ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical Chemical and Materials Engineering

Program of Mechanical Design and Manufacturing Engineering

Optimisation of Deep Drilling Parameters on Tool Wear, Tool Surface Temperature and Job Surface Roughness

A Thesis proposal submitted in partial fulfillment of the

Requirements for the award of the degree of

Master of Science

In

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By

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Approved by Board of Examines

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Candidate Declarations

I hereby declare that the work which is being presented in this thesis entitled **"Optimisation of deep drilling parameters on tool wear, cutting tool surface temperature and Job surface roughness"** in partial fulfilment of the requirements for the award of the degree of masters of science in Manufacturing Engineering is an authentic record of my own work carried out **November 2017 to June 2018** under the supervision of **Dr. J. Bhaskaran and Dr.Guteta Kabeta** Program of Mechanical Design and Manufacturing Engineering, Adama science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Anjelo Lidetu Goshu	___________________	_____________
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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with our approval:

Dr. J. Bhaskaran	___________________	_____________
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ABSTRACT

Optimization methods in deep drilling processes, is one of a vital role for continuous enhancement on quality production and processes by investigating of optimal cutting conditions for required responses. This study presented the optimization of cutting parameters (cutting speed, feed and depth of cut) in dry deep drilling of AISI 304 austenitic stainless steel with HSS drill bit in order to achieve minimum tool wear, cutting tool surface temperature and good job surface finish. The experimental analysis was conducted on CNC vertical machining center. The Taguchi's L9 Orthogonal array technique and analysis of variance (ANOVA) are used to identify the effect of the cutting parameters on the response. Data collection instruments such as Electronic weighting balance, Infrared Thermometer, and BELLSTONE surface roughness tester used to measure tool wear, tool surface temperature, and surface roughness respectively. Minitab 17 software is used to run Taguchi orthogonal array and to analyses the collected data. The experimental ANOVA analysis and Taguchi technique revealed that the parameters at Cutting Speed 6.28m/min, Feed rate 0.15mm/rev and depth of cut 0.3mm yields minimum tool wear. The minimum tool surface temperature is observed at Cutting speed of 6.28m/min, feed rate 0.15mm/rev and depth of cut 0.3mm with a percentage contribution of 16.94%, 30.59%, and 34.87% respectively. The good surface roughness of workpiece is obtained at cutting speed 6.28m/min (level-1), feed 0.2mm/rev (level-3) and depth of cut of 0.7mm (level-3).

Keywords: Orthogonal array; Taguchi; ANOVA; S/N ratio, and Minitab 17

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ABBREVIATIONS AND ACRONYMS

DOE Design of experiments
CNC Computer numerical control
ANOVA Analysis of Variance
VMC Vertical milling center
HSS High speed steel
RSM Response surface methodology
IC Integrated circuit
NC Numerical control
BTA Boring Trepanning Association
RPM Revolutions per minute
SFPM Surface feet per minute
CS Cutting speed
f Feed rate
N Spindle speed
f_r= Feed per revolution
ANN Artificial neural networking
GA Genetic algorithm
SS_T Total sum of squared deviations
SS_d Sums of the squares of the deviations
AFM Atomic force microscope
Ra Arithmetical mean deviation of profile
Rz Ten point height of irregularities
Rq Root mean- square deviation of profile
Rt Total peak-to-valley height
S/N Signal to noise ratio
LED Light emitting diode
S.D Standard division
Δ Delta
DOF Degree of freedom
SS Sum of square

CHAPTER 1

1. Introduction

1.1 Background and justification

The growing demand for higher productivity, product quality and overall economy in manufacturing under machining, grinding and drilling, particularly to meet the challenges thrown by liberalization and global cost competitiveness, insists high material removal rate and high stability and long life of cutting tool [1]. Among those machining process drilling is considered as one of the most complex cutting operations performed in metal cutting industry. Compared to turning and milling, drills are subjected to severe machining conditions in terms of higher thrust force, poor heat evacuation and chip jamming due to the depth of the cutting zone within the work-piece. Chip clogging with the drill (termed as packing factor) due to lesser penetration of the cutting fluid into the cutting zone, vibrations, greater susceptibility of the drill to deflect and problems of heat evacuation from the cutting edge are the common problems associated with this process [2]. Drilling is one of the most important machining process as 60% of the parts rejection is due to poor quality hole. It has been estimated that 33% of all metal cutting operations are spent in drilling . The process parameters such as cutting speed, drill tool diameter and cutting fluid plays a significant role in surface finish of drilled hole. In addition to these high production machining and grinding with high cutting velocity, feed and depth of cut are inherently associated with generation of large amount of heat and high cutting temperature [1, 3, 4]. In order to overcome those problems and other during drilling process, proper selections of process parameters is very important to obtain good quality in the product. The most well-known methods used to reduce tooling costs are various applications of more resistant tool materials, heat treatments, cutting fluids, speed and feed rates, and the development of coated cutting tool. One of these methods is the application of cryogenic treatment used in recent years. Over the past few years, there has been an increasing interest in the application of cryogenic treatment. Cryogenic treatment has been an effective method in improving the tool life of different cutting tools (in particular HSS and cemented carbide) used in machining processes. It was reported that deep cryogenic treatment increased tool life by 90 to 100%. In addition, lower cutting forces and surface roughness were obtained with treated cutting tools [5]. In similar manner cutting parameters namely cutting speed, feed rate and helix angle affect the tool life. The effects of cutting parameters were analysed by evaluating the amplitude of drill bit vibration and surface roughness. From the experimental results, it show that vibration of drill bit increased with the progression of the tool wear [6]. Hence statistical design of experiments (DOE) and statistical/mathematical model are used quite extensively in order to analysis the parameters which affect the final responses. Design and methods such as factorial design, response surface methodology (RSM) and Taguchi method are now widely used in place of one factor-at-a-time experimental approach, which is time consuming and exorbitant in cost [7].

Process optimization is the discipline that adjusting a process to optimize some specified set of parameters without violating some constraint. The most common goals of process optimization are; minimizing cost, maximizing throughout, and/or efficiency. This is one of the major quantitative tools in industrial decision-making. When optimizing a process, the goal is to maximize one or more of the process specifications, while keeping all others within their constraints. Among different optimization methods, Taguchi method has been widely used in engineering analysis and is a powerful tool to design a high quality system. Moreover, the Taguchi method employs a special design of orthogonal array to investigate the effects of the entire machining parameters through the small number of experiments. Recently, Taguchi design of experiment is widely employed in several industrial fields, and research works [5, 8].

1.2 Statement of the problem

Deep drilling is one of machining process which produces long round holes in a solid material or workpiece with the use of multi-point cutting tools called drills or drill bits. Since twist drill possesses a complex geometry and tool-feed motion as compared to other cutting tools used for machining processes, there is poor outcome of the product if cutting parameters are not well optimized. When deep drilling process parameters (machining condition) are well optimized, there is increases in product quality, reduction of production time, improved cutting tool life obtained. In order not to get those and other advantages, there are challenges either in work-piece material or machining parameters. The real time problems faced during dry deep drilling process are:

- Lose of tool edges
- The higher temperature either cutting tool surface or workpiece material
- Bad surface finish at the internal section of drilled hole

1.3 Objectives

1.3.1 Main objective

This study is to investigate the influence of cutting parameters (cutting speed, feed rate and depth of cut) on tool wear, tool surface temperature and surface roughness under deep drilling of AISI 304 Stainless Steel with HSS twist drill tool.

1.3.2 Specific objectives

Optimization of cutting parameters, although quite important for planning efficient machining processes, is a complicated target not only challenged by the complex nature of the involved phenomena but also by the need of carefully defining realistic optimization objectives, and developing and implementing powerful and versatile optimization techniques.

In order to analysis those challenges, this study specifically focused on the following objectives:

- To obtain the effect of cutting parameters on response values of each run experiment.
- To determine and analyse most affecting cutting parameters in order to get minimum cutting tool tip temperature, tool wear and surface roughness.
- To estimate the relative contributions of each control factors on the measured response.

1.4. The scope of the study

In this work, the procedure cared on by deep drilling of commercially available round bar AISI 304 stainless steel using twist HSS drill tool with CNC milling machine. The experimental test conducted within nine work-pieces of AISI 304 stainless steel and drill bit. During these experimental test each response on each experimental run performed by optimizing cutting parameters (speed, feed and depth of cut). Taguchi Design of Experiment and ANOVA analysis methods are used in order to conduct experimental run and analyse the result. In L_9 orthogonal array the optimization of cutting parameters performed in order to minimize tool wear, cutting tool surface temperature and surface roughness. In $L9$ orthogonal array there are three machining parameters each of three levels are selected to minimize the number of experiment to optimize the cutting parameters to get minimize tool wear, minimum cutting tool surface temperature and good surface finish.

1.5. Significance of the Study

Now days, the world is competitive in market in order to supply better product for the customers and company itself to reduce the unwanted cost in production process. Among those production processes deep drilling is one of machining process, which performed in most of industry. If the production process is not well optimized, there is challenge in market competition ether to get a good product or minimum production process cost. This study investigate those challenges in order to benefits mainly the following focused areas:

- To increase production quality of the product;
- To decrease cost for purchasing tool and
- In order to reduce the damage of cutting tool by increasing the tool life.

CHAPTER 2

2. Literature Review

2.1 Background of drilling process

Machining is one of most versatile and accurate of other manufacturing processes in its capability to produce a diversity of part geometries and geometric features, in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. Many processes that have this common theme, controlled material removal, are today collectively known as subtractive manufacturing and in other way the machining processes which controlled of material addition to fabrication of required part are known as additive manufacturing. In most industrial work, there are three principal subtractive manufacturing processes, which are turning, drilling and milling. The other operations process classified into miscellaneous categories include: shaping, planning, boring, broaching and sawing.

Among manufacturing industrial process, the production of holes in workpiece is a common and most important process. There are many tools and processes for producing the holes. The selection of tools and process mainly depends on type of material, the size of the hole, quantity of holes produce in given time periods. From many hole making processes, drilling is a major and commonly use hole making process [9].

Drilling is a subtractive machining operation used to create a round hole in a work part, which usually performed with a rotating cylindrical tool that has 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. As the drill rotates and feed into the workpiece, material is removed in the form of chips that move along the fluted shank of the drill. Drilling process involves relative motion between the drill and the work piece. Generally, the drill rotates and feed into the work-piece, but sometimes work-piece rotate and feed into the drill as shown in Figure 2.1. The cutting tool used in drilling process is called as drill or drill bit. Among different drill bit type, the most common drill bit is the twist drill [10, 11, and 12]. In the drilling operation, the material removal process in metals is used for making holes required for assembly of different machined parts or direct use. This hole making procedure is done on either of conventional upright drilling machines, milling machines, lath machine, or various specialized machines (CNC machines).

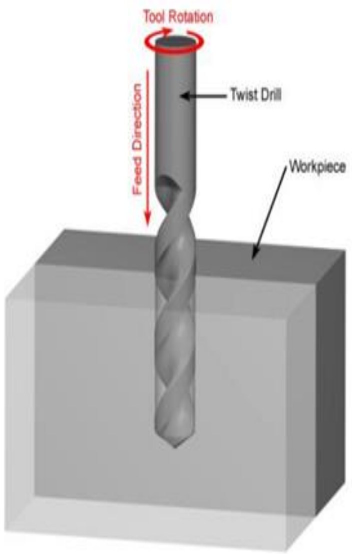

Figure 2.1 Drilling process in which the drill is fed into the workpiece [11].

2.1.2 CNC vertical milling machine

The milling machine is subtractive machining process in which removes unwanted section of metal with a revolving cutting tool called a milling cutter. With various attachments, milling machines are used for boring, slotting and drilling. Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. Vertical milling machine may be used effectively for drilling, which is perform the operation when twist drills supported in drill chucks that are fastened in the milling machine spindle or mounted directly in the milling machine collets or adapters. The work-piece to be drilled is fastened to the milling machine table by means of clamps, vises, or angle plates. Proper speeds and feeds are important functions to consider when performing drilling operations on the milling machine. The challenges such as bad part quality, tool cost, setup time, manufacturing time, unproper tool motion under a given cutting condition etc. in manual or conventional machine brings the technology in to computer numerical control (CNC) machine. Due to existence of microprocessor and microcomputer technology, they replaced into integrated circuit (IC) used in numerical control (NC) machine to advance NC to CNC machine.

Computer numerical control (CNC) machine is one of modified form of NC machine in which dedicated computer (microcomputer) are performed in order to control over all motion of machine and parameter changes. For desired part production, machining process on CNC machine is performed with the help of programed software which is implemented by designer. In each motion of machine components, there is control unit which are made up of electronic components that reads and interprets instruction from programed code in order to take mechanical action of the machine tool. Among various types of CNC machines, vertical CNC milling machine is one that perform drilling operation in addition to milling process.

CNC Machines usually have a 3D Cartesian coordinate system as shown in Figure 2.2. Material to be machined is fastened to the machine table, which moves in the XY-Plane. The machine column grips and spins the tool. The column controls the Z-axis and moves up-down [13].

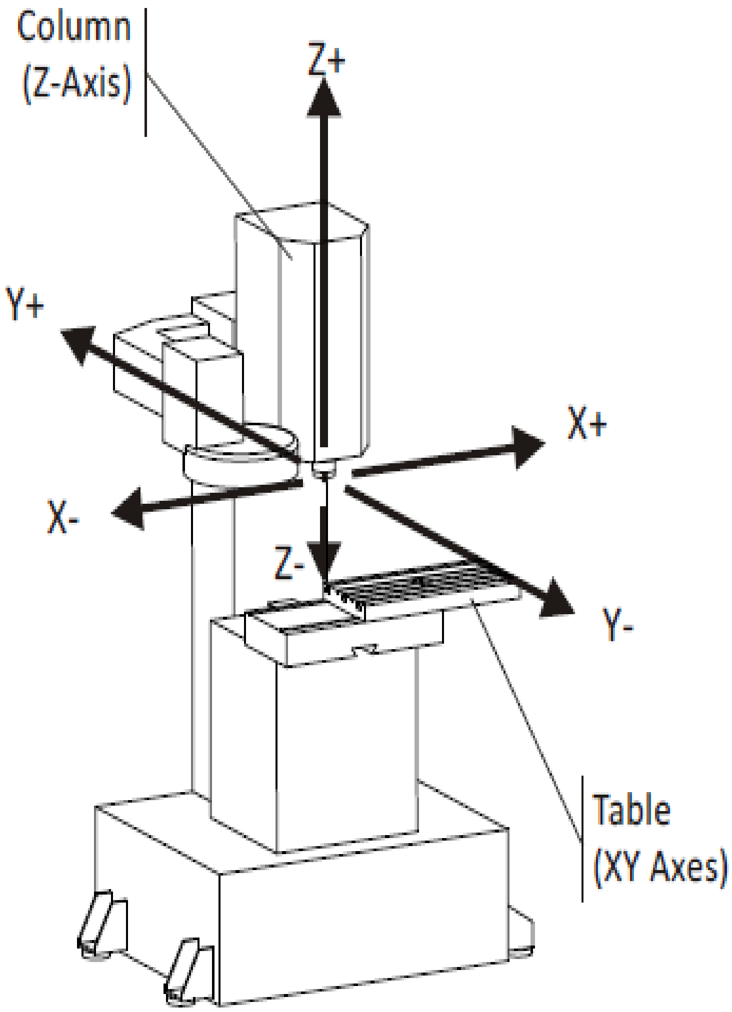

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Figure 2.2 Coordinate system of vertical milling machine [13]

2.2 Deep drilling process

Drilling is considered as one of the most complex cutting operations performed in metal cutting industry. Compared to turning and milling, drills are subjected to severe machining conditions in terms of higher thrust force, poor heat evacuation and chip jamming due to the depth of the cutting zone within the work-piece. With increasing depth, the process becomes even more difficult and complex [2]. If the depth of the hole being drilled is greater than four times the diameter of the drill, remove the drill from the work-piece at frequent intervals to clean the chips from the flutes of the drill and the hole being drilled. A slight increasing speed and decrease in feed is often used to give the chips a greater freedom of movement. In deep hole drilling, the flutes of the smaller drills will clog up very quickly and cause the drill to drag in the hole, causing the diameter of the hole to become larger than the drill diameter. The larger drills have larger flutes which carry away chips easier [14].

Deep hole drilling is a particular case of drilling processes for machining holes with length-to-diameter ratio greater than five. With an increased hole depth the demands increase on both machine and tool, which requires a specialized drilling technique [15]. Several technologies with main characteristics based on the surface roughness of the hole are available. The application fields of deep drilling process technology are numerous, such as aeronautics, naval, automotive and nuclear. In deep hole drilling the combination of chip removal, lubrication and localization of the thermo-mechanical loading in a confined cutting zone has a direct impact on the tool life and machining performances [11]. Cutting tool types used in deep drilling procedure various with the ratio of hole depth to diameter of cutter as shown in Table 2.1.

Table 2.1 Recommended cutting tool for a given hole depth to diameter ratio

Hole depth to diameter ratio (D: d)	Recommended tool
5:1	Common twist drills
10:1	High performance twist drills with through-tool coolant
20:1	Special deep hole drilling tools with through-tool coolant
100:1	Deep hole drilling tools on dedicated deep hole drilling machines
200:1	Gun-drilling tools on high performance gun-drilling machines
400:1	Extreme drilling range, proprietary processes and equipment required

Deep drilling process basically maintained by the following methods:

- **Conventional twist drill deep drilling**
- **Gun drilling**: - is a deep hole drilling process that uses a long, thin cutting tool to produce holes in metal at high depth-to-diameter ratios. Gun drilling is effective in diameters from 1 – 50mm [0.04 – 2.00 in]. A gundrill tool differs from a conventional twist drill by its unique head geometry; a standard gundrill has a single effective cutting edge that removes chips as it advances into a metal workpiece. The gun drilling process differs from Boring Trepanning Association (BTA) drilling due to coolant entry and chip

removal; gundrills introduce coolant internally through a small hole within the tool, and chips are removed by coolant through a groove outside the length of the tool.

