	M35	160	0.10	8	HCHCr	0.102	0.108	0.105	19.57621
14	M35	160	0.125	12	En 31	0.084	0.060	0.072	22.85335
15	M35	160	0.150	4	H 11	0.098	0.060	0.079	22.04746
16	M35	244	0.10	12	H 11	0.090	0.104	0.097	20.26457
17	M35	244	0.125	4	HCHCr	0.112	0.088	0.10	20
18	M35	244	0.150	8	EN 31	0.120	0.126	0.123	18.2019

6.3 ANALYSIS OF VARIANCE – HOLE DIAMETER ERROR

The results were analysed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean hole diameter error at 95% confidence interval is given in Table 6.2. The variation data for each factor were F-tested to find significance of each. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that Work piece with F value of 5.57, Feed with F value of 6.03, Drill material with F value of 10.57, Cutting speed with F value of 50.69 are the factors that significantly affect the hole diameter error. All others factors, namely, drill diameter and Drill material ×cutting speed were found to be insignificant. Table 6.3 shows the ranks of various factors in the terms of their relative significance. Cutting speed has the highest rank, signifying highest contribution to hole diameter error and drill diameter has the lowest rank and was observed to be insignificant in affecting hole diameter error. Main effect plot for the mean hole diameter error is shown in the Figure 6.1 which shows the variation of hole diameter error with the input parameters. As it can be seen hole diameter error decrease with increase in cutting speed from 80 to 244. hole diameter error increases with increase in drill diameter from 4 mm to 12 mm. Interaction plot is shown in figure 6.2 which is insignificant for hole diameter error.

Table 6.2: ANOVA for Hole diameter error

Sources	SS	v	V	F	p	SS’	%	Status

							contribution	
Work piece (A)	0.000669	2	0.000334	5.57	0.043	0.0004556	4.96	significant
Feed (B)	0.000724	2	0.000362	6.03	0.037	0.0005106	5.56	significant
Dill diameter (C)	0.000279	2	0.000139	2.32	0.179			insignificant
Drill material (D)	0.000636	1	0.000636	10.59	0.017	0.0004226	4.60	significant
Cutting speed (E)	0.006088	2	0.003044	50.69	0.000	0.0058746	63.96	significant
Drill material ×Cutting speed (F)	0.000428	2	0.000214	3.57	0.095			insignificant
Residual Error	0.000360	6	0.000060					
total	0.009185	17				0.009185	100	
E pooled	0.001067	10	0.0001067			0.0019216	20.92	

Table 6.3: Response table for means of Hole diameter error

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	0.08900	0.08500	0.08267	0.09289	0.06383
2	0.07867	0.08033	0.09217	0.08100	0.08817
3	0.09317	0.09550	0.08600		0.10883
Delta	0.01450	0.01517	0.00950	0.01189	0.04500
Rank	3	2	5	4	1

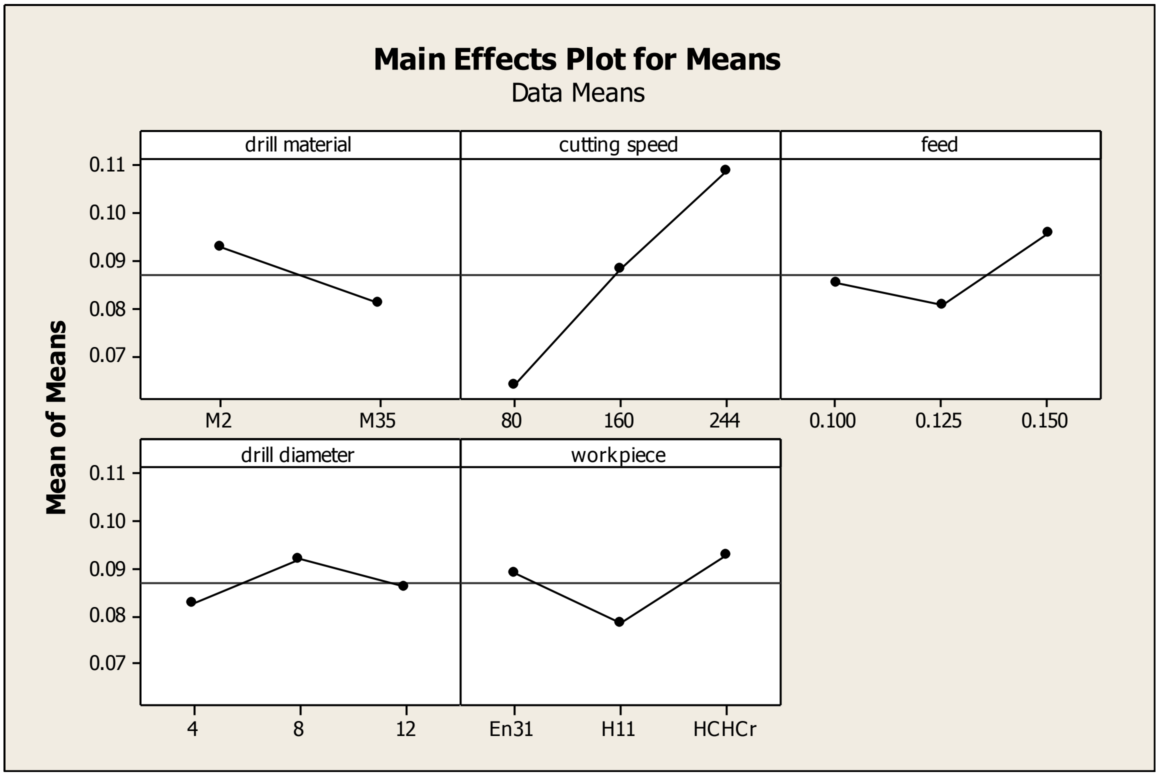


Figure 6.1: Main effect plot for Mean Hole diameter error

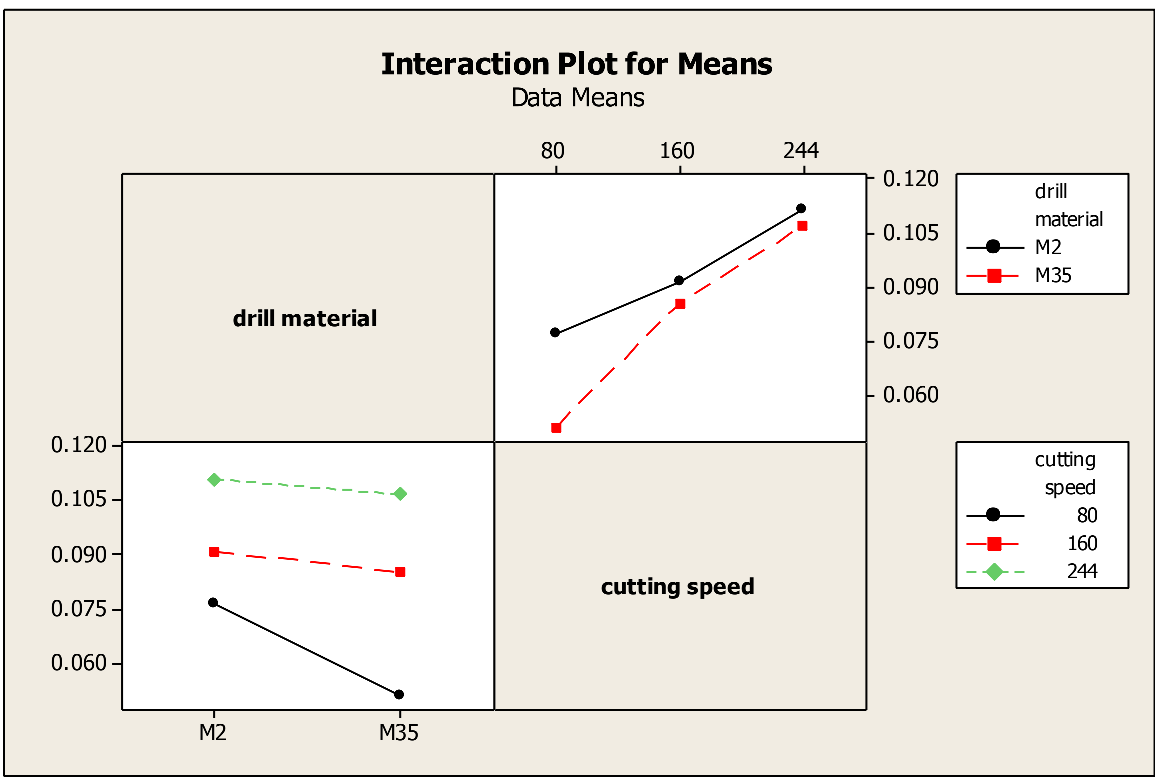


Figure 6.2: Interaction plot for Mean Hole diameter error

6.4 RESULTS FOR S/N RATIO – HOLE DIAMETER ERROR

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in hole diameter error. Hole diameter error is a "lower the better" type response and it is given by a logarithmic function based on the mean square deviation:

$(S/N)_{LB} = -10 \log (MSD_{LB})$ (6.1)

Where MSD_{LB} $[(1/r \sum_i^r y_i^2]$ (6.2)

MSD_{LB}= Mean Square Deviation for lower-the-better response.

Table 6.4 shows the ANOVA results for S/N ratio of hole diameter error at 95% confidence interval. Feed, drill material, cutting speed and Drill material ×cutting speed are the factors, which are found to be significant. According to F-test cutting speed was found to be the most significant factor affecting the hole diameter error, followed by drill material, Drill material ×cutting speed and feed. Main effect plot of S/N ratio for hole diameter error are shown in the Figure 6.3. Table 6.5 shows the ranks of various factors in the terms of their relative significance. Cutting speed has the highest rank, which signifies, that it provides highest contribution to hole diameter error and drill diameter has the lowest rank and was found to be insignificant in affecting hole diameter error. Interaction between Drill material ×cutting speed is insignificant for burr height, shown in figure 6.4

Table 6.4: ANOVA for S/N ratio of Hole diameter error

Sources	SS	v	V	F	p	SS’	% contribution	Status
Work piece (A)	5.658	2	2.8288	4.31	0.069			significant
Feed (B)	6.653	2	3.3267	5.07	0.008	4.2354	3.91	significant
Dill diameter (C)	2.496	2	1.2478	1.90	0.229			insignificant
Drill material (D)	9.790	1	9.790	14.93	0.008	7.3724	6.81	significant
Cutting speed (E)	70.879	2	35.4396	54.06	0.000	68.4614	63.20	significant
Drill material ×Cutting speed (F)	8.907	2	4.4537	6.79	0.029	6.4894	6.00	insignificant
Residual Error	3.934	6	0.6556					
Total	108.317	17				108.317	100	
E pooled	12.088	10	1.2088			21.7584	20.08	