- **(BTA) drilling: -** drilling machines introduce coolant externally, through an assembly around the tool, while chips are evacuated through the drill itself.

2.3 Cutting process parameters

Drilling is one of complex subtractive manufacturing process, performed by technically skilled operator in order to make hole by adjusting different cutting process parameters. In each of conventional upright drilling machines, milling machines or other various specialized drilling machines drilling of work-piece material for required design need the optimum cutting parameters. In drilling, the drill bit is rotating and penetrating into the workpiece. In many engineering applications, there is urgent requirement to realize the suitable cutting parameter that depends on work piece material, tool material, tool dimension etc., in order to drill a highly precise hole at low price. Mostly known cutting parameters selected in drilling process metal are, cutting speed, feed rate, depth of cut, cutting fluid, and tool diameter [16, 9, 17].

2.3.1 Cutting speed

In drilling machine, speed refers to the revolutions per minute (RPM) of the drilling machine spindle. For drilling, the spindle should rotate at a set speed that is selected for the material being drilled. The speed of a drill is measured in terms of the rate at which the outside or periphery of the tool moves in relation to the work being drilled. The speed at which a drill turns and cuts is called the peripheral speed. Peripheral speed is the speed in which drill turns and cuts the work-piece at its circumference and it is expressed in surface feet per minute (SFPM). This speed is related to the distance a drill would travel if rolled on its side. Different materials have different cutting speed as shown in Table 2.2. It has been determined through experience and experiment that various metals machine best at certain speeds; this best speed for any given metal is known as cutting speed (CS). If the cutting speed of a material is known, then a simple formula can be used to find the recommended RPM of the twist drill as shown in equation 2.1. The slower of the two recommended speeds is used for the following formulas due to the varying conditions that may exist, such as the rigidity of the setup, the size of the drilling machine, and the quality of finish. Correct cutting speed is essential parameters for satisfactory for drilling process. In the research of optimizing parameters at the time of deep drilling of AISI 321 steel, Arshad Noor Siddique and others worked in order to maintain minimum surface roughness. They investigate that among four cutting parameters (speed, cutting fluid, feed, and hole-depth); speed is most significantly affecting surface roughness of working material [18, 19]. Similarly S.V. Alagarsamy and other researchers are carried out to optimize drilling process parameters on surface roughness and material removal rate. Using Taguchi method they finally conclude that cutting speed play a grate significant role at the surface roughness either from feed or depth of cut in aluminum alloy drilling with a HSS spiral drill [20]. In contrary when dry drilling AISI 304 austenitic stainless steel in order to obtain optimized parameters which affect drill tool bit temperature, speed has smaller influence as compere to feed selecting other parameters constant [21]. From those researchers it show that at the time of drilling process, it is necessary to study the effect of cutting speed either on the work-material or cutting tool and optimizing this parameters to maintain required minimum or maximum response.

$$RPM = \frac{4 \times CS}{D} \qquad \text{2.1[18]}$$

Where; RPM = drill speed in revolutions per minute.

CS = Recommended cutting speed in surface feet per minute.

4 = A constant in all calculations for RPM (except metric).

D = the diameter of the drill itself in inch

Table 2.2 cutting speeds and feeds specification of material using HSS cutting tool [22]

Material	Cutting Speed, CS (SFM)
Aluminum and its Alloys	200-300
Brass and Bronze (Ordinary)	150-300
Bronze (High Tensile)	70-150
Die Castings (Zinc Base)	300-400
Iron-Cast (Soft)	100-150
Cast (Medium hard)	70-100
Hard Chilled	30-40
Malleable	80-90
Magnesium and its Alloys	250-400
Monel Metal or High-Nickel Steel	30-50
Plastics or Similar Materials (Bakelite)	100-300
Steel – Mild (.2 carbon to .3 carbon)	80-110

Steel (.4 carbon to .5 carbon)	70-80
Tool (1.2 carbon)	50-60
Forgings	40-50
Alloy – 300 to 400 Brinell	20-30
High Tensile (Heat-Treated) 35 to 40 Rockwell C	30-40
40 to 45 Rockwell C	25-35
45 to 50 Rockwell C	15-25
50 to 55 Rockwell C	7-15
Stainless Steel Free Machining Grades	30-80
Work Hardening Grades	15-50
Wood	300-400

2.3.2 Feed

In order to penetrate the work-piece to make the hole using drill in drilling machine, it need a parameters which cut out unwanted material from the work-piece with in a given revolution of spindle. The penetration pressure must be applied and maintained to the adjusted tip of dill at a given rate constantly. This cutting parameter is called feed and is measured in either decimal fraction of an inch or millimeters per revolution. The feed for drilling process depends primarily on the size of the drill and by the work-piece material to be drilled. The feed rate of different drill diameter have different feed rate as shown in Table 2.3. When the flow of feed is constantly given more, or less the accuracy of process meet. Machines such as hand-free drill press cannot be controlled feed accurately. Specifically the feed rate in drilling depends on:

- Surface finish desired.
- Availability of power at the spindle
- Rigidity of the drilling machine and tooling setup
- Cut Width

When deciding what feed rate to use for a certain cutting operation, the calculation is most important thing to adjust the optimum condition for required work-piece material. Recommended feed rate formula is given:

$$f = N \times f_r \quad \text{.......} 2.2\ [18]$$

Where; f = calculated linear feed rate of the drill [in/min]

N = spindle speed [rpm]

f_r= feed per revolution of the drill [in/rev]

Table 2.3 Recommended Average Feed Rates HSS Drills [25]

Drill diameter (in)	Feed (in/rev)
under 1/8″	up to 0.002
1/8″ to 1/4″	0.002 to 0.004
1/4″ to 1/2″	0.004 to 0.008
1/2″ to 1″	0.008 to 0.012
1″ and over	0.012 to 0.020

2.3.3 Depth of cut

In addition to cutting speed and feed, material removal in drilling process depends on the vertical distance where the cutting tool enter in to work-piece. This travelling distance either to make blind hole or through hole is called depth of cut, which expressed in millimeter or inch. When the depth of cut increases and the uncut chip thickness is kept the same, the specific contact stresses at the tool–chip interfaces, the chip compression ratio (the ratio of the chip and the uncut chip thicknesses) and the average contact temperature remain unchanged. Therefore, an increase in the depth of cut should not change the tool wear rate if the machining is carried out at the optimum cutting regime [23]. Since depth of cut is one of main cutting parameters, so its value affect greatly on the machining performance and economy. Various effects of DOC are during machining are [24]:

- Larger DOC indicates higher material removal rate (MRR), as MRR is proportional to the DOC. So productivity of machining can be enhanced by employing larger DOC.
- Cutting force requirement depends on chip load, which is proportional to DOC. Thus larger value of DOC can increase cutting force, which may hamper machining performance and induce vibration.
- Higher DOC may also break the cutting tool catastrophically, which is highly undesirable.
- DOC also influence chip thickness, type of chip produces, shear deformation, etc., which are indication of machinability

Since DOC value is an important parameter to judge machining performance as well as economy, so an optimum value should be chosen depending on a number of factors, as discussed below [24].

- Larger DOC increases MRR and thus better productivity is obtained.
- For finish cut, lower DOC should be provided; whereas, for rough cut larger value of DOC can be provided.
- Various machining operations have the capability to handle various ranges of depth of cut.
- For machining hard and brittle material, a lower value of DOC is provided, otherwise the force may be very high and cutting tool may break.
- Since higher DOC increases cutting force and vibration, so the capability of machine tool should also be considered.
- Higher DOC needs more cutting power, as power is proportional to the DOC value. So available power should be taken care while selecting DOC.

Generally in drilling process as drilling holes deeper than three times the diameter of the drill, it is advisable to use optimum depth of cut intervals to remove the chips easily in order to minimize it effect on either cutting tool or work material. Therefore depth of cut is one of cutting parameters that to be considered in drilling operation to obtain optimum responses in addition to tool wear.

2.4 Tool wear in machining

Form productivity aspect, product quality and overall economy manufacturing by machining is core issues in order to be competent in global market. To manage those problems technical way of machining processes to be considered in manufacturing industry. During machining process either product quality or cost in manufacturing is affected due to unproper use of cutting tool for required work-piece with unoptimized cutting parameters (seed, feed, depth of cut, etc.). Among various types of machining challenges in metal manufacturing cutting tool wear is known response.

Prediction of tool wear is complex because of the complexity of machining system. Tool wear in cutting process is produced by the contact and relative sliding between the cutting tool and the work-piece and between the cutting tool and the chip under the extreme conditions of cutting area Thus, knowledge of tool wear mechanisms and capability of predicting tool life are important and necessary in metal cutting [25]. Generally, wear of cutting tools depends on tool material and geometry, work-piece materials, cutting parameters (cutting speed, feed rate and depth of cut), cutting fluids and machine-tool characteristics.

Tool wear illustrated using a curve to demonstrate the relationship between the amounts of flank (rake) wear and the cutting time or the overall length of the cutting path. Figure 2.3 shows the evolution of flank wear as measured after a certain length of cutting path. Normally, there are three distinctive regions that can be observed in such curves. The first region (region I in Figure 2.3) is the region of primary or initial wear. The relatively high wear rate (an increase of tool wear per unit time or length of the cutting path) in this region is explained by accelerated wear of the tool layers damaged during manufacturing or re-sharpening. The second region (region II in Figure 2.3) is the region of steady-state wear. This is the normal operating region for the cutting tool. The third region (region III in Figure 2.3) is known as the tertiary or accelerated wear region. Accelerated tool wear in this region is usually accompanied by high cutting forces, temperatures and severe tool vibrations. Normally, the tool should not be used in this region [26, 27].

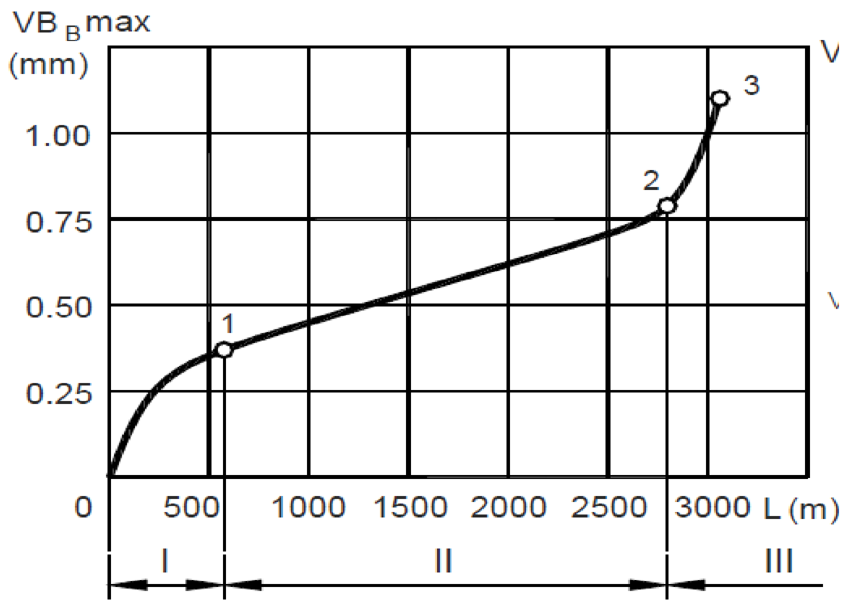


Figure 2.3 Tool wear curve [26]

In case of drilling, tool wear formed due to friction between work-piece material and cutting tool make the life span of cutting tool be short. In order to reduce this problem correct use of cutting parameters is necessary during machining time. At a time of drilling steel with a carbide drill bit by varying the cutting parameters (speed, feed, and helix angle), make vibration at the drill bit. If acceleration of this vibration is not well managed, it increases progression of tool wear [6]. In addition to vibrational effect on tool wear, high cutting temperature made during drilling process reduces tool life of cutter. High production machining and drilling with high cutting velocity, feed, and depth of cut associated with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces dimensional accuracy and surface integrity but also imparities in tool wear [1].

When drilling stainless steel using uncoated carbide drill with different level of speed and feed diameter error, cylindercity, and surface roughness mostly influenced on them. From these as the cutting speed increase, the surface roughness decrease. In contrary when feed rate increase, surface roughness increase. At the same time tool wear also influence surface roughness [16]. During drilling of stainless steel AISI 303 work material with carbide tool material, influence of the depth of cut on the tool wear rate is negligibly small if the machining is carried out at the optimum cutting regime as shown in Figure 2.4 [23].

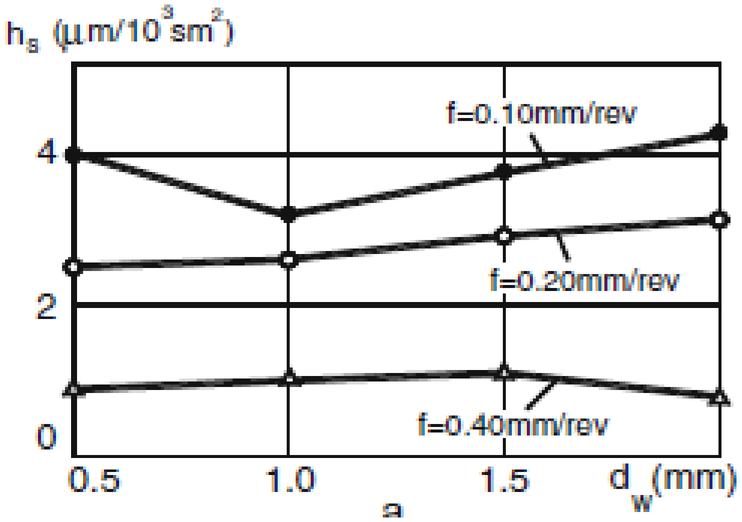


Figure 2.4 Influence of the depth of cut on the tool wear rate [23]

In generally the performance of cutting tool depends on either internal or external (environment) parameters which affect tool wear. There are different types of that based on the appearance of cutting tool. The major wear mechanisms that causes wear at cutting tool are [28]:

- Thermo-mechanical wear
- Chemical wear (diffusion and oxidation)
- Adhesive wear
- Abrasive wear

2.4.1 Thermo-mechanical wear

Thermo-mechanical wear is one of wear mechanism which formed due to consequence of the combination of, mechanical load and elevated temperature during machining, which depends on cutting parameters (speed, feed, cutting fluid etc.). Thermal load or temperature and mechanical load have a direct relationship with cutting velocity and feed rate respectively.

2.4.2 Adhesive wear

When two surface under plastic contact that has enough bonding strength to one another which prevent the relative sliding (adhesive wear). In this case there is large plastic deformation in the contact zone due to compression and shearing, which made crack initiation and propagation.

2.4.3 Chemical wear

Either diffusion or oxidation is main characterization of chemical wear during machining. When tool material has high affinity to the work-piece, diffusion wear is formed. Another type of chemical wear is a wear due to oxidation. This wear is formed when supply of oxygen either from atmosphere or cutting fluid into tool work- piece contact zone.

2.4.4 Abrasive wear

If the particles abrade and removes tool material due to the hardness of work-piece, it forms abrasive wear mechanism. This wear usually occurs on the flame of tool and has largest impact on tool wear at low to medium cutting speed.

2.5 Cutting tool Temperature in machining

A thermal phenomenon is one of the most important issues in machining of the metal, especially in drilling process which generated at tool work interface. The increase of tool temperature caused by it has strong effect on tool wear tool life and tool thermal deformation. The studies of these thermal fields in machining are very important for the development of new technologies aiming to increase the tool lives and to reduce production costs [29]. Specially the deeper the hole, the greater the tendency of chips to pack and clog the flutes of the drill which form friction. This friction creates heat, and heat build-up in the drill bit can cause failure and breakage. This increases the amount of heat generated and prevents the cutting lubricant from conducting heat away from the drill point (where all the cutting occurs). Excessive buildup of heat at the drill point results in premature failure [25].

During machining, the consumed power is largely converted into heat resulting high cutting temperature near the cutting edge of the tool. Many of the economic and technical problems of machining are caused directly or indirectly by this heating action. Excessive temperatures directly influence the tool wear on the tool face and tool flank and inducing thermal damage to the machined surface. The amount of heat generated varies with the type of material being machined and machining parameters especially cutting speed, which had the most influence on the temperature as shown main effect plot in Figure 2.5. All these difficulties lead to high tool wear, low material removal rate (MRR) and poor surface finish. In actual practice, there are many factors which affect these performance measures, i.e. tool variables (tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle, etc.), work-piece variables (material, hardness, other mechanical properties, etc.) and cutting conditions (cutting speed, feed, depth of cut and cutting fluids). So it is necessary to select the most appropriate machining settings in order to improve cutting efficiency [30]. Therefore, a reduction in speed and feed to reduce the amount of heat is required in deep-hole applications where coolant cannot be effectively applied. Consequently, feeds and speeds should be reduced up to 50% when drilling holes deeper than 3 drill diameters [25]. Dry drilling of AISI 304 austenitic stainless steel using vertical machining center (VMC) machine with HSS drill tool carried out taking different level of speed and feed to demonstrate the effect of those parameters on the cutting tool. After machining of material, the feed rate has a greater influence on a twist drill bit temperature and in contrary the spindle speed has smaller influence [21, 31].