Table 6.5: Response table for S/N ratio of Hole diameter error

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	21.42	21.73	21.97	20.80	24.13
2	22.28	22.17	21.06	22.28	21.20
3	20.92	20.72	21.59		19.30
Delta	1.36	1.45	0.91	1.47	1.45
Rank	4	3	5	2	1

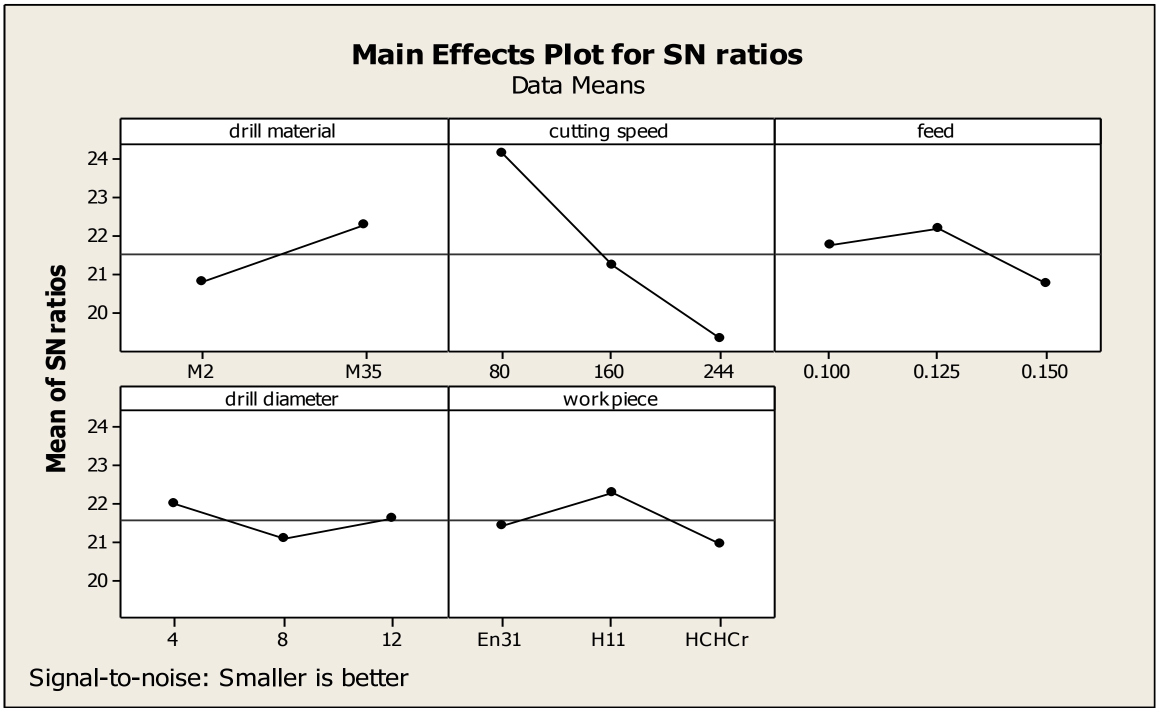


Figure 6.3: Main effects plot for S/N ratio of Hole diameter error

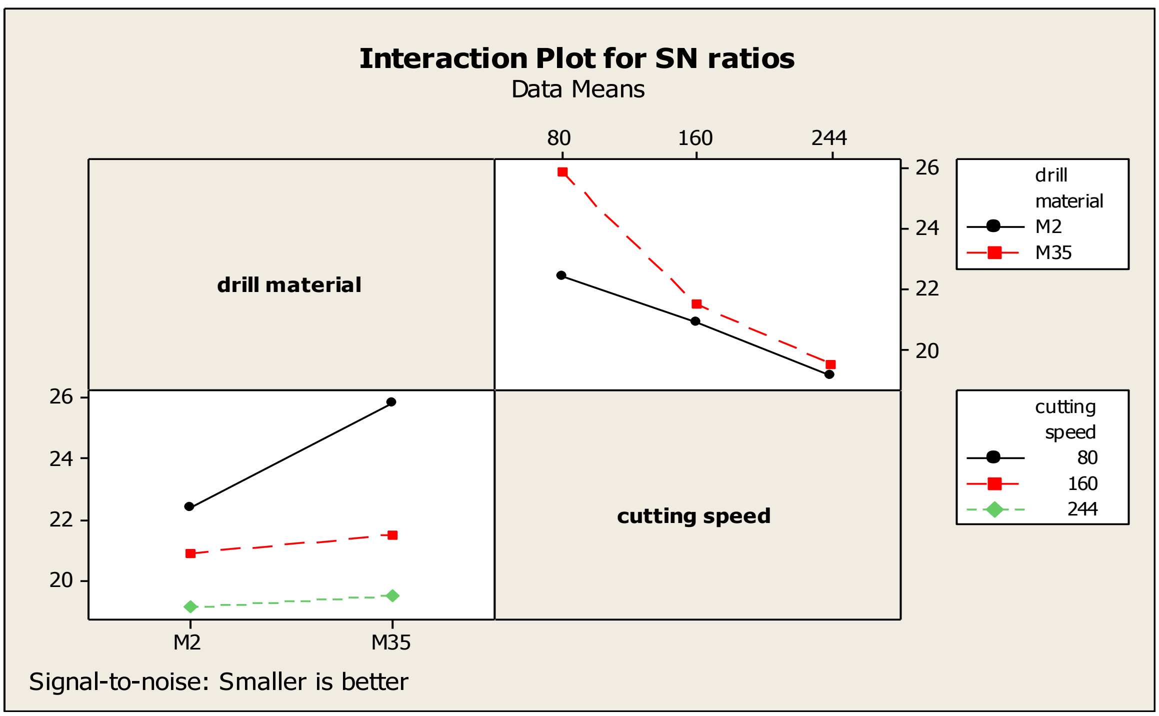


Figure 6.4: Interaction plot for S/N ratio of Hole diameter error

6.5 OPTIMAL DESIGN

In this experimental analysis, the main effect plot in Figure 6.1 is used to estimate the mean hole diameter error with optimal design conditions. From Table 6.6 it is concluded that minimum hole diameter error was achieve when H11 Work piece, feed of 0.125 mm, M35 drill material and cutting speed of 80 rpm was selected in the experiment trial. In S/N ratio minimum hole diameter error was achieve when feed of 0.125 mm, M 35 drill material and cutting speed of 80 rpm was selected in experiment trial. In addition, the interaction between drill material and cutting speed will affect the variation that should be considered. The results were conflicting according to their relative significance Moreover, a compromise may have to occur when multiple responses are considered and the same level factor may cause one response to improve and another to reduce.

Estimating the mean

Hole diameter error is a "lower the better" type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of hole diameter error is given by:

$$\mu = A_2 + B_2 + D_2 + E_1 - 3T = 0.07867+0.08033+0.08100+0.06383-3(0.087) = 0.21683 \text{ mm} \quad (6.3)$$

Where T = total mean value of hole diameter error

Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically it specifies that there is 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

Confidence Interval around the estimated hole diameter error

$$CI=\sqrt{(F_{\alpha}, v_1, v_2\ V_e/\eta_{eff})} \quad (6.4)$$

Table 6.6: Significant factors and interaction for Hole diameter error

Factors	Affecting mean		Affecting variation (S/N ratio)	
	Contribution	Best level	Contribution	Best level
Work piece material (A)	significant	Level 2 (H 11)	insignificant	
Feed (B)	significant	Level 2 (0.125)	significant	Level 2 (0.125)
Dill diameter (C)	insignificant		insignificant	
Drill material (D)	significant	Level 2 (M35)	significant	Level 2 (M35)
Cutting speed (E)	significant	Level 1 (80)	significant	Level 1 (80)
Drill material ×Cutting speed (F)	insignificant		significant	

α = risk (0.05)   Confidence = $1-\alpha$

ν_1 = dof for mean which is always =1

ν_2 = dof for error = ν_e

V_{e} = variance of e pooled

n_{eff} =Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+dof A\ B\ D\ E} = \frac{36}{1+2+2+1+2} = 4.5$$

Where N = number of trials in the experiment

$$CI = \sqrt{(F_{\alpha}, v_1, v_2\ V_e/\eta_{eff})} = \sqrt{4.96 \times 0.0001067)/4.5} = 0.0108$$

Thus the confidence interval around the estimated mean of hole diameter error is given by 0.21683±0.0108 mm

CHAPTER 7

EXPERIMENTAL RESULTS AND ANALYSIS OF BURR HEIGHT

7.1 INTRODUCTION

The effect of various parameters such as cutting speed, work piece, feed, drill material, drill diameter and interaction between drill material and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. 18 trials were conducted in the experiment using L18 experimental design. One repetition for each of 18 trials was completed to measure Signal to Noise ratio (S/N ratio).

7.2 RESULTS FOR BURR HEIGHT

The results for burr height for each of the 18 trials with repetition are given in Table 7.1 the burr height was measured from digital calliper at three different positions. The drilling process produces burrs on both the entrance and the exit surface of a work piece. An entrance burr forms where the drill undergoes plastic flow. The exit burr is the extension of the material off the exit surface of the work piece. Since the exit burr is much larger than the entrance burr. [34]

Table: 7.1 Result for Burr height

Trial no	Tool material	Cutting speed (RPM)	Feed (mm/rev)	Drill diameter (mm)	Work-piece material	Burr height (mm)		Mean Burr height (mm)	S/N Ratio
						I	II		
1	M2	80	0.10	4	EN 31	0.030	0.050	0.04	27.9588
2	M2	80	0.125	8	H 11	0.040	0.020	0.03	30.45757
3	M2	80	0.150	12	HCHCr	0.055	0.045	0.05	26.0206
4	M2	160	0.10	4	H 11	0.049	0.051	0.05	26.0206
5	M2	160	0.125	8	HCHCr	0.048	0.056	0.052	25.67993
6	M2	160	0.150	12	EN 31	0.076	0.084	0.08	21.9382
7	M2	244	0.10	8	EN 31	0.110	0.130	0.12	18.41638
8	M2	244	0.125	12	H 11	0.115	0.105	0.11	19.17215
9	M2	244	0.150	4	HCHCr	0.135	0.125	0.13	17.72113
10	M35	80	0.10	12	HCHCr	0.092	0.038	0.04	27.9588
11	M35	80	0.125	4	EN 31	0.032	0.028	0.03	30.45757
12	M35	80	0.150	8	H 11	0.049	0.036	0.04	27.9588
13	M35	160	0.10	8	HCHCr	0.048	0.042	0.045	26.93575
14	M35	160	0.125	12	En 31	0.052	0.068	0.06	24.43697
15	M35	160	0.150	4	H 11	0.068	0.720	0.07	23.09804
16	M35	244	0.10	12	H 11	0.087	0.093	0.09	20.91515
17	M35	244	0.125	4	HCHCr	0.095	0.750	0.1	20
18	M35	244	0.150	8	EN 31	0.120	0.100	0.11	19.17215

7.3 ANALYSIS OF VARIANCE – BURR HEIGHT

The results were analysed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean burr height at 95% confidence interval is given in Table 7.2. The variation data for each factor were F-tested to find significance of each. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that feed with F value of 15.05 drill material with F value 9.58 of and cutting speed with F value of 236.54 are the factors that significantly affect the burr height. All others factors, namely, drill diameter, work piece and Drill material ×cutting speed were found to be insignificant. Table 7.3 shows the ranks of various factors in the terms of their relative significance. Cutting speed has the highest rank, signifying highest contribution to burr height and drill material has the lowest rank and was observed to be insignificant in affecting burr height. Main effect plot for the mean burr height is shown in the Figure 7.2, which shows the variation of burr height with the input parameters. As it can be seen burr height decrease with increase in cutting speed from 80 to 244 rpm. Burr height increases with change in drill material from M2 to M35 and interaction plot is shown in Figure 7.2, which is insignificant for burr height.