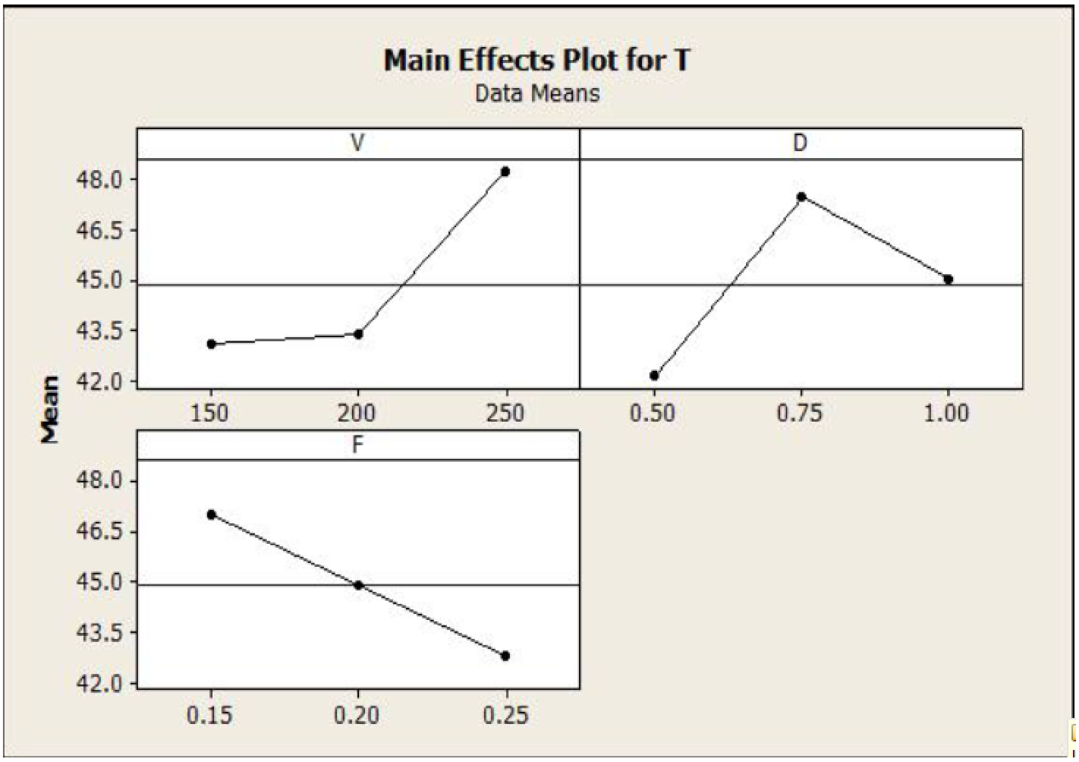


Figure 2.5 Main effect plot of cutting parameter vs workpiece temperature [30]

2.6 Surface Roughness in machining

The manufacturing industries are focus on producing high quality products in time at minimum cost. However, the poor machinability makes it a typical difficult-to-cut material, often resulting low hole quality when drilling process is conducted on material [13]. Since surface roughness is one of the critical performance parameter that has an appreciable effect on several mechanical properties of machined parts such as fatigue behavior, corrosion resistance, creep life, etc., achieving the desired surface quality of products has great importance for the functional behavior of the mechanical parts in manufacturing industry. The most obvious factors influencing the surface finish of drilled holes are cutting speed, feed rate and depth of cut. Among those parameters, cutting speed and feed rate significantly affect the surface roughness of the machined surface whereby high cutting speed and low feed rate resulted in the better surface finish. In material removal processes, an improper selection of cutting conditions will result in rough surfaces and dimensional errors. Therefore, it is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling.

To deeply drill AISI 321 austenitic stainless steel material with solid carbide cutting tool by varying the level of parameters (cutting fluid, speed, and feed) made a change in surface roughness of work-piece. From those parameters in order to get minimum surface roughness the contribution of speed takes highest position and cutting fluid and feed maintain next position. However hole-depth has a lowest effect on the surface roughness as shown in Table 2.4 of ANOVA result in percentages contribution [18, 32, and 3]. Maintaining lowest spindle speed and feed rate and an increase in peck depth results in maximum tool life. But decrease in peck depth maintains good surface finish on working material. In another way the quality of hole at exit periphery is poor related to entry of hole as shown in Figure 2.6 [2]. Sultan and other worked to demonstrate the effect of machining parameters on tool wear and hole quality of AISI 316L stainless steel. In this investigation they concluded from the result that, the quality characteristics of hole mostly influenced by cutting speed and feed rate [13].

Table 2.4 ANOVA result [18]

Machining parameters	% Contribution
Cutting fluid	25.1
Speed	27.02
Feed	22.99
Hole-depth	14.29
Total	100

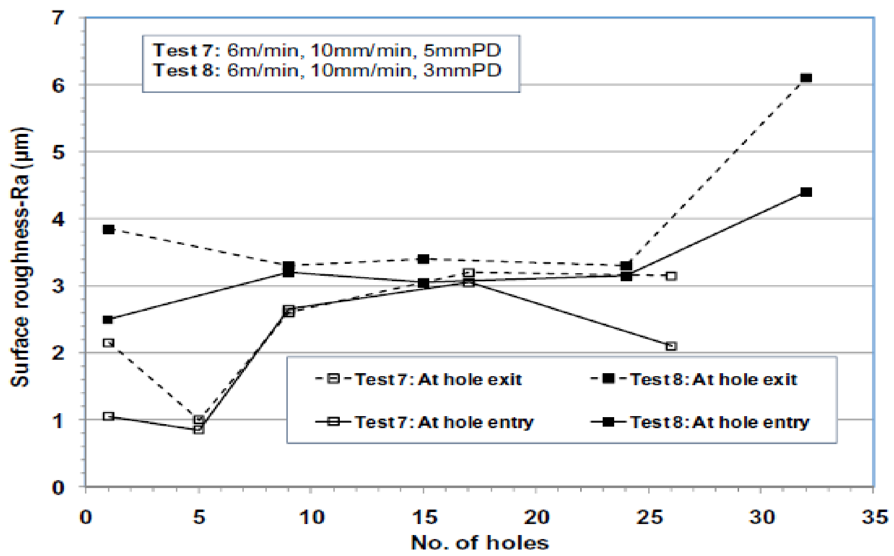


Figure 2.6 Work-piece surface roughness's vs. number of hole [2]

2.7 Optimization method

Optimization of machining processes is one of the most widely investigated problems in machining. The objective functions in the machining problems are: (1) minimization of cost of machining, (2) maximization of production rate, (3) maximization of profit rate and (4) continual improvement of output quality in product and processes include modeling of input-output and in process parameters relationship and determination of optimal cutting conditions. A weighted combination of these objectives may be taken, or the problem can be solved as a multi-objective optimization problem. In the machining optimization problem, there are constraints on tool life, surface finish, cutting force, machining power, etc. [28, 7].

Basically in drilling process the optimizing of cutting parameters (cutting speed, feed, depth of cut, cutting fluid etc.) is necessary to minimize the surface roughness of working material, tool wear, tool temperature etc. Among different optimization techniques well known methods method are:

- Taguchi method
- Artificial neural networking (ANN)
- Genetic algorithm(GA)

2.7.1 Taguchi method

Design of experiment (DOE) is one of a scientific method of conducting experiments, which enable the experimenter to draw valid inferences on the unknown parameters based on the data collected through experiments. The use of the DOE makes behaviors of the researcher purposeful and organized, and appreciably facilitates and an increase in the productivity of the work and also in the reliability of the results obtained. The techniques for laying out experiments when multiple factors are involved, has been known for a long time and is popularly known as the factorial design of experiments. This technique helps the researcher to determine the possible combinations of factors and to identify the best combination for desired results. DOE provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. DOE involves a well-planned set of experimental runs, in which all parameters of interest are varied over a specified range, which are based on the preliminary experiments and systematic data results. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Factors may be either qualitative or quantitative [33]. In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. When the process conditions and product components that influence product quality identified, direct improvement maintained to enhance a product's manufacturability, reliability, quality, and field performance. Since resources are limited, it is very important to get the most information from each experiment work. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. In addition, a well-designed experiment will evaluate the effects that have identified as important. Designed experiments are often carried out in four phases: planning, screening, optimization, and verification.

- **Planning: -** Careful planning can avoid problems that can occur during the execution of the experimental plan. The preparation required before beginning experimentation based on problem. Steps need during planning are:
    - ✓ Define the problem
    - ✓ Define the objective
    - ✓ Develop an experimental plan that will provide meaningful information.
    - ✓ Make sure the process and measurement systems are in control.

- **Screening: -** In many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality. This reduction allows focusing process improvement efforts on the really important variables, or the "vital few." Screening may also suggest the "best" or optimal settings for these factors, and indicate whether or not curvature exists in the responses.
- **Optimization: -** After identified the important variables or "vital few" by screening, it is necessary to determine the "best" or optimal values for the experimental factors. Optimal factor values depend on the process objective that either to maximize process yield or reduce product variability.
- **Verification: -** Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

Essentially, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [12]. The Taguchi Method, transformed from traditional experimental design methods, was developed by Dr. Taguchi Genichi in 1949. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation. After World War II, the Japanese manufacturers were struggling to survive with very limited resources. If it were not for the advancements of Taguchi the country might not have stayed afloat let alone flourish as it has. Taguchi revolutionized the manufacturing process in Japan through cost savings. He understood, like many other engineers, that all manufacturing processes are affected by outside influences, noise. However, Taguchi realized methods of identifying those noise sources, which have the greatest effects on product variability. His ideas have been adopted by successful manufacturers around the globe because of their results in creating superior production processes at much lower costs. He wanted to reduce the number of experiments and effectively examine problems in the research and development of communication systems. Such a unique experimental design method could be used to improve the process and product design by combining orthogonal arrays with simple function computation.

Taguchi Method uses parameter design to improve the quality by defining the target functions aiming at the quality required for improvement, identify the factors and levels in the target functions, and apply orthogonal arrays to determine the allocation of experimental factors and the number of times so that fewer experiments are needed to acquire the same information obtained in full-factorial experiments. As a result, little experimental data needs to be analyzed to effectively improve product quality. Orthogonal Arrays and S/N Ratios are the major tools used in the Taguchi Method and emphasized the consideration of quality in product and process design. In other words, the emphasis was on reducing the variability of product performance by utilizing ANOVA to understand the effects of various significant factors in tolerance design and further setting the tolerance of different significant factors based on the costs of the significant factors to acquire the best quality and most robust design. Utilizing engineering knowledge to plan the experiments, the Taguchi Method focuses on finding a solution to achieve the objectives. The experimental results of Taguchi's experimental design method have the following advantages: high reproducibility, easy identification of the experimental variables, a reduced number of experiments, and easily understood analyses. The Taguchi Method therefore has been utilized for improving the industry and optimizing parameter design [38, 17]. As a result, the Taguchi method has become a powerful tool in the design of experiment methods. During experimental work, production of part affected either from external means or internal factors. Those factors made variation on the output result of product. In Taguchi experimental procedure, main factor influencing at the product/process are:

1) **Control factor**: - are one of design factor that are to be set at optimum level to improve quality and reduce sensitivity to noise. When drilling of metal with different cutting parameters (speed, feed, depth of cut etc.), the level of each parameters can be change up to maintain optimized result at the product. This parameter is called control factor.

2) **Noise factors:** - factor that represent the noise that is expected in production or in actual use of the product. Are factor whose values are hard to control during normal process or use condition.

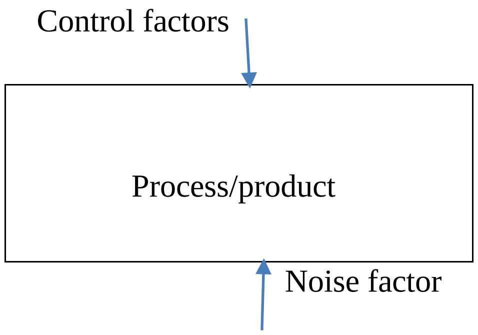


Figure 2.7 Taguchi factors of product

The steps followed during Taguchi method in order to get productive process are shown in Figure 2.7.

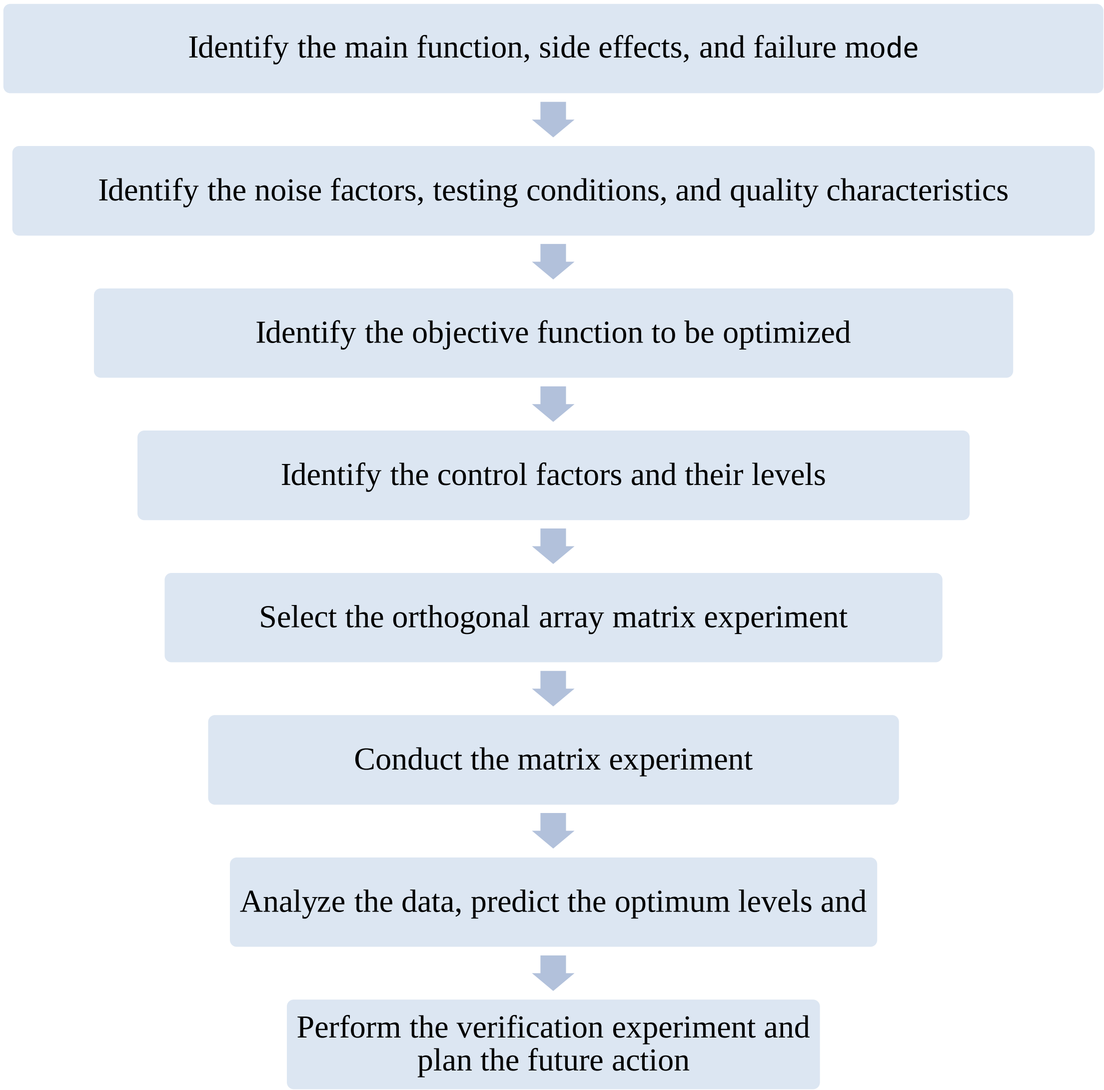


Figure 2.8 Steps in Taguchi method of optimization

2.7.2 Analysis of variance (ANOVA)

ANOVA is a statistical method used for determining individual interactions of all control factors with degree of Difference or similarity between two or more groups of data. In the analysis, important parameters are identified and the percentage distributions of each control factor were calculated to measure the corresponding effects on the quality characteristics. The performed experimental plan was evaluated at a confidence level of 95% [5, 20]. Analysis of variance (ANOVA) is a statistical procedure concerned with comparing means of several samples. It can be thought of as an extension of the F-test for two independent samples to more than two groups. This technique is very useful in revealing important information particularly in interpreting experimental outcomes and in determining the influence of some factors on other processing parameters. When performing an ANOVA procedure the following assumptions are required [34]:

- ✓ The observations are independent of one another.
- ✓ The observations in each group come from a normal distribution.

- ✓ The population variances in each group are the same (homoscedasticity)

The basic property of ANOVA is that the total sums of the squares (total variation) is equal to the sum of the SS_d (sums of the squares of the deviations) of all the condition parameters and the error, SS_e. In order to investigate which parameters significantly affected the performance characteristics, ANOVA was accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. The percentage contribution p by each of the process parameter in the total sum of squared deviations SS_T is a ratio of the sum or squared deviations SS_ddue to each process parameter to the total sum of squared deviations SS_T [18].

CHAPTER 3

3. Materials and Methodology

3.1 Tool and Work Materials

In this study the optimization of cutting parameters (speed, feed and depth of cut) are investigated on deep drilling of austenitic stainless steel with Rockwell hardness of 85B [27]. Holes are made by drilling each experimental selected work-piece using twist HSS drill bit of hardness value (Rockwell C scale) 65HRC [27].

3.2 Workpiece

Now days, the need of material with high corrosion or heat resistant, good mechanical properties and durability is enhancing in home and medical equipment, industry work, aerospace, logistics and others in different part of the world. In order to get those and other advantages, the selection of various grades of stainless steel work-piece material is important issues.

Stainless steel is one of the families of engineered materials selected primarily for its resistance to heat and corrosion. Stainless steel is an alloy based on iron which contains 10.5% or more of chromium. Chromium is the alloying element that gives corrosion resistance to stainless steels. It does this by combining with oxygen to form a transparent and thin chromium oxide protective film on the metal surface. The chromium oxide film is stable and protective in normal atmospheric or mild atmospheres and can be enhanced with higher chromium, nickel, molybdenum or other alloying elements. Chromium improves the stability of the film; molybdenum and chromium increase resistance to chloride penetration; and nickel improves film strength in strongly acidic environments. The increase of the chromium content above the minimum of 10.5% gives greater resistance to corrosion. Corrosion resistance can be further improved and a wide range of properties can be provided by adding 8% or more nickel [35].

Depending on their crystalline structure, stainless steel base metals are grouped in to three categories.