Table 7.2: ANOVA for Burr height

Sources	SS	v	V	F	p	SS’	% contribution	Status
Work piece (A)	0.000209	2	0.000104	3.04	0.123			insignificant
Feed (B)	0.001035	2	0.000518	15.05	0.005	0.0009008	4.88	significant
Dill diameter (C)	0.000095	2	0.000048	1.39	0.320			insignificant
Drill material (D)	0.000329	1	0.000329	9.58	0.021	0.0001948	1.06	significant
Cutting speed (E)	0.016269	2	0.008134	236.54	0.000	0.01613	87.49	significant
Drill material ×Cutting speed (F)	0.000295	2	0.000148	4.30	0.070			insignificant
Residual Error	0.000206	6	0.000034					
Total	0.018440	17				0.018440	100	
E pooled	0.000805	12	0.0000671			0.00121	6.57	

Table 7.5: Response table for Mean ratio of Burr height

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	0.07333	0.06417	0.07000	0.07356	0.03833
2	0.06500	0.06367	0.06617	0.06500	0.05950
3	0.06950	0.08000	0.07167		0.11000
Delta	0.00833	0.01633	0.00550	0.00856	0.07167
Rank	4	2	5	3	1

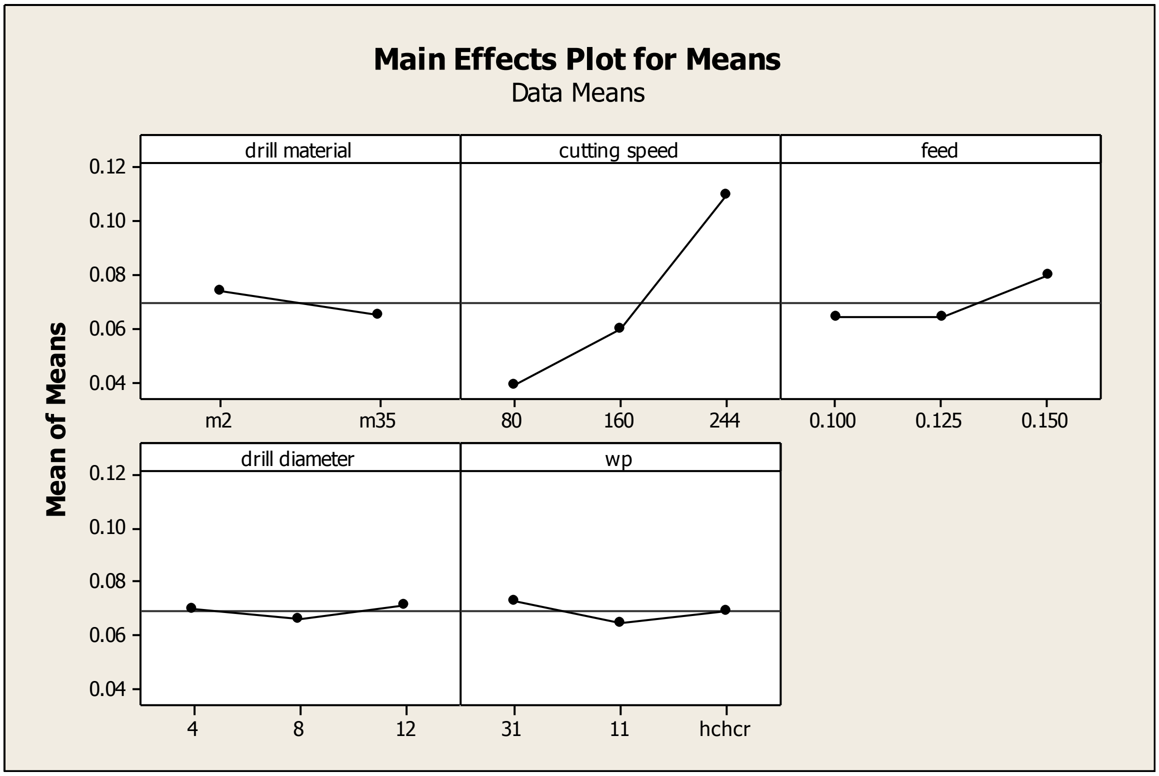


Figure 7.1: Main effect plot for Mean Burr height

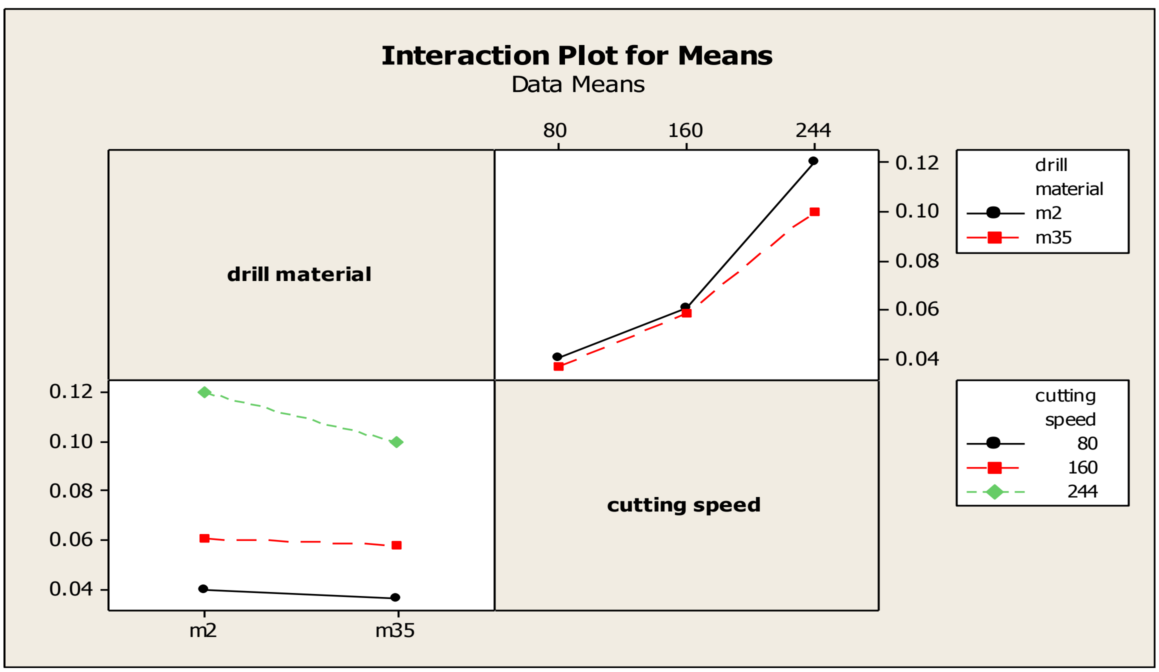


Figure 7.2: Interaction plot for Mean Burr height

7.4 RESULTS FOR S/N RATIO – BURR HEIGHT

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in burr height. Burr height is a "lower the better" type response and it is given by a logarithmic function based on the mean square deviation:

$$(S/N)_{LB} = -10 \log (MSD_{LB}) \qquad (7.1)$$

$$\text{Where } MSD_{LB} \left[(1/r \ \ \sum_{i}^{r} y_i^{2}\right] \qquad (7.2)$$

MSD_{LB}= Mean Square Deviation for Lower-the-better response.

Table 7.4 shows the ANOVA results for S/N ratio of burr height at 95% confidence interval. Feed and cutting speed are the factors which are found to be significant. According to F-test cutting speed was found to be the most significant factor affecting the burr height, are followed by feed. Main effect plot of S/N ratio for burr height are shown in the Figure 7.3. Table 7.5 shows the ranks of various factors in the terms of their relative significance. Cutting speed has the highest rank, which signifies that it provides highest contribution to burr height and drill diameter has the lowest rank and was found to be insignificant in affecting burr height. Interaction plot is shown in Figure 7.4, which is insignificant for burr height.

Table 7.4: ANOVA for S/N ratio of Burr height

Sources	SS	v	V	F	p	SS'	% contribution	Status
Work piece material (A)	2.342	2	1.171	1.08	0.399			insignificant
Feed (B)	19.975	2	9.988	9.18	0.015	17.045	5.72	significant
Dill diameter (C)	5.633	2	2.816	2.59	0.155			insignificant
Drill material (D)	3.165	1	3.165	2.91	0.139			insignificant
Cutting speed (E)	258.687	2	129.343	118.83	0.000	255.757	85.91	significant
Drill material ×Cutting speed (F)	1.381	2	0.690	0.63	0.562			insignificant
Residual Error	6.531	6	1.088					
Total	297.714	17				297.714	100	
E pooled	19.052	13	1.465			24.912	8.37	

Table 7.3: Response table for S/N ratio of Burr height

Level	Work piece material (A)	Feed (B)	Dill diameter (C)	Drill material (D)	Cutting speed (E)
1	23.73	24.70	24.21	23.71	28.47
2	24.60	25.03	24.77	24.55	24.68
3	24.05	22.65	23.41		19.23
Delta	0.87	2.38	1.36	.84	9.24
Rank	4	2	3	5	1

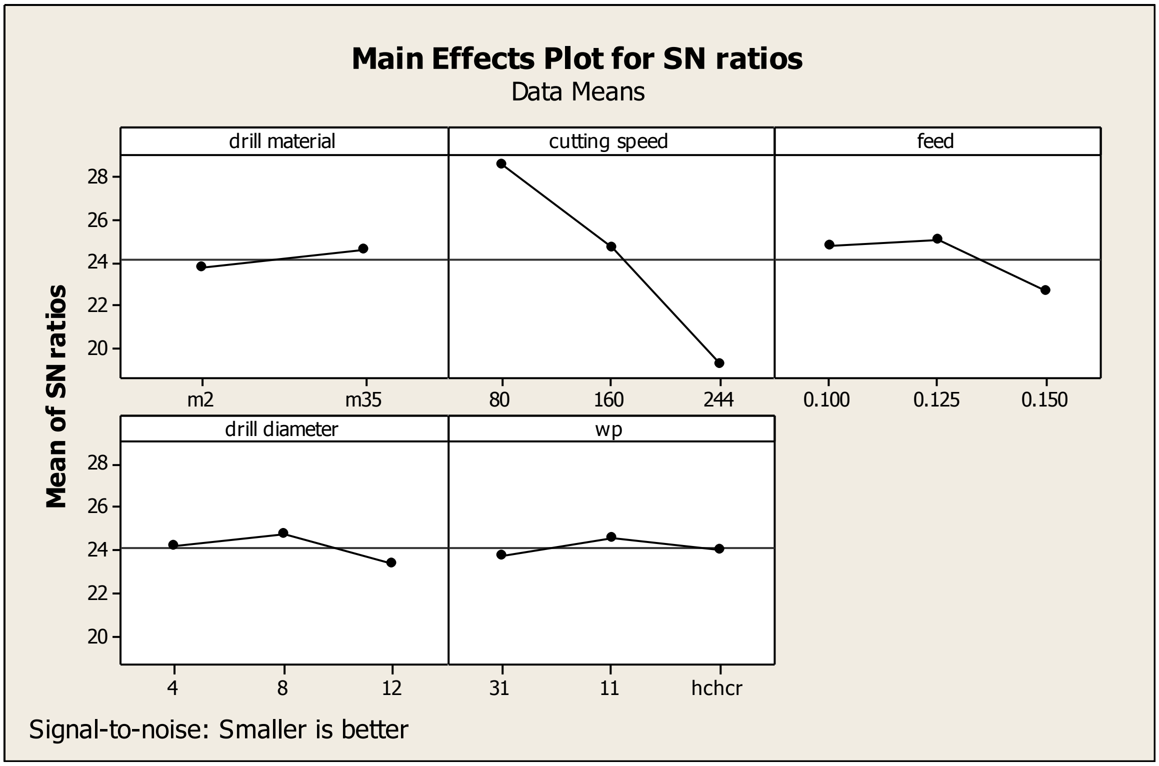


Figure 7.3: Main effects plot for S/N ratio of Burr height

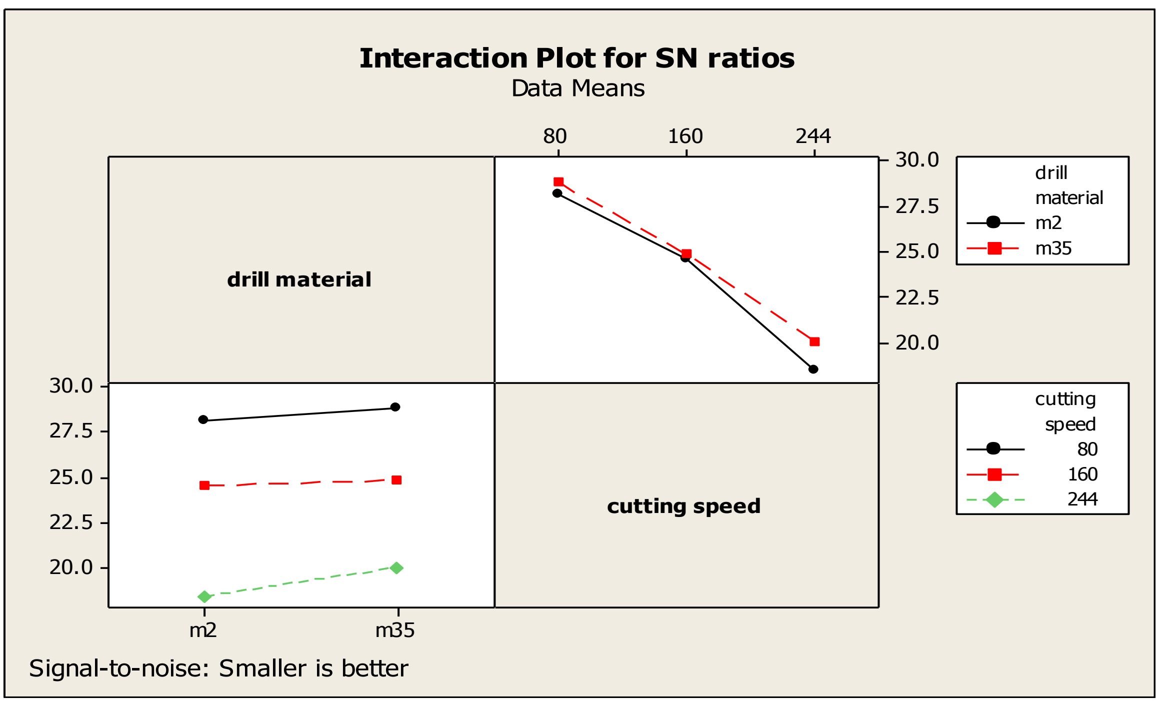


Figure 7.4: Interaction plot for S/N ratio of Burr height

7.5 OPTIMAL DESIGN

In this experimental analysis, the main effect plot in Figure 7.1 is used to estimate the mean burr height with optimal design conditions. In Table 7.6 it is concluded that minimum burr height was achieve when feed of 0.125, drill material of M 35 cutting speed of 80 rpm was selected in the experiment trial. In S/N ratio minimum burr height was achieve when feed of 0.125, cutting speed of 80 rpm was selected in experiment trial. In this case, not same levels of the significant factors provide the higher average and reduced variability; hence, we have to be compromised. The results were conflicting according to their relative significance .The best burr height value was compromised to get best result. In some case, the levels of factors, which improve the average and improve the uniformity may conflict which means compromise may have to be reached. Moreover, a compromise may have to occur when multiple responses are considered and the same level factor may cause one response to improve and another to reduce.

Estimating the mean

Burr height is a "Lower the better" type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of burr height is given by:

$$\mu = B_2 + D_2 + E_1 - 2T = 0.06367 + 0.06500 + 0.03833 - 2(0.069) = 0.029 \text{ mm} \quad (7.3)$$

Where T = total mean value of burr height

Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically it specifies that there is 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

Confidence Interval around the estimated burr height

$$CI = \sqrt{(F_{\alpha}, v_1, v_2\ V_e/\eta_{eff})} \quad (7.4)$$

Table 7.6: Significant factors and interaction for Burr height

Factors	Affecting mean		Affecting variation (S/N ratio)	
	Contribution	Best level	Contribution	Best level
Work piece (A)	insignificant		insignificant	
Feed (B)	significant	Level 2(.125)	significant	Level 2(.125)
Dill diameter (C)	insignificant		insignificant	
Drill material (D)	significant	Level 2(M35)	insignificant	
Cutting speed (E)	significant	LEVEL 1 (80)	significant	LEVEL 1(80)
Drill material × Cutting speed (F)	insignificant		insignificant	

α = risk (0.05) Confidence = $1-\alpha$

ν_1 = dof for mean which is always =1

ν_2 = dof for error = ν_e

V_{e} = variance of e pooled

n_{eff} =Number of tests under that condition using the participating factors

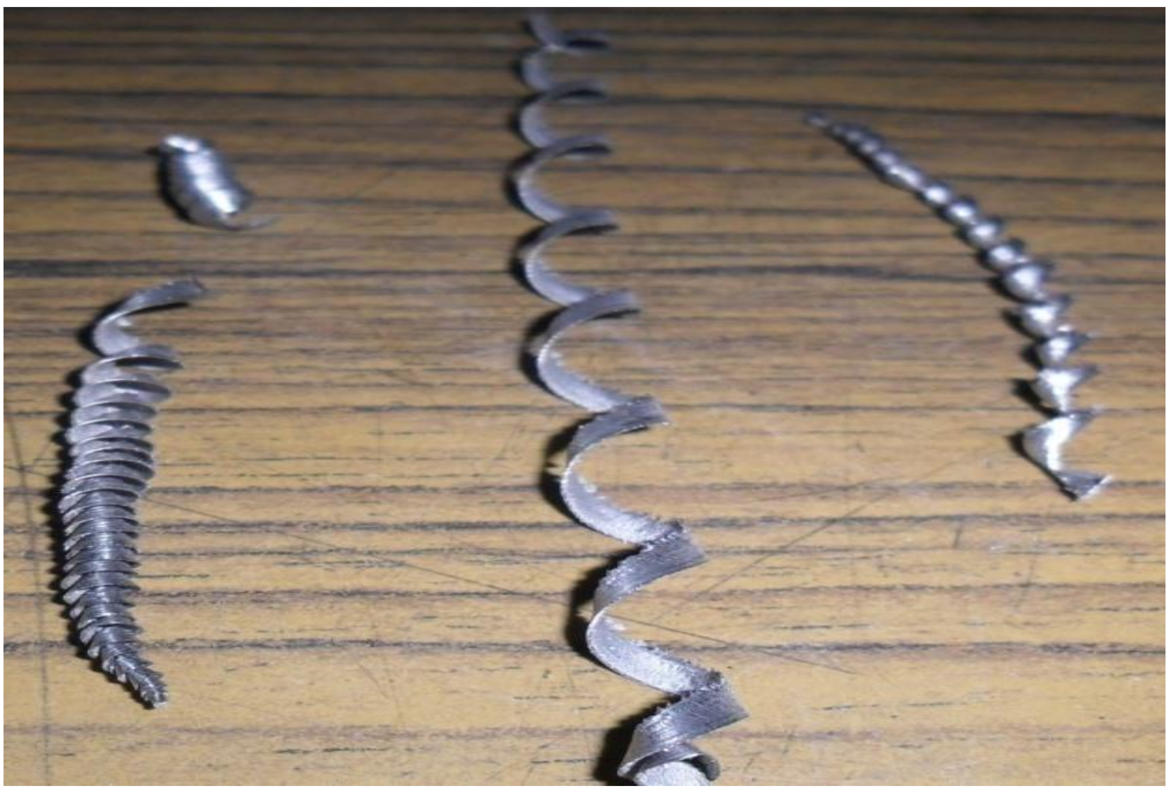
$$n_{eff} = \frac{N}{1+dofB\ D\ E} = \frac{36}{1+2+1+2} = 6$$

Where N = number of trials in the experiment

$$CI = \sqrt{(F\alpha, v1, v2\ Ve/\eta eff)} = \sqrt{(4.75 \times 0.0000671)}/6 = 0.00728 \text{ mm}$$

Thus, the confidence interval around the estimated mean of burr height is given by 0.029 ±0.00728 mm