1) Austenitic stainless steel
2) Martensitic stainless steel
3) Ferritic stainless steel

3.2.1 Austenitic stainless steel

Austenitic stainless steels are those that contain chromium, nickel and manganese or simply chromium and nickel as the main alloying elements. They are identified as AISI 200 or 300 series types, respectively. Austenitic stainless steels can be hardened only with cold; the heat treatment only serves to soften them. In the ricotta condition, they are not attracted to a magnet, although some may become slightly magnetic after cold operation. The stainless steels of the 200 and 300 series are characterized by an excellent corrosion resistance, an exceptionally good formability and the ability to develop excellent resistance characteristics through cold working. Annealing, maximum corrosion resistance, ductility, good performance and tensile strength, high impact strength and no notch effect [35]. Typical of the 300 series, grade 304 is widely known as austenitic stainless steel.

Due to different type of corrosive environment, 304 series austenitic stainless steel is used in wide application areas. The most advantageous areas of 304 series austenitic stainless steel are:

- It can withstand corrosion in architecture
- It strongly resist rust in food processing industry
- It resist either organic or inorganic chemicals
- Type 304 austenitic stainless steel withstands different type of acid i.e. sulfuric acid, nitric acid etc. at moderate temperature
- It also widely used for storage of liquefied gases, equipment used for kitchen, hospital, transportation, waste-water treatment etc.

3.2.2 Martensitic stainless steel

Martensitic stainless steels are also straight-chromium types bearing AISI 400 series numbers, but having a carbon- to-chromium ratio higher than the Ferritic group. Consequently, when cooled rapidly from high temperature, they do harden, and in some cases to tensile strengths exceeding 200,000 psi. The martensitic 400 series types resist corrosion in mild environments (atmosphere, fresh water, weak acids, etc.); they have fairly good ductility; and they are always strongly magnetic. Typical of the martensitic grades is Type 410 with 12 percent chromium. Some of the martensitic have been modified to improve machinability, such as Types 416, 420F and 440F [35].

3.2.3 Ferritic stainless steel

Ferritic stainless steels are straight chromium types identified by 400 series numbers. The low carbon-to-chromium ratio in the Ferritic eliminates effects of thermal transformation, which simply means that they are not hardenable by heat treatment. They can be hardened slightly by cold working.

The Ferritic 400 series stainless steels are strongly attracted to a magnet, have good ductility, and have good resistance to corrosion and oxidation. The corrosion resistance of Ferritic stainless steels is improved by increased chromium and molybdenum contents, while ductility, toughness, and weldability are improved by reducing carbon and nitrogen contents. The base composition is Type 430, with nominally 17 percent chromium. The free-machining Ferritic is Type 430F. There are several new Ferritic stainless steels with improved characteristics, which can be classified as follows; those with about 18 percent chromium having corrosion resistance similar to Type 304, such as Type 444, and those with more than 18 percent chromium with resistance to corrosion comparable or superior to Type 316 in many media [35].

Due to its many application areas, the present study on optimization of cutting parameters in order to get minimum tool wear, work-piece surface roughness and tool surface temperature is carried out by deep drilling of round AISI 304 austenitic stainless steel workpiece with diameter of 40mm and lengths of 50mm as shown in Figure 3.1.

Figure 3.1 AISI 304 austenitic stainless steel

As shown in Table 3.1 the chemical composition of AISI 304 austenitic stainless steel is measured using spectrometry (from Hibret manufacturing and machine building industry), which is a non-destructive analytical technique used to identify and determine the concentration of elements present in solid, powdered and liquid samples.

Table 3.1 Chemical composition of AISI 304 Austenitic stainless steel as workpiece

Chemical composition											
C	Si	Mn	P	S	Cr	Mo	Ni	Co	Cu	V	Fe
0.17	0.55	1.18	0.012	0.022	15.82	0.24	8.76	0.077	0.30	0.05	72.8

3.3 Cutting tool

Different types of cutting tool materials, ranging from high carbon steel to diamonds, are used in today's manufacturing industry. It is important to note that there are differences between the materials of the instruments, what these differences are and how the correct tool is applied for each type of material selected. Different tool manufacturers give different names and numbers to their tool products. Although many of these names and numbers are similar, the applications of these materials can be completely different. When a tool change is required, a performance comparison must be performed before selecting the tool for the required job. The best tool is the one that has been carefully chosen to perform the job quickly, efficiently and economically. To produce economical and good quality parts, a cutting tool must have the following characteristics [36]:

Hardness: Hardness and strength of the cutting tool must be maintained at elevated temperatures also called Hot Hardness

Toughness: Toughness of cutting tools is needed so that tools don't chip or fracture, especially during interrupted cutting operations.

Wear Resistance: Wear resistance means the attainment of acceptable tool life before tools need to be replaced.

The materials from which cutting tools are made are all characteristically hard and strong. There is a wide range of tool materials available for machining operations as shown in Figure 3.2. General they classified in to [36]:

- ❖ Tool Steels and Cast Alloys
- ❖ Cemented Tungsten Carbide
- ❖ Ceramic and Cermet Tools
- ❖ Diamond Tools

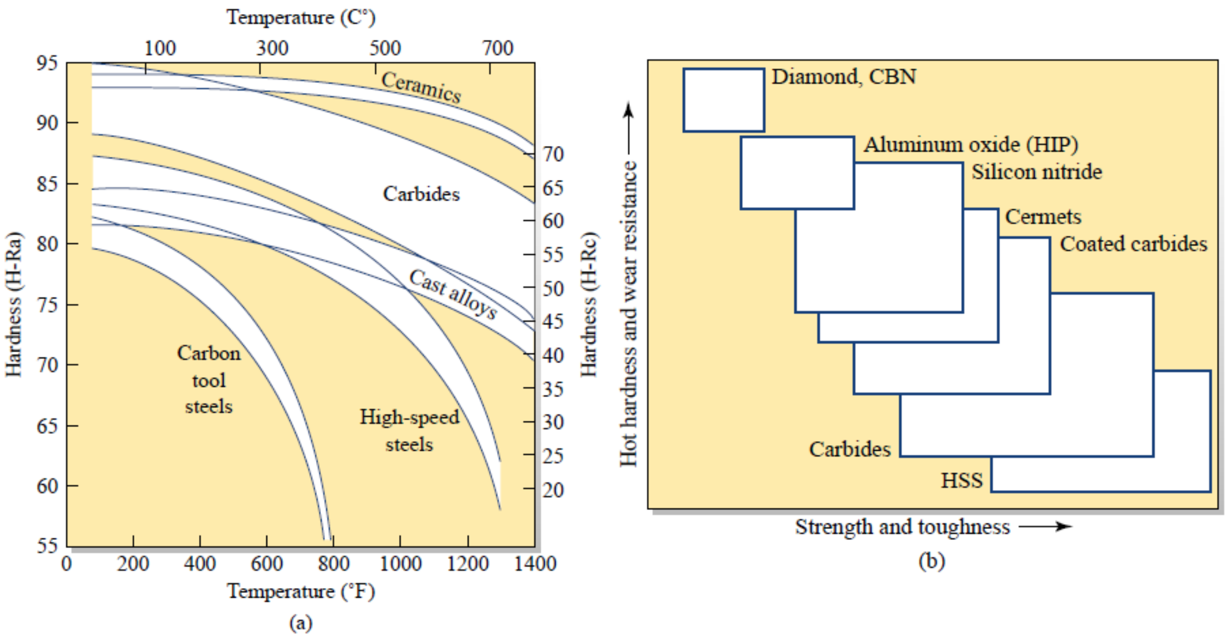


Figure 3. 2 Hardness of various cutting-tool materials as a function of temperature. (b) Ranges of properties of various groups of materials [36]

3.3.1 Tool Steels and Cast Alloys

a) Plain carbon tool steel: - It is the oldest of the instrument's materials. In simple terms, it is a steel with a high carbon content (steel containing about 1.05% carbon). This high carbon content allows hardening of the steel, offering greater resistance to abrasion wear. High carbon steel has worked well for many years. However, because it quickly quenches (softens) at relatively low cutting temperatures (300 to 500 degrees F), it is now rarely used as cutting material, except in rows, saw blades, chisels, etc. Carbon steel is limited to low temperature applications.

b) High Speed Tool Steel: The need for tool materials capable of withstanding cutting speeds and higher temperatures has led to the development of high-speed tool steels (HSS). The main difference between high speed steel and high carbon steel is the addition of alloy elements to harden and strengthen the steel and make it more heat resistant (hot hardness). Some of the most commonly used alloying elements are [36]:

Manganese	Molybdenum
Chromium	Vanadium
Tungsten	Niobium (columbium)
Cobalt	

While each of these elements will add some specific desirable features, it can generally be said that they add a deep hardening capability, high heat hardness, abrasive wear resistance and high speed steel resistance. These features enable relatively higher processing speeds and improved performance compared to high-carbon smooth steel. The most common high-speed steels used primarily as cutting tools are divided into the M and T series. The M series represents molybdenum tool steels and the T series represents tungsten type steels.

c) Cast Alloys: High-speed steel alloy elements, mainly cobalt, chromium and tungsten, improve the cutting properties, which metallurgical researchers have developed fusion alloys, a family of these materials without iron. The atypical composition for this type of tooling material was 45% cobalt, 32% chromium, 21% tungsten and 2% carbon. The goal of this alloy was to obtain a cutting tool with hot hardness higher than high speed steel [36].

3.3.2 Cemented Tungsten Carbide

At this time, the hard carbides consisted of the tungsten carbide base system with cobalt binders. These carbides had superior performance in the processing of cast iron, non-ferrous and non-metallic materials, but were disappointing when used for steel processing. Most of the subsequent hard carbide developments have been changes to the original patents, which mainly relate to the replacement of one or all of the tungsten carbide with other carbides, in particular titanium carbide and / or tantalum carbide. This led to the development of modern multi-metal cutting tool materials that enable high speed steel processing [36].

3.3.3 Ceramic and Cermet Tools

a) Ceramic Cutting Tools: The use of ceramics as cutting tool material has distinct advantages and disadvantages. The application of ceramic cutting tools is limited because of their extreme brittleness. They will fracture more easily when making heavy or interrupted cuts. However, the strength of ceramics under compression is much higher than HSS and carbide tools.

b) Cermet Cutting Tools: cermets are basically a combination of ceramic and titanium carbide. The word cermet is derived from the words 'ceramic' and 'metal'. The materials, approximately 70 percent ceramic and 30 percent titanium carbide. The strength of cermets is greater than that of hot pressed ceramics.

3.3.4 Diamond Tools

The two types of diamond are used as cutting tools are natural diamonds and industrial grade polycrystalline synthetic diamonds. As diamonds are pure carbon, they have an affinity for carbon ferrous metals. Therefore, they can only be used in non-ferrous metals.

There are several types of deep drilling processes currently used to make holes in metals. Among the approaches, the Drilling Gun and Drilling and Drilling Hole Drilling Association (BTA) are some of the known methods for deep drilling. But these approaches require special equipment or tools, machines and accessories. The costs for reliability, productivity and process stability. When compared to drilling methods, the drill bit is a more advantageous and dominant helical cutting tool in most industrial work. Helical drill bits are designed in a torsional way, as shown in Figure 3.3 to drill round holes quickly and accurately in most materials. They took the name of drill twist because they drill helical shape or slot structure used to support a high torque to withstand downward pressure on the drill and to withstand heat generated by friction [36].

Generally there are two well-known types of twist dills in drilling of engineering materials; the first one is high-speed steel (HSS) and the other one is carbide –tipped drill bit. HSS drills can be operated at much higher cutting speed than carbon steel drill without damage of burning and drill damage.

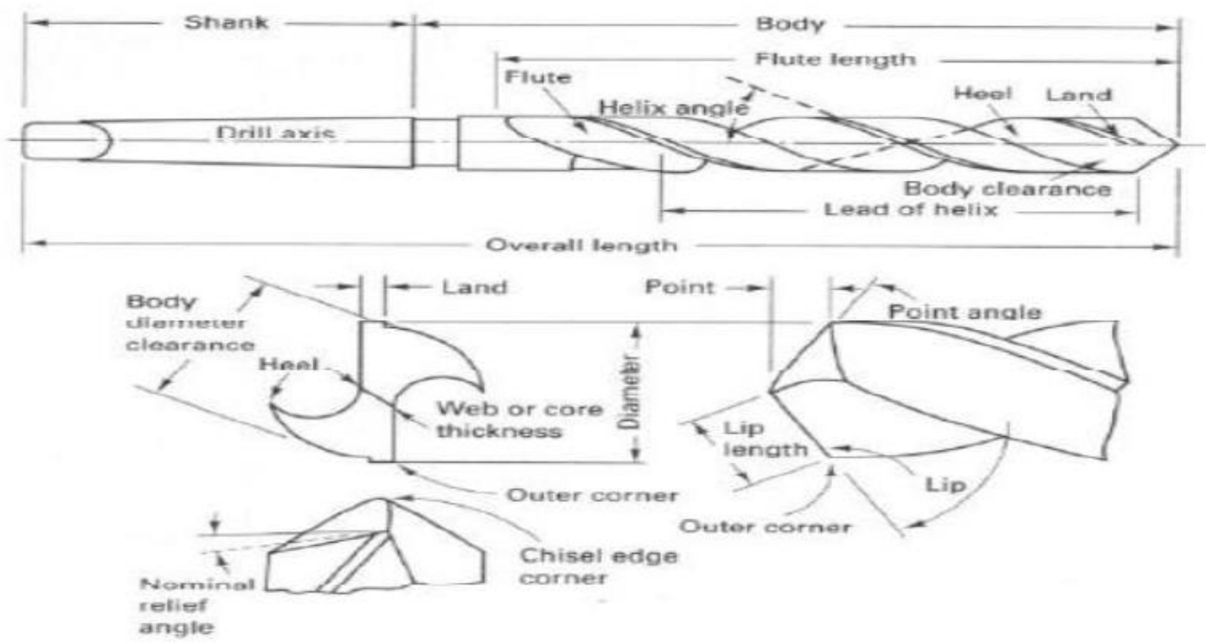


Figure 3 3 Twist drill nomenclatures [40]

The current work on deep hole making on austenitic stainless steel is performed by using twist high speed steel (HSS) drill bit as cutting tool. HSS twist drill has a dimension with a diameter of 10mm and flute length of greater than 5D, where D is diameter of drill bit.

3.4 Data collection instruments

In this experimental work, data collections of each experimental run output performed by measuring response either in work-piece or cutting tool. Those measuring instrument require in this work are:

- Electronic balance
- Infrared thermometer
- Mitutoyo surface tester

3.4.1 Electron weighting balance

The digital mass balances mostly used in the general Chemistry labs are very sensitive instruments applied for weighing substances in gram (g) up to four digital level (0.0000g). The electron balance pan is surrounded by a glass draft shield. The doors on the right, left, and top of the shield slide open to allow access to the weighing pan. When weighing objects, draft shield doors are closed to prevent changes in air pressure (and measured mass). The front of the balance has a bar and a display window. In order to turn most balances on, pressing the bar once and wait a few seconds for the digital display to read "0.0000 g". However, some balances require you to press "on/off" and then press the small circle to right of display for the digital display to read 0.000g. At the time of weigh an object, slide open one of the draft doors and place the object in the center of the pan.

After putting the draft door closed and wait a few seconds for the digital display to read a constant mass.

Different researchers used various types of instruments in order to measure tool wear of drill bit after machining of workpiece. Taskesen and other worked on analyzing and optimization of drilling parameters for tool wear and hole dimension accuracy in B4C reinforced Al-alloy. In the work they used Mitotoyo-TM-20x optical microscope having accuracy of 5 micro meters by manufacturing special tool holder in order to keep cutting tool edge parallel to horizontal [37]. The other researchers worked to analysis the effect of drilling parameters on tool wear and other output. During on their investigation they measure tool wear by using a techniques of drill weight comparison method before and after machining [38].

In present work each experimental run outcomes on drill bit with an effect of tool wear is measured using electron balance device as shown in Figure 3.4. Electron balance is a four digit weight measuring machine, which gives the values in gram. During the experimental work, each cutting tool, drill bit weight is measured before machining and measured again after machining has been done. Tools wear value, in this case taken as the weight difference before and after machining.

Figure 3. 4 Electron balance machine

3.4.2 Infrared thermometer

Temperature is the most frequently measured physical parameter. Temperature plays an important role as an indicator of the condition of a product or piece of machinery, both in manufacturing and in quality control. Accurate temperature monitoring improves product quality and increases productivity. Downtimes are decreased since the manufacturing processes can proceed without interruption and under optimal conditions. Infrared technology is not a new phenomenon. It has been utilized successfully in industry and research for decades. But new developments have reduced costs, increased reliability, and resulted in smaller noncontact infrared measurement devices. All of these factors have led to infrared technology becoming an area of interest for new kinds of applications and users. Advantages offered by noncontact temperature measurement are [39]:

- It is fast time saving
- It facilitates measurement of moving targets
- Measurements can be taken of hazardous or physically inaccessible objects
- Measurements of high temperatures (above 1300°C) present no problems
- There is no interference as no energy is lost from the target. Noncontact temperature measurement is wear free – there is no risk of contamination and no mechanical effect on the surface of the object.

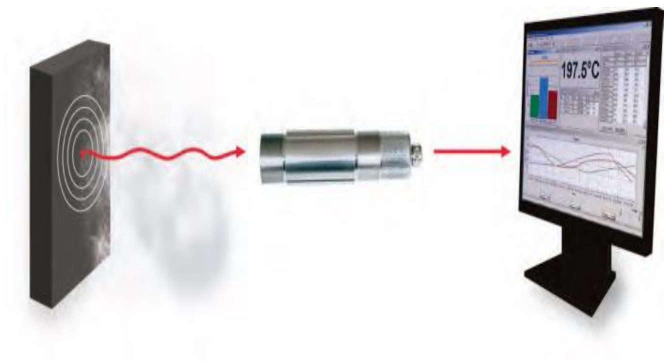


Figure 3. 5 Infrared measuring system [39]

Handheld infrared thermometers are ideal for applications where noncontact temperature measurements are required. Typical examples include moving objects, materials in contaminated or hazardous areas, and locations of high voltage or very high temperature.