(a)Natural broken Chips produced at Exp. No 13 (b) Chips produced at Exp. No 07



(c) Chips produced at Exp. No 18

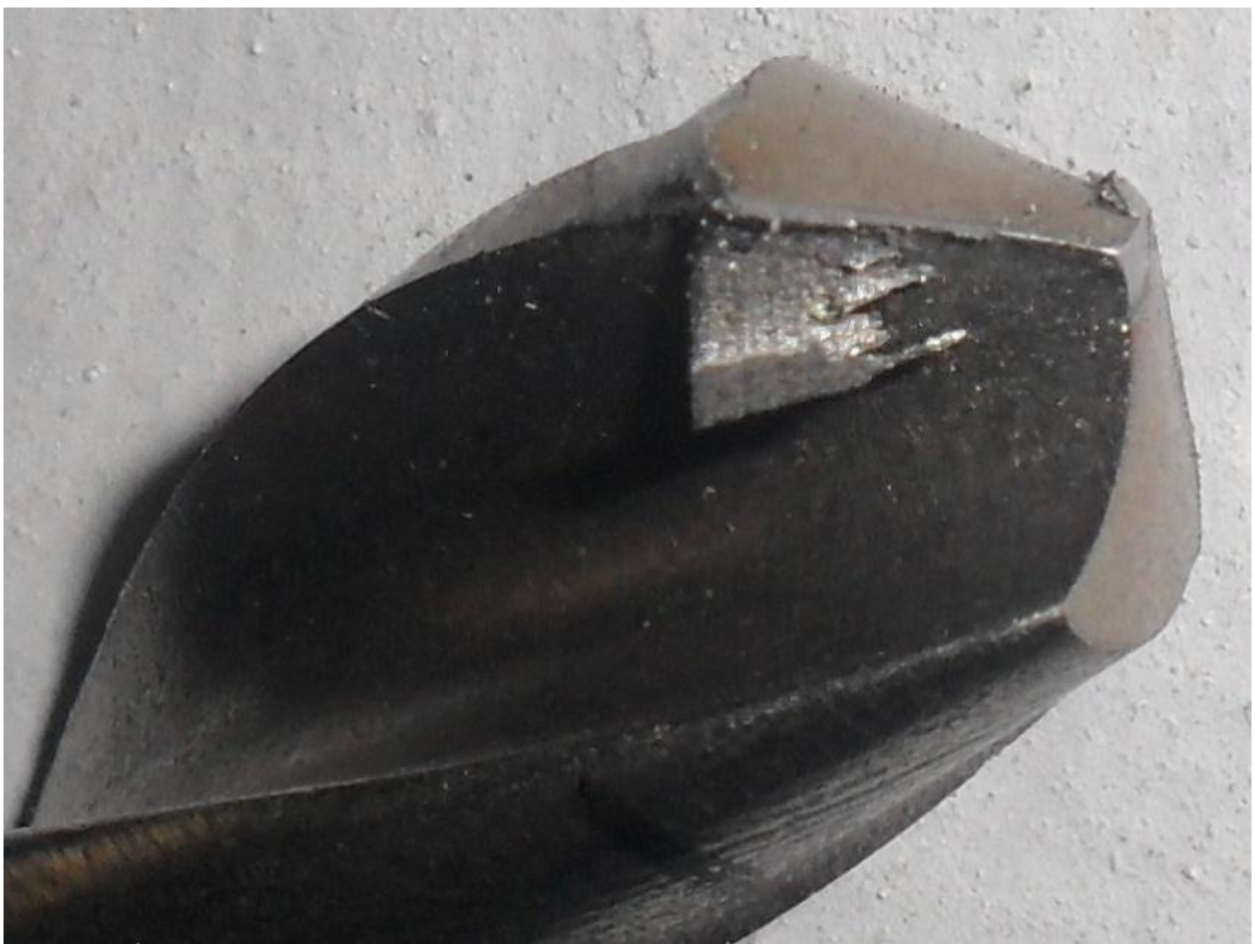
Figure: 7.5 Different chips produced during experiment

Figure: 7.6 conical helical chips are producing during machining EN 31-work piece at 244 rpm, 0.15 mm feed with 4 mm drill

Figure 7.7 Long ribbon types of chips produced during machining H 11-work piece at 244 rpm

(a) 4 MM M 2 drill

(b) 12 MM M 2 drill



(c) 8MM M35 drill

Figure 7.8 Chips are getting entangled with tool during machining

CHAPTER 8

MULTIPLE REGRESSION ANALYSIS

8.1 INTRODUCTION

A statistical procedure used to find relationships among a set of variables. In regression analysis, there is a **dependent variable**, which is the one you are trying to explain, and one or more **independent variables** that are related to it. You can express the relationship as a linear equation, such as:

$$y = a + bx \qquad (12.1)$$

- y is the dependent variable
- x is the independent variable
- a is a constant
- b is the slope of the line

For every increase of 1 in x, y changes by an amount equal to b.

Regression finds the line that best fits the observations. It does this by finding the line those results in the lowest sum of squared errors. Since the line describes the mean of the effects of the independent variables, by definition, the sum of the actual errors will be zero. If you add up all of the values of the dependent variable and you add up all the values predicted by the model, the sum is the same. That is, the sum of the negative errors (for points below the line) will exactly offset the sum of the positive errors (for points above the line). Summing just the errors would not be useful because the sum is always zero. So, instead, regression uses the sum of the squares of the errors. An Ordinary Least Squares (OLS) regression finds the line those results in the lowest sum of squared errors.

Multiple Regressions

When, several factors affecting the independent variable. Each of these factors has a separate relationship with the price of a home. The equation that describes a multiple regression relationship is:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \dots b_nx_n + e \qquad (12.2)$$

This equation separates each individual independent variable from the rest, allowing each to have its own coefficient describing its relationship to the dependent variable.

“p-values” and Significance Levels

Each independent variable has another number attached to it in the regression result its “p-value” or significance level. The p-value is a percentage. It tells you how likely it is that the coefficient for that independent variable emerged by chance and does not describe a real relationship. P-value of .05 means that there is a 5% chance that the relationship emerged randomly and a 95% chance that the relationship is real. It is generally accepted practice to consider variables with a p-value of less than .1 as significant, though the only basis for this cutoff is convention.

The regression equation =b_0 +$b_1$wp+ $b_2$feed +$b_3$dia.+$b_4$drill material + $b_5$cutting speed+ e

Where $b_{0,}$ b_1, b_2, b_3, b_4, b_5 are estimates of the process parameters and e is the error

The regression equation for burr Height is

Burr height is = - 0.0032 - 0.00856 A + 0.0358 B + 0.00792 C + 0.00083 D - 0.00192 E+ e

R^2=0.89 (12.3)

The regression equation for MRR is

MRR is = - 842 + 189 A + 434 B - 93.2 C + 492 D - 172 E +e (12.4)

R^2= 0.814

The regression equation for Surface roughness is

Surface roughness is = 0.468 - 0.0478 A + 0.0550 B + 0.0308 C + 0.0792 D + 0.0742 E+e

R^2=0.67 (12.5)

The regression equation for Hole Diameter accuracy is

Hole Diameter error is = 0.0418 - 0.0119 A + 0.0225 B + 0.00525 C + 0.00167 D + 0.00208 E+e (12.6)

R^2= 0.78

Where A = work piece material

B = feed

C= drill diameter

D =drill material

E =cutting speed

In multiple linear regression analysis, (R^2>0.80) for the models, which indicate that the fit of the experimental data is satisfactory.

CHAPTER 9

EXPERIMENTAL RESULTS AND CONCLUSIONS

9.1 RESULTS

The effect of parameters i.e. cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed evaluated using ANOVA design analysis and Regression analysis. The purpose of the ANOVA was to identify the important parameters in prediction of MRR, Surface Roughness, hole diameter error and burr height. Some results concluded from ANOVA and plots are given below:

9.1.1 MRR

The effect of parameters cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed were determined using ANOVA and DOE approch. A confidence interval of 95% has been used for the analysis. One repetition for each 18 trails was completed to measure the Signal to Noise ratio (S/N Ratio).

ANOVA table shows that drill diameter with F value 9.13 and cutting speed with F value 6.38 are the factors that significantly affect the MRR. With % contribution of 36.97%, 24.45% to MRR. All others factors, namely, work piece material, feed, drill material ×cutting speed and drill material were found to be insignificant. For S/N ratio drill diameter and cutting speed were significant to reduce the variation of MRR. With 95% confidence interval mean value of MRR was found to be 1675.2 ±322.77 mm^3/min.

9.1.2 SURFACE ROUGHNESS

The effects of parameters i.e. cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed were evaluated using ANOVA analysis. A confidence interval of 95% has been used for the analysis. One repetition for each of 18 trails was completed to measure the Signal to Noise ratio(S/N Ratio). In this experiment work surface roughness (Ra) has measured at position center. ANOVA table shows that work piece material with F value 26.47, drill diameter with F value 26.61 and cutting speed with F value 7.74 are the factors that significantly affect the surface roughness. The percentage contribution of these factors is 33.19%, 33.38%, 7.55%.

All others factors, namely, feed, drill material ×cutting speed and drill material were found to be insignificant. The estimated mean values of roughness considered with 95% confidence interval found to be 0.8017 ± 0.0667 μm

9.1.3 HOLE DIAMETER ERROR

The effects of parameters i.e. cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed were evaluated using ANOVA analysis. A confidence interval of 95% has been used for the analysis. One repetition for each of 18 trails was completed to measure the Signal to Noise ratio(S/N Ratio).

For hole diameter error ANOVA table shows that work piece with F value of 5.57, Feed with F value of 6.03, Drill material with F value of 10.57, Cutting speed with F value of 50.69 are the factors that significantly affect the hole diameter error. The percentage contribution of these factors is 4.96%, 5.56%, 4.60%, 63.96%. All others factors, namely, drill diameter and Drill material ×cutting speed were found to be insignificant. The estimated mean values of hole diameter error considered with 95% confidence interval found to be 0.21683±0.0108 mm

9.1.4 BURR HEIGHT

The effects of parameters i.e. cutting speed, feed rate, drill diameters, work piece material, drill material and interaction effect between drill material and cutting speed were evaluated using ANOVA analysis. A confidence interval of 95% has been used for the analysis. One repetition for each of 18 trails was completed to measure the Signal to Noise ratio(S/N Ratio).