Pyrometers are often fitted with an integrated aligning telescope for directly optically aiming at the spot. Sighting devices with video cameras and connected displays simplify this task for the user and/or allow the regular control of the pyrometer position also from a control station. Moreover pyrometers can be fitted with lasers that are either built-in or screwed in front of the device. The laser beam enables the user to aim at the measuring spot even more quickly and precisely, which considerably simplifies the handling, in particular of portable IR measuring devices. In particular, it is very useful to sight on the measuring spot with a laser for the measurement of moving objects and in poor light conditions. Basically laser sighting setups are classified in the following manner [39]:

A) Laser beam:-This is the simplest model, especially for devices with low optical resolution (for big measuring objects). The laser spot aims approximately at the center of the measuring object, but there is a noticeable error at close range as shown in Figure 3.6a.

B) Coaxial laser beam: - This laser beam comes out of the center of the optics and remains along the optical axis. The center of the measuring spot is precisely marked at any measuring distance shown in figure 3.6b.

C) Dual laser:-Twin laser with two aiming points can be used to show the diameter of the measuring spot over a long distance as shown in Figure 3.6c. With this, the user does not need to guess the size of the diameter or calculate it beforehand. Furthermore it prevents the user from making mistakes during the measurement. The infrared radiation (IR) and laser spot diameters are not the same at close distances. The distance between the laser beams is slightly greater than the spot being measured. This prevents the user from making full use of the geometrical resolution stated for this device.

D) Crossed laser: - The crossed laser is special version of the dual laser and is used for sensors with dedicated focal point as shown in Figure 3.6d.

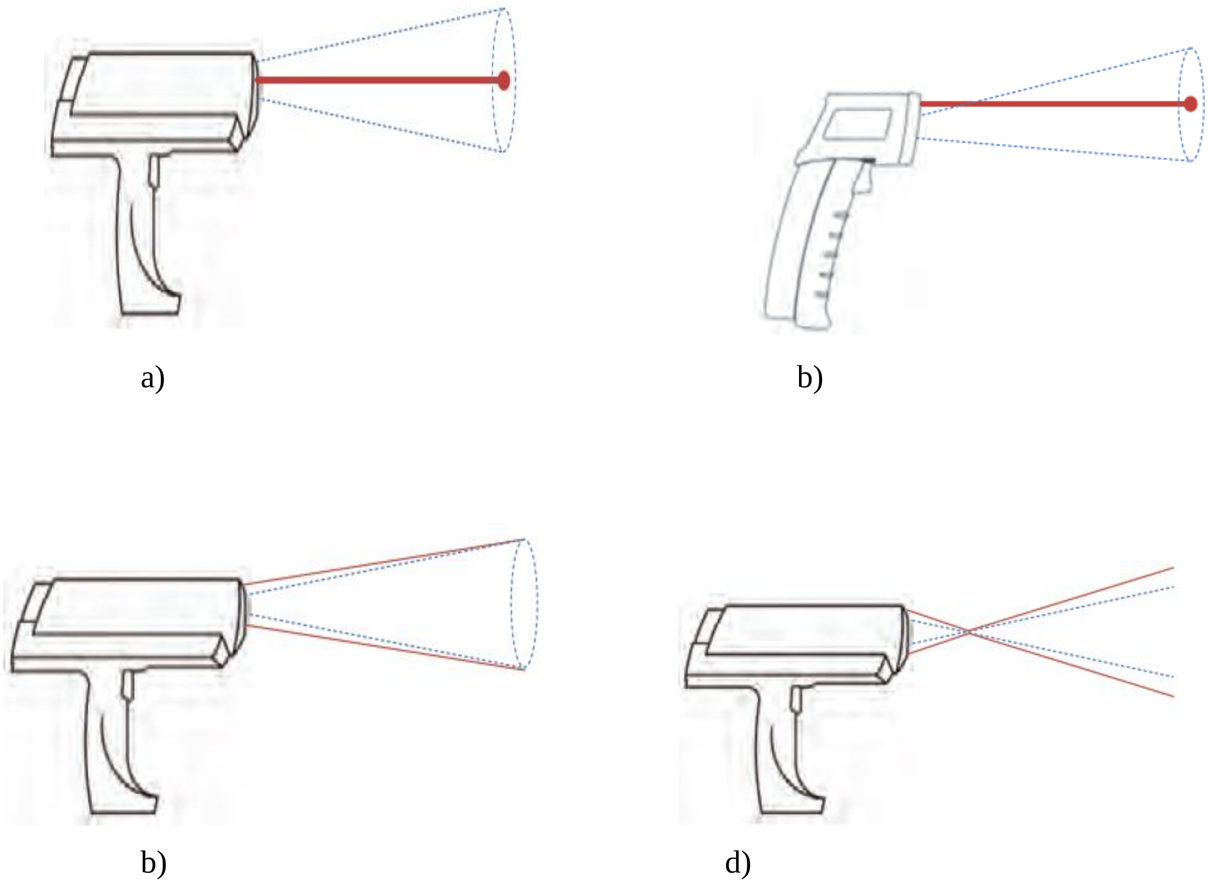


Figure 3. 6 Laser sighting [39]

In this study, in order to analyze the temperature difference appear in drill bit tip during changing the level of cutting parameters is measured using crossed laser infrared thermometer as shown on figure 3.7. Infrared thermometer is non-surface contact measuring device of temperature with LCD display. Table 3.2 show the description of infrared thermometer device used in this study.

Table 3.2 Specification of infrared thermometer

Mode	Specification
Distance to spot diameter ratio	50:1
Laser sighting	Crossed laser
Inferred radiation (IR)	-50^{o}C to 1600^{o}C

At each experimental step, the workpiece is drilled at CNC vertical machining center throughout hole at different level of parameters. When the drilling process finish, immediately HSS drill bit retract above workpiece then pressing on button of infrared thermometer, it emits laser light. During emitted light contact with drill bit tip it display the value of temperature at required position.

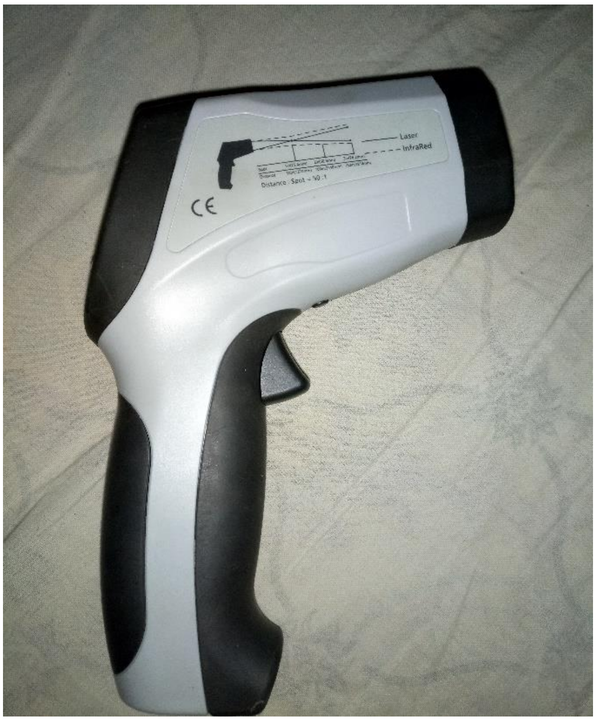


Figure 3. 7 VOLTCRAFT Infrared thermometer

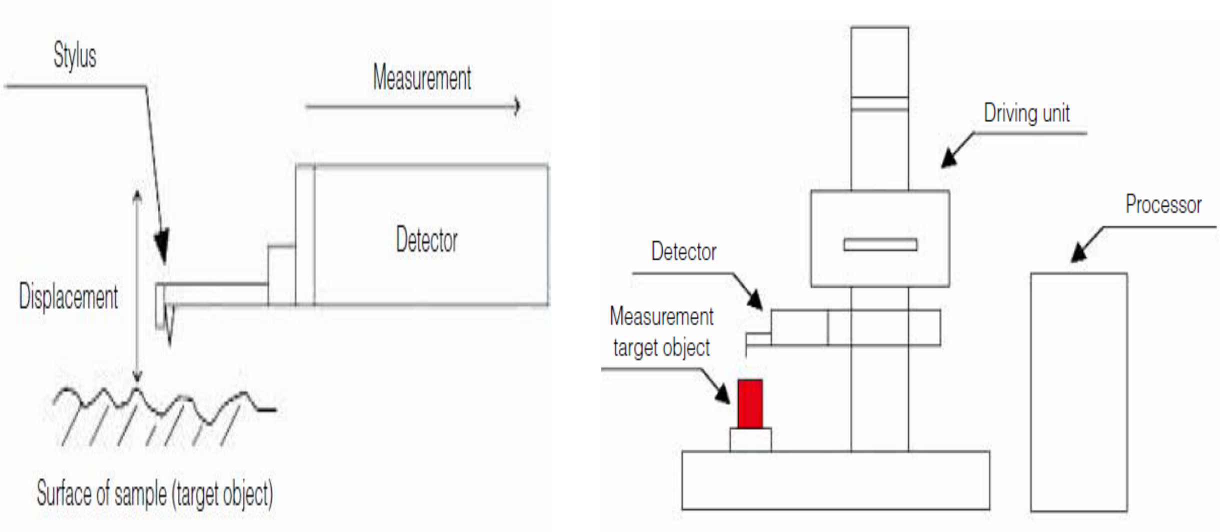
3.4.3 Surface roughness tester

When look at machined parts, it will notice that their surfaces embody have a complex shape made of a series of peaks and troughs of varying heights, depths, and spacing. Surface roughness is defined as the shorter frequency of real surfaces relative to the troughs. Specifically whether something is shiny and smooth or rough and matte, are due to the difference in surface roughness. Surface roughness not only affects the object's appearance, but it also produces texture or tactile differences. Appearance and texture can influence a product's added value such as class and customer satisfaction. If a part makes contact with something, its surface roughness affects the amount of wear or the ability to form a seal. If the part is to be painted, the roughness also affects the thickness of the paint. It has therefore been required in recent years to quantify the asperity of a surface. Various measurement tools are available for analyzing and evaluating surface roughness and shape. Generally, they are characterized as contact-type measuring instruments and non-contact type measuring instruments. Specifically surface roughness measurement is classified as [33]:

a) Contact-type Surface Roughness and Profile Measuring Instruments;
b) Atomic force microscope (AFM);
c) White Light Interferometer and
d) 3D Laser Scanning Microscope.

a) Contact-type Surface Roughness and Profile Measuring Instruments

In contact-type instruments, the stylus tip makes direct contact with the surface of a sample as shown in Figure 3.8. The detector tip is equipped with a stylus, which traces the surface of the sample. The vertical motion of the stylus is electrically detected. The electrical signals go through an amplification and digital conversion process to be recorded [33].



a) b)

Figure 3. 8 a) Surface roughness data collection b) Contact type surface roughness measuring system [33].

To accurately measure delicate shapes and roughness with a contact surface roughness tester, the tip radius of the stylus should be as small as possible with low contact pressure. The optical pencils are made of sapphire or diamond and their tip radius is usually about 10 µm or less. A tapered ballpoint pen shape is considered ideal for a needle [40].

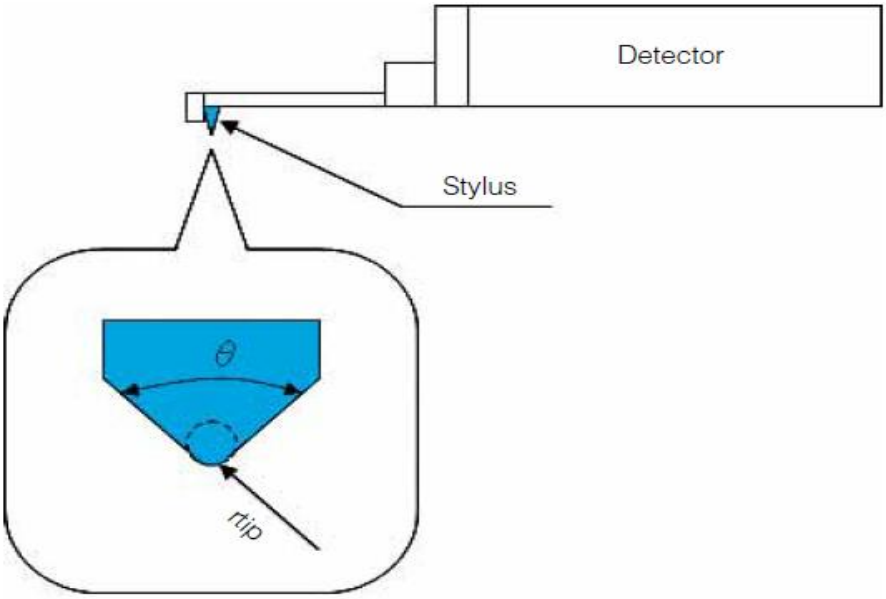


Figure 3.9 Shape of the stylus tip [33]

Contact-type Surface Roughness and Profile Measuring Instruments have its own advantages and disadvantage at the time of measuring surface of sample.

Advantages

- Clear wave profile
- Capable of long distance measurement

- Contact-type surface roughness testers provide reliable measurement, because they directly touch the sample

Disadvantages

- Stylus wear
- Measuring pressure can cause scratches on the sample surface
- Inability to measure viscous samples
- Measurement limited by radius of stylus tip
- Measurement takes time
- Requires sample cutting and processing for tracing by the detector

b) Atomic force microscope (AFM)

The atomic force microscope is one of the contact surface roughness measuring devices that measures the roughness of a sample using the atomic forces between the tip and the sample. Perform the measurement by moving the cantilever, equipped with a sharp tip (probe) at the end, near a sample surface at a distance of several nanometers. To maintain a constant force between the tip and the sample (a constant deflection of the cantilever), the atomic force microscope provides feedback to the piezoelectric scanner during the scan. The displacement provided as feedback to the piezoelectric scanner is measured to obtain the z-axial displacement, which is the structure of the surface. A common way to measure the movement of the piezoelectric scanner is by adopting the optical lever method in which a laser beam is emitted at the back of the cantilever and the reflected beam is detected by four-segment (or two-segment) photodiodes [33].

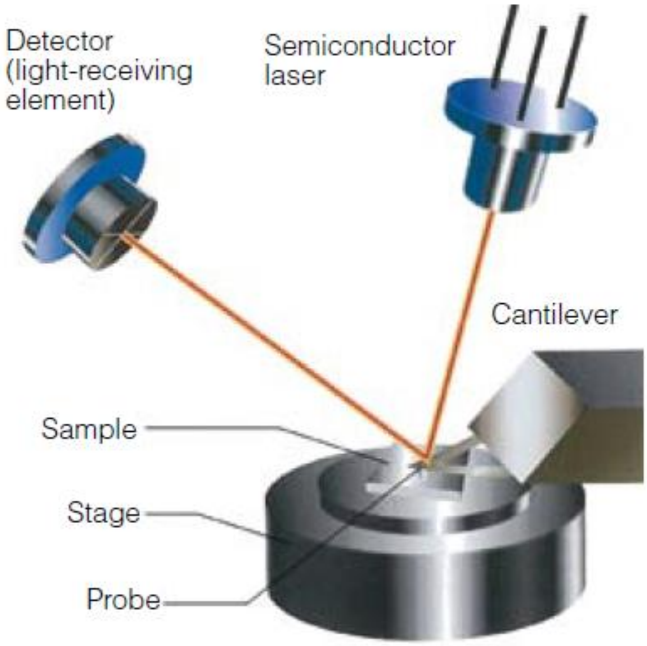


Figure 3.10 Atomic force microscope system [33]

C) White Light Interferometer

Light interference occurs when there is a difference in the distance traveled by light (light path) from the surface of a target object to a certain point. The white light interferometer uses this phenomenon to measure the roughness of a sample surface. The light emitted from the source (semiconductor laser, etc.) is separated into reference and measuring beams. While the reference beam is passed to the reference mirror through a mirror medium, the measuring beam is reflected and guided on the sample surface. The past beam is reflected by the reference mirror to the CCD image sensor and forms an interference pattern. The other beam is reflected on the sample surface, passes the mirror medium and forms an image on the CCD image sensor. The white light interferometer is designed such that the optical path length of the CCD element to the reference mirror and that of the CCD element to the sample surface are the same. The roughness on the sample surface makes these path lengths not the same, which results in the formation of an interference model on the CCD element. The number of lines in the interference pattern translates into peaks and valleys (heights) on the sample surface [33].

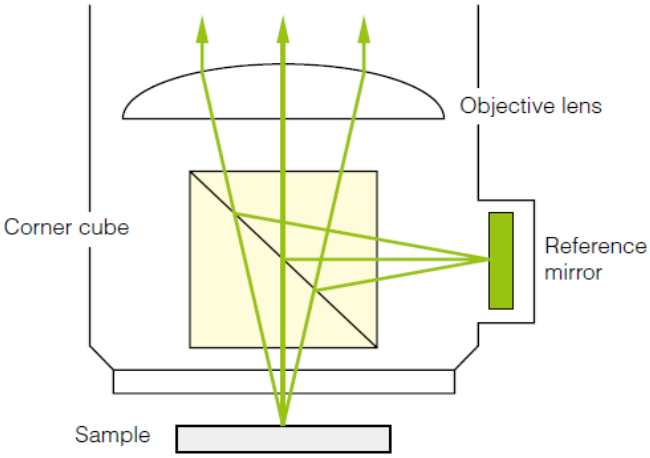


Figure 3.11 Diagram of an interferometer [33]

At the present work, surface roughness of the machined AISI 304 austenitic stainless steel holes was measured using Bellstone surface tester as shown in figure 3.12. It is one of surface roughness instrument which compatible with four standards namely, international standard (ISO), German standard (DIN), Japanese industrial standard (JIS), and American standard (ANSI) and is widely used in production site to measure surface roughness of various machinery processed parts by calculating corresponding parameters according to selected measuring condition and clearly display all measurement parameters. Table 3.3 show the description of Bellstone surface roughness tester used in this study.