For burr, height ANOVA table shows that feed with F value of 15.05 drill material with F value 9.58 of and cutting speed with F value of 236.54 are the factors that significantly affect the burr height. With % contribution of 4.88%, 1.06%, 87.49%. All others factors, namely, drill diameter, work piece and Drill material ×cutting speed were found to be insignificant. The estimated mean values of hole diameter error considered with 95% confidence interval found to be 0.029 ±0.00728 mm

9.2 CONCLUSIONS

The present study was carried out to study the effect of input parameters on the MRR, surface roughness, hole diameter error, burr height. The following conclusions have been drawn from the study:

- MRR is mainly affected by cutting speed and drill diameter.
- Surface roughness is mainly affected by work piece material, drill diameter and cutting speed
- Hole diameter is mainly affected by work piece, feed, drill material and cutting speed
- Burr height is mainly affected by feed drill material and cutting speed

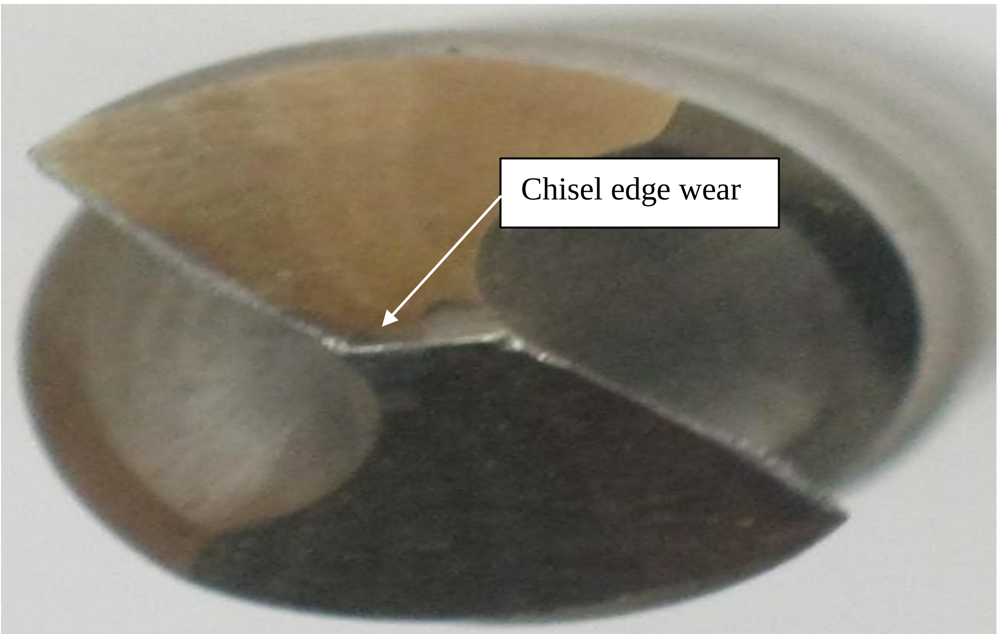


Figure: 9.1 Wear of 12 mm M35 HSS drill after machining

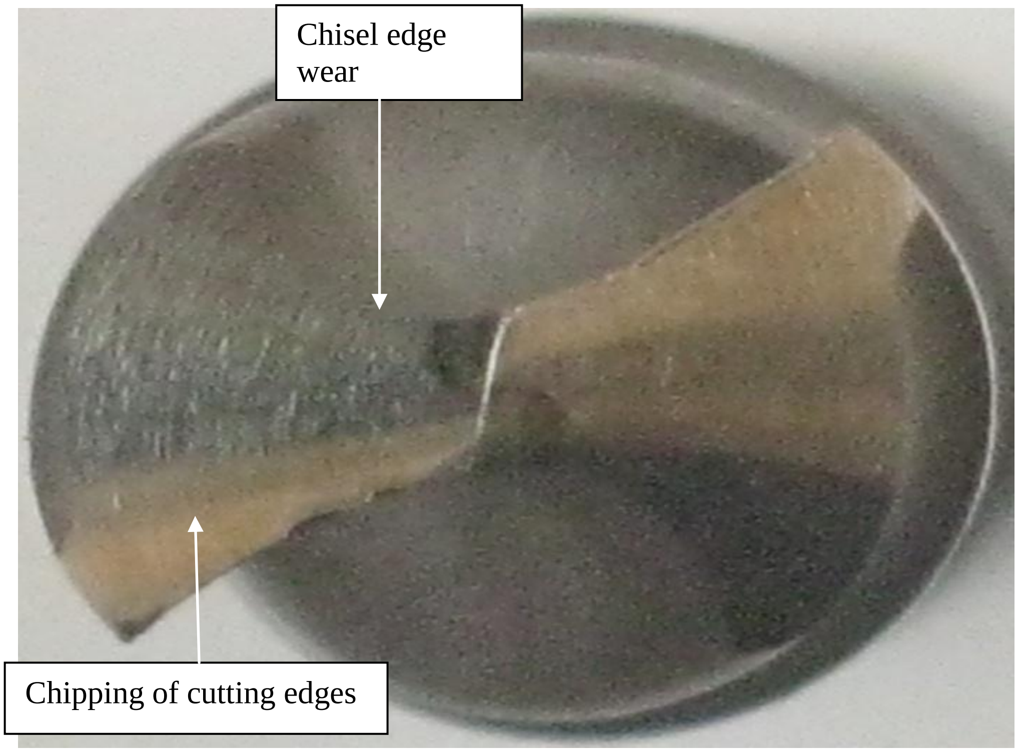


Figure: 9.2 Wear of 8 mm M35 HSS drill after machining

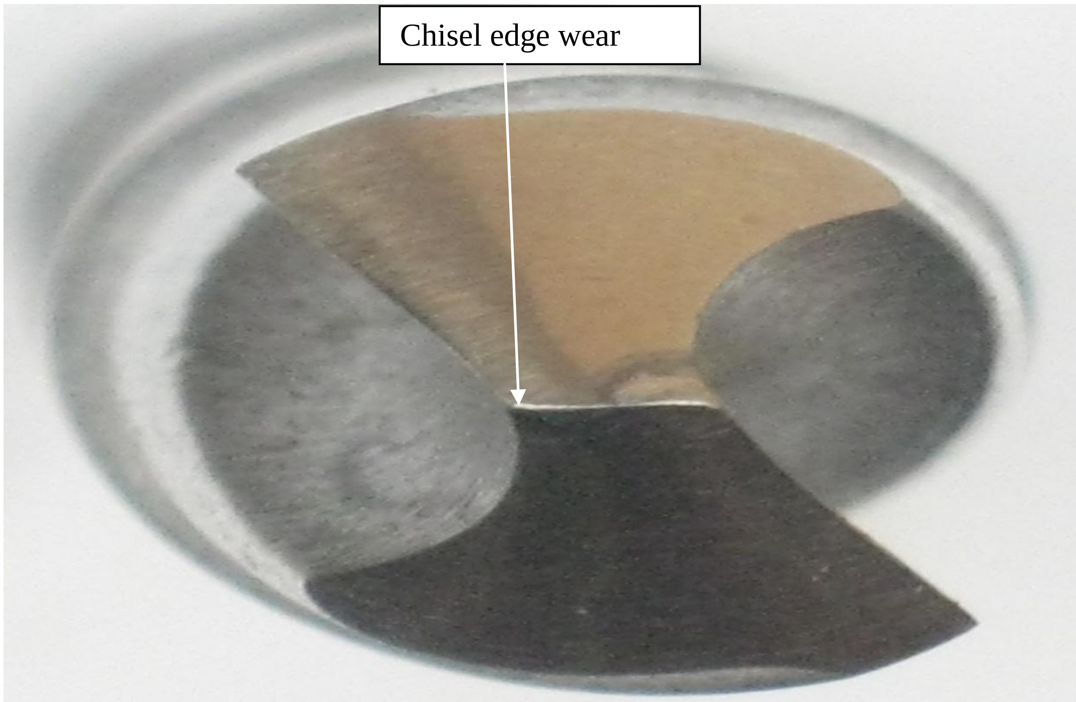


Figure: 9.3 Wear of 12 mm M2 hss drill after machining

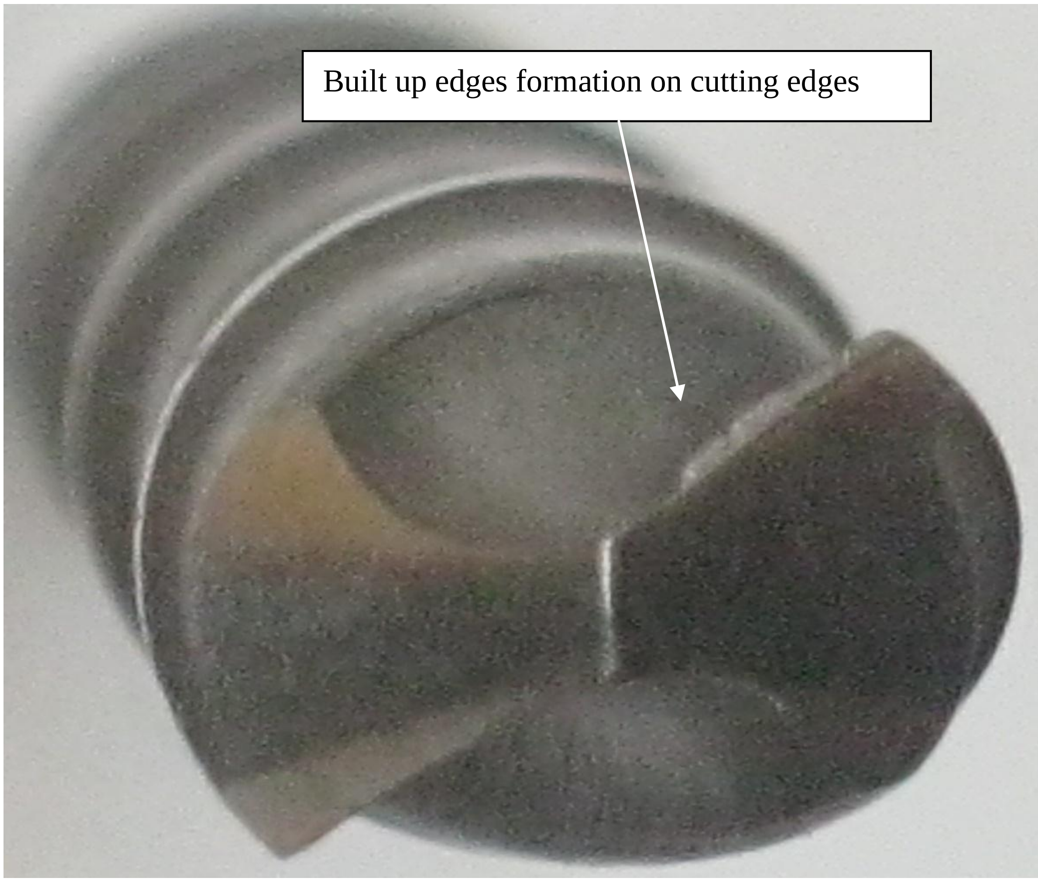


Figure: 9.4 Wear of 8 mm M 2HSS drill after machining

CHAPTER 10

In the present work, the effect of various parameters such as cutting speed, work piece, feed, drill material, drill diameter on the surface properties of the work piece material has been evaluated. Micro structural analysis was carried out using a Scanning Electron Microscope (SEM) and Lieca Metallurgical Microscope. During this analysis chemical composition of machined surface and micro structure of machined surface was determined.