Table 3.3 Specification of Bellstone roughness tester

Specification	
Parameter measurement	Ra, Rz, Rq, and Rt
Battery	Built-in lithium ion rechargeable
Display	Four digit
Radius of probe pin	5µm
Material of probe pin	Diamond
Operating condition	0-50 °C
Cutoff length (l)	0.25mm/0.8mm/2.5mm

Figure 3.12 Setup of Bellstone roughness tester

In order to distinguish the surface roughness of hole, first tester must have to calibrate using sample of roughness 1.56µm. After calibration the workpiece and tester are position at correct place by adjusting probe pin 90° with surface of material to be test. RS232 cable is connect both personal computer (PC) and tester in order to display either parameter value or flow chart of each parameters value. For each sample parametric value measured five times. Among four types of parameters value, Ra is selected at this study. In each sample test final Ra value evaluated as average of five measured values, which calculated using equation 3.1.

$$Ra_{av} = \frac{1}{n} \sum_{i=1}^{n} Ra_i \quad \ldots\ldots 3.1$$

Where; n is number of test for one sample

3.5 Experimental setup and procedure

Design of Experiment (DOE) is one of interesting method to improve product design or improve process performance in experimental investigation used to reduce cycle time required to develop new product or processes. Design of experiment is a test or series of test that the input or independent variable (parameter) of a process is change so that observation and identifying corresponding changes in the output response can be verify. The result of the process is analysed to find the optimum value or parameters that have a most significant effect to the process. One of approach from design of experiment Taguchi and analysis of variance (ANOVA) methods were used to analyse the experimental data to find out effect and contribution of independent variable (parameters) in the output response.

3.5.1 Taguchi method

Taguchi Method is one of the simplest and effective approaches for parameter design and experimental planning developed by a Japanese engineer Dr Genichi Taguchi. Taguchi method is not only reducing number of experimental design technique, but also a beneficial technique for high quality system design [5].

The Taguchi technique includes the following steps:

- Selection and evaluation of quality characteristics (responses) and process parameters or independent variable.
- Identification of number of levels for the process parameters and possible interactions between the process parameters.
- Selected appropriate orthogonal array for process parameters.
- Run experiments based on the arrangement of the orthogonal array.
- Analyse the experimental results using the S/N ratio and ANOVA.
- Selection of the optimal levels of process parameters.
- investigating the optimal process parameters through the confirmation experiment

3.5.2 Signal-to-Noise (S/N) ratio characteristics

Taguchi method uses *S/N* ratio to measure the variations of experimental design. In this the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value i.e. standard deviation (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D.

Generally there are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given as shown in equation 3.2, 3.3 and 3.4 [20].

Smaller the better: It is used where the smaller value is desired.

$$S/N = -10\log\frac{1}{n}\sum_{i=1}^{n} yi^2 \ldots\ldots (3.2)\ [20]$$

Where y = the measured value in a run/row or observed response value and n = number of replications or the number of measurements in a trial/row, in this study, n=1

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$S/N = -10\log\frac{\mu^2}{\sigma^2} \ldots\ldots (3.3)\ [20]$$

Where σ = mean and μ= variance

Higher the better: It is used where the larger value is desired.

$$S/N = -10\log\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2} \ldots\ldots (3.4)\ [20]$$

In the present work, the aim is to minimize a given responses i.e. tool wear, tool surface temperature and surface roughness by optimizing parameters. From these point of view, the selected signal to noise ratio is smaller the better and which mathematical calculated by using equation 3.2.

3.5.3 Selection of cutting parameters and their levels

In this study, machining process parameters like Speed, Feed and depth of cut of the drill were selected as control factor and each of them are conducted with three levels as shown in table 3.4.

Table 3.4 Machining Parameters and there Levels

Symbol	Machining parameters	Level 1	Level 2	Level 3
A	Speed(m/min)	6.28	9.42	12.56
B	Feed(mm/rev)	0.1	0.15	0.2
C	Depth of cut(mm)	0.3	0.5	0.7

3.5.4 Selection of Orthogonal Array

In the Taguchi method, orthogonal array can provide an effective experimental performance with a minimum number of experimental trials. The configuration of orthogonal arrays is determined with respect to total degrees of freedom of the targeted function [5]. In order to select an appropriate orthogonal array for experiments, the total degrees of freedom need to be calculated. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. Total degree of freedom computed by summation of all values which gain from subtracting one from each level and adding overall degree of freedom. For example if there are six two-level process parameter, then the total degree of freedom be seven.

Since in this study there are three process parameters (speed, feed and depth of cut) each of them with three levels, the total degree of freedom is seven. Once the degrees of freedom are evaluated, the appropriate orthogonal array is selected to serve the specific purpose. To select appropriate orthogonal array, there are two basic conditions. First the number of runs in orthogonal design greater than or equal to total degrees of freedom and second condition is the selected orthogonal array should be able to accommodate the factor level combination in the experiment. Therefore, the appropriate orthogonal array in this study is L_9 orthogonal array. The drilling parameters were assigned to each column and nine combinations of drilling parameters were formed as shown at Table 3.5.

Table 3.5 Orthogonal array of Taguchi L9

Experiment No.	Cutting parameters		
	A	B	C
1	6.28	0.1	0.3
2	6.28	0.15	0.5
3	6.28	0.2	0.7
4	9.42	0.1	0.5
5	9.42	0.15	0.7
6	9.42	0.2	0.3
7	12.56	0.1	0.7
8	12.56	0.15	0.3
9	12.56	0.2	0.5

After successfully selecting the level of cutting parameters (speed, feed, and depth of cut) as shown in Table 3.4 and arranging cutting parameters on selected orthogonal array as shown in

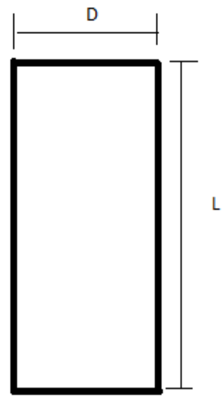
Table 3.5, the experimental work on deep drilling of AISI 304 austenitic stainless steel proceed. The experimental setup for drilling of AISI 304 austenitic stainless steel involved with in DMTG CNC vertical machining center (VMC) by mounting workpiece using three jaw vies on the table of machine as in Figure 3.13, which process work at required cutting condition of workpiece with a help of programed code. The detail information of CNC vertical machining center (VMC) is shown in Table 3.6.

Table 3.6 Specification of CNC vertical machining center (VMC)

Parameters	Specification
Feed rate	(1-10000) mm/min
Spindle speed range	(60-8000) rpm
The distance from spindle nose end face to table upper surface	(150-670)mm
Maximum X-axis travel distance	600mm
Maximum Y-axis travel distance	420mm
Maximum Z-axis travel distance	520mm
Work size of surface/table (L x W)	800mm x 420mm
Maximum tool diameter/ length	100/280mm

Figure 3.14 DMTG CNC vertical machining center (VMC)

When the required program code is decided, round bar AISI 304 austenitic stainless steel is tighten at base or table of vertical CNC milling machine. The selected diameter (D) of work-piece for experimental work of 40mm and has equal lengths value of 50mm with a total number of nine as shown in Figure 3.14.



a) b)

Figure 3.14 a) photo picture of AISI 304 austenitic Stainless steel sample b) dimensional Specification

To dry drilling of AISI austenitic stainless steel, twist HSS drill bit is used as a cutting tool with specification as shown in Table 3.7. For each experimental work new drill bit is used as shown in Figure 3.15.

Table 3.7 Specification of twist HSS drill bit

Parameters	Specification
Tool diameter(mm)	10
Flute length(mm)	50
Shank length(mm)	46
Point angle(degree)	118

Figure 3.15 HSS drill bit for drilling

The drilling procedure starts by following steps in selected Taguchi orthogonal array as listed in Table 3.5. At each experimental run of drilled the hole, infrared thermometer immediately induced to measure the temperature at the tip of drill bit.

As described in section 3.4.1 after completing drilling process in each of experimental steps, the tool wear of HSS drill bit is measured using electron balance device taking the values by differentiating the weight of HSS drill before dry drilling and after drilling accomplish.

In similar manner as mansions in section 3.4.3, the hole surface finish of AISI 304 austenitic stainless steel when drilling accomplish is measured using Bellstone surface tester.

CHAPTER 4

4 Results and Discussion

4.1 Analysis of the signal-to-noise (S/N) ratio

The Taguchi method uses S/N ratio to analysis the variations of the experimental design. As defined in Signal-to-Noise (S/N) ratio characteristics, there are three categories of performance characteristics, i.e., the lower-the-better, nominal the-better and the higher-the-better. Since in this study the aim is to obtain minimum tool wear, tool surface temperature and surface roughness, lower-the-better performance characteristic is chosen. The equation of "smaller is the better" (Eq. (3.2)) was selected for the calculation of S/N ratio. The experimental values of each response and calculation of S/N ratio in column of run formatted in Table 4.1, 4.2, and 4.3

Table 4.1 S/N ratios of experimental results for tool wear

Exp. No.	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Tool wear (g)	S/N ratio
1	6.28	0.1	0.3	0.0311	30.1448
2	6.28	0.15	0.5	0.0263	31.6009
3	6.28	0.2	0.7	0.0367	28.7067
4	9.42	0.1	0.5	0.0481	26.3571
5	9.42	0.15	0.7	0.0361	28.8499
6	9.42	0.2	0.3	0.0298	30.5157
7	12.56	0.1	0.7	0.0399	27.9805
8	12.56	0.15	0.3	0.0293	30.6626
9	12.56	0.2	0.5	0.0475	26.4661

Table 4.2 S/N ratios of experimental results for tool surface temperature

Exp. No.	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Tool surface Temperature(°C)	S/N ratio
1	6.28	0.1	0.3	54.9	-34.79
2	6.28	0.15	0.5	46.2	-33.29
3	6.28	0.2	0.7	58.3	-35.31
4	9.42	0.1	0.5	81.0	-38.17
5	9.42	0.15	0.7	56.3	-35.01
6	9.42	0.2	0.3	51.8	-34.29
7	12.56	0.1	0.7	61.0	-35.71
8	12.56	0.15	0.3	50.1	-33.99
9	12.56	0.2	0.5	80.0	-38.06

Table 4.3 S/N ratios of experimental results for surface roughness

Exp. No.	Speed (rpm)	Feed (mm/rpm)	Depth of cut (mm)	Surface roughness (µm)	S/N ratio
1	6.28	0.1	0.3	4.9984	-13.98
2	6.28	0.15	0.5	11.558	-21.26
3	6.28	0.2	0.7	5.145	-14.23
4	9.42	0.1	0.5	13.786	-22.79
5	9.42	0.15	0.7	9.8128	-19.84
6	9.42	0.2	0.3	10.8686	-20.72
7	12.56	0.1	0.7	7.4716	-17.47
8	12.56	0.15	0.3	6.9042	-16.78
9	12.56	0.2	0.5	7.3428	-17.32

In order to find the find out the effects of different parameters and as well as their levels, mean S/N ratio has been calculated. The mean S/N ratio calculated by, averaging the S/N ratios for each level of the cutting parameters as shown in Table (4.4, 4.5 and 4.6). Which mean that for "R" response with a level of "i", mean S/N ratio be dividing total sum of S/N ratio at a given level "i" into total number of level that given at equation 4.1 and 4.2.

Total S/N ratio, $\eta_i = \sum_{j=1}^{n} S/N_j$ ……………………………………………….4.1

Where; i= nomclature of level

j = number for$i$'s level

Mean S/N ratio, m = $\frac{\eta_i}{n}$ ……………………………………………………………….4.2

Where; n is total number of level

In each mean S/N ratio table, the lager value of delta (Δ) selected as most affecting cutting parameter responses. In order to distinguish the rank of each cutting parameters on a given response, delta value (Δ) value is calculated by subtracting minimum value of mean S/N ratio form maximum value of mean S/N ratio as shown in equation 4.3.

Delta (Δ) = $(\text{mean S/N})_{\text{max}}$ - $(\text{mean S/N})_{\text{min}}$ …………………………...4.3

The optimum conditions on this approach obtained by sorting the delta in an order of significantly affecting the process.

Table 4.4 Mean S/N ratio of tool wear

Level	speed	Feed	Depth of cut
1	30.15	28.16	30.44
2	28.57	30.37	28.14
3	28.37	28.56	28.51
Delta (Δ)	1.78	2.21	2.30
Rank	3	2	1

Table 4.5 Mean S/N ratio of cutting tool temperature

Level	speed	Feed	Depth of cut
1	-34.46	-36.22	-34.36
2	-35.82	-34.09	-36.51
3	-35.92	-35.89	-35.34
Delta (Δ)	1.46	2.13	2.15
Rank	3	2	1

Table 4.6 Mean S/N ratio of surface roughness

Level	speed	Feed	Depth of cut
1	-16.49	-18.08	-17.16
2	-21.12	-19.29	-20.46
3	-17.19	-17.42	-17.18
Delta (Δ)	4.63	1.87	3.3
Rank	1	3	2

From Table 4.4 it is clear show that depth of cut (DOC) is the most influencing factor on the tool wear followed by feed and cutting speed. In similar manner, Mean S/N ratio of tool surface temperature table show that depth of cut is more influencing parameter at when related to speed and feed. Table 4.6 show that speed is major affecting factor at the surface roughness of workpiece and feed is least influencing parameter.

4.2 Analysis of Variance (ANOVA)

The purpose of ANOVA was to determine effect of individual parameters which significantly affected the performance characteristics with the help of percentage contribution of individual parameters**.** In this study, Minitab 17 software ANOVA module used to investigate the effect of parameters and further analysed by main effect plot on each responses. In each Table (4.7, 4.8, and 4.9) of ANOVA result for a given responses the following formulas are used: in order to find percentage contribution, it is necessary of calculating degree of freedom, sum of square, mean square and P-value of each machining parameters. When formulating, procedure maintained by Minitab 17 software it follows the equations at 4.3, 4.4, 4.5, and 4.6.

Degree of freedom (DOF) = level of parameter-1…………………4.3

Sum of square (SS) = $(\sum(\frac{A^2}{n})) - \frac{T^2}{N}$ ………………………………4.4

Where; A is measured value of responses in each level

N is total number of experiment that run

T is total measured value of responses

N is number of sample run in a given level

Mean square is calculated easily dividing sum of squire in to DOF, which mean:

Mean squire (MS) = SS/DOF ……………………………….4.5

%C = (sum of square of individual factor)/ (total sum of square)………….4.6

Where; %C is Percentage contribution

Statistically, there is a tool called the P - test to see which process parameters have significant effect on the quality characteristic. Usually, when P-values less than 0.05 are considered to have a statistically significant contribution to the performance measures. This analysis was carried out for significance level of α=0.01 i.e. for a confidence level of 95%.

Table 4.7 ANOVA result for tool wear

Machining Parameters	DOF	Sum of Square	Mean Square	p-value	Contribution (%)
Speed	2	0.000102	0.000051	0.426	20.56
Feed	2	0.000142	0.000071	0.347	28.62
Depth of cut	2	0.000177	0.000089	0.298	35.69
Error	2	0.000075	0.000038		
Total	8	0.000496			

Table 4.8 ANOVA result for cutting tool surface temperature

Machining Parameters	DOF	Sum of Square	Mean Square	p-value	Contribution (%)
Speed	2	210.1	105.1	0.510	16.94
Feed	2	379.4	189.7	0.365	30.59
Depth of cut	2	432.5	216.2	0.335	34.87
Error	2	218.2	109.1		
Total	8	1240.3			

Table 4.9 ANOVA result for surface roughness

Machining Parameters	DOF	Sum of Square	Mean Square	p-value	Contribution (%)
Speed	2	36.167	18.083	0.217	49.63
Feed	2	4.075	2.038	0.711	5.59
Depth of cut	2	22.628	11.314	0.307	31.05
Error	2	10.004	5.002		
Total	8	72.874			

Table 4.5 shows ANOVA results for tool wear. It is observed that, depth of cut (35.69%) is the most significant cutting condition followed by feed (28.62%) and cutting speed (20.56%) which has least effect in controlling the tool wear. However all of the parameters are not statistically significant. From the analysis of the Table 4.6 shows that P-value for all of cutting parameters (cutting speed, feed and depth of cut) greater than 0.05. It means that neither of those factor are statically significant on tool surface temperature. But they have a percentage contribution of 16.94%, 30.59%, and 34.87% for speed, feed, and depth of cut (DOC) respectively. ANOVA result for surface roughness at mention in Table 4.9 show that cutting speed is most significant parameter with a contribution of (49.63%), depth of cut has a contribution of (31.05%) and feed with a least contribution of (5.59%) at the surface roughness of workpiece. Since for all of factors calculated P-value is greater than α-value, they are not statically significant.

4.3 Main effect plots

The data in this study was further analyzed by using main effect plot, which determine the optimal design conditions to obtain the maximum or minimum value of responses. Since at this work main objective is to reduce the effect of cutting parameters on tool wear, surface roughness (good surface finish) and cutting tool surface temperature, factor which give minimum response has been selected as optimum value. In order to analysis cutting condition, Minitab 17 software package is used, which is plotted by evaluating mean of response at each level of parameters. In the plots it show the variation of individual response with the cutting parameters (cutting speed, depth of cut and feed) separately. At the time of plotting Minitab 17 display horizontal-axis as process parameters at three level and vertical-axis as the response value.