10.1 MICROSTRUCTURE ANALYSIS

Microstructure analysis was carried out on some selected samples using Scanning Electron Microscope to study the change in the microstructure after machining. The samples were prepared as per standard before SEM analysis on three different magnifications, namely, 100× and 200×

10.1.1 Method of Sample Preparation for SEM

The steps for the sample preparation for SEM are given below:

1) Cut out the samples in 14×16mm

2) Clean the surface with wire brush.

3) Clean the samples with acetone.

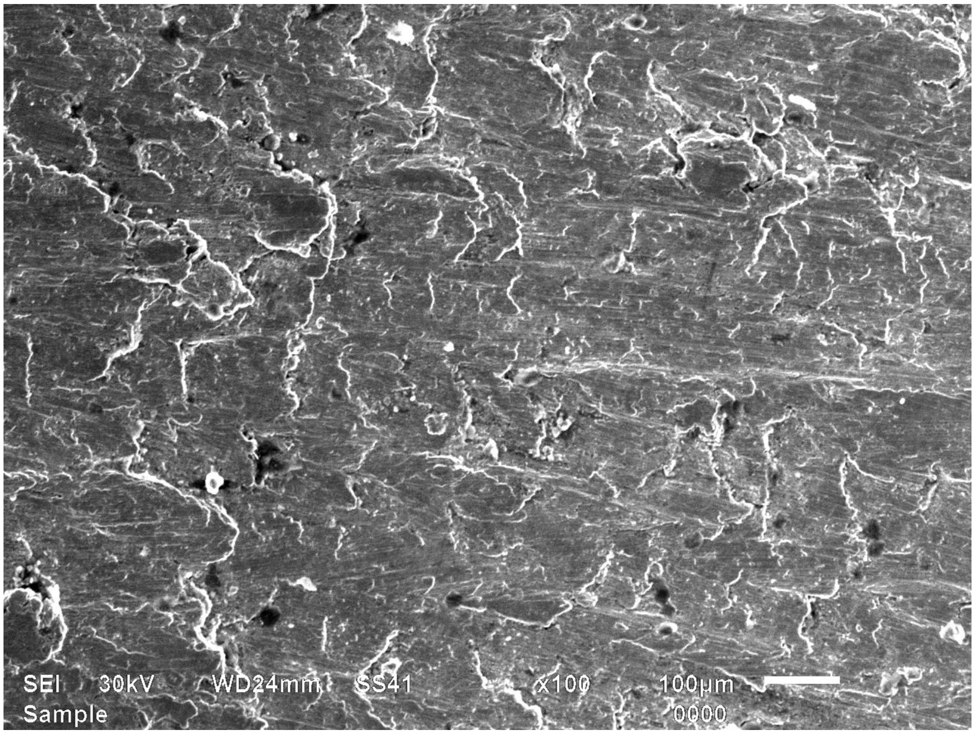


Figure 10.1 SEM micrograph at 100× of EN 31 machined with 244 RPM, 0.15 Feed With 8 mm drill

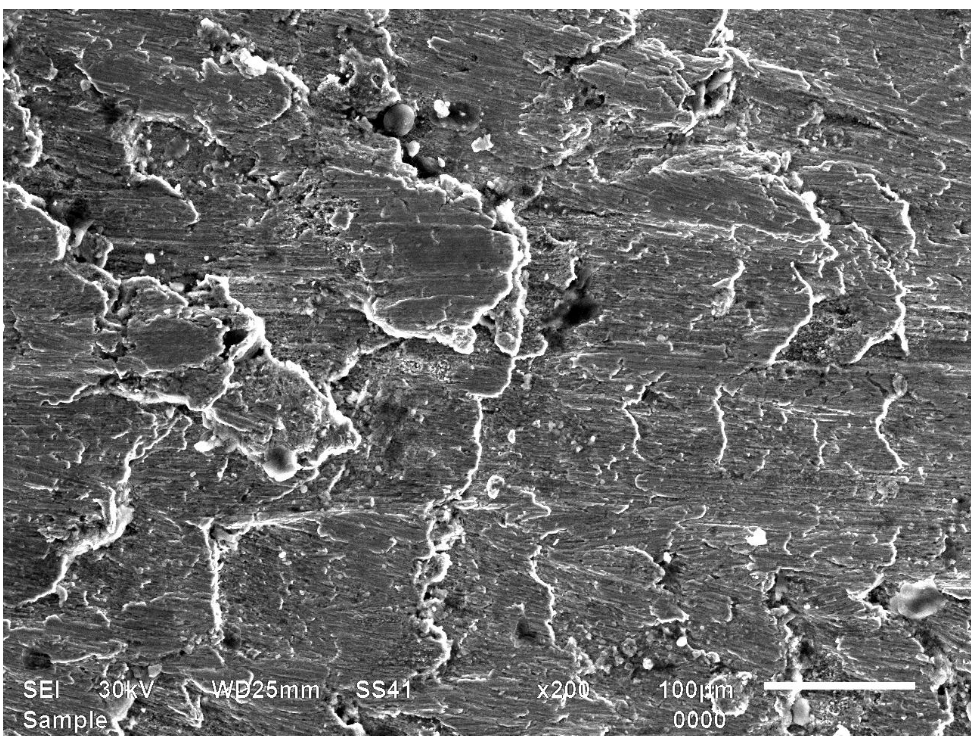


Figure 10.2 SEM micrograph at 200× of EN 31 machined with 244 RPM, 0.15 Feed With 8 mm drill

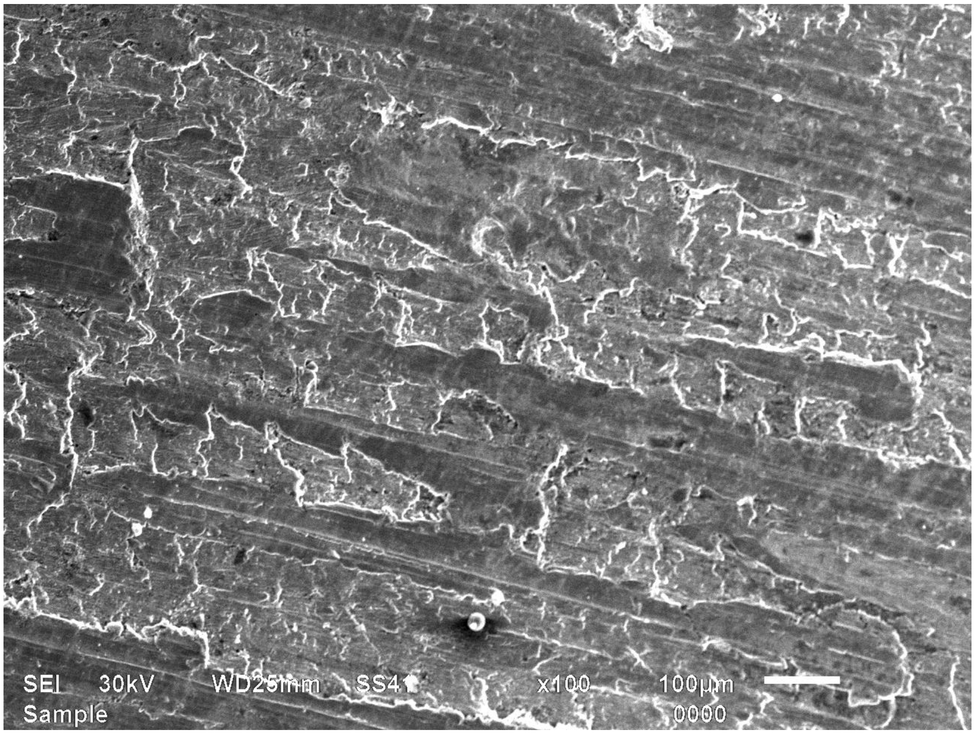


Figure 10.3 SEM micrograph at 100× of EN 31 machined with 244 RPM, 0.15 Feed With 8 mm drill

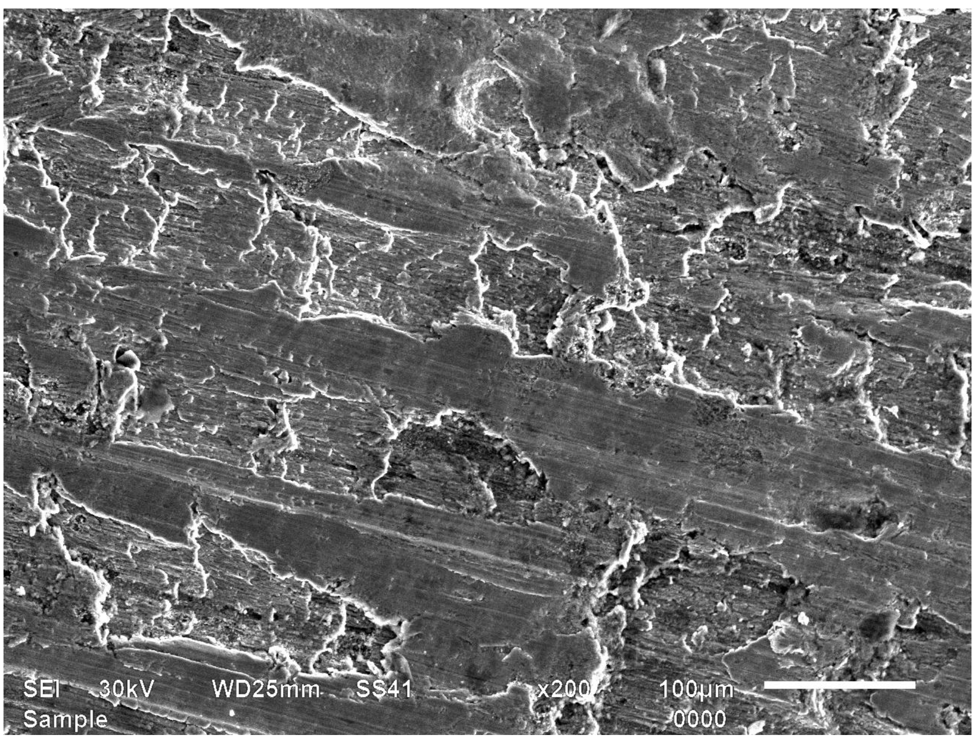


Figure 10.4 SEM micrograph at 200× of EN 31 machined with 244 RPM, 0.15 Feed With 8 mm drill