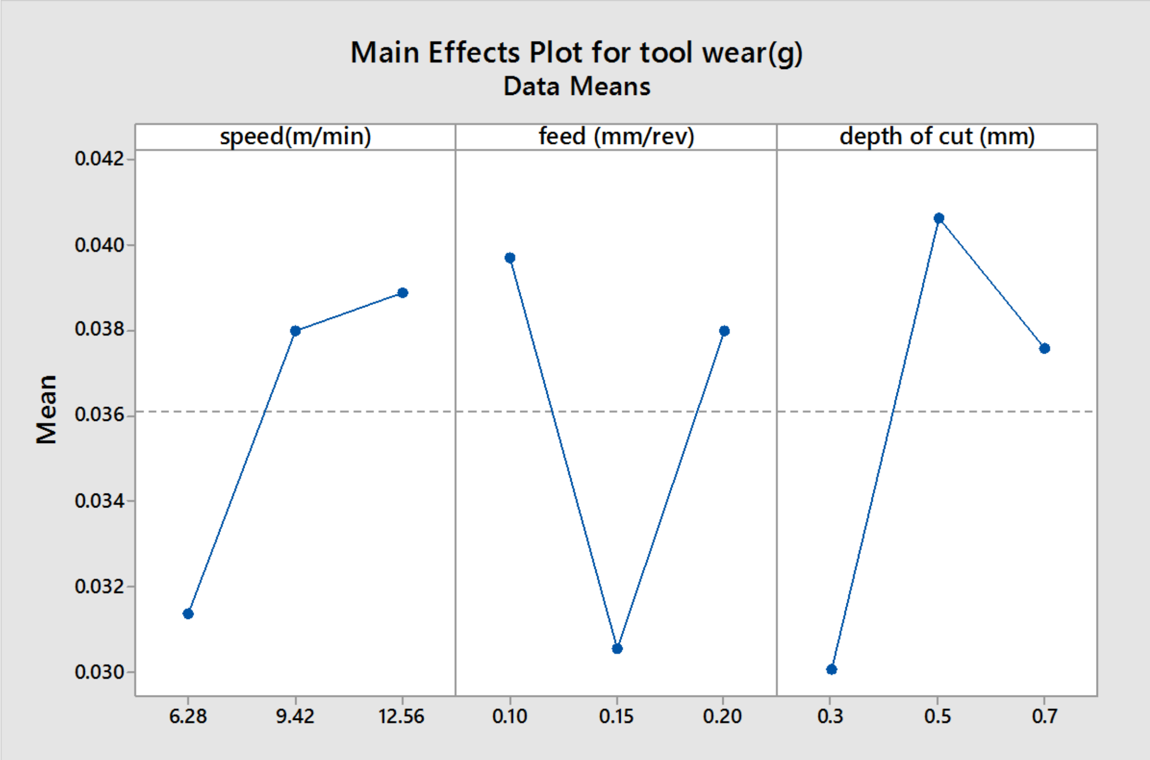


Figure 4.1 Main effect plot for tool wear

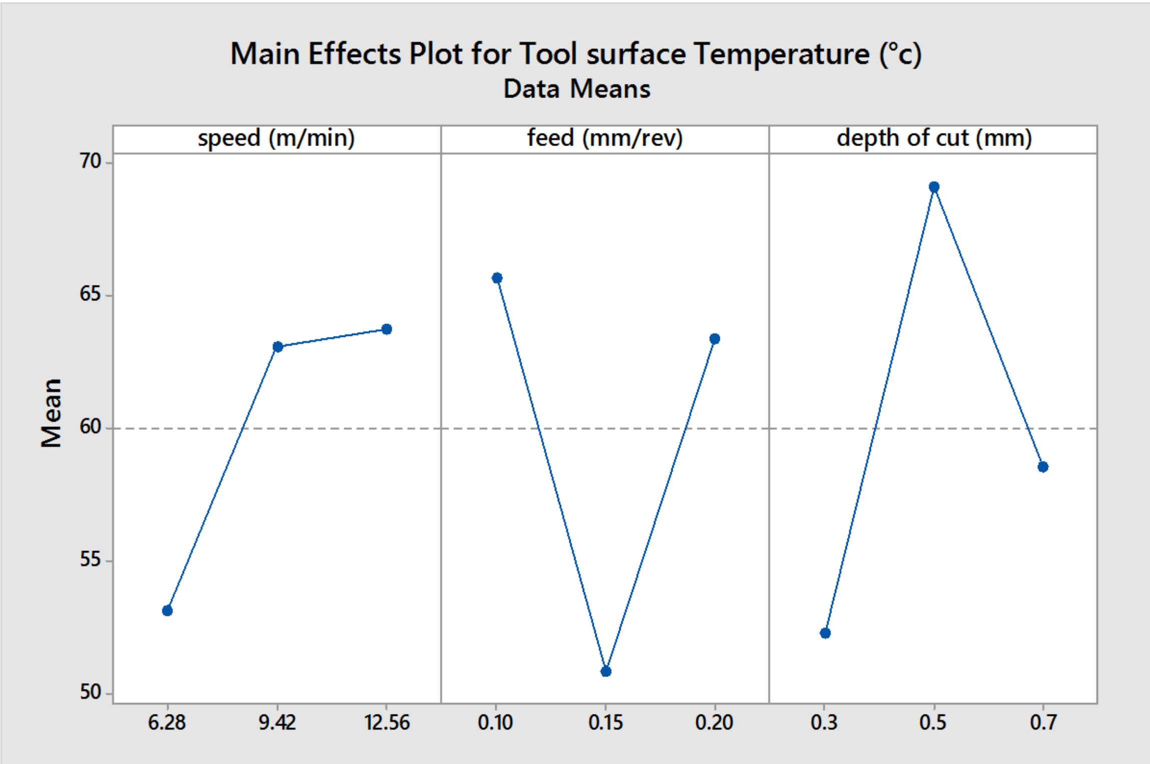


Figure 4.2 Main effect plot for tool surface temperature

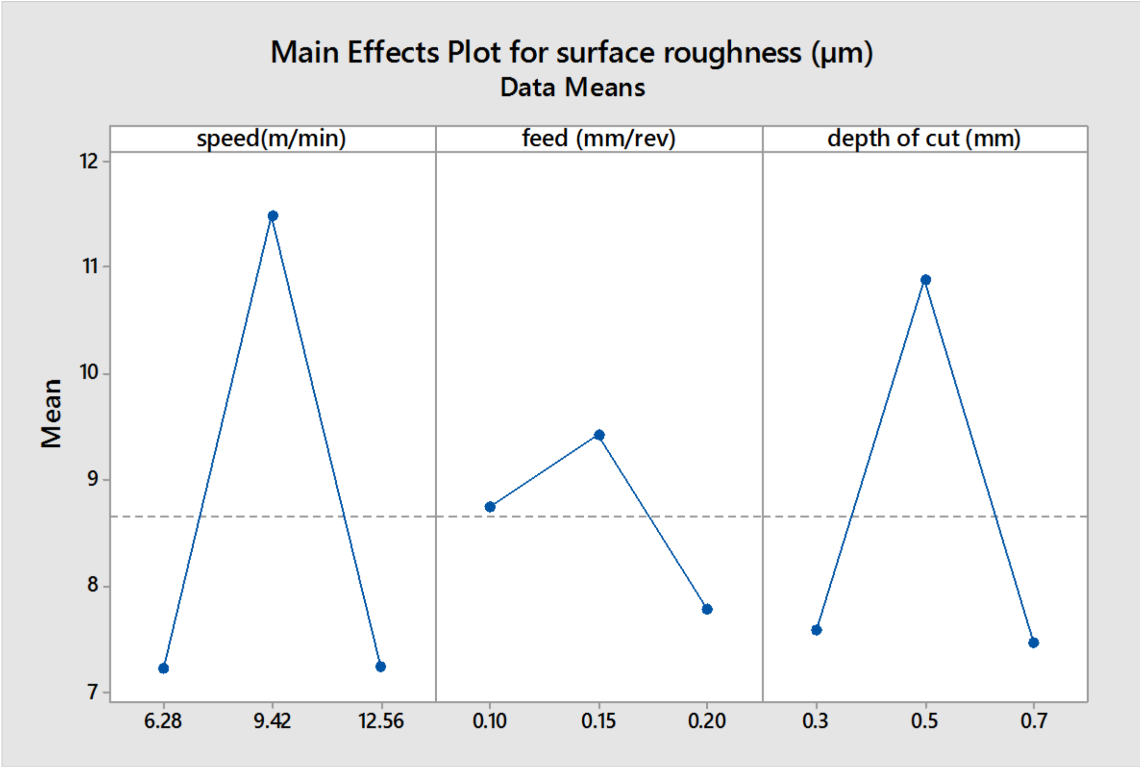


Figure 4.3 Main effect plot for surface roughness

From Figure 4.1 shows that with the increase in cutting speed there is increase in tool wear. On the other hand, as the feed change there is un-evenly (increase and decrease) of tool wear. However, with the increase in depth of cut there is decrease in tool wear. A plot shows the optimal design condition for obtaining low tool wear is archived at speed 6.28m/min (level-1), feed of 0.15mm/rev (level-2), and depth of cut of 0.3mm (level-1). The main effect plot for tool surface temperature at Figure 4.2 show that at the level of speed 6.28m/min, feed 0.15mm/rev, and depth of cut 0.3mm maintain low tool surface temperature compare to other levels. Figure 4.3 of main effect plot of workpiece surface roughness analysis that minimum surface roughness obtained at speed of 6.28m/min, feed of 0.2 and depth of cut of 0.7mm.

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CHAPTER 5

5 Conclusions and Recommendations

5.1 Conclusions

Deep drilling is one of the common machining process in the field of industry to maintain required product. At the time of deep drilling there is well known challenges either at the work part or tool during machining process. Due to this problem, the quality of product decrease and increase in machining cost. In order to overcome those difficult, optimization of parameters is necessary in dry deep drilling process. This study was focused on the application of the Taguchi Design of Experiment technique and ANOVA analysis methods for the finding optimized process parameters in dry deep drilling operations of AISI 304 austenitic stainless steel workpiece material with HSS twist drill bit. For machining operation CNC vertical machining center (VMC) is used. Required Taguchi orthogonal array was selected with various level of cutting parameters (cutting speed, feed and depth of cut). At each experimental work, steps in Taguchi orthogonal array follows to analyses the effect of parameters on the responses (tool wear, tool surface temperature, and surface roughness). Data collection was performed at the time of machining operation and after machining process. The optimum value obtained after machining process are:

1. The optimum cutting conditions obtained for minimum tool wear during drilling of AISI 304 under dry condition was observed at Cutting Speed of 6.28m/min, Feed rate of 0.15mm/rev and Depth of Cut (DOC) of 0.3mm.
2. From main effect plot of tool surface temperature it shows that lower tool surface temperature was obtained at the cutting speed of 6.28m/min, feed rate 0.15mm/rev, and depth of cut 0.3mm with the percentage contribution of 16.94%, 30.59%, and 34.87% respectively.
3. Analysis of Variances (ANOVA) for surface roughness indicate that, cutting speed is most significant parameter with a contribution of (49.63%), depth of cut has a contribution of (31.05%) and feed with a least contribution of (5.59%) at the surface roughness of workpiece with optimum condition at Cutting Speed of 6.28m/min, Feed 0.2mm/rev and depth of cut of 0.7mm.

5.2 Recommendations

Since deep drilling process is one of most important machining process in the application of automotive industry, aerospace, water transport system, and Medical Equipment, it has to be maintain the products at desired level of quality with minimum cost. The knowledge of optimization of cutting parameter will be the key factor resolving the problem in tool-work combination for quality product outcome. It is recommended that Taguchi Design of Experiment and ANOVA analysis will have performed before routine work in deep drilling operation since it is complex machine process imposed heavily on Tool part.

5.3 Future works

- In this work, deep drilling of AISI 304 austenitic stainless steel using HSS drill bit carried out under dry condition. It should be studied using different types of cutting fluid.
- Instead of through deep drilling, blind deep drilling can also be used to study the effect of tool tip temperature and tool wear.

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APPENDEX I

SECTION A: MEASURED SURFACE ROUGHNESS RESULTS FOR VARIOUS POINTS OF WORPIECE WITH DIFFERENT PARAMETRIC VALUES

a) Measured values for sample 1

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 12:52:51 AM	Real time measurement	0	um
True	1	1980-01-04 12:52:52 AM	Subjected to: Ra,Cutoff=2.5m	4.407	
True	2	1980-01-04 12:52:52 AM	Subjected to: Rz,Cutoff=2.5m	12.46	
True	3	1980-01-04 12:52:52 AM	Subjected to: Rq,Cutoff=2.5m	4.574	
True	4	1980-01-04 12:52:52 AM	Subjected to: Rt,Cutoff=2.5m	12.58	
True	0			0	
True	0	1980-01-04 12:53:25 AM	Real time measurement	0	um
True	5	1980-01-04 12:53:25 AM	Subjected to: Ra,Cutoff=2.5m	3.145	
True	6	1980-01-04 12:53:26 AM	Subjected to: Rz,Cutoff=2.5m	8.894	
True	7	1980-01-04 12:53:26 AM	Subjected to: Rq,Cutoff=2.5m	3.145	
True	8	1980-01-04 12:53:26 AM	Subjected to: Rt,Cutoff=2.5m	8.982	
True	0			0	
True	0	1980-01-04 12:53:55 AM	Real time measurement	0	um
True	9	1980-01-04 12:53:56 AM	Subjected to: Ra,Cutoff=2.5m	5.289	
True	10	1980-01-04 12:53:56 AM	Subjected to: Rz,Cutoff=2.5m	14.95	
True	11	1980-01-04 12:53:56 AM	Subjected to: Rq,Cutoff=2.5m	5.551	
True	12	1980-01-04 12:53:57 AM	Subjected to: Rt,Cutoff=2.5m	15.1	
True	0			0	
True	0	1980-01-04 12:54:29 AM	Real time measurement	0	um
True	13	1980-01-04 12:54:29 AM	Subjected to: Ra,Cutoff=2.5m	5.67	
True	14	1980-01-04 12:54:29 AM	Subjected to: Rz,Cutoff=2.5m	16.03	
True	15	1980-01-04 12:54:30 AM	Subjected to: Rq,Cutoff=2.5m	5.693	
True	16	1980-01-04 12:54:30 AM	Subjected to: Rt,Cutoff=2.5m	16.19	
True	0			0	
True	0	1980-01-04 12:55:00 AM	Real time measurement	0	um
True	17	1980-01-04 12:55:00 AM	Subjected to: Ra,Cutoff=2.5m	6.481	
True	18	1980-01-04 12:55:00 AM	Subjected to: Rz,Cutoff=2.5m	18.32	
True	19	1980-01-04 12:55:01 AM	Subjected to: Rq,Cutoff=2.5m	6.528	
True	20	1980-01-04 12:55:01 AM	Subjected to: Rt,Cutoff=2.5m	18.5	

b) Measured values for sample 2

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 12:45:32 AM	Real time measurement	0	um
True	1	1980-01-04 12:45:32 AM	Subjected to: Ra,Cutoff=2.5m	12.58	
True	2	1980-01-04 12:45:33 AM	Subjected to: Rz,Cutoff=2.5m	35.57	
True	3	1980-01-04 12:45:33 AM	Subjected to: Rq,Cutoff=2.5m	12.96	
True	4	1980-01-04 12:45:33 AM	Subjected to: Rt,Cutoff=2.5m	35.92	
True	0			0	
True	0	1980-01-04 12:46:06 AM	Real time measurement	0	um
True	5	1980-01-04 12:46:06 AM	Subjected to: Ra,Cutoff=2.5m	12.2	
True	6	1980-01-04 12:46:07 AM	Subjected to: Rz,Cutoff=2.5m	34.5	
True	7	1980-01-04 12:46:07 AM	Subjected to: Rq,Cutoff=2.5m	12.29	
True	8	1980-01-04 12:46:07 AM	Subjected to: Rt,Cutoff=2.5m	34.83	
True	0			0	
True	0	1980-01-04 12:46:37 AM	Real time measurement	0	um
True	9	1980-01-04 12:46:38 AM	Subjected to: Ra,Cutoff=2.5m	10.57	
True	10	1980-01-04 12:46:38 AM	Subjected to: Rz,Cutoff=2.5m	29.91	
True	11	1980-01-04 12:46:38 AM	Subjected to: Rq,Cutoff=2.5m	10.67	
True	12	1980-01-04 12:46:39 AM	Subjected to: Rt,Cutoff=2.5m	30.2	
True	0			0	
True	0	1980-01-04 12:47:10 AM	Real time measurement	0	um
True	13	1980-01-04 12:47:11 AM	Subjected to: Ra,Cutoff=2.5m	10.72	
True	14	1980-01-04 12:47:11 AM	Subjected to: Rz,Cutoff=2.5m	30.31	
True	15	1980-01-04 12:47:11 AM	Subjected to: Rq,Cutoff=2.5m	10.76	
True	16	1980-01-04 12:47:11 AM	Subjected to: Rt,Cutoff=2.5m	30.61	
True	0			0	
True	0	1980-01-04 12:47:45 AM	Real time measurement	0	um
True	17	1980-01-04 12:47:45 AM	Subjected to: Ra,Cutoff=2.5m	11.72	
True	18	1980-01-04 12:47:45 AM	Subjected to: Rz,Cutoff=2.5m	33.14	
True	19	1980-01-04 12:47:45 AM	Subjected to: Rq,Cutoff=2.5m	12.15	
True	20	1980-01-04 12:47:46 AM	Subjected to: Rt,Cutoff=2.5m	33.47	