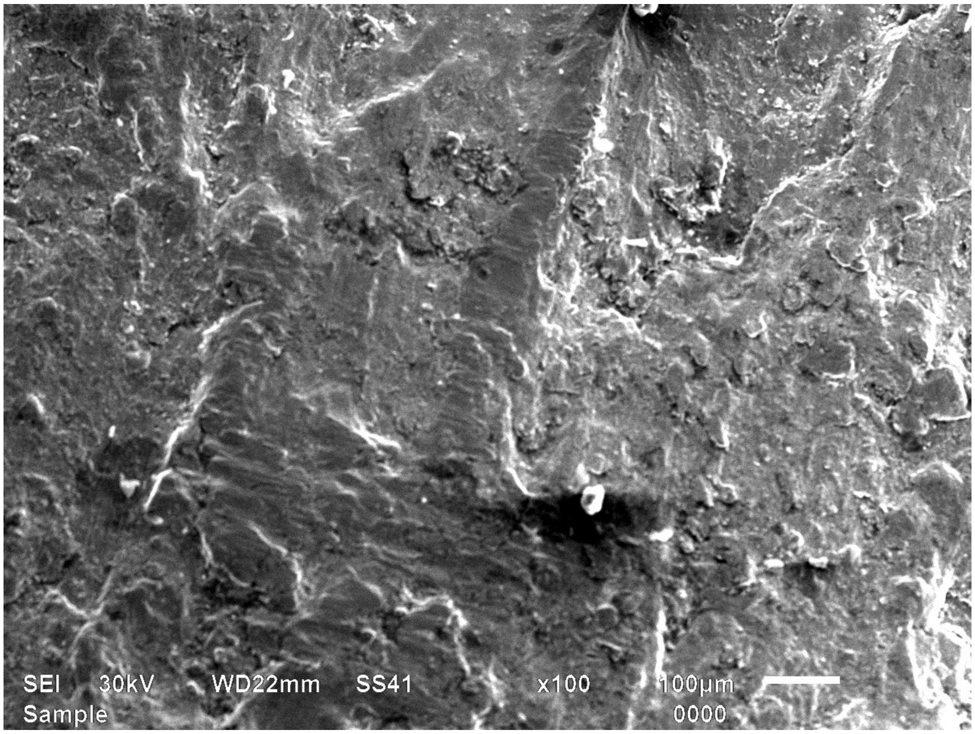


Figure 10.5 SEM micrograph at 100× of H 11 machined with 244 RPM, 0.125 Feed With 12 mm drill

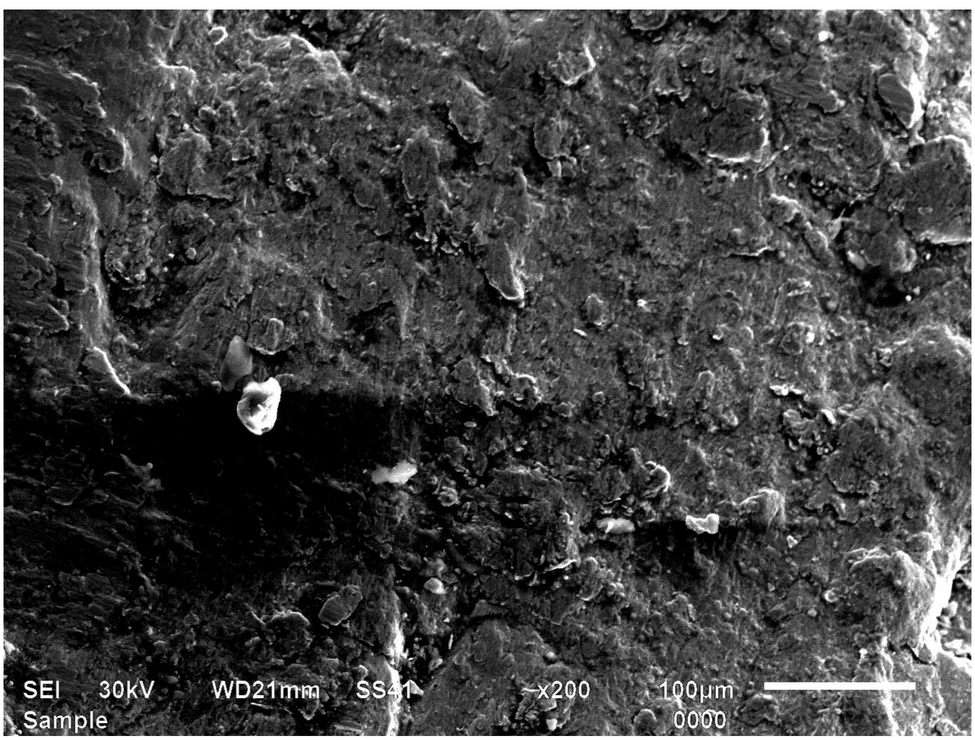


Figure10.6 SEM micrograph at 200× of H 11 machined with 244 RPM, 0.125 Feed With 12 mm drill

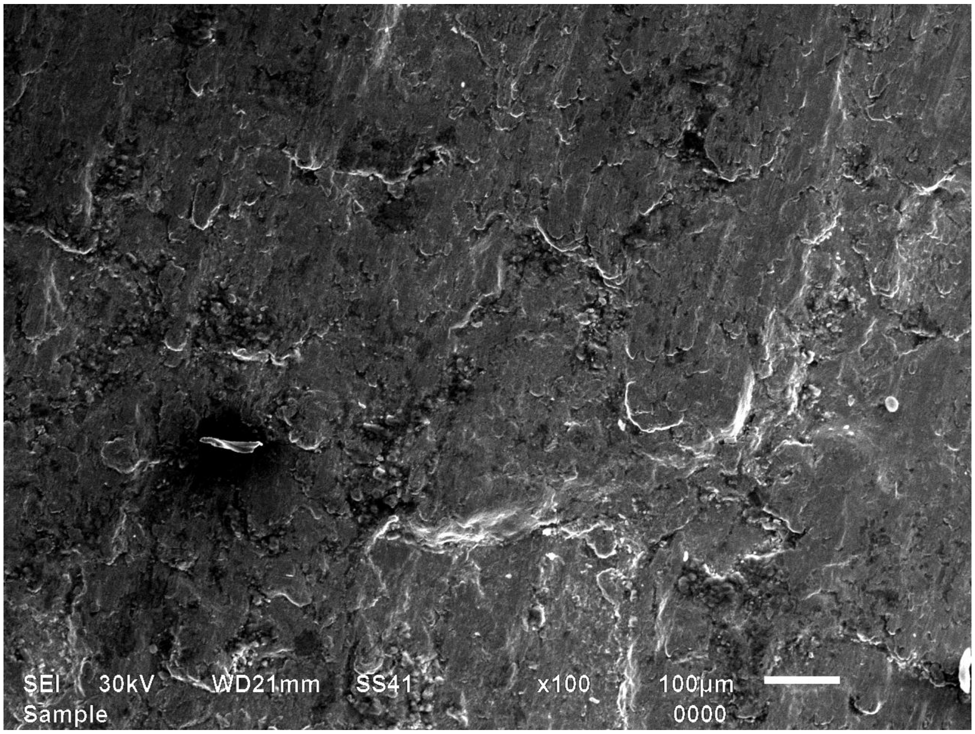


Figure 10.7 SEM micrograph at 100× of H 11 machined with 244 RPM, 0.125 Feed With 12 mm drill

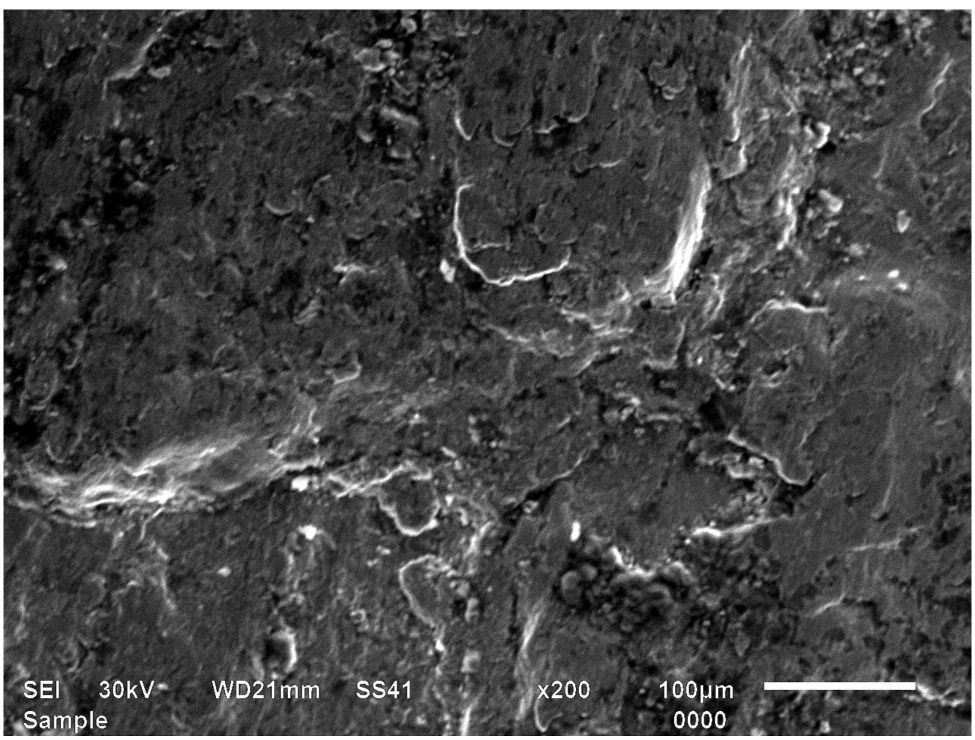


Figure 10.8 SEM micrograph at 200× of H 11 machined with 244 RPM, 0.125 Feed With 12 mm drill

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APPENDIX-A

TECHNICAL SPECIFICATION OF RADIAL DRILLING MACHINE

The experiment has been conducted on **Radial drilling machine having** different range of speed Different range of speed can be chosen in machine by shifting the gears acc. to needed speed

Speeds (rpm)			
160	244	580	890
80	122	290	445

Speed ranges of radial drilling machine

Different range of feed like coarse, fine and manual can be chosen from this machine like coarse have feed of the range 0.2 mm/rev. and fine have range of 0.1 mm/rev. And manual feed we can give my own acc. to time a drill takes to travel into work piece.

Coarse (mm/rev)	Fine	Manual
0.2	0.1	Acc. to thickness

Feed ranges of radial drilling machine

APPENDIX-B

SPECIFICATIONS OF MEASURING INSTRUMENTS

1. OPTICAL EMISSION SPECTROMETER

Make and model	Baird, DV-6, and USA
Base	Iron, Aluminum, Copper
Medium	ARGON GAS
Accuracy	0.0001%

2. SCANNING ELETRON MICROSCOPE

Make and model	JSM-840A Joel, Japan
Magnification range	10× to 3, 00,000×

3. SURFACE ROUGHNESS TESTER

Make and model	Mitutoyo SJ-400
Measurement method	Stylus
Profile resolution	0.01 µm
Cut-off wavelength	0.8 mm
Tracing length	3 mm