c) Measured values for sample 3

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:19:32 AM	Real time measurement	0	um
True	1	1980-01-04 01:19:32 AM	Subjected to: Ra,Cutoff=2.5m	10.43	
True	2	1980-01-04 01:19:32 AM	Subjected to: Rz,Cutoff=2.5m	29.5	
True	3	1980-01-04 01:19:33 AM	Subjected to: Rq,Cutoff=2.5m	10.67	
True	4	1980-01-04 01:19:33 AM	Subjected to: Rt,Cutoff=2.5m	29.8	
True	0			0	
True	0	1980-01-04 01:20:04 AM	Real time measurement	0	um
True	5	1980-01-04 01:20:04 AM	Subjected to: Ra,Cutoff=2.5m	4.836	
True	6	1980-01-04 01:20:05 AM	Subjected to: Rz,Cutoff=2.5m	13.67	
True	7	1980-01-04 01:20:05 AM	Subjected to: Rq,Cutoff=2.5m	5.074	
True	8	1980-01-04 01:20:05 AM	Subjected to: Rt,Cutoff=2.5m	13.81	
True	0			0	
True	0	1980-01-04 01:20:36 AM	Real time measurement	0	um
True	9	1980-01-04 01:20:36 AM	Subjected to: Ra,Cutoff=2.5m	5.313	
True	10	1980-01-04 01:20:36 AM	Subjected to: Rz,Cutoff=2.5m	15.02	
True	11	1980-01-04 01:20:36 AM	Subjected to: Rq,Cutoff=2.5m	5.431	
True	12	1980-01-04 01:20:37 AM	Subjected to: Rt,Cutoff=2.5m	15.17	
True	0			0	
True	0	1980-01-04 01:21:08 AM	Real time measurement	0	um
True	13	1980-01-04 01:21:08 AM	Subjected to: Ra,Cutoff=2.5m	3.978	
True	14	1980-01-04 01:21:09 AM	Subjected to: Rz,Cutoff=2.5m	11.25	
True	15	1980-01-04 01:21:09 AM	Subjected to: Rq,Cutoff=2.5m	4.074	
True	16	1980-01-04 01:21:09 AM	Subjected to: Rt,Cutoff=2.5m	11.36	
True	0			0	
True	0	1980-01-04 01:21:40 AM	Real time measurement	0	um
True	17	1980-01-04 01:21:40 AM	Subjected to: Ra,Cutoff=2.5m	6.481	
True	18	1980-01-04 01:21:40 AM	Subjected to: Rz,Cutoff=2.5m	18.32	
True	19	1980-01-04 01:21:41 AM	Subjected to: Rq,Cutoff=2.5m	6.576	
True	20	1980-01-04 01:21:41 AM	Subjected to: Rt,Cutoff=2.5m	18.5	

d) Measured values for sample 4

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:25:33 AM	Real time measurement	0	um
True	1	1980-01-04 01:25:33 AM	Subjected to: Ra,Cutoff=2.5mm,I	14.1	
True	2	1980-01-04 01:25:33 AM	Subjected to: Rz,Cutoff=2.5mm,I	39.88	
True	3	1980-01-04 01:25:34 AM	Subjected to: Rq,Cutoff=2.5mm,I	14.67	
True	4	1980-01-04 01:25:34 AM	Subjected to: Rt,Cutoff=2.5mm,F	40.28	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0	1980-01-04 01:27:51 AM	Real time measurement	0	um
True	5	1980-01-04 01:27:51 AM	Subjected to: Ra,Cutoff=2.5mm,I	12.86	
True	6	1980-01-04 01:27:52 AM	Subjected to: Rz,Cutoff=2.5mm,I	36.38	
True	7	1980-01-04 01:27:52 AM	Subjected to: Rq,Cutoff=2.5mm,I	13.05	
True	8	1980-01-04 01:27:52 AM	Subjected to: Rt,Cutoff=2.5mm,F	36.74	
True	0			0	
True	0	1980-01-04 01:28:24 AM	Real time measurement	0	um
True	9	1980-01-04 01:28:24 AM	Subjected to: Ra,Cutoff=2.5mm,I	14.2	
True	10	1980-01-04 01:28:25 AM	Subjected to: Rz,Cutoff=2.5mm,I	40.15	
True	11	1980-01-04 01:28:25 AM	Subjected to: Rq,Cutoff=2.5mm,I	14.2	
True	12	1980-01-04 01:28:25 AM	Subjected to: Rt,Cutoff=2.5mm,F	40.55	
True	0			0	
True	0	1980-01-04 01:28:57 AM	Real time measurement	0	um
True	13	1980-01-04 01:28:57 AM	Subjected to: Ra,Cutoff=2.5mm,I	15.91	
True	14	1980-01-04 01:28:57 AM	Subjected to: Rz,Cutoff=2.5mm,I	45.01	
True	15	1980-01-04 01:28:57 AM	Subjected to: Rq,Cutoff=2.5mm,I	16.1	
True	16	1980-01-04 01:28:58 AM	Subjected to: Rt,Cutoff=2.5mm,F	45.45	
True	0			0	
True	0	1980-01-04 01:29:33 AM	Real time measurement	0	um
True	17	1980-01-04 01:29:33 AM	Subjected to: Ra,Cutoff=2.5mm,I	11.86	
True	18	1980-01-04 01:29:34 AM	Subjected to: Rz,Cutoff=2.5mm,I	33.55	
True	19	1980-01-04 01:29:34 AM	Subjected to: Rq,Cutoff=2.5mm,I	12	
True	20	1980-01-04 01:29:34 AM	Subjected to: Rt,Cutoff=2.5mm,F	33.88	

e) Measured values for sample 5

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 12:57:16 AM	Real time measurement	0	um
True	1	1980-01-04 12:57:16 AM	Subjected to: Ra,Cutoff=2.5m	10.43	
True	2	1980-01-04 12:57:16 AM	Subjected to: Rz,Cutoff=2.5m	29.5	
True	3	1980-01-04 12:57:16 AM	Subjected to: Rq,Cutoff=2.5m	11	
True	4	1980-01-04 12:57:17 AM	Subjected to: Rt,Cutoff=2.5m	29.8	
True	0			0	
True	0	1980-01-04 12:57:48 AM	Real time measurement	0	um
True	5	1980-01-04 12:57:49 AM	Subjected to: Ra,Cutoff=2.5m	10.24	
True	6	1980-01-04 12:57:49 AM	Subjected to: Rz,Cutoff=2.5m	28.97	
True	7	1980-01-04 12:57:49 AM	Subjected to: Rq,Cutoff=2.5m	10.48	
True	8	1980-01-04 12:57:49 AM	Subjected to: Rt,Cutoff=2.5m	29.25	
True	0			0	
True	0	1980-01-04 12:58:22 AM	Real time measurement	0	um
True	9	1980-01-04 12:58:22 AM	Subjected to: Ra,Cutoff=2.5m	8.958	
True	10	1980-01-04 12:58:22 AM	Subjected to: Rz,Cutoff=2.5m	25.33	
True	11	1980-01-04 12:58:22 AM	Subjected to: Rq,Cutoff=2.5m	9.149	
True	12	1980-01-04 12:58:23 AM	Subjected to: Rt,Cutoff=2.5m	25.58	
True	0			0	
True	0	1980-01-04 12:58:52 AM	Real time measurement	0	um
True	13	1980-01-04 12:58:52 AM	Subjected to: Ra,Cutoff=2.5m	11.05	
True	14	1980-01-04 12:58:53 AM	Subjected to: Rz,Cutoff=2.5m	31.26	
True	15	1980-01-04 12:58:53 AM	Subjected to: Rq,Cutoff=2.5m	11.24	
True	16	1980-01-04 12:58:53 AM	Subjected to: Rt,Cutoff=2.5m	31.57	
True	0			0	
True	0	1980-01-04 12:59:24 AM	Real time measurement	0	um
True	17	1980-01-04 12:59:25 AM	Subjected to: Ra,Cutoff=2.5m	8.386	
True	18	1980-01-04 12:59:25 AM	Subjected to: Rz,Cutoff=2.5m	23.71	
True	19	1980-01-04 12:59:25 AM	Subjected to: Rq,Cutoff=2.5m	8.958	
True	20	1980-01-04 12:59:25 AM	Subjected to: Rt,Cutoff=2.5m	23.95	

f) Measured values for sample 6

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:03:45 AM	Real time measurement	0	um
True	1	1980-01-04 01:03:45 AM	Subjected to: Ra,Cutoff=2.5m	11.91	
True	2	1980-01-04 01:03:46 AM	Subjected to: Rz,Cutoff=2.5m	33.68	
True	3	1980-01-04 01:03:46 AM	Subjected to: Rq,Cutoff=2.5m	11.96	
True	4	1980-01-04 01:03:46 AM	Subjected to: Rt,Cutoff=2.5m	34.01	
True	0			0	
True	0	1980-01-04 01:04:17 AM	Real time measurement	0	um
True	5	1980-01-04 01:04:17 AM	Subjected to: Ra,Cutoff=2.5m	10.14	
True	6	1980-01-04 01:04:17 AM	Subjected to: Rz,Cutoff=2.5m	28.7	
True	7	1980-01-04 01:04:17 AM	Subjected to: Rq,Cutoff=2.5m	10.19	
True	8	1980-01-04 01:04:18 AM	Subjected to: Rt,Cutoff=2.5m	28.98	
True	0			0	
True	0	1980-01-04 01:04:49 AM	Real time measurement	0	um
True	9	1980-01-04 01:04:50 AM	Subjected to: Ra,Cutoff=2.5m	8.863	
True	10	1980-01-04 01:04:50 AM	Subjected to: Rz,Cutoff=2.5m	25.06	
True	11	1980-01-04 01:04:50 AM	Subjected to: Rq,Cutoff=2.5m	8.863	
True	12	1980-01-04 01:04:50 AM	Subjected to: Rt,Cutoff=2.5m	25.31	
True	0			0	
True	0	1980-01-04 01:05:22 AM	Real time measurement	0	um
True	13	1980-01-04 01:05:22 AM	Subjected to: Ra,Cutoff=2.5m	11.38	
True	14	1980-01-04 01:05:22 AM	Subjected to: Rz,Cutoff=2.5m	32.2	
True	15	1980-01-04 01:05:22 AM	Subjected to: Rq,Cutoff=2.5m	11.57	
True	16	1980-01-04 01:05:23 AM	Subjected to: Rt,Cutoff=2.5m	32.52	
True	0			0	
True	0	1980-01-04 01:05:54 AM	Real time measurement	0	um
True	17	1980-01-04 01:05:54 AM	Subjected to: Ra,Cutoff=2.5m	12.05	
True	18	1980-01-04 01:05:54 AM	Subjected to: Rz,Cutoff=2.5m	34.09	
True	19	1980-01-04 01:05:55 AM	Subjected to: Rq,Cutoff=2.5m	12.2	
True	20	1980-01-04 01:05:55 AM	Subjected to: Rt,Cutoff=2.5m	34.42	

g) Measured values for sample 7

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:14:07 AM	Real time measurement	0	um
True	1	1980-01-04 01:14:07 AM	Subjected to: Ra,Cutoff=2.5m	9.482	
True	2	1980-01-04 01:14:07 AM	Subjected to: Rz,Cutoff=2.5m	26.81	
True	3	1980-01-04 01:14:07 AM	Subjected to: Rq,Cutoff=2.5m	9.53	
True	4	1980-01-04 01:14:08 AM	Subjected to: Rt,Cutoff=2.5m	27.08	
True	0			0	
True	0	1980-01-04 01:14:40 AM	Real time measurement	0	um
True	5	1980-01-04 01:14:40 AM	Subjected to: Ra,Cutoff=2.5m	6.481	
True	6	1980-01-04 01:14:40 AM	Subjected to: Rz,Cutoff=2.5m	18.32	
True	7	1980-01-04 01:14:41 AM	Subjected to: Rq,Cutoff=2.5m	6.528	
True	8	1980-01-04 01:14:41 AM	Subjected to: Rt,Cutoff=2.5m	18.5	
True	0			0	
True	0	1980-01-04 01:15:11 AM	Real time measurement	0	um
True	9	1980-01-04 01:15:11 AM	Subjected to: Ra,Cutoff=2.5m	6.766	
True	10	1980-01-04 01:15:12 AM	Subjected to: Rz,Cutoff=2.5m	19.13	
True	11	1980-01-04 01:15:12 AM	Subjected to: Rq,Cutoff=2.5m	6.814	
True	12	1980-01-04 01:15:12 AM	Subjected to: Rt,Cutoff=2.5m	19.32	
True	0			0	
True	0	1980-01-04 01:15:43 AM	Real time measurement	0	um
True	13	1980-01-04 01:15:43 AM	Subjected to: Ra,Cutoff=2.5m	6.862	
True	14	1980-01-04 01:15:44 AM	Subjected to: Rz,Cutoff=2.5m	19.4	
True	15	1980-01-04 01:15:44 AM	Subjected to: Rq,Cutoff=2.5m	6.909	
True	16	1980-01-04 01:15:44 AM	Subjected to: Rt,Cutoff=2.5m	19.59	
True	0			0	
True	0	1980-01-04 01:16:16 AM	Real time measurement	0	um
True	17	1980-01-04 01:16:16 AM	Subjected to: Ra,Cutoff=2.5m	7.767	
True	18	1980-01-04 01:16:17 AM	Subjected to: Rz,Cutoff=2.5m	21.96	
True	19	1980-01-04 01:16:17 AM	Subjected to: Rq,Cutoff=2.5m	7.91	
True	20	1980-01-04 01:16:17 AM	Subjected to: Rt,Cutoff=2.5m	22.18	

h) Measured values for sample 8

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:41:02 AM	Real time measurement	0	um
True	1	1980-01-04 01:41:03 AM	Subjected to: Ra,Cutoff=2.5m	7.433	
True	2	1980-01-04 01:41:03 AM	Subjected to: Rz,Cutoff=2.5m	21.02	
True	3	1980-01-04 01:41:03 AM	Subjected to: Rq,Cutoff=2.5m	7.481	
True	4	1980-01-04 01:41:03 AM	Subjected to: Rt,Cutoff=2.5m	21.23	
True	0			0	
True	0	1980-01-04 01:41:35 AM	Real time measurement	0	um
True	5	1980-01-04 01:41:35 AM	Subjected to: Ra,Cutoff=2.5m	6.957	
True	6	1980-01-04 01:41:35 AM	Subjected to: Rz,Cutoff=2.5m	19.67	
True	7	1980-01-04 01:41:36 AM	Subjected to: Rq,Cutoff=2.5m	7.005	
True	8	1980-01-04 01:41:36 AM	Subjected to: Rt,Cutoff=2.5m	19.87	
True	0			0	
True	0	1980-01-04 01:42:07 AM	Real time measurement	0	um
True	9	1980-01-04 01:42:08 AM	Subjected to: Ra,Cutoff=2.5m	5.884	
True	10	1980-01-04 01:42:08 AM	Subjected to: Rz,Cutoff=2.5m	16.64	
True	11	1980-01-04 01:42:08 AM	Subjected to: Rq,Cutoff=2.5m	5.86	
True	12	1980-01-04 01:42:08 AM	Subjected to: Rt,Cutoff=2.5m	16.8	
True	0			0	
True	0	1980-01-04 01:42:40 AM	Real time measurement	0	um
True	13	1980-01-04 01:42:40 AM	Subjected to: Ra,Cutoff=2.5m	6.957	
True	14	1980-01-04 01:42:40 AM	Subjected to: Rz,Cutoff=2.5m	19.67	
True	15	1980-01-04 01:42:41 AM	Subjected to: Rq,Cutoff=2.5m	7.1	
True	16	1980-01-04 01:42:41 AM	Subjected to: Rt,Cutoff=2.5m	19.87	
True	0			0	
True	0	1980-01-04 01:43:11 AM	Real time measurement	0	um
True	17	1980-01-04 01:43:11 AM	Subjected to: Ra,Cutoff=2.5m	7.29	
True	18	1980-01-04 01:43:11 AM	Subjected to: Rz,Cutoff=2.5m	20.61	
True	19	1980-01-04 01:43:12 AM	Subjected to: Rq,Cutoff=2.5m	7.386	
True	20	1980-01-04 01:43:12 AM	Subjected to: Rt,Cutoff=2.5m	20.82	

i) Measured values for sample 9

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	1980-01-04 01:48:14 AM	Real time measurement	0	um
True	1	1980-01-04 01:48:14 AM	Subjected to: Ra,Cutoff=2.5m	5.36	
True	2	1980-01-04 01:48:14 AM	Subjected to: Rz,Cutoff=2.5m	15.15	
True	3	1980-01-04 01:48:15 AM	Subjected to: Rq,Cutoff=2.5m	5.384	
True	4	1980-01-04 01:48:15 AM	Subjected to: Rt,Cutoff=2.5m	15.3	
True	0			0	
True	0	1980-01-04 01:48:47 AM	Real time measurement	0	um
True	5	1980-01-04 01:48:47 AM	Subjected to: Ra,Cutoff=2.5m	8.767	
True	6	1980-01-04 01:48:47 AM	Subjected to: Rz,Cutoff=2.5m	24.79	
True	7	1980-01-04 01:48:47 AM	Subjected to: Rq,Cutoff=2.5m	8.767	
True	8	1980-01-04 01:48:48 AM	Subjected to: Rt,Cutoff=2.5m	25.03	
True	0			0	
True	0	1980-01-04 01:49:18 AM	Real time measurement	0	um
True	9	1980-01-04 01:49:18 AM	Subjected to: Ra,Cutoff=2.5m	7.672	
True	10	1980-01-04 01:49:19 AM	Subjected to: Rz,Cutoff=2.5m	21.69	
True	11	1980-01-04 01:49:19 AM	Subjected to: Rq,Cutoff=2.5m	7.814	
True	12	1980-01-04 01:49:19 AM	Subjected to: Rt,Cutoff=2.5m	21.91	
True	0			0	
True	0	1980-01-04 01:49:49 AM	Real time measurement	0	um
True	13	1980-01-04 01:49:49 AM	Subjected to: Ra,Cutoff=2.5m	8.434	
True	14	1980-01-04 01:49:49 AM	Subjected to: Rz,Cutoff=2.5m	23.85	
True	15	1980-01-04 01:49:50 AM	Subjected to: Rq,Cutoff=2.5m	9.291	
True	16	1980-01-04 01:49:50 AM	Subjected to: Rt,Cutoff=2.5m	24.08	
True	0			0	
True	0	1980-01-04 01:50:20 AM	Real time measurement	0	um
True	17	1980-01-04 01:50:20 AM	Subjected to: Ra,Cutoff=2.5m	6.481	
True	18	1980-01-04 01:50:20 AM	Subjected to: Rz,Cutoff=2.5m	18.32	
True	19	1980-01-04 01:50:21 AM	Subjected to: Rq,Cutoff=2.5m	6.719	
True	20	1980-01-04 01:50:21 AM	Subjected to: Rt,Cutoff=2.5m	18.5